Upper Extremity Injuries in the Paediatric Athlete

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Abstract

Injuries to the upper extremity in paediatric and adolescent athletes are increasingly being seen with expanded participation and higher competitive levels of youth sports. Injury patterns are unique to the growing musculoskeletal system and specific to the demands of the involved sport. Shoulder injuries include sternoclavicular joint injury, clavicle fracture, acromioclavicular joint injury, osteolysis of the distal clavicle, little league shoulder, proximal humerus fracture, glenohumeral instability and rotator cuff injury. Elbow injuries include supracondylar fracture, lateral condyle fracture, radial head/neck fracture, medial epicondyle avulsion, elbow dislocation and little league elbow. Wrist and hand injuries in-
clude distal radius fracture, distal radial physeal injury, triangular fibrocartilage tear, scaphoid fracture, wrist ligamentous injury thumb metacarpalphalangeal ulnar collateral ligament injury, proximal and distal interphalangeal joint injuries and finger fractures. Recognition of injury patterns with early activity modification and the initiation of efficacious treatment can prevent deformity/disability and return the youth athlete to sport.

Injuries to the upper extremity in paediatric and adolescent athletes are increasingly being seen with expanded participation and higher competitive levels of youth sports. Injury patterns are unique to the growing musculoskeletal system and specific to the demands of the involved sport. Recognition of injury patterns with early activity modification and the initiation of efficacious treatment can prevent deformity/disability and return the young athlete to sport. This paper reviews the diagnosis and management of common upper extremity injuries in the paediatric athlete.

1. Shoulder Injuries

1.1 General

The shoulder complex involves 4 articulations and multiple ossification centres. The secondary centre of ossification of the proximal humeral epiphysis is usually seen after 6 months of age. Additional ossification centres appear at the greater tuberosity between 7 months and 3 years of age, and at the lesser tuberosity 2 years later. By the age of 5 to 7 years, these centres coalesce to form the proximal humeral epiphysis. The proximal humeral physis contributes approximately 80% of the longitudinal growth of the humerus and usually fuses between 19 and 22 years of age. The clavicle forms by intramembranous ossification in its central portion by the sixth gestational week. The medial secondary ossification centre appears between 12 and 19 years of age and does not fuse to the shaft until the age of 22 to 25 years. The proximal humeral physis is extra-articular, except medially where the capsule extends beyond the anatomic neck, inserting on the medial metaphysis. The lateral epiphysis is inconstant: appearing, ossifying, and fusing over a period of a few months at about the age of 19 years.

The scapula appears as a cartilaginous anlage in the first gestational week at the C4-C5 level and gradually descends to its adult-like position overlying the first to fifth ribs. Failure to descend results in persistent elevation of the scapula and limited glenohumeral motion, Sprengel’s deformity. The scapula ossifies via intramembranous ossification with multiple remaining secondary ossification centres. The ossification centre of the coracoid process appears at approximately 1 year, coalescing with the ossification centre of the upper glenoid by the age of 10 years. The acromion ossifies by multiple (2 to 5) ossification centres, which usually appear about puberty and fuse by the age of 22 years. Failure of fusion of one of these ossification centres may result in an os acromionale. Various other scapular malformations may occur, including bipartite coracoid, acromion duplication, glenoid dysplasia and scapular clefts.

Injury patterns to the paediatric athlete’s shoulder tend to be sport specific. In football, the shoulder ranks second only to the knee in number of overall injuries. [11]–[31] These injuries tend to result from macrotrauma, such as glenohumeral dislocation, acromioclavicular separation and clavicle fractures. Bicycle is a popular recreational and sporting activity among children and adolescents. 60% of all bicycle injuries occur in children between the ages of 5 and 14 years, and 85% of injuries involve the upper extremity. [14,31] A common injury pattern during bicycling involves lateral clavicle fracture or acromioclavicular separation from landing on the point of the shoulder when thrown from the bicycle. Shoulder injuries during alpine skiing and snowboarding are being seen with increased frequency and ac-
count for approximately 40% of upper extremity injuries and 10% of all injuries.\[6\] Thirty percent of wrestling injuries occur in the upper extremity, with the shoulder being the most commonly involved location.\[7\] Injury to the acromioclavicular joint is frequent, resulting from a direct blow of the shoulder against the mat.\[7,8\]

In baseball, injury to the paediatric shoulder from throwing is a result of microtrauma from repetitive motions of large rotational forces.\[9-11\] The proximal humeral physis is particularly vulnerable to these large, repetitive forces resulting in a chronic physeal stress fracture (Little League shoulder).\[10-17\] The shoulder in tennis is similarly subjected to repetitive overhead motions involving large torques. Impingement and depression of the shoulder (tennis shoulder) may result.\[18\] Repetitive microtrauma also frequently leads to shoulder dysfunction in swimmers.\[19\] The risk of injury is related to competitive level and event type. Injuries include impingement syndrome and glenohumeral instability. Multidirectional instability is often seen and is related to the underlying ligamentous laxity often seen in swimmers. Similarly, multidirectional instability can be seen in gymnasts, who also frequently demonstrate generalised ligamentous laxity. Additional shoulder injuries unique to gymnasts include cortical hypertrophy at the pectoralis major insertion, ringman’s shoulder and supraspinatus tendinitis.\[20-22\]

