INTRODUCTION

Fractures about the elbow are common in children and adolescents and comprise 5% to 10% of fractures in this age group.1–4 They also account for most operatively treated injuries, up to 85% in some series.2,3 Supracondylar humerus fractures are the most common injury in this region, followed by lateral condyle and medial epicondyle fractures. The unique developmental anatomy of the elbow makes radiographs sometimes difficult to interpret. Combined with the potential for complications in the growing child, this often provokes anxiety in referring primary care providers, emergency medicine physicians, or even treating orthopedic surgeons. This article discusses the diagnosis and management of the most common complications encountered by treating orthopedic surgeons.

SUPRACONDYLAR HUMERUS FRACTURES

Malunion

Cubitus varus is defined as a loss of carrying angle of more than 5° compared with the contralateral elbow. It is the most common angular deformity following supracondylar humerus fractures.5,6 Historically, it has been reported in up to 58% of nonoperatively treated patients.7 Pirone and colleagues8 observed a 3% incidence after operative management of supracondylar humerus fractures. In current practice, an estimated 5% to 10% of supracondylar humerus fractures develop cubitus varus; although rates are lower with operative treatment, varus deformity can occur, typically caused by suboptimal Kirschner wire (K-wire) placement. The typical deformity includes varus malalignment, internal malrotation, and hyperextension or recurvatum (Fig. 1).9
Cubitus varus has traditionally been regarded as a cosmetic concern but recent studies have shown the potential for functional complications. Two recent studies have identified cubitus varus as a risk factor for subsequent fracture.\textsuperscript{10,11} Davids and colleagues\textsuperscript{10} reported on 6 children who sustained lateral condyle fractures at an average of 32 months after their initial elbow fracture. These patients had cubitus varus as a sequela of their initial injury (supracondylar fracture in 5 and lateral condyle in 1), and the investigators suggest that varus deformity increases both the shear force and torsional moment generated by a fall. In a similar study, Takahara and colleagues\textsuperscript{11} described 9 patients with previous supracondylar fractures who sustained epiphyseal injuries (8 lateral condyle fractures and 1 physeal separation). These patients all had cubitus varus deformity following their initial fracture, and sustained the second fracture at an average of 18 months after the first.

Cubitus varus from remote fracture was also identified as a contributing factor in 18 patients with posterolateral rotatory instability (PLRI).\textsuperscript{12} The average varus was 15° and the tardy PLRI presented more than 20 years following the fracture. The investigators illustrate the mechanism whereby cubitus varus leads to chronic attenuation of the lateral collateral ligament complex.

Multiple studies have also identified cubitus varus as a precursor to tardy ulnar nerve palsy,
despite being more commonly associated with cubitus valgus. Various mechanisms by which varus deformity leads to ulnar nerve symptoms have been described. In 14 of their 15 patients, Abe and colleagues\(^\text{13}\) found the ulnar nerve to be constricted by a fibrous band between the 2 heads of the flexor carpi ulnaris; 9 of these patients also had an ulnar nerve that ran anterior to the deformity. Spinner and colleagues\(^\text{14}\) reported on 5 patients with snapping (dislocation) of the medial portion of the triceps with the ulnar nerve, leading to either friction neuritis or compression of the ulnar nerve by the snapping triceps muscle. In contrast, Mitsu-
nari and colleagues\(^\text{15}\) showed a significant association between tardy ulnar palsy and the internal rotation deformity that occurred as a sequela of supracondylar humerus fracture, rather than the varus deformity. They proposed that the internal rotation involves posterior displacement of the distal medial fragment, which causes stretching of the ulnar nerve with elbow flexion.

Various osteotomies have been advocated, all of which attempt to correct varus angulation; complex and dome osteotomies may also improve rotation or hyperextension, or minimize lateral prominence. Proponents of complex osteotomies cite better correction and cosmesis,\(^\text{9,16}\) whereas advocates for simple closing wedge osteotomies cite functional improvement and lower complication rates.\(^\text{17,18}\)

In most cases, a simple closing wedge osteotomy fixed with percutaneously placed K-wires suffices.\(^\text{19,20}\) In a systematic review of 40 studies involving nearly 900 patients, Sofelt and colleagues\(^\text{20}\) found a mean angular correction of 27.6° across all osteotomy types. No technique showed statistically significant superiority to another, and there were no differences in complication rates. The overall complication rate was 14.5%, with transient nerve palsy being the most common. In a recent retrospective study of 90 patients treated with a French osteotomy (a lateral closing wedge osteotomy that relies on an intact medial hinge and lateral screw and wire tension-band construct), North and colleagues\(^\text{18}\) reported a complication rate of 3.3% and no nerve injuries.

The timing of corrective osteotomy is controversial. At a minimum, surgery should be delayed until the fracture has healed, remodeling is mature, and range of motion has reached maximum improvement. Ippolito and colleagues\(^\text{21}\) recommended waiting until close to skeletal maturity because several of their patients showed loss of correction with continued growth. However, Voss and colleagues\(^\text{22}\) found that 11% of the patients in their series showed disruption of medial-sided growth. They thought that this could lead to progressive worsening of deformity and recommended corrective osteotomy at least 1 year after injury, but not necessarily waiting until skeletal maturity.

