Elbow Fractures and Dislocations

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INTRODUCTION

Young children are at a significant risk for traumatic injuries that can lead to morbidity and mortality. Approximately 70% of fractures involve the upper extremity, with 8% to 10% involving the distal humerus or proximal radius and ulna.1,2 In 2005 alone, trauma to the upper extremity in children less than 19 years of age resulted in approximately $8 billion in direct health care costs and loss of estimated future income.3 The shoulder and elbow are the 2 joints responsible for positioning the hand in space for functional use. These actions allow infants and children to explore and interact with the world around them but place the upper extremity at risk for injury. The incidence of various fractures about the elbow peaks at different ages for children and depends highly on the specific activities performed as well as the maturity of the elbow.

The distal humerus physis develops as 4 distinct ossification centers, whereas the proximal radius and ulna each contribute 1 ossification center. The sequence of ossification is fairly predictable: the capitellum appears first between 1 and 2 years of age, followed by the radial head at 2 to 4 years of age, then the medial epicondyle at 4 to 6 years of age, the trochlea at 9 to 10 years of age, the olecranon at 9 to 11 years of age, and lateral epicondyle at 9.5 to 11.5 years of age. The appearance of the radial head is occasionally preceded by the medial epicondyle in girls, whose ossification centers typically appear 1 to 2 years earlier than boys. The trochlea, lateral epicondyle, and capitellum ossification centers fuse into the distal humeral epiphysis at around 11 years of age in girls and 13 to 14 years of age in boys. The radial head and olecranon ossification centers close at 12 to 13 years of age in girls and 14 to 15 years of age in boys. The medial epicondyle is the last to fuse to the distal humerus at 13 to 14 years of age in girls and 15 years of age in boys.4

SUPRACONDYLAR HUMERUS FRACTURES

Supracondylar humerus fractures are the most common pediatric elbow fracture, accounting for 3.3% of all pediatric fractures5 and 60% of...
pediatric elbow fractures. Biomechanically, the supracondylar region of the humerus is prone to injury because of the thin sheet of bone that sits between the medial and lateral columns. During a fall, children will attempt to brace themselves with their hand and wrist, which can transmit the force of the fall through an extended elbow joint to the supracondylar area. Tension on the anterior joint capsule, via elbow hyperextension, acts to further displace the fracture. Extension-type injuries resulting from a fall onto an outstretched hand (FOOSH) make up 97% of supracondylar fractures, whereas flexion-type injuries from a direct blow to the posterior olecranon compose the rest. Transphyseal injuries have been described in infants and should be considered in patients with elbow swelling and pain before the development of ossification centers, especially in the setting of suspected or confirmed nonaccidental trauma. This injury is difficult to diagnose on plain radiographs, although it can be apparent as a misalignment of the humerus and ulna; ultrasound is a useful adjunct modality to confirm a suspected diagnosis. Because of this misalignment, transphyseal injuries can be misinterpreted as an elbow dislocation. However, the latter is exceedingly rare in infants and toddlers. The treatment of transphyseal injuries is the same as that in displaced supracondylar fractures. Closed reduction and percutaneous pinning are the mainstay of treatment, and an elbow arthrogram can assist with identifying appropriate landmarks during pinning to ensure that anatomic alignment is obtained.

The peak age for supracondylar fractures is between 5 and 7 years. The child presents with elbow pain, edema, and variable ecchymosis, often with significant deformity in severe injuries. Open fractures are noted in up to 3% of patients; concomitant injuries, typically involving the forearm or wrist, are seen in 11% of patients. Occult fractures are common in the developing elbow, typically presenting as painful, swollen elbows without definitive radiographic evidence of fracture. An anterior and/or posterior fat pad sign (Fig. 1A) is often the only indication of occult injury. A careful physical examination including palpation of the radial neck, olecranon, medial and lateral epicondyles, and supracondylar region will often reveal the location of an occult fracture, which is often only manifested radiographically as a healing fracture on routine follow-up radiographs. A careful neurologic and vascular examination must be performed in the emergency department and documented, such that it can be compared with a postreduction or postoperative examination in displaced fractures. Any evidence of vascular compromise or insufficiency to the hand, especially in patients with a cool, white, pulseless extremity, is considered an indication for emergent reduction and surgical fixation. Nerve injuries are present in 11.3% of supracondylar fractures, most commonly in the anterior interosseous nerve, median nerve, and radial nerve for extension-type injuries and the ulnar nerve in flexion-type injuries.

Standard anteroposterior (AP) and lateral radiographs are obtained to evaluate the injured elbow. Once a supracondylar humerus fracture is identified, AP and lateral forearm and posteroanterior and lateral wrist radiographs are mandatory for the evaluation of concomitant injuries to the forearm or wrist. The diagnosis of an additional forearm or wrist fracture, a pediatric floating elbow, imparts a substantially increased risk of compartment syndrome and indicates surgical fixation of unstable radius and ulna fractures, which could otherwise be managed nonoperatively with closed reduction and casting. Preoperative grading of supracondylar humerus fractures is based on the lateral view (Table 1). A line drawn along the anterior cortex of the humerus shaft (anterior humeral line) should intersect or touch the capitellum. On the AP view, a postreduction determination of the angle between the long axis of the humerus shaft and the proximal capitellum ossification center, known as the Baumann angle, is typically performed. This angle, also known as the shaft-capitellum angle, normally lies between 64° and 81°; an increasing angle correlates with increasing clinical cubitus varus. It should be noted that there is confusion in the literature as to which angle Baumann was referring; the Baumann angle has been frequently described, incorrectly, as the angle between a line perpendicular to the humeral shaft line and the superior border of the capitellum (the complement of the true Baumann angle).

Treatment in children is based on the Gartland classification, with type I fractures requiring only above-elbow cast treatment for 3 to 4 weeks until radiographic healing is noted. The treatment of type II injuries (see Fig. 1B) remains controversial as some researchers advocate closed reduction and casting, whereas others advocate closed reduction and percutaneous pinning. Type II fractures, whereby the anterior humeral line touches the capitellum, can be treated in an above-elbow cast with weekly radiographs to ensure maintenance of alignment. Parikh noted that in type II injuries, closed reduction and casting in 90° to 100° of flexion resulted in adequate maintenance of alignment in 72% of patients; those that lost alignment during subsequent weekly follow-up were successfully converted to operative fixation.
when necessary. O'hara\textsuperscript{15} showed that closed reduction and plaster immobilization in type IIB (see Fig. 1C) and III (see Fig. 1D) fractures resulted in a 26% loss of reduction and surgical fixation. Type III injuries require expedient closed reduction and percutaneous pinning. In patients without neurovascular compromise, fixation can be delayed beyond 8 hours without an increased risk of patient morbidity and complications, allowing for patients presenting overnight to be treated the following morning, provided a qualified physician or assistant is available for close neurovascular monitoring.\textsuperscript{16}

Patients with type II and III injuries with neurovascular compromise or with concomitant unstable injury to the ipsilateral extremity should be
Table 1
Wilkins modification of the Gartland classification for extension-type supracondylar humerus fractures

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>I</td>
<td>Nondisplaced fracture</td>
</tr>
<tr>
<td>IIA</td>
<td>Displaced fracture with intact posterior cortical hinge</td>
</tr>
<tr>
<td>IIB</td>
<td>Displaced fracture with malrotation or lateral displacement without loss of cortical contact</td>
</tr>
<tr>
<td>III</td>
<td>Completely displaced fracture</td>
</tr>
<tr>
<td>IVb</td>
<td>Completely displaced fracture with multidirectional instability</td>
</tr>
</tbody>
</table>


taken to the operating room urgently for reduction and pinning. Indications for open reduction include open fractures and when interposed periosteum or neurovascular structures prevent anatomical alignment. This soft tissue interposition can often be detected during reduction maneuvers as a rubbery feeling instead of normal crepitus between fracture fragments. Any worsening of the vascular status of patients after reduction and pinning warrants an immediate surgical exploration by a qualified hand or vascular surgeon. Invasive vascular studies will delay diagnosis and add cost and possible morbidity while providing limited additional information that can be used in clinical decision making. In most cases of vascular compromise, the artery is simply tethered to the fracture by a supratrochlear branch of the brachial artery; however, arterial thrombus and intimal tear injuries can be seen and require exploration and repair or interpositional vein grafting.

During closed reduction, the fracture can be reduced via a milking procedure to remove interposed periosteum or brachial muscle. The fracture is then distracted and flexed with anterior pressure on the olecranon. AP alignment can be verified via the Baumann angle, and lateral alignment is verified using the anterior humeral line. Typically, 2 divergent percutaneous 0.062-in Kirschner (K) wires are then placed through the lateral condyle into the medial metaphyseal distal humerus. One pin is fixated into the medial column, just above the fracture line, while the other is passed superior to the olecranon fossa to hold fixation into the lateral column. In patients with significant medial comminution or unstable reduction during fluoroscopic evaluation, a third pin can be placed either from a lateral or medial entry point. If a medial pin is used, 2 steps are performed to protect the ulnar nerve. First the elbow is brought into extension to decrease anterior ulnar nerve subluxation; secondly, a small incision is made to dissect down to the medial epicondyle and verify that the pin does not transect or impinge on the ulnar nerve during motion. The placement of a medial and lateral pin (cross pinning) is biomechanically equivalent in torsional stability to the placement of 2 divergent lateral pins in anatomically reduced fractures but provides superior fixation in malreduced fractures and those with medial comminution. In patients whereby reduction is blocked by soft tissue or edema, and the previously described milking procedure does not help, a posteriorly placed, percutaneous intrafocal K wire can be placed to assist with reduction. Care must be taken not to penetrate past the anterior cortex and risk damaging the neurovascular bundle. Open reduction is reserved for patients with arterial injury or when anatomic reduction cannot be obtained via closed methods. Compartment syndrome has been noted in 0.5% of all supracondylar fractures and in up to 6% of patients with questionable vascular status. In children, compartment syndrome is best diagnosed using the 3 As (anxiety, agitation, and analgesia).

The first sign of impending compartment syndrome is an increasing need for narcotic analgesia, and sedating medications are contraindicated in the postoperative period as they can mask this need. This diagnosis is made clinically, and the measurement of compartment pressure often confuses the picture in that the natural diastolic pressure in children is often around 30 mm Hg. However, the measurement of compartment pressure can be useful in the operating room in order to compare preoperative and postoperative measurements, whereby a significant decrease in pressures can indicate that adequate release has been performed.

Nerve injuries associated with supracondylar humerus fractures typically resolve spontaneously over time. However, if no clinical or electromyographic recovery is noted after 5 months, exploration is warranted. Excellent recovery is typically noted with neurolysis, and sural nerve grafting is only required if a complete transection is identified. Cubitus varus or valgus can be seen in patients with inadequate initial reduction or inadequate fixation resulting in a loss of reduction. Symptomatic cubitus varus initially presents as a loss of carrying angle and painless, cosmetic
deformity but can lead to tardy posterolateral elbow instability. The preferred treatment of cubitus varus is a closing wedge osteotomy, whereas more severe cubitus varus requires a step-cut osteotomy or dome osteotomy to prevent lateral prominence. Superficial pin tract infections are seen in approximately 1% of patients; deep infections, including osteomyelitis and septic arthritis, are noted in 0.2%.

Postoperative management includes the placement of a plaster splint or loose above-elbow cast in 50° to 60° of flexion. Patients with a neurovascular abnormality or at risk for compartment syndrome are admitted for frequent neurovascular checks. The cast is removed at 4 weeks, and pins are pulled if fracture healing is noted on postoperative radiographs. Gentle elbow range of motion is begun and continued until full motion is obtained.

**INTRAARTICULAR HUMERUS FRACTURES**

Fractures involving the articular surface of the distal humerus are the second most common elbow fractures, accounting for approximately 20% of all elbow fractures. Lateral condyle fractures are the most common at 16.9% of elbow fractures, followed by medial condyle fractures. Lateral condyle fractures occur when a varus force is directed across an extended elbow, leading to an avulsion force across the distal humerus physis via the lateral collateral ligament complex. The fracture line travels through the epiphysis and will sometimes dissipate before reaching the articular cartilage surface because of the inherent pliability of this structure. Medial condyle fractures occur via a valgus-directed force through a similar mechanism, although the trochlea does not ossify until 9 to 10 years of age, making this fracture difficult to identify on radiographs in young children.

Occasionally, the only sign of injury is a small avulsion fracture noted on plain radiographs, which frequently represents a large osteochondral avulsion fracture (Fig. 2). Waters and colleagues termed these as TRASH lesions (The Radiographic Appearance Seemed Harmless) and recommended a low threshold for further imaging studies, including ultrasound, arthrography, or magnetic resonance imaging (MRI). In young children who require sedation for MRI, the author recommends an elbow arthrogram under anesthesia in the operating theater, with the plan for subsequent surgical fixation in the same setting as indicated by the radiographic findings.

The incidence of lateral condyle fractures peaks at 6 years of age, whereas the peak for medial condyle fractures is between 8 and 10 years of age. Patients complain of swelling and tenderness about the elbow following a fall from substantial height. AP and lateral radiographic images are often misleading with these injuries because of the oblique posterior fracture plane. The internal oblique view is usually the best view to detect a lateral condyle fracture and to evaluate displacement; therefore, 4 views of the elbow, including AP, lateral, internal, and external oblique, are advised for suspected or confirmed condylar fractures.

**Fig. 2.** (A) Small avulsion fracture in the anterior elbow, which (B) corresponds to a large osteochondral capitellar shear fracture on exploration of the joint.
Computed tomography (CT) scans have been advocated by some as it allows for 3-dimensional (3D) visualization of the displacement seen in this complex fracture pattern; however, it does not allow for visualization of the articular surface and is not routinely recommended.31

Lateral condylar fractures of the humerus were originally classified by Milch32 as entering the joint surface through the trochlea-capitellar groove (type I) or through the lateral wall of the trochlea (type II). Although this scheme postulated that type I fractures were more stable than type II, this was not borne out in later studies, which additionally showed a 52% rate of disagreement between radiographs and surgical findings.33 More recent classification schemes are based on the amount of displacement seen on the internal oblique radiograph34 and can be used to indicate the amount of displacement seen on the internal oblique radiograph.34 More recent classification schemes are based on the amount of displacement seen on the internal oblique radiograph34 and can be used to indicate surgical treatment (Table 2). Fractures displaced less than 2 mm can be treated with close observation in an above-elbow cast until radiographic healing is noted (Fig. 3A). Weekly radiographs can be obtained in the cast to assess for changes in alignment; but the practitioner should have a low threshold for obtaining out-of-cast images, in cases when such assessment is difficult. Late fracture displacement, even 2 to 3 weeks after injury, can be seen (see Fig. 3B), often in patients with initial examination findings of significant soft tissue swelling or pain out of proportion to the radiographic findings.

Type II and type III injuries require surgical fixation because of the high rates of nonunion and malunion seen following closed treatment of these injuries. Intraoperative arthrogram is useful for assessing joint surface congruity following closed reduction in type II injuries. Although type II injuries can be treated with closed reduction if adequate reduction is identified, most researchers would advocate open reduction through a direct lateral approach in type III injuries.35 Dissection posteriorly along the capitellum should be avoided because of the increased risks of damaging the blood supply to the developing capitellum ossific nucleus. Song and colleagues36 recently published good results with closed reduction under arthrogram and pinning of significantly displaced type III injuries; however, they warned that the technique was difficult to master and should not be undertaken by those unfamiliar with the treatment of pediatric lateral condyle injuries.

Medial condyle fractures were originally described and classified by Milch,32 but the classification was expanded by Kilfoyle37 to include indications for surgical treatment. Type I injuries are incomplete and dissipate at the physis, whereas type II injuries progress through to the articular surface without displacement. Type III injuries are complete and unstable, typically with the fragment being pulled anteriorly and medially because of the pull of the flexor-pronator mass. Nondisplaced injuries, such as those seen in type I and type II fractures, can be treated in an above-elbow cast, with close follow-up to ensure the fracture remains aligned. Unstable injuries, including type II fractures that subsequently displace and type III fractures, should be treated with open reduction and internal fixation through a medial approach.38 Care must be taken to protect the ulnar nerve during this dissection, and anterior transposition may be indicated in patients with a difficult reduction. Extensive posterior and medial dissection should be avoided as it can lead to the development of trochlear osteonecrosis and subsequent fishtail deformity (see Fig. 3C).

The surgical technique for condylar fractures is similar to supracondylar fractures. The c-arm can be used as a hand table or, alternatively, the patient’s arm can be placed on a hand table. The author’s preferred method for the arthrogram is via a posterior approach into the olecranon fossa just superior to the tip of the flexed olecranon. In comparison with the standard approach into the soft spot between the radial head, lateral epicondyle, and olecranon, this approach minimizes the risk of extravasated dye hindering the assessment of articular congruity because of the more superior entry portal. Patients are managed in a cast for 4 to 6 weeks postoperatively, until fracture healing is noted on radiographs and percutaneous pins can be pulled. Range-of-motion exercises are then recommended with the addition of occupational or physical therapy as needed. Stiffness is

### Table 2

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<th>Type</th>
<th>Displacement</th>
<th>Treatment</th>
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<tr>
<td>I</td>
<td>&lt;2 mm</td>
<td>Cast with weekly follow-up</td>
</tr>
<tr>
<td>II</td>
<td>&gt;2 mm with intact cartilage hinge seen on arthrogram</td>
<td>Closed reduction and percutaneous pinning</td>
</tr>
<tr>
<td>III</td>
<td>&gt;2 mm with complete disruption of articular surface</td>
<td>Open reduction and pinning or internal fixation</td>
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a frequent complication following articular injury in the elbow and occupational or physical therapy is often required, even after nonoperative treatment. Other complications in condylar fractures included malunion and nonunion, especially following lateral condyle injury whereby the fragment migrates in a superolateral direction. This complication results in significant cubitus valgus, which is initially a painless deformity but can develop into tardy ulnar nerve palsy or symptomatic arthritis. Surgical treatment of established nonunions and malunions is difficult because of the high rates of complications, such as stiffness, osteonecrosis of the capitellum, and persistent nonunion. A recent report by Bauer and colleagues evaluating intraarticular osteotomy to treat established malunions of lateral condyle fractures demonstrated an improvement in the end range of motion of the elbow but noted that the procedure was technically demanding and not without risk. The indications for open reduction and internal fixation of the lateral condyle nonunions are narrow and include patients with a large metaphyseal fragment; less than 1 cm of joint line displacement; and an open, viable lateral condylar physes. Patients that do not meet these criteria could be considered candidates for in situ fusion of the displaced articular surface and subsequent varus osteotomy to correct the valgus.

Fig. 3. Lateral condyle fractures: (A) Minimally displaced fracture of the lateral condyle. (B) Displaced lateral condyle fracture consistent with an unstable fracture pattern. (C) Fishtail deformity 2 years after open reduction and internal fixation of the fracture noted in Fig. 3B.
deformity at the elbow. Those patients with tardy ulnar nerve palsy undergo anterior ulnar nerve transposition in addition to a supracondylar varus osteotomy. Medial condyle nonunion is rare and typically presents as a painless cubitus varus. Fishtail deformities can develop following lateral, medial, or supracondylar fractures of the distal humerus and often present as a painless radiographic finding (see Fig. 3C). In most cases, the radiographic deformity does not progress to functional losses or cosmetic findings and should be observed radiographically on a yearly basis.

**APOPHYSEAL ELBOW INJURIES**

The olecranon, medial epicondyle, and lateral epicondyle are apophyseal centers of attachment for the triceps, flexor/pronator, and extensor muscles, respectively. The medial and lateral epicondyles additionally serve as the origin of the anterior and posterior bands of the ulnar (medial) collateral ligament and radial (lateral) collateral ligament, respectively. Injuries to the medial epicondyle are the most common injuries to the apophyseal elbow structures, composing 14% of distal humerus fractures. Approximately 50% of medial epicondyle fractures are associated with pediatric elbow dislocations, the most serious of which involve an incarcerated fragment in the joint following reduction. Fractures of the lateral epicondyle are rare and are usually only diagnosed during a narrow age range when the epicondyle is ossified but not yet fused to the trochlea. Olecranon apophyseal fractures are associated with osteogenesis imperfecta (OI) in approximately 50% of cases. In patients with a suspected or confirmed apophyseal elbow injury, there is an association with MORE fractures about the elbow: medial epicondyle, olecranon, radial head, lateral epicondyle (Fig. 4).

Medial epicondyle fractures are seen with a fall or sports injury inducing a valgus stress across the elbow, often resulting in an elbow dislocation, which can spontaneously reduce. The most common presenting symptom is swelling and ecchymosis about the medial elbow, whereas injury to the ulnar nerve is rare despite significant trauma in the region. Anatomically, the medial epicondyle sits posteriorly along the distal ulna. Most commonly, the avulsed fragment translates anteriorly and inferiorly, making a true radiographic determination of displacement difficult. AP and lateral radiographs of the elbow are the first step in diagnosis, although internal oblique radiographs serve as a better approximation of true displacement. The 3D CT scan has been shown to be the most precise method for the measurement of displacement. The treatment of medial epicondyle fractures is based on the amount of displacement noted; however, a lack of consensus exists as to how much displacement warrants surgical intervention. Cast treatment is indicated for avulsions of the medial epicondyle with less than 5 mm of displacement as measured on both the AP and lateral radiographs. Radiographic union is not always apparent; however, most patients develop a stable fibrous union that allows for painless range of motion and return to full activities. In patients with greater than 15-mm displacement (Fig. 5),

![Fig. 4. Concomitant displaced fractures of the radial neck and olecranon.](image1)

![Fig. 5. Medial epicondyle fracture with 15 mm of displacement.](image2)
nonoperative treatment yields a high rate of persistent valgus elbow instability. The controversy lies with the treatment of fractures with 5 to 15 mm of displacement whereby some researchers have shown good functional results with closed treatment, whereas others have shown a higher incidence of instability, especially in gymnasts or athletes who compete in throwing sports. In patients with incarcerated epicondyle fractures, prompt diagnosis and treatment is essential to prevent articular necrosis. Closed reduction under sedation or anesthesia via the Robert maneuver (placing a valgus stress across the elbow with wrist and finger flexion to extract the fragment) is occasionally successful, and open reduction is often performed concomitantly with internal fixation. In young patients with small fragments, internal fixation is typically performed with divergent K wires, whereas partially threaded, cannulated screws plus a washer are advised in older children.

Lateral epicondyle fractures are rare and are typically associated with a varus force directed across the elbow leading to avulsion via the lateral collateral ligament. Occasionally, these fractures are associated with medial elbow dislocations and present with tenderness and swelling about the lateral elbow. It is important to differentiate between fractures of the radial neck, lateral epicondyle, and supracondylar humerus based on the exact location of tenderness, especially in cases when radiographs are inconclusive. Additionally, the lateral epicondyle ossifies peripherally first, then proceeds centrally, such that the normal ossification pattern can be mistaken for a displaced fracture on AP elbow radiographs. Advanced imaging, such as MRI or ultrasound, can be used to confirm the diagnosis. Most lateral epicondyle fractures are minimally displaced and can be treated with a cast or brace until symptoms subside, although incarcerated lateral epicondyle fragments requiring open reduction have been reported with medial elbow dislocations.

Olecranon apophyseal avulsion fractures are rare in children, except in patients with OI. Non-displaced fractures can be treated in an above-elbow cast, although in patients with OI, there is a high rate of refracture even after radiographic healing, such that operative fixation should be considered in these patients. Fractures with more than 3 to 5 mm of displacement are indicated for surgical stabilization. The fracture is exposed from a posterior approach and coapted using a tension band construct. In patients with OI, consideration should be taken to leave the hardware in place in order to reduce the refracture risk.

ELBOW DISLOCATIONS

Dislocations of the elbow joint are rare in the first decade of life and become more common in older children involved in sporting activities, with a peak age noted at around 12 years old. These injuries are more common in boys and typically involve the nondominant extremity. In patients less than 2 years of age without a capitellum osseous nucleus, displaced transphyseal fractures are often confused with elbow dislocations. This differentiation is important, as the former requires a child abuse work-up and closed reduction and pinning of the fracture. Elbow dislocations are classified based on the direction of dislocation, which includes straight posterior, posterolateral, posteromedial, lateral, medial, and anterior.

Concomitant fractures (medial and lateral epicondyles, coronoid, radial head, radial neck, and osteochondral avulsion fractures) to the elbow are common and should be assessed before and after reduction. Conscious sedation or general anesthesia is typically required for reductions and the stability of the elbow should be assessed after joint relocation. Advanced imaging, such as CT or MRI, is indicated in patients with incongruent reductions or significant instability to assess for occult injuries or incarcerated articular shear injuries.

Simple, stable dislocations can be treated conservatively with a splint or cast for 2 to 3 weeks, followed by active range-of-motion exercises, or formal occupational or physical therapy. Medial, lateral, or straight posterior dislocations can be treated using a hinged elbow brace that blocks terminal extension at the angle noted to maintain stability, which allows for immediate range of motion to mitigate stiffness. Surgical fixation is usually limited to patients in whom concomitant displaced elbow fractures are noted or in patients with incongruent reductions.

Complex dislocations involving separation of the proximal radioulnar joint, so-called divergent elbow dislocations, or those involving translocation of the radius and ulna have been described in pediatric patients. Although these injuries seem to involve significant destabilizing forces about the elbow, simple closed reduction and brief immobilization is often sufficient for treatment provided that they are promptly and accurately diagnosed. Open reduction is indicated in patients with incongruent reductions or unstable concomitant fractures. The most common complication following elbow dislocation is a loss of terminal motion in extension or flexion, which can be ameliorated by encouraging early, protected range of motion within the limits of stability.
Ligamentous injuries to the elbow are common in children, especially in early childhood. The most common injury results from a pulled arm, whereby the radial head subluxes out of the annular ligament leading to pain and decreased motion. This injury has been termed a nurse-maid’s elbow, and patients typically present with arm held in a flexed and pronated posture at the elbow. Radiographs of the elbow are taken to rule out true fracture or dislocation but are not suggestive of radiocapitellar subluxation as has been previously suggested. The reduction technique involves elbow flexion and hyperpronation, which has been shown to be less painful and more successful than elbow flexion and supination. Following successful reduction, patients are typically able to use the elbow without pain; any subsequent refusal to use the arm should warrant splinting and close follow-up to rule out associated cartilaginous or ligamentous injury to the elbow.

PROXIMAL RADIUS AND ULNA FRACTURES

Fractures of the proximal radius and ulna account for approximately 7% and 6% of elbow fractures, respectively. The radial neck can be injured during impaction against the capitellum with longitudinal compression or a valgus force. Transphyseal fractures of the radial neck can occur during reduction of elbow dislocations if the head gets caught on the posterior capitellum during anterior translation. Age differences in injury pattern are present with physeal or metaphyseal compression injuries occurring in younger children, whereas articular surface fractures typically occur in older children. Most fractures occur following a FOOSH injury and present with elbow pain, swelling, and tenderness over the radial neck. AP and lateral radiographs of the radial neck view can be obtained to confirm the diagnosis when radiographs are inconclusive or to verify displacement.

Radial neck fractures were classified by Judet and are based on displacement and angulation noted on AP radiographs (Table 3). Judet type I and II injuries are nondisplaced or angulated less than 30°, respectively, and can be treated in an above-elbow cast. In children with greater than 30° of angulation (Judet III and IV), closed reduction under conscious sedation or general anesthesia should be performed. Various reduction techniques have been described, and reduction is frequently successful. Following failed closed reduction, a percutaneous pin can be inserted into the fracture site and used for leverage and/ or fixation of the fragment. Additionally, a distally inserted flexible intramedullary nail can be used to assist with fracture reduction and for definitive fixation until healing is noted. Open reduction is only indicated following failed closed reduction and leads to an increased risk of complications, including stiffness, nonunion, or avascular necrosis. Following open reduction, internal fixation with either a flexible nail or K wires should be performed to lessen the risk of postoperative radial head avascular necrosis.

Radial head fractures are rare in children and are predominantly found following closure of the radial neck physis. In skeletally immature children, radial neck fractures are associated with progressive subluxation of the radiocapitellar joint and arthritis, such that even nondisplaced injuries should be followed closely. Thus, a low threshold for surgical fixation is advised in these injuries. Operative indications are similar to those seen in adults and include greater than 50% involvement of the articular surface or greater than 2-mm articular step-off. Fractures are fixed from either a posterolateral (Kocher) approach between the anconeus and extensor carpi ulnaris (ECU) muscles or a lateral approach between the extensor digitorum communis and ECU muscles. Radial head excision is not advised in children because of bony overgrowth of the radial shaft, and every attempt should be made to fix even comminuted articular fractures in these patients.

Olecranon fractures often occur following a direct blow to the proximal ulna and present with posterior elbow pain, swelling, and olecranon tenderness. AP and lateral radiographs of the elbow are typically sufficient. In rare cases, osteochondral sleeve injuries involving a substantial portion of the articular surface are possible and are best diagnosed using MRI. Minimally displaced fractures can be treated in an above-elbow cast. Olecranon fractures with 1 to 3 mm of displacement are often stable because of the

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<th>Type</th>
<th>Description</th>
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<tbody>
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<td>I</td>
<td>Nondisplaced or horizontal shift of epiphysis</td>
</tr>
<tr>
<td>II</td>
<td>&lt;30° angulation</td>
</tr>
<tr>
<td>III</td>
<td>30°–60° angulation</td>
</tr>
<tr>
<td>IVa</td>
<td>60°–80° angulation</td>
</tr>
<tr>
<td>IVb</td>
<td>&gt;80° angulation or complete dislocation of epiphysis</td>
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thick periosteum found in children and can be casted in slight extension to alleviate undue tension on the fracture from the triceps muscle. Fractures with displacement of more than 3 mm along the articular surface should be reduced and fixed with a tension band construct. The use of a nonabsorbable suture for the figure-of-8 band has been advocated in children in order to limit the dissection necessary during hardware removal.64

**MONTEGGIA FRACTURES**

Giovanni Monteggia first described a fracture of the proximal ulna with dislocation of the radial head in 1814, before the advent of radiography. Bado65 subsequently classified these injuries based on the direction of the radial head dislocation (Table 4). Additionally, because of the presence of incomplete fractures and open physes in children, Bado also described Monteggia-equivalent fractures in skeletally immature patients. Type I equivalents involve greenstick or plastic deformation fractures of the ulna and are the most common.65 Less common equivalent types include both-bone proximal-third forearm fractures with the radial fracture more proximal than the ulnar fracture, elbow dislocations with an ulnar diaphyseal fracture with or without a proximal radius fracture, and isolated radial neck fractures with radiocapitellar dislocation. Patients often present with forearm pain following a FOOSH injury, which often masks the elbow pain caused by the radiocapitellar dislocation, making it easy to miss the Monteggia component both clinically and radiographically. Standard AP and lateral radiographs of the forearm are obtained along with AP and lateral views of the elbow. Both sets of radiographic films are recommended during the initial and subsequent evaluations, as it is important to follow both fracture healing and radiocapitellar alignment throughout the treatment regimen. The radiocapitellar line has been used to verify appropriate radiographic alignment but has been shown to be unreliable, especially in younger patients.66 Additionally, a line should be drawn along the posterior cortex of the ulna on the lateral view (Fig. 6A). The ulnar bow sign is found if any portion of the ulna lies anterior to this line, which indicates that there is a pathologic lesion, such as plastic deformation or malunion of the ulna.67 Furthermore, congenital radial head dislocations have been described in patients with proximal ulna fractures. A careful radiographic assessment of the radial head will reveal a concave radial head in acute dislocations and a convex radial head in chronic injuries.

Monteggia fractures are treated based on the ulnar fracture with careful consideration as to the direction of dislocation as identified with the Bado classification.69 Closed reduction under conscious sedation or general anesthesia should be attempted for all angulated incomplete fractures. Plastic deformation injuries often require significant force over a bolster to achieve reduction. In complete injuries, the ulnar fracture should be brought out to length followed by correction of the angular deformity, which often will lead to relocation of the radiocapitellar joint. If spontaneous reduction is not achieved, the elbow can be flexed to 90° and the forearm can be fully supinating in Bado I injuries and pronating in Bado II and III injuries to assist with reduction. Following reduction, the fracture should be immobilized in a splint or cast in 100° to 110° of flexion in full supination or pronation (based on the reduction maneuver) to increase stability. If closed treatment is chosen, the fracture should be monitored with weekly biplanar forearm and elbow radiographs to ensure that late fracture displacement or radiocapitellar subluxation does not occur. Operative fixation is often required in patients with short oblique or transverse injuries to the proximal ulna metadiaphysis because of the inherent instability seen with these fractures. Internal fixation is typically performed with K wires or a plate-and-screw construct to maintain alignment, whereas in type IV injuries intramedullary fixation of the radius and ulna are often required.

Monteggia fracture/dislocations often present as missed Monteggia lesions in cases when the initial treating physician missed the dislocation or when progressive subluxation of the radiocapitellar joint occurs over time because of a malunited ulna fracture. Most often these are Bado I injuries because an anterior radial head dislocation is often clinically silent. An ulnar bow sign is often present in these patients, and early operative intervention is indicated in order to prevent the development of radial head dysplasia. The operative technique involves a tricortical osteotomy of the ulna at the apex of deformity and open reduction of the radiocapitellar joint (see Fig. 6B). The osteotomy should

**Table 4**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>I</td>
<td>Anterior dislocation of radial head</td>
</tr>
<tr>
<td>II</td>
<td>Posterior dislocation of radial head</td>
</tr>
<tr>
<td>III</td>
<td>Lateral dislocation of radial head</td>
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<tr>
<td>IV</td>
<td>Anterior dislocation of radial head with concomitant radial shaft fracture</td>
</tr>
</tbody>
</table>

be progressively angulated until the radiocapitellar articulation is stable throughout the entire range of elbow motion, both in pronosupination and flexion/extension. Reconstruction of the annular ligament is seldom required unless persistent instability remains.

**SUMMARY**

Injuries to the elbow are common in children and occur throughout all age groups. Careful clinical and radiographic evaluation can lead to an accurate diagnosis and prompt, appropriate treatment. Although many injuries about the elbow present pitfalls during diagnosis and treatment, most children recover excellent function and are able to return to premorbid activities with no limitations.

**REFERENCES**

39. Bauer AS, Bae DS, Brustowicz KA, et al. Intra-articular corrective osteotomy of humeral lateral condyle...