1.2 Sternoclavicular Joint Injury

True sternoclavicular joint dislocations are rare in the skeletally immature. The characteristic injury involves a physeal fracture of the medial clavicle, commonly a Salter-Harris I or II injury, as the medial clavicular physis does not fuse until the early 20s.\[23,24\] The epiphysis stays attached to the sternum via the stout sternoclavicular ligaments and the medial clavicular shaft displaces posteriorly or anteriorly. Medial clavicular injury often results from an indirect force transmitted along the clavicle from a direct blow to the lateral shoulder during contact sports. If the shoulder is driven forward, posterior displacement of the medial clavicle occurs. Conversely, if the shoulder is driven posteriorly, anter- rior displacement of the medial clavicle occurs. The patient often describes a pop in the region of the sternoclavicular joint and there is tenderness to palpation of the medial clavicle. The direction of displacement may be obscured by marked swelling.

Posterior displacement can be a medical emergency, as the medial clavicle can impinge on vital mediastinal structures including the innominate great vessels, trachea or oesophagus (fig. 1).\[25,26\] Venous congestion, diminished pulses, dysphagia or dyspnoea should alert the clinician to the possibility of such injury. Standard anteroposterior radiographs of the chest or sternoclavicular joint are often hard to interpret given the overlapping spinal, thoracic and mediastinal structures. A tangential x-ray taken in a 40° cephalad directed manner, the serendipity view, may aid in visualisation of the medial clavicle displacement. Definitive delineation of the fracture pattern and direction of displacement is provided by CT scan.\[27\]

Minimally displaced fractures heal readily. Attempted reduction of anteriorly displaced fractures can be accomplished under local anaesthesia or sedation by placing the patient supine with a bolster between the scapulae. The arm is abducted 90° and then extended with gentle posterior pressure directly over the medial clavicle followed by protraction of the shoulder. After reduction, the shoulder is immobilised in a figure-of-8 dressing or shoul-
der immobiliser and gentle range of motion exercises are started as pain allows. Most fractures heal in 3 to 4 weeks, and return to sport requires full painless range of motion and strength. Unstable fractures usually heal and remodel rapidly.

Posteriorly displaced medial clavicular fractures with impingement of mediastinal structures require emergent reduction with thoracic surgery standby for the rare but potential injury of the major thoracic vessels.[28] Under general anaesthesia with the patient supine, traction is applied to the arm with the shoulder extended, and a towel clip can be used to reduce the medial clavicle. There is little indication for open reduction and internal fixation of medial clavicular physeal fractures, and catastrophic complications of pin migration from hardware about the sternoclavicular joint have been reported.[29,30] On rare occasions, open reduction with stabilisation of the torn periosteum and ligamentous structures with heavy nonabsorbable suture may be indicated.

1.3 Clavicle Fracture

The clavicular shaft is vulnerable to injury from direct blows during contact sports. In addition, indirect forces on the outstretched arm may lead to clavicular fracture. The clavicular shaft is mechanically vulnerable as a strut, given its S-shaped configuration and the strong ligamentous bindings at either end. With fracture, there is limited shoulder motion, tenderness over the fracture site, and the skin overlying the fracture may be tented and compromised. The proximal fragment may be elevated superiorly due to spasm of the sternoclavicular or trapezius muscles. Significant neurovascular injury is rare, but should be assessed clinically given the proximity of the subclavian vessels and the brachial plexus. Plane radiographs are usually sufficient for diagnosis and management. Younger children may exhibit a greenstick fracture or plastic deformation.[14,31]

The prognosis of most clavicular shaft fractures in children is excellent. Immobilisation is accomplished by a figure-of-8 bandage or shoulder immobiliser. Slings which exert significant pressure to affect a reduction should be avoided. Even displaced fractures usually heal readily with a bump of healing callus which remodels over a period of 6 to 12 months. Return to sport is allowed when the clavicle is nontender, there is radiographic union, and motion and strength are full. This usually occurs by 4 to 6 weeks in younger children and 6 to 10 weeks in the adolescent. Significant malunion which does not remodel and nonunion of clavicular shaft fractures in the skeletally immature are rare.[32] Open reduction and internal fixation is indicated for open fractures, fractures with significant neurovascular compromise, threatened skin from fracture displacement, and floating shoulder injuries.[33,34]

1.4 Acromioclavicular Joint Injury

A fall on the point of the shoulder usually results in acromioclavicular separation in the adult and older adolescent, but results in physeal fracture of the lateral clavicle in children.[35-40] With lateral clavicle fracture and true acromioclavicular separation in the paediatric patient, displacement of the lateral clavicle occurs superiorly through a tear in the thick periosteal tube surrounding the distal clavicle. The lateral clavicular epiphysis, along with the acromioclavicular and coracoclavicular ligaments, usually remain intact to the periosteal tube. The paediatric athlete with lateral clavicle physeal fracture or acromioclavicular injury usually presents after a fall or contact to the point of the shoulder. Pain and deformity are localised to the acromioclavicular joint. Plane radiographs are usually sufficient to evaluate the injury, and stress x-rays with 5 to 10lb of traction may aid in delineating the degree of instability. An axillary lateral demonstrates anteroposterior displacement.

Similar to adult acromioclavicular injuries, Rockwood[40] has classified paediatric acromioclavicular injuries based on the position of the lateral clavicle and the accompanying injury to the periosteal tube. Type I injuries involve mild sprain of the acromioclavicular ligaments without disruption of the periosteal tube. Type II injuries involve partial disruption of the dorsal periosteal tube with slight widening of the acromioclavicular joint. Type III
injuries involve a large dorsal disruption of the periosteal tube with gross instability of the distal clavicle. Type IV injuries involve disruption of the periosteal tube with posterior displacement of the lateral clavicle (fig. 2). Type V injuries involve periosteal tube disruption with >100% superior subcutaneous displacement of the lateral clavicle. Type VI injuries involve an inferior subcoracoid dislocation of the lateral clavicle.

Non-operative management of acromioclavicular injuries in children under 13 years old is the mainstay of treatment, as these injuries almost always represent a physeal fracture rather than a true acromioclavicular joint dislocation.\textsuperscript{[35-40]} Thus, these injuries exhibit a great potential for healing and remodelling, as the periosteal tube usually remains in continuity with the epiphyseal fragment, and acromioclavicular and coracoclavicular ligaments. For type IV, V and VI injuries with very large displacement, operative stabilisation may be indicated. Repair of the periosteal tube with or without internal fixation is usually performed. For late adolescent and adult type true acromioclavicular joint separations, non-operative management results in good outcomes for type I and II injuries, while operative management is indicated for type IV, V and VI injuries. The management of type III injuries in the athlete remains controversial, with many recommending initial non-operative management.\textsuperscript{[41-43]}

1.5 Osteolysis of the Distal Clavicle

Osteolysis of the distal clavicle is an overuse injury resulting from repetitive microtrauma. It has also been described as a sequelae following traumatic injury to the distal clavicle or acromioclavicular joint. However, it is seen most commonly in adult weightlifters. In addition, this entity is being identified in other sports as crosstraining has become more popular, and in younger athletes who are weight training year-round for higher level sports. Patients complain of an aching discomfort about the acromioclavicular joint after workouts, which progresses to interfere with training and eventually with activities of daily living. There is tenderness to palpation of the distal clavicle and pain with cross-
chest adduction. Treatment consists of rest, particularly from weight training, and anti-inflammatory medications. For those who fail conservative treatment or who are unable to refrain from weight training, distal clavicle resection usually results in resolution of pain and return to sport.[44,45]

1.6 Little League Shoulder

As a result of repetitive microtrauma from the large rotational torques involved in throwing, chronic stress fracture of the proximal humeral physis can occur. This entity has been termed ‘little league shoulder’ and is most commonly seen in high performance male pitchers between 11 and 13 years of age.[10-17,46] In addition to age and the large rotational forces of pitching, poor throwing mechanics and frequent pitching may predispose to injury. In an extensive study of little league pitchers, Albright et al.[12] found that those who had poor pitching skills were more likely to be symptomatic. Patients complain of shoulder pain and there is typically widening of the proximal humeral physis on x-rays. Good results can usually be obtained by enforcing rest from pitching for the remainder of the season, with a vigorous preseason conditioning programme and limits on the frequency of pitching during the subsequent year. Proper throwing mechanics should be stressed, with an emphasis on control instead of speed.

1.7 Proximal Humerus Fracture

Approximately 20% of proximal humeral fractures in the skeletally immature occur in sporting events. The peak age is 10 to 14 years. Two-thirds involve the proximal humeral metaphysis and one-third involve the proximal humeral physis. Approximately one-fourth of fractures in this region occur through unicameral bone cysts.[47] Proximal metaphyseal fractures are characterized more likely in children under 10 years old. The vast majority of physeal fractures in this region are Salter-Harris type I or II lesions, with type II fractures being more common in children over 10 years of age. With physeal fracture, the distal fragment usually displaces anteriorly and laterally through a relatively weaker area of periosteum. Patients present with shoulder pain, limited motion and tenderness to palpation. Routine roentgenograms are usually sufficient to demonstrate the fracture pattern, amount of displacement or presence of a unicameral bone cyst.[47-53]

Nondisplaced or minimally angulated metaphyseal or physeal fractures can usually be treated adequately with a shoulder immobiliser. Since most of these fractures are intrinsically stable, shoulder motion can be initiated early. There is tremendous potential for remodelling of proximal humerus fractures since the physis is so active. Thus, many moderately displaced, angulated or bayoneted fractures can be accepted in less than anatomic alignment with good functional outcomes. For severely angulated or displaced fractures in older children, closed reduction should be performed. Reduction is usually achieved by bringing the distal shaft fragment into flexion, abduction and external rotation to align it with the proximal fragment. If stable after reduction, the fracture can be immobilised next to the chest. If unstable, the reduction must be held immobilised by a shoulder spica cast or shoulder spica brace. These are usually poorly tolerated by patients and parents, and thus percutaneous pinning is advantageous as it allows immobilisation in an immobiliser (fig. 3). Open reduction is rarely indicated and often results in poor outcomes.[47-53]

1.8 Glenohumeral Instability

The glenohumeral joint is the most commonly dislocated large joint in adolescents and adults, but is less commonly involved in children before skeletal maturity. In large series of patients with glenohumeral instability, the proportion of skeletally immature patients ranges from 1 to 5%.[54-59] Although traumatic anterior dislocation is by far the most common type of instability seen in adolescent athletes, multidirectional instability, posterior subluxation and recurrent subluxation are being recognised with increased frequency, particularly in gymnasts, swimmers and throwers. The patient with a traumatic anterior dislocation presents with pain, limited motion and deformity. The humeral head may
be palpated anteriorly or in the axilla and the arm is typically held in a slightly abducted, externally rotated position. Careful examination, particularly of the axillary nerve, is essential to rule out neurovascular injury.

With posterior dislocation, the coracoid process may be prominent anteriorly and the arm is often held in internal rotation and adduction. Anteroposterior and lateral views of the glenohumeral joint demonstrate the dislocation and identify associated fractures or Hill-Sachs lesions. Posterior dislocations are frequently missed because of inadequate lateral images. Gentle reduction of an anterior dislocation is performed by one of several techniques, including traction-countertraction, Stimson manoeuvre or abduction manoeuvres. After a brief period of immobilisation, a rehabilitation programme focused on rotator cuff strengthening and avoiding the apprehension position is initiated.

Rates of recurrent instability in adolescents and young adults vary between 25 and 90% in various series,55,60-62 Rowe57,58 reported 100% recurrence in children less than 10 years old and 94% recurrence in patients from 11 to 20 years old. Rockwood61 reported a recurrence rate of 50% in adolescent patients between 14 and 16 years old, and Marans and colleagues56 reported a 100% recurrence rate in children between 4 and 15 years old with open physes at the time of dislocation. Management of the adolescent patient with significant recurrent instability is usually surgical, involving capsulorrhaphy or a Bankart type repair for capsuloligamentous disruption. Both arthroscopic and open techniques have been utilised with, in general, higher recurrence rates with arthroscopic repair.
Atraumatic instability is seen in the paediatric athlete without a clear history of trauma and may occur with throwing, hitting, swimming or overhead serving. Initially, there is usually a lack of pain with these episodes of subluxation with spontaneous reduction. Clinical examination often reveals signs of generalised ligamentous laxity including hyperextensibility of the elbows, knees and metacarpophalangeal joints. Examination may also show signs of multidirectional instability including the sulcus sign and excessive translation with anterior and posterior drawer tests or the load and shift test. A vigorous rehabilitation programme stressing rotator cuff strengthening is successful in most patients. For patients who fail non-operative management, a capsular shift reconstruction is recommended.

1.9 Rotator Cuff Injury

Much less common than in adults, rotator cuff tendinitis and subacromial impingement can occur in the paediatric overhead athlete. Repetitive micro-trauma in high level overhead sports such as swimming, baseball and tennis can lead to tendinitis, secondary muscle weakness, mechanical imbalance and secondary instability. In the paediatric athlete with joint laxity, true impingement with compromise of the subacromial space is uncommon. Rather impingement secondary to muscle imbalance and instability is seen. The usual presenting symptom is pain with overhead activities progressing to constant pain or night pain. As the process continues, range of motion and strength may be diminished. Impingement may be elicited with forward elevation or secondary to provocative instability tests. Although magnetic resonance imaging (MRI) may be useful to assess the integrity of the rotator cuff, full-thickness tears in the paediatric or adolescent shoulder are uncommon.

Treatment of rotator cuff tendinitis consists of rest, nonsteroidal anti-inflammatory medications and a rehabilitation programme emphasising range of motion, parascapular stabilisation and rotator cuff strengthening to restore dynamic stability. Rehabilitation of secondary impingement should focus on improving dynamic joint stability instead of the subacromial space. For cases refractory to non-operative management, shoulder arthroscopy may be of benefit for debridement or repair of partial tears and assessing intra-articular lesions as superior labral tears. Subacromial decompression is rarely indicated in the paediatric athlete.

2. Elbow Injuries

2.1 General

The elbow joint has 3 major articulations: humero-radial, humero-ulnar and proximal radioulnar joints. Delineating injury patterns in children can be challenging given the cartilaginous composition of the distal humerus and the multiple ossification centres. A site-specific clinical exam and radiographs of the contralateral uninjured elbow can prove useful in identifying injury. There are 6 major secondary centres of ossification, which appear and unite with the epiphysis at characteristic ages (table 1). Except for the medial and lateral eplcondyles, the remaining ossification centres are intra-articular. The clinical carrying angle of the elbow averages 7° valgus alignment. There are several radiographic lines which are useful in assessing post injury alignment. Bauman's angle, the angle between the capitellar physeal line and a line perpendicular to the humeral shaft, is a guide to the varus attitude of the distal humerus and should be within 5 to 8° of the contralateral elbow. On the lateral x-ray, the capitellum forms an angle flexed forward 30 to 40° from the humeral shaft and the anterior humeral line should bisect the capitellum. Elbow stability is provided by congruous articular
surfaces and soft tissue constraint via capsular and ligamentous structures.