**LATERAL CONDYLE FRACTURES**

**Nonunion and Malunion**

Nonunion is more common in lateral condyle fractures than supracondylar humerus fractures (Fig. 2). The reason for this is likely multifactorial and may involve the intra-articular nature of the fracture, poor blood supply of the epiphyseal fragment, and the pull of the common forearm extensor tendon.\(^\text{23,24}\) Risk factors for nonunion include delayed diagnosis and nonoperative treatment.\(^\text{7,23}\) Symptomatic patients may complain of ulnar nerve dysfunction, pain, instability, or deformity.\(^\text{25}\) Treatment depends on the timing of

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**Fig. 2.** Lateral condyle nonunion in a 5-year-old boy. (A) At 7 weeks postinjury, the lateral condyle shows evidence of nonunion on this AP radiograph. (B) AP and (C) lateral radiographs following open reduction and internal fixation.
diagnosis and the distinction between delayed union and nonunion. Most investigators agree that acute fractures (<3 weeks from injury) with more than 2 mm of displacement should be reduced and stabilized surgically. In addition, there is agreement that symptomatic nonunions (>12 weeks from injury) also benefit from surgery.

Delayed presentation (3–12 weeks from injury) of a displaced fracture continues to be a controversial problem. Cited reasons for nonoperative treatment include the possibility of asymptomatic malunion with immobilization alone, difficulty with reduction given soft tissue swelling and callus formation, tenuous blood supply to the distal fragment, and the risk of physeal arrest. Although older studies found no benefit with surgery in patients treated greater than 3 to 6 weeks after injury, newer studies advocate open reduction and fixation. Wattenberger and colleagues reported on 9 patients who underwent open reduction and pin fixation greater than 3 weeks postinjury. Union was universal and there was no avascular necrosis. Similarly, Agarwal and colleagues treated 22 patients greater than 4 weeks from injury with open reduction and pinning or screw fixation in older children. They reported overall favorable results, with 2 cases each of nonunion and physeal arrest, and 1 case of avascular necrosis. Both studies emphasized the importance of maintaining the posterior soft tissue attachments in order to avoid avascular necrosis.

Treatment of an established nonunion should be guided by the severity of symptoms, patient age, and functional goals, as well as the patient’s and family’s expectations and commitment to participate in therapy. Risks of surgery include osteonecrosis, loss of range of motion, physeal arrest, and persistent nonunion. Long-standing nonunions from fractures extending lateral to the capitellotrochlear groove (Milch type I) are more likely to be symptomatic, and may benefit from surgical correction more than fractures with an intact radiocapitellar joint.

Given the complexity of lateral condyle nonunion, multiple surgical strategies have been suggested. Papandrea and Waters describe the surgeon’s dilemma as choosing between fixation in situ with the potential for angular deformity, or reduction with the potential for avascular necrosis. Either choice may also require a supracondylar osteotomy, bone grafting, and nerve decompression/transposition, which can be performed at the time of fracture fixation or in a staged fashion.

High union rates with good functional outcomes have been reported with fibrous take-down, reduction, and fixation with K-wires, as long as soft tissue stripping is minimized. These investigators recommend ranging the joint after provisional anatomic fixation; if range of motion is decreased compared with baseline, the fragment is replaced in its displaced location and stabilized. They also recommend fixation adjuncts, as needed, including cancellous screws for large fragments, a tension-band technique, or a narrow plate. If the pull of the common extensor tendon makes reduction difficult, a lengthening of the common extensor aponeurosis can be performed.

An alternative is in situ stabilization with supracondylar osteotomy to treat the resulting valgus angulation. Knight and colleagues showed good results with fragment compression alone using a percutaneously placed cancellous screw, as long as the interval between injury and nonunion diagnosis was less than 16 weeks.

The timing of corrective osteotomy is subject to the same considerations cited earlier for varus deformity. Correction is generally delayed until the child has neared skeletal maturity and most investigators recommend waiting at least 1 year from initial injury before pursuing late angular correction.

In the rare case of lateral condyle malunion, an intra-articular osteotomy can improve elbow range of motion by more than 35°; there was a trend toward better results in Milch type I fractures. For all treatment strategies of nonunions and malunions, the authors emphasize the importance of maintaining the posterior soft tissue attachments to the lateral fragment in order to avoid osteonecrosis.

Lateral spurring or overgrowth following lateral condyle fracture is common. In a study of 212 fractures, spurring was seen in 73%, and the size of the spur correlated with the degree of displacement. Range of motion was not significantly affected in this series. Although potentially a cosmetic concern, the lateral spur seems to be of no functional importance.

MEDIAL EPICONDYLE FRACTURES

Nonunion

Medial epicondyle nonunion or fibrous union is reported in most displaced fractures treated nonoperatively; however, only 21% of all nonunions are symptomatic. Symptoms may include pain, weakness, decreased range of motion, and ulnar nerve compression. Treatment should be tailored accordingly. Fragment excision and fixation have both been advocated. Smith and colleagues reported union in 7 out of 8 patients and return to athletics in all patients treated with...
open reduction and screw fixation. In 5 patients with valgus instability at an average of 10 years from injury, Gilchrist and McKee performed fragment excision and advancement of the ulnar collateral ligament; all patients had good patient-reported outcome scