THE IMMATURE ATHLETE
Common Injuries and Overuse Syndromes of the Elbow and Wrist

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People of all ages are becoming increasingly involved in both organized and recreational sports, including children and adolescents. As many as 30% of adolescents are participating in organized high school athletics. Concurrent with this trend has been an increase in the number of sports-related injuries presenting for medical attention. Historically, care of the skeletally immature athlete has focused on injuries resulting from macrotrauma, such as fractures and dislocations. However, there has been a rise in the number of overuse-type syndromes brought on by repetitive microtrauma, especially in the ever-enlarging population of sports specialists among skeletally immature athletes. Many elite athletes now have musculoskeletal problems that are specific to the presence of open growth plates. These injuries can run the spectrum from the permanent disability of osteochondritis dissecans of the elbow to exacerbation of the muscle-tendon "growing pains" of active children.

Repetitive microtrauma is the unifying cause of overuse syndromes in the upper extremity. Overuse injuries may be the result of repetitive impact, as experienced in gymnastics, or of the repetitive whiplike motion of throwers and tennis players. Symptoms of overuse injuries often begin insidiously. They are frequently discovered after an acute trauma is superimposed on the site of previous microtrauma. Such a
pattern is seen in throwers. The child may complain of minor aching in the elbow for several weeks stemming from an untreated medial apophysitis. During a game, the child sustains a sudden increase in pain after a particularly hard throw. The increased pain is the result of a fracture or avulsion at the site of the previously compromised medial epicondyle.

The history of participation in a given sport offers the clinician a clue as to whether the patient's symptoms are due to macrotrauma and a possible fracture, a shearing injury and possible cartilage or ligamentous injury, or the cumulative effect of repetitive microtrauma causing tissue injury at a subacute level. At the Division of Sports Medicine at Children's Hospital in Boston, a checklist of risk factors is used to evaluate the skeletally immature athlete presenting with complaints of chronic pain. Identification of these risk factors is used not only to determine the cause of an overuse injury, but as a means of preventing the occurrence or recurrence of future overuse syndromes. These risk factors include training error, muscle-tendon imbalance, cultural deconditioning, deficient nutrition, associated disease state, and growth.

The most frequently associated risk factor for overuse injuries in the skeletally immature athlete is a misguided training regimen. Such programs are best described as "too much, too soon." They are often encountered in sport-intensive summer camps, in which a child who normally plays baseball 1 hour per day each weekend suddenly is being trained 6 hours per day, 7 days per week.

The second most important risk factor for an overuse injury in the young athlete is muscle-tendon imbalance. This may be manifest as an imbalance of strength, flexibility, or bulk. Growth leads to longitudinal increase in the bone. However, the soft tissue structures surrounding the bone—the muscles, tendons, ligaments, and joint capsules—have no growth centers of their own and elongate or "grow" secondarily in response to the bone. The result is often an increase in strength with a decrease in flexibility, causing muscle-tendon imbalances around the joint. If intensive, repetitive motions continue to be performed by joints in the upper extremity, overuse injuries may occur. This is exemplified by adolescent throwers and swimmers. Their continuous overhead activity puts them at risk for developing a tight posterior shoulder capsule and a loose anterior capsule. Impingement syndrome secondary to anterior subluxation of the shoulder may result. Careful stretching and warm-up exercises are thus particularly mandatory for the young athlete.

Muscle-tendon imbalance can also result in nerve entrapment syndromes. The patient who presents with medial elbow pain must not be hastily diagnosed with medial epicondylar apophysitis. The pain may instead be due to ulnar neuritis caused by entrapment of the nerve at the origin of the flexor carpi ulnaris or subluxation of the nerve at the medial epicondyle.

Nutritional factors are a third risk factor for the development of
overuse injuries. Deficient intakes of calcium and vitamins in amenorrheic distance runners and ballet dancers have been documented. These girls suffer from 22% to 25% lower bone density, leaving them with an increased susceptibility to skeletal injuries and stress fractures. Such a physiologic state is especially worrisome in young gymnasts, who are already prone to physeal injuries of the distal radius and ulna.

Cultural deconditioning plays a role in overuse syndromes as well. It stands to reason that the more poorly trained or conditioned an individual is prior to initiating participation in sports, the more likely he or she is to incur injury. During the 1980s, the United States experienced a 40% to 64% increase in obesity among its school-aged children. Concomitant with this increased obesity was an increase in television viewing.

The general health of the patient must never be overlooked when assessing sports-related injuries. Infection, neoplasm, and cervical spine pathology can all present with elbow and wrist symptoms that appear temporally related to athletic participation. Arthritis, circulatory disturbances, nerve injury, and old fractures should also be considered when evaluating chronic elbow and wrist pain.

GROWTH-RELATED INJURIES

Whereas the preceding risk factors for sports injury are common to all age groups, the growing athlete has an additional and unique set of risk factors due to the process of growth itself. First, the presence of physeal cartilage not only at the plate but also on the joint surface and at all sites of major tendinous insertions adds a special class of both overuse and acute traumatic injuries in this age group. Second, the process of growth itself, occurring primarily in the bones, can result in injury risk to muscle-tendon units, bone, and joints from relative strength and flexibility imbalance, especially during "spurt" periods of growth. The three sites of injury in the young athlete are the epiphyseal plate, the joint surface, and the apophyseal insertions of major muscle-tendon units.

Growth cartilage, including the articular cartilage, is more susceptible to injury from repetitive microtrauma than is adult cartilage (Fig. 1). Treating these injuries effectively requires an understanding of epiphyseal anatomy and development.

The epiphyseal plate is an undulating cartilaginous disk through which skeletal growth occurs between the epiphysis and metaphysis. Pressure epiphyses are located at the ends of long bones. They provide longitudinal growth and are subject to pressures transmitted by the adjacent joint.

The epiphyseal plate is composed of four distinct cell layers. The resting cell layer lies adjacent to the epiphysis and is composed of compact cartilage cells. These cells are the germinal layer for future cartilage cells and receive their blood supply from epiphyseal vessels.
The zone of proliferation is characterized by increased cellular activity and division of the cartilage cells. The zone of hypertrophy is the most important layer from the standpoint of injury to the skeletally immature athlete. The cells align in vertical columns as they hypertrophy. Fractures most commonly occur here because it is the structurally weakest portion of the epiphyseal plate. The zone of mineralization is characterized by endochondral ossification of the hypertrophied cartilage cells (Fig. 2).

During the adolescent growth spurt, the epiphyseal plate is weaker than its surrounding ligaments. As a result, adolescents tend to sustain epiphyseal plate injuries, whereas the prepubescent child or skeletally mature athlete may sustain a tendinous or ligamentous injury. Traumatic dislocations are less common than epiphyseal plate separations because the plate is weaker than the fibrous joint capsule.

The three main types of epiphyseal injuries are separation of the physis, transphyseal fracture, and crush injuries. Acute injuries to the physes have been described by Salter and Harris and Ogden. Type I injuries result from a shearing, torsional, or avulsion force. Radiographs are often negative as in fractures of the distal fibular physis, and the diagnosis is made by tenderness over the epiphyseal plate. Healing is typically uneventful and occurs in 3 weeks. Type II fractures result from a laterally applied force that ruptures the periosteum on one side of the physis and leaves it intact with the metaphyseal fragment (Thurston-Holland fragment) on the opposite side. This periosteal hinge aids in
the reduction of the fracture. Type III fractures occur in partially closed physes, such as the Tillaux fracture of the distal tibial epiphysis. They are intra-articular injuries and require anatomic reduction. Type IV fractures require open reduction and internal fixation to avoid bony bridging and growth disturbances, the central issue with this injury. Type V injuries are somewhat controversial but are the result of crush from an axial load. They can be difficult to distinguish from type I

Figure 2. Schematic of the major patterns of endochondral growth. Longitudinal growth occurs in the cell columns, which may be divided on the basis of physiologic function (growth, maturation, transformation, and remodeling), or histologic structure and appearance. Two relatively independent vascular systems supply the two sides of the physi. Additional branches supply a specialized region, the zone of Ranvier, where undifferentiated mesenchymal cells (M) give rise to chondroblasts. The peristome (PO) and perichondrium (PC) are continuous in this region. The metaphyseal cortex also extends into this region, becoming the osseous ring of Lacroix (ORL), which acts as a peripheral restraint to the cell columns but does not impede latitudinal growth of the adjacent zone of Ranvier or the more external peristome and perichondrium. (From Ogden JA: Anatomy and physiology of skeletal development. In Skeletal Injury in the Child. Philadelphia, Lea & Febiger, 1982, pp 16–40; with permission.)
injuries on presentation but have a much greater rate of growth complications. All fractures must be followed for at least 6 to 12 months. This not only ensures the clinician that an accurate diagnosis has been made but allows for early detection of any growth disturbances that may result.

One third of all fractures in children involve the epiphyseal growth plate. Inherent to such injuries is rapid, predictable healing, especially if the deformity is in the axis of motion of the joint. However, the potential for acute or delayed growth disturbances or angular deformities exists as well. Within certain limits, tension or compression of the physis may stimulate growth. When these limits are surpassed, growth is halted. The cause of the changes in growth may be avascular necrosis of the physis, crush injury and bony bridging, infection, or nonunion. Local overgrowth may also occur secondary to hyperemia. The growth plate is most resistant to tension and least resistant to torsion. Many osteochondroses have their origins in chronic, repetitive trauma to the cartilaginous epiphysis, which sustains injury preferentially over ligaments, tendons, or bones.

APOPHYSIS INJURIES

Apophyses are nonarticular and do not contribute to joint formation or longitudinal growth. They serve as the site of origin or insertion of major muscle-tendon units. Examples include the medial epicondyle of the humerus and the tibial tubercle. In skeletally immature athletes, apophysitis develops instead of tendinitis at the site of the tendon insertion. A treatment program consisting of "relative rest" is used in order to promote revascularization and repair while discouraging muscle atrophy and deconditioning.

ELBOW INJURIES

In the evaluation of a painful elbow in the young athlete, a careful history is essential to determine the exact mechanism of injury and onset of pain in relationship to duration of play or sport-specific technique. The presence of any neurologic symptoms is identified. The physical examination requires a detailed knowledge of the anatomy of the elbow because the diagnosis is often made by location of maximal tenderness in the setting of negative radiographs. In the elbow, a posterior fat pad sign indicates that a significant injury may be present even if no fracture is seen.

The specific fracture incurred by a given mechanism of trauma is directly related to the age of the patient and the stage of development of the multiple ossification centers (Table 1). Epicondylar fractures of the distal humerus are rarely seen in young children; rather, condylar or supracondylar fractures predominate. Olecranon fractures are rarely
Table 1. ELBOW OSSIFICATION CENTERS AND THEIR ROENTGENOGRAPHIC APPEARANCE ACCORDING TO AGE

<table>
<thead>
<tr>
<th>Site</th>
<th>Age at Appearance</th>
<th>Age Epiphysis Unites with Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capitellum</td>
<td>18 months</td>
<td>14 years</td>
</tr>
<tr>
<td>Radial head</td>
<td>5 years</td>
<td>16 years</td>
</tr>
<tr>
<td>Medial epicondyle</td>
<td>5 years</td>
<td>15 years</td>
</tr>
<tr>
<td>Trochlea</td>
<td>8 years</td>
<td>14 years</td>
</tr>
<tr>
<td>Olecranon</td>
<td>10 years</td>
<td>14 years</td>
</tr>
<tr>
<td>Lateral epicondyle</td>
<td>12 years</td>
<td>16 years</td>
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</table>


seen in children but are relatively common in adolescence. Fractures of the radial head or neck occur at all ages. The diagnosis of an "elbow sprain" must be a diagnosis of exclusion because the epiphysis is more likely to be injured than the ligamentous complexes. A careful physical examination and radiographs that include comparison views of the contralateral elbow are mandatory before such a diagnosis is made. Buckle fractures and greenstick fractures are frequently seen as a result of the plasticity of young bone. Plastic deformation of bone, particularly the radius and ulna, must be recognized when evaluating injuries to the upper extremity because it is potentially disabling.

Fractures around the elbow have one of the highest rates of complications because remodeling is not as vigorous around the elbow as in the proximal humerus or distal radius. Malunion or non-union and neurovascular compromise are not uncommon. It should be remembered that simultaneous fractures of the supracondylar humerus and forearm can occur, especially if the mechanism of injury involved falling from a height.

Supracondylar fractures of the humerus are the most common elbow fracture between 5 and 10 years of age. Special concerns about neurovascular compromise and long-term deformity exist because these injuries usually result in posterior and medial displacement. Nondisplaced fractures can be treated with cast immobilization in 90 deg of flexion and neutral rotation. Displaced fractures require rapid, anatomic reduction under general anesthesia followed by percutaneous pin fixation. The reduction is performed initially with the elbow extended and the forearm in supination. Traction is applied, and direct pressure over the distal fragment is used to correct the varus/valgus alignment. Posterior to anterior pressure then brings the extended fragment anteriorly. Flexion of the elbow to 120 deg and pronation (supination if the fragment is displaced laterally) of the forearm hold the fracture reduced until the percutaneous pins are placed. If the elbow is too swollen medially, two lateral pins should be used in order to avoid injury to the ulnar nerve (Fig. 3). Motion is begun after the pins are removed at 3 to 4 weeks. Failure to produce an adequate reduction can result in
persistent vascular obstruction or nerve entrapment, with increased swelling and a chance for late neurovascular compromise. If a satisfactory reduction cannot be obtained or acute flexion of the elbow causes ischemia, olecranon skeletal traction should be performed.

Complications from supracondylar fractures are not uncommon and are often serious. Injury to the median or ulnar nerve occurs in 10% of

Figure 3. A, Anteroposterior (AP) radiograph of displaced supracondylar fracture in a 9-year-old child. B, A posterolateral displaced fracture requires traction, flexion, and supination of the flexed elbow to attain reduction.

Illustration continued on opposite page
Figure 3 (Continued). AP (C) and lateral (D) radiographs of postreduction maneuver. Having attained satisfactory reduction, internal fixation with transfixion pins may be required to maintain reduction. E, Illustration of potential for neurovascular entrapment and consequence with a displaced supracondylar fracture.
The most feared complication is Volkmann’s ischemic contracture due to injury to the brachial artery at the medial aspect of the proximal fragment. Left untreated, paralysis, sensory loss, and muscle contracture may occur. The signs of pain, paralysis, pallor, paresthesias, and pulselessness warrant surgical exploration and fasciotomy. Angiograms are not needed and serve only to delay the needed revascularization. Technical complications from treating supracondylar fractures include loss of reduction (usually due to inadequate flexion in a cast), failure to obtain anatomic reduction prior to pinning, and cubitus varus secondary to medial tilting of the distal fragment. Terminal extension is most frequently lost, although loss of supination may occur owing to excessive pronation in the cast.

The next most common elbow fracture occurs at the lateral condyle. The peak incidence is between 6 and 10 years of age. By 14 years, the capitellum and trochlea have fused, making the injury uncommon. Lateral condyle fractures are both transepiphyseal and intra-articular, making anatomic reduction essential. They are produced by a varus stress on an outstretched hand, often by impaction of the radial head on the capitellum. If the force is not dissipated by the condylar fracture, dislocation can occur. A subgroup of lateral condylar fractures (Wadsworth type IV) is the result of repetitive microtrauma to the capitellum, resulting in osteochondritis dissecans. Displacement and rotation are common owing to the pull of the extensor muscles of the forearm which originate at the lateral condyle. Open reduction and internal fixation are more the rule than the exception (Fig. 4). If the fracture is nondisplaced, cast immobilization with the forearm in supination for 3 weeks is indicated. The cast is then bivalved and early motion begun. Delayed union can occur owing to the pull of the extensor group while in the cast, and frequent follow-up with radiographs is essential. Complications are due to the extent of displacement and rotation at the time of injury which are not recognized. Malunion or nonunion can occur with resultant valgus deformity, leading to late tethering of the ulnar nerve. Growth disturbances and deformity from the epiphyseal injury may require humeral osteotomy or bone grafting. Avascular necrosis of the capitellum is rare, as are neurovascular injuries at the time of presentation.

Proximal radius injuries in the skeletally immature athlete are either physeal fractures of the radial head or fractures of the radial neck. They occur most commonly in children over the age of nine as the result of valgus stress with a longitudinal force on an outstretched arm. Moderate forces produce fractures of the radial neck alone. Excessive forces result in fracture of the proximal ulna and dislocation of the elbow in 50% of patients with radial neck fractures. Treatment depends on the degree of angulation, age of the patient, amount of displacement, and presence of associated fractures. Children less than 10 years old can accept 30 to 40 deg of angulation of the radial neck due to the resultant remodeling. A child over 10 years of age, cannot accept a deformity greater than 15 deg. Cast immobilization with early motion in 10 to 14 days is usually required. Reduction can be performed with direct pres-
Figure 4. A, AP radiograph of a displaced supracondylar fracture in an 8-year-old child. B, AP radiograph after open reduction and internal pin fixation. C, Posteroanterior (PA) radiograph following pin removal and physical therapy. D, Illustration of extensor muscle insertion on lateral condyle fracture fragment promoting displacement and potential non-union without internal fixation.
sure over the radial head and varus stress for injuries with greater angulation. If the radial head is separated from the shaft or if greater than 60 deg of angulation is present, open reduction is required\(^2^3\) (Fig. 5).

Complications from injuries to the proximal radius depend on the amount of initial displacement/angulation and the patient's age. Patients older than 10 years have a worse prognosis if the initial angulation is greater than 60 deg.\(^2^3\) Common complications in this group include hypermia, which can lead to both growth arrest and secondary overgrowth as well as heterotopic ossification and proximal radioulnar synostoses.

Radial head fractures can be particularly worrisome, as loss of motion can result from even a minimally displaced injury. These injuries can occur from repetitive microtrauma. If the offending force is not removed, disabling overgrowth can occur.\(^1^4\) Greater than 2 mm of displacement is an indication for open reduction and internal fixation in these injuries. Radial head excision is contraindicated, as wrist instability, weakness, pain, radial deviation of the hand, and an increased valgus carrying angle result.

Medial epicondylar fractures are the childhood counterpart of the adult elbow dislocation.\(^3^3\) They are apophyseal injuries, not epiphyseal injuries, and thus have no effect on the longitudinal growth of the

![Figure 5. Radial head physeal fractures in children. Illustration of nondisplaced (A) and completely displaced (C) radial head fractures. Manipulative reduction with rotation and manual pressure usually can reduce partially displaced fractures (B). Completely displaced fractures may require open reduction and fixation.](image-url)
humerus. Medial epicondylar fractures occur most commonly at age 11 and result from a valgus strain or a rotational injury (Fig. 6). If the periosteum is disrupted at the time of injury, elbow dislocation may result. Treatment of minimally displaced fractures is cast immobilization for 3 weeks with the elbow flexed 90° and the forearm in full pronation. Early motion is then initiated. Frequent follow-up is mandatory because the pull of the flexor/pronator group can lead to displacement even within a cast. The indication for open reduction internal fixation (ORIF) is displacement greater than 5 mm, especially if instability is noted on physical examination. The clinician must be aware of possible entrapment of the medial epicondylar fragment within the joint, especially if a dislocation occurred. This is an absolute indication for ORIF (Fig. 7). Complications of this injury include stiffness, ulnar nerve injury, and instability. Painful nonunions do occur and require excision of the fibrous union. Fractures of the medial condyle are rare in children.

DISLOCATIONS

Elbow dislocations are not common in the pediatric age group. They are the result of hyperextension forces that injure the anterior capsule and brachialis muscle and are often seen in association with a medial epicondylar fracture. The brachial artery, median nerve, and ulnar nerve are at risk in this injury. Diagnosis may be difficult owing to marked swelling. Sedation is required for reduction in order to decrease the risk of iatrogenic physeal injury to the distal humerus or proximal radius and ulna (Fig. 8).
OVERUSE INJURIES OF THE ELBOW

Overuse injuries of the elbow are most commonly seen in sports that involve overhead activity, such as serving in tennis or throwing a baseball. Pappas\textsuperscript{32} reviewed the injury patterns at the elbow in young athletes and related them to three separate stages of development. Childhood is defined as terminating with the appearance of all secondary centers of ossification. The most common injuries in this group relate to these ossification centers, as demonstrated by their irregular and fragmented appearances. These problems are usually self-limited if the repetitive trauma is removed. The adolescent phase is defined as ending when all secondary centers have fused. The increase in physical strength of the young athlete leads to avulsions of the medial epicondyle, physeal separations, and avascular necrosis of the capitellum. With maturity to
In young throwers, a specific pattern of changes due to repetitive microtrauma has been documented. Osteochondral changes in the capitellum, premature proximal radial epiphyseal closure, and fragmentation of the medial epicondyle are collectively known as "Little League elbow." The cause is predominately a result of the forces applied during the late cocking phase of throwing: valgus strain at the elbow. This overuse pattern is most commonly seen between 9 and 12 years of age. A medial traction apophysitis produces medial tenderness and swelling. The compromised apophysis can become avulsed (a separation of greater than 5 mm compared with the opposite elbow) with persistent throwing by the pull of the common flexor/pronator muscles and strain of the ulnar collateral ligament, both of which originate at the medial epicondyle. The bony fragment can ultimately lodge in the joint, requiring open reduction for removal. Fibrous non-union can result, as can ectopic bone, traction osteophytes, and spurring. Loss of extension occurs as a result of a tightening of the ulnar collateral ligament, producing pain with valgus stress. Ulnar neuritis may be present due to subluxation or compression by fascial adhesions. The incidence of neuritis increases with maturity and the number/velocity of balls thrown. Radiographically, these forces produce medial condyle hypertrophy and fragmentation, trochlear and olecranon fragmentation, and widening of the distance between the medial epicondyle and distal humeral metaph-
ysis. It should be remembered that because the medial epicondyle is extra-articular, nondisplaced fractures can occur without causing a radiographic "fat pad sign." The diagnosis must be made on physical examination.

Treatment of Little League elbow is directed at removing the recurrent microtrauma. Cessation of all throwing until the elbow is asymptomatic is the first line of treatment. Range-of-motion exercises and dynamic splinting are useful if contractures are present. A triceps-strengthening program with concurrent stretching of the anterior elbow capsule is helpful for both treatment and prevention of recurrence. Arthroscopy is useful for removal of loose bodies as well as drilling of subchondral bone. An open procedure may be needed if subchondral bone grafting is required. Lastly, the young athlete's throwing mechanics must be reassessed to encourage a more overhead delivery and thus minimize valgus stress at the elbow. Results are generally favorable when treatment is instituted early.31

Laterally, the capitellum and radial head ossify before the medial epicondyle. The repetitive valgus compression and shearing may lead to damage to the radiocapitellar articulation. Osteochondritis dissecans can affect the capitellum, radial head, or both. These changes have been documented in young throwers, gymnasts, and basketball players.33 Subchondral avascular necrosis may develop,6 leading to articular depression and joint surface changes.

These changes include chondromalacia with softening and fissuring of the articular surface, subchondral collapse, and bony eburnation.3 Osteochondritis dissecans of the capitellum can present with wide variations in radiographic appearance depending on the extent of avascular necrosis and the presence of loose bodies. Pain, tenderness, and contracture dominate the clinical presentation (Fig. 9).

Not all lateral elbow pain in the throwing athlete is due to osteochondritis. In the follow-through phase of throwing, extension and traction forces can cause an avulsion of the lateral apophysis and/or lateral condyle.2 Differentiating this injury from an extension-type supracondylar fracture is essential because the repetitive valgus stress can lead to a proximal radial physeal injury. Pain with pronation/supination, local tenderness, and a positive "fat pad sign" are indicative of proximal radius injury. A sling is often all that is needed. Posterior intersosseous nerve entrapment is a less common source of lateral elbow pain but nonetheless must be recognized.

Anterior elbow pain in the young athlete may be due to anterior capsulitis, biceps strain or avulsion, supracondylar fracture, or pronator syndrome.2 The elbow is susceptible to hyperextension forces seen in young throwers with muscle-tendon imbalances and poor mechanics. Radiographic changes include trochlear hypertrophy, fragmentation, or osteophytes, loose bodies, and coronoid osteophytes.

Posterior elbow pain in throwers is frequently due to the powerful contraction of the triceps mechanism in the early acceleration phase of
throwing, coupled with the impaction of the olecranon into its fossa in the late follow-through phase. Olecranon apophysitis or an avulsion fragment may form with subsequent pain, or a non-union may develop between the olecranon and its secondary ossification center (Fig. 10). Heterotopic ossification can form at the tip of the olecranon, leading to loss of extension and bony ankylosis. Radiographic changes depend on the extent of ossification of the secondary centers. Traction apophysitis, avulsion fragments, posteromedial osteophytes, and loose bodies are seen. In young adults, avulsions of the triceps mechanism can occur.

WRIST INJURIES

Fractures are the most common sports-related injury to the wrist in the skeletally immature athlete. (Overuse injuries are more common in the adolescent age group.) Fractures occur in those sports requiring frequent snapping motions and rotation of the wrist, such as baseball, basketball, and racquet sports (Fig. 11). Injuries initially thought to be sprains are commonly fractures. One of the most commonly missed fractures is the scaphoid.

The scaphoid is the most common site of fracture in the carpus. It results from a fall on an outstretched hand, with its peak incidence in the 12 to 15 age group. The pattern of fracture is different from that

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Figure 9. A, Oblique radiograph of the elbow of a 16-year-old with elbow pain who had been a baseball pitcher between ages 11 and 13, demonstrating osteochondritis dissecans of the capitellum. B, Lateral radiograph shows a loose body in the joint as well.
Comparison lateral radiographs (A and B) show stress fracture with displacement through the symptomatic olecranon.

seen in the adult. In adults, 70% are waist fractures. Injury to the distal one third occurs in 87% of children’s scaphoid fractures, with 44% being avulsions.45 In 4.6% of cases, there is another fracture in the same extremity, usually the distal radius.8,19 The child complains of pain on
the radial spect of the wrist, pain with range of motion, and snuff box tenderness. Initial radiographs are often negative. If there is a high clinical suspicion, treatment involves 2 to 3 weeks in a short-arm thumb spica cast. If repeat radiographs show evidence of a fracture, 6 to 10 weeks of casting allows healing of almost all pediatric scaphoid fractures.\(^9\),\(^{20}\),\(^{45}\) Although some advocate primary internal fixation of scaphoid waist fractures,\(^13\) this is seldom necessary. Cast immobilization followed by bone grafting if nonunion occurs gives excellent results.\(^9\),\(^{13}\),\(^{35}\),\(^{42}\) Stress fractures of the navicular must be included in the differential diagnosis of chronic wrist pain (Fig. 12).

If the scaphoid fracture is old with an established non-union, initial treatment remains cast immobilization.\(^42\) Sclerosis and cystic changes are indications for bone grafting,\(^39\) with or without internal fixation.\(^12\) If bone grafting is performed, a cast is required for 4 to 6 months.\(^42\)

In distal one third fractures of the scaphoid, a short-arm thumb spica cast is sufficient and athletic participation can be allowed. For all other fractures, a long-arm thumb spica for 6 weeks followed by a short-arm thumb spica is recommended.\(^42\) If displaced at the time of

Figure 12. Scaphoid stress fracture in a 12-year-old male gymnast (arrow). Patient noted slow, progressive increase of wrist pain while using bars and rings.

Figure 13. Displaced distal radius physeal fracture in a 14-year-old football player. Gentle, atraumatic reduction with adequate anesthesia should be done to minimize further physeal trauma.
presentation, open reduction and internal fixation should be performed or avascular necrosis and carpal instability may result.

Fractures of other carpal bones are uncommon. Fractures of the hook of the hamate are missed frequently. The mechanism of injury is repetitive microtrauma to the ulnar side of the hand just distal to the wrist crease, as occurs in batting or golfing.

Treatment involves 6 weeks of immobilization. If pain persists, the hook can be excised.

Carpal instability due to ligamentous disruption is very rare in children. The mechanism of injury for a scapholunate dissociation is dorsiflexion and rotation, which puts the greatest stress on the volar, extrinsic radiocarpal ligaments. The same mechanism is responsible for perilunate or lunate dislocations in adolescents.

Tendinitis in the wrist does occur in young athletes who repeatedly flex and extend their wrists and fingers, as is the case with gymnastics. Persistent tenosynovitis despite conservative management of rest and ice may require release of the constricting tendon sheath. Repeated steroid injections are not indicated in this age group. Ganglions, especially if occult, may be difficult to distinguish from tendinitis.

Keinboch’s disease (avascular necrosis of the lunate) does not occur in the immature carpus. It may be seen rarely in the adolescent as the result of repetitive impact. No treatment has been widely successful, although ulnar lengthening or radial shortening is recommended when there has been no collapse.

The distal radius and ulna are common sites of injury in the young athlete. They are subject to a wide array of both macrotrauma and microtrauma from virtually every sport. Fractures may occur from a fall on an extended hand and wrist with loads as small as 55% of body weight. Careful physical examination is required to differentiate pain in the distal radius and ulna from pain in the proximal carpal row. It is essential to avoid growth arrests in the distal radius because 75% to 80% of the growth potential of the radius and 40% of the potential of the ulna arises from their distal physes.

If closed reduction under nitrous oxide or local block is unsuccessful after one attempt, the patient should be taken to the operating room for closed reduction under general anesthesia. If an acceptable reduction is not obtained, an open reduction and internal fixation are required to prevent further growth plate injury from multiple closed attempts.

The distal radial physis is particularly susceptible to the repetitive microtrauma of axial loading in extension. This is the common mechanism of wrist pain in young gymnasts. Epiphysiolysis or Salter I fractures of the distal radius can produce chronic pain in these athletes. Radiographs often demonstrate widening and irregularity of the growth plate. Simple splinting and rest may not resolve the epiphysiolysis, and growth arrest can occur.

Intra-articular fractures of the radiocarpal joint are unusual owing to the presence of a cartilaginous carpus and epiphysis. Adolescents who sustain these injuries require anatomic reduction.
Specific elbow and wrist injuries are predictable in the skeletally immature athlete based on the biomechanics of the sport and the age of the patient. The physician must be aware of the potential for overuse injuries. Modification in training regimens is essential for recovery. A greater emphasis must be placed on the prevention of these injuries. As a general rule, the young athlete should not progress more than 10% per week in the amount and frequency of training. Correction of muscle-tendon imbalances is accomplished by maintaining strength and flexibility of susceptible tissues. In throwers, a triceps-strengthening program of progressive resisted extension exercises and a forearm flexor/extensor-strengthening program using the French curl technique are helpful. Careful attention to throwing technique and proper coaching are essential. The goal for the young athlete is early recognition of the injury and thereby prevention of a long-term disability.

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