Elbow injury patterns in the paediatric athlete are dependent on the age-related stage of elbow development and the sport-specific mechanism of injury. Acute macrotraumatic injuries often result in fractures about the elbow. In younger children, supracondylar and lateral condyle fractures predominate. Physeal injury is more likely than ligamentous injury given the relatively weaker physis. In adolescence and near skeletal maturity, epicondylar and olecranon fractures are more common. In addition, elbow dislocations, ligamentous injuries and muscular avulsions about the elbow can occur. Repetitive microtraumatic injuries are often sport-specific, involving upper extremity overuse. Repetitive throwing places high demands on the vulnerable developing elbow. Tension overload of the medial elbow restraints occurs during late cocking and can lead to medial epicondyle fragmentation, ulnar collateral ligament strain, flexor muscle strains and traction ulnar neuritis. Compression overload of the lateral articulation also occurs during late cocking and can lead to chondral injuries and growth disturbances of the capitellum or radial head. Postero-medial shear overload of the posterior articular surface occurs during follow-through and can lead to posterior spurs, olecranon apophyseis or avulsion, and traction spurs of the coronoid process.\(^{[69]}\)

In gymnastics, the elbow becomes a weight-bearing joint often subjected to repetitive large loads. Medial epicondyle traction injuries, partial tears of the flexor origin mass, ulnar collateral ligament strains, subluxation/dislocation often with medial epicondyle avulsion, osteochondral fractures of the capitellum, and posterior elbow spurring have been described.\(^{[2,22,70]}\)

2.2 Supracondylar Fracture

Supracondylar humerus fractures are the most common elbow fracture in children, accounting for approximately 75% of injuries. The mechanism of injury is usually an acute hyperextension load on the elbow from falling on an outstretched arm. The injury typically occurs in children aged 5 to 10 years because of thin bony architecture in the supracondylar region and ligamentous laxity. The distal fragment displaces posteriorly in over 95% of cases and the fracture is classified according to displacement: minimally displaced (type I), posterior angulation hinged on an intact posterior cortex (type II) and completely displaced (type III) \(^{[71,72]}\). With complete displacement, rotational malalignment often occurs and can lead to cubitus varus deformity if unreduced. Injury to the anterior interosseous nerve, radial nerve, median nerve and brachial artery can occur in 10 to 18% of displaced fractures.\(^{[71,72]}\)

Type I fractures are treated in a long arm cast for 3 weeks with the elbow flexed 90 to 100°. Type II fractures can be treated with closed reduction and casting alone. However, the elbow should be flexed beyond 90° to maintain reduction and this position may not be tolerated secondary to vascular insufficiency and swelling. Thus, closed reduction and percutaneous pinning with 2 lateral pins is often the treatment of choice. Closed reduction and percutaneous pinning is the preferred method of treatment for type III fractures, obviating the problems of ischaemic contracture (compartment syndrome) and cubitus varus deformity seen with closed treatment. Reduction is accomplished by extension of the elbow, with subsequent correction of mediolateral translation, followed by traction and flexion.
arm is pronated, which tightens the reduction against the intact medial periosteum while closing the lateral column. The most stable pin configuration involves medial and lateral pins crossing above the fracture line. Care must be taken to avoid ulnar nerve injury with the medial pin. Motion is begun after the pins are removed at 3 to 4 weeks.\textsuperscript{[71,72]}

2.3 Lateral Condyle Fracture

Lateral condyle fractures are the second most common elbow fracture in children and occur typically between 6 and 10 years of age. The mechanism of injury is often a valgus compressive force from the radial head or a varus tensile force on a supinated forearm from the extensor longus and brevis muscles. A significant portion of the fragment is unossified, leaving often only a thin lateral metaphyseal rim of bone to herald the injury. This fracture involves both the physis and the articular surface, making anatomic reduction essential. Displacement and rotation are common due to the lateral extensor muscle mass.

Treatment depends on the degree of displacement and fragment stability. Minimally displaced fractures, \( \leq 2\text{mm} \), are treated with cast immobilisation for approximately 3 to 4 weeks. Follow-up x-rays (particularly the oblique view) are essential every week for 3 weeks after injury to rule out further displacement. Fractures with a small initial amount of displacement, 3 to 4mm, are at risk of late displacement and nonunion, and thus many recommend percutaneous pinning to stabilise these fractures (fig. 5). Fractures with over 4mm of displacement are often also rotated, necessitating open reduction and internal fixation to restore articular continuity. Complications of lateral condyle fractures include nonunion, progressive valgus deformity and tardy ulnar neuritis.\textsuperscript{[72]}

2.4 Radial Head/Neck Fracture

Proximal radius injuries in the skeletally immature athlete are either physeal fractures of the radial head or fractures of the radial neck (fig. 6). They occur most commonly in children over the age of 9 years, as the result of valgus stress with longitu-
dinal force on an outstretched arm. Treatment depends on the degree of angulation, amount of displacement, age of child, and associated fractures. Children less than 10 years old can tolerate up to 40 to 45° of angulation of the radial neck due to expected remodelling. In older children, less angulation (15 to 20°) is acceptable due to less remodelling potential. For fractures with acceptable angulation, cast immobilisation with early motion in 10 to 14 days is recommended. Closed reduction can be performed by direct pressure over the radial head with a varus stress. Alternatively, a percutaneous pin can be used to manipulate the proximal fragment. Indications for open reduction include complete displacement of the radial head, irreducible angulation over 45° or a displaced Salter-Harris IV fracture. Radial head fractures with significant displacement should be anatomically reduced and fixed. Radial head excision is contraindicated, as proximal radial migration, radial deviation of the hand and valgus deviation of the elbow can occur.\[72-74\]

2.5 Medial Epicondyle Fracture

The medial epicondyle can be avulsed from a valgus load applied to the extended elbow (fig. 7). The flexor-pronator origin and the medial collateral ligament play a role in fracture displacement. These fractures occur typically in children 10 to 14 years old. Almost 50% of these injuries occur concomitantly with elbow dislocation (fig. 8). Many advocate closed treatment of this injury, particularly when there is less than 5mm of displacement. Although nonunion may occur, it is often asymptomatic or can be treated with fragment excision when symptomatic. Relative indications for open reduction and fixation include competitive athletes with >2mm displacement or valgus instability to restore the integrity of the medial collateral ligament and retention the forearm flexors. An absolute indication for open reduction and internal fixation is medial epicondylar entrapment within the joint associated with elbow dislocation (fig. 8). A common complication of medial epicondyle fracture is joint stiffness. Internal fixation allows for early postoperative range of motion at 2 to 3 weeks.\[72,75-77\]

2.6 Elbow Dislocation

Elbow dislocation is relatively uncommon in the child athlete as the peak incidence is in the second decade. However, elbow dislocation may be encountered in the adolescent athlete in contact sports such as football or wrestling, or in noncontact sports such as gymnastics. The most common pattern of injury is posterolateral displacement without disruption of the proximal radioulnar joint. The injury may also involve disruption of the anterior capsule, tearing of the brachialis muscle, avulsion of the medial epicondyle, injury to the ulnar collateral ligament and, rarely, brachial artery compromise or nerve injury to the median or ulnar nerves.

Fig. 6. Radial head fracture. Anteroposterior view demonstrating angulation and displacement of proximal radial physeal fracture in a 12-year-old boy.
Prompt and gentle reduction is performed under sedation. Nonconcentric reduction should alert the clinician to the possibility of interposed soft tissue or medial epicondylo. For simple elbow dislocations, a posterior splint is used for the acute phase of pain and swelling for 1 to 2 weeks, followed by range of motion.172,78

2.7 Little League Elbow

The term ‘little league elbow’ describes a group of pathological entities about the elbow joint in young throwers. Although these findings were originally noted in baseball pitchers, the throwing motion is common to the nonpitcher’s throw, the tennis serve and the football pass. The entity includes medial epicondylo fragmentation and avulsion, growth alteration of the medial epicondylo, osteochondritis of the capitellum, deformation or osteochondritis of the radial head, hypertrophy of the ulna and olecranon apophysis. Osteochondritis of the capitellum may also be seen in high performance female gymnasts.79 Most cases of little league elbow present with medial elbow complaints: medial pain and decreased throwing effectiveness/distance. Medial tension overload results from repetitive valgus stress and flexor forearm pull.

Injuries are age dependent. During childhood, irregular appearance of the secondary centres of ossification of the medial epicondylo may be seen. In adolescence with increasing muscle strength, avulsion fracture of the medial epicondylo may occur. After fusion of the medial epicondylo in young adulthood, injuries of the ulnar collateral ligament and flexor muscle origin become more apparent. Laterally, repetitive valgus compression may lead to damage of the radiocapitellar articulation. Osteochondritis dissecans can affect both the capitellum and the radial head. Changes include chondromala-cia with softening and fissuring of the articular surface, subchondral collapse, and bony eburnation. Osteochondritis dissecans of the capitellum can present with wide variations in radiographic appearance depending on the extent of osteonecrosis and the presence of loose bodies. Pain, tenderness and contracture dominate the clinical presentation.

Additional lateral injuries seen during throwing in the skeletally immature athlete include lateral apophysis avulsion from traction during follow-through and radial physeal injury from repetitive valgus overload. Posterior elbow pain in throwers is frequently due to the powerful contraction of the triceps in the early acceleration phase, coupled with the impaction of the olecranon into its humeral fossa in the late follow-through phase. Olecranon apophysitis, avulsion fracture (fig. 9), posteromedial osteophytes and loose bodies may form.10,12,16,17,69,80-83

Treatment of little league elbow is directed at removing the recurrent microtrauma. Cessation of all throwing until the elbow is asymptomatic fol-
lowed by reassessing throwing mechanics and number of pitches thrown is essential. Range of motion exercises and dynamic splinting may be useful for contractures. Triceps strengthening with stretching of the anterior capsule is helpful for avoidance of contracture. Arthroscopy is useful for assessing chondral injury, removal of loose bodies and management of osteochondritis dissecans through drilling or fragment fixation. Open reduction of displaced medial epicondyle fractures is indicated in the throwing athlete. Results of treatment of little league elbow are generally favourable when instituted early.[10, 12, 16, 17, 69, 80-85]

3. Wrist and Hand Injuries

3.1 General

In most sports, the hand and wrist are exposed and thus are vulnerable to injury. Injury patterns are sport-specific, with macrotraumatic injury or repetitive microtraumatic injury depending on the demands placed on the upper extremity. Injuries are also age-specific, related to the stage of skeletal development. In several large series of paediatric and adolescent athletic injuries, hand and wrist injury rates varied from 15 to 65% of all injuries in paediatric and adolescent athletes, depending on the sport involved.[86-88] Injuries to the hand are particularly common during snowboarding, basketball, football, boxing, 16-inch softball, skateboarding and alpine skiing. Repetitive stress injuries, particularly of the wrist, are common in gymnasts. Injuries are relatively infrequent during swimming and soccer.[89-91]

3.2 Distal Radius Fractures

Distal radial metaphyseal fracture is the most common fracture of childhood.[92] If treated properly, these fractures usually heal without residual disability. Initial management consists of splinting and careful neurovascular evaluation of the hand. Radiographs are usually sufficient to define the fracture and its angulation/displacement. On occasion, this fracture may occur in association with distal radio-ulnar joint disruption or elbow injury. Torus and greenstick fractures are often fairly stable and may be treated in a short arm cast in older children and a long arm cast in children less than 5 years old. The completely displaced distal radial metaphyseal fracture often requires intravenous sedation or general anaesthesia for reduction followed by long arm casting with an appropriate mould (fig. 10).

In the young child less than 8 years old, bayonet apposition may be accepted. In the rare irreducible fracture, an open reduction may be necessary through a volar approach which allows for release of the carpal canal. The position of immobilisation of this fracture is controversial, with advocates of prona-
tion, neutral and supination positioning. Approximately 10 to 30% of distal third radius fractures reangulate to an unacceptable position (>20°), requiring repeat closed manipulation. For the healing fracture, acceptable limits of angulation are wider. In a child under 8 years, up to 30° may be acceptable due to remodelling potential with an estimated correction of 1° per month.[93] In the child over 12 years, these fractures become increasingly unstable, with less remodelling potential leading to treatment resembling that of an adult.

Physeal fractures of the distal radius occur most commonly in the adolescent. Salter-Harris I and II fracture patterns predominate. The distal fragment is usually dorsally displaced with an intact dorsal periosteum. Associated acute carpal tunnel syndrome or compartment syndrome has been described. Reduction should be as atraumatic as possible to avoid further injury to the physis. The fracture should be immobilised in the position of stability as determined during reduction. Intraepiphyseal fracture extension, such as in Salter-Harris III or IV injuries, is uncommon but should be treated with anatomical reduction of the articular surface and intraepiphyseal or transphyseal fixation.

3.3 Wrist Injuries

Wrist pain has become extremely common in young, highly competitive gymnasts related to chronic, repetitive, upper extremity weight-bearing during growth and development. Chronic repetitive stress injury to the distal radial and ulnar physes was described by Roy and colleagues[94] in young, highly competitive gymnasts who practiced approximately 36 hours per week. The presenting symptoms were stiffness and dorsiflexion pain. Radiographs showed widened physes, cystic changes and distal metaphyseal beaking. Nearly all patients returned to competitive gymnastics without growth arrest after treatment with rest with or without casting. Subsequently, others have reported acquired Madelung's deformity and increased ulnar variance in young, competitive gymnasts.[95,96] A spectrum of pathological entities may be found on clinical exam, x-rays, MRI and arthroscopy, including stress changes of the distal radial/ulnar physes, articular cartilage changes of the wrist/carpal joints, distal radioulnar joint injury, triangular fibrocartilage (TFCC) tears and ganglion cysts. Management is primarily non-operative with rest, immobilisation if necessary, and activity modification.

Distal radioulnar joint injuries in the child and adolescent athlete are rare. Acute dislocations present with pain and deformity of the joint. Acute dislocations are treated with long arm cast immobilisation with the wrist in supination for dorsal dislocations and pronation for volar dislocations. TFCC injuries are increasingly being recognised in patients with repetitive wrist loading, particularly...
gymnasts. Patients typically present with ulnar wrist pain and TFCC injury may be demonstrated on MRI arthrogram or arthroscopy. For patients who fail non-operative management, patients with neutral or negative ulnar variance can be treated by arthroscopic debridement and patients with positive ulnar variance can be treated by ulnar shortening and/or debridement. In a child or adolescent with significant growth remaining, bony procedures should be delayed until growth ceases.\textsuperscript{67}

The scaphoid fracture is the most common carpal fracture in children with a peak incidence between 12 and 15 years of age. In the skeletally immature, the majority of fractures are minimally displaced and involve the distal pole, with fewer waist and proximal pole fractures. However, with increased athletic participation at increasingly intense competitive levels by children and adolescents, more adult-type displaced waist fractures are being seen. Patients present with wrist pain, limited motion and tenderness in the anatomic snuff box. Management of minimally displaced fractures (<1mm) involves a short arm thumb spica cast for 6 weeks for distal pole fractures and a long arm thumb spica for 4 weeks for waist fractures, followed by short arm casting until union occurs. Occult fractures can be diagnosed with bone scanning or MRI. Acute displaced fractures should be treated with open reduction and internal fixation. Scaphoid nonunion usually requires bone grafting with or without fixation (fig. 11).\textsuperscript{98-100} Scaphoid malunion or nonunion can lead to degenerative changes of the wrist in the long term. Stress fracture of the scaphoid waist can be seen, particularly in competitive gymnasts.\textsuperscript{101,102} Initial x-rays are often negative, with follow-up x-rays revealing a stress fracture.

Ligamentous injuries of the wrist are unusual in children but are being seen with increased frequency in the adolescent athlete engaged in high level sports. The volar intercarpal ligaments, particularly the radioscapholunate and radioscapoholocapitate ligaments, are important stabilisers of the wrist. Patients present with wrist pain and limited motion. Radiographs may reveal widening of the scapholunate interval or alteration of the scapholunate angle (normal 30 to 60°). Dorsal intercalated segment instability (DISI) can result from scaphoid fracture or scapholunate dissociation, resulting in an increased scapholunate angle. Volar intercalated segment instability (VISI) can result from disruption of the radiocarpal ligaments on the ulnar side of the wrist, resulting in a decreased scapholunate angle. Wrist arthrography, MRI and arthroscopy can be used to further delineate the extent of ligamentous injury. Partial injuries are treated with immobilisation. Acute complete ligamentous injuries are treated with ligament repair and K-wire fixation. Chronic carpal instability is usually treated with limited carpal fusions or proximal row carpectomy, often with unpredictable results.

Fig. 11. Scaphoid nonunion.
3.4 Hand Injuries

The thumb metacarpal phalangeal joint is commonly injured, particularly during skiing. These injuries result from excessive radial deviation during a fall on the outstretched hand with the thumb in abduction. In adults and older adolescents, injury to the ulnar collateral ligament of the thumb metacarpal phalangeal joint occurs (‘gamekeeper’s or skier’s thumb’). In children and adolescents, physical fracture of the proximal phalanx is more common. The ulnar collateral ligament inserts onto the proximal phalangeal epiphysis, thus predisposing to Salter-Harris III fracture (fig. 12). Nondisplaced fractures and partial ulnar collateral ligament injuries are treated with 4 to 6 weeks of immobilisation in a short arm thumb spica cast. Displaced fractures are treated with open reduction and internal fixation. Complete ligamentous injuries (>35 to 40° opening in flexion without a firm endpoint) and Stener’s lesions (interposition of the adductor aponeurosis) are treated with ligament repair.[103-107]

The ‘jammed finger’ is the most common joint injury in the paediatric and adolescent athlete’s hand. Axial compressive forces applied to the end of the finger can result in proximal interphalangeal joint (PIP) hyperextension with subluxation or dislocation of the joint. This injury is common in ball catching sports such as basketball or football. Reduction of the dislocated joint is accomplished by linear traction. Volar plate injury/avulsion or volar Salter-Harris III fracture may be associated, but rarely requires fixation. Treatment involves a very brief period of immobilisation (dorsal aluminioam splint) followed by oedema control (elastoplast wrapping) and motion (buddy-taping to adjacent digit) to avoid stiffness and a fixed flexion deformity. Most athletes can return to sports (with buddy-taping) in 1 to 2 weeks, although some pain and swelling may persist for months. Axial loading of the finger may also result in boutonniere deformity [PIP flexion, distal interphalangeal joint (DIP) extension] secondary to rupture of the central slip or a dorsally displaced Salter-Harris III fracture at the base of the middle phalanx. Acute injuries should be splinted in full extension for 4 to 5 weeks. Chronic reconstruction results in less reliable outcomes.[103-107]

Mallet finger is the most common injury occurring at the DIP joint, resulting from hyperflexion injury producing either extensor tendon (terminal tendon) rupture or Salter-Harris III avulsion of the distal phalangeal epiphysis (fig. 13). Although the patient is unable to actively extend the DIP joint, there is full passive motion. Unless there is significant displacement of a substantial epiphyseal fragment, the DIP should be splinted with a dorsal splint in full extension for approximately 6 weeks. Terminal tendon repair may be necessary if an extensor lag persists after 10 weeks, although this is unusual.[103-107] Hyperextension of the DIP joint may result in a dorsal DIP dislocation or avulsion of the
flexor digitorum profundus (FDP). FDP avulsion most commonly involves the ring finger and occurs during football or rugby as the finger catches on the opposing player’s shirt (‘jersey finger’). If identified early, the injury can be successfully treated. Missed diagnosis occurs when the patient does not recognise a significant injury or the care provider believes that the inability to flex the DIP joint is secondary to pain and swelling. Direct repair to the distal phalanx is accomplished if possible. With late diagnosis, direct repair is usually not possible as the tendon retracts and fibrosis occurs. In these cases, tendon grafts may be necessary.\textsuperscript{108}

Hand fractures are common athletic injuries in children. Fractures involving the physis are frequent, accounting for approximately 40% of hand fractures in the skeletally immature.\textsuperscript{104} Ossific nuclei appear in the metacarpals and phalanges by 3 years of age and fuse between 14 and 17 years. Remodelling potential exists for fractures near the epiphysis in the plane of motion, although there is minimal remodelling of rotational deformity. The vast majority of hand fractures in children can be managed non-operatively with splinting of nondisplaced fractures and closed reduction of angulated or displaced fractures. Fingertip crush injuries occur in tackling and collision sports. These injuries often involve a nailbed laceration and tuft fracture requiring splinting and nailbed repair. Phalangeal neck fractures typically occur between 5 and 10 years of age and involve the proximal phalanx. These fractures may redisplace after reduction and may have substantial rotation not appreciated on x-ray, thus requiring careful clinical examination. Metacarpal fractures in children are less common than adults. Little finger metacarpal neck fractures (‘boxer’s fracture’) can usually be managed by closed reduction and cast immobilisation for 3 weeks. Thumb metacarpal fractures often involve a Salter-Harris II fracture through the base of the metacarpal.\textsuperscript{103-107}

4. Conclusion

Upper extremity injury patterns in the paediatric athlete are unique to the growing musculoskeletal system and specific to the demands of the involved sport. Recognition of common injury patterns with early activity modification and the initiation of efficacious treatment can prevent deformity/disability and return the youth athlete to sport.

References
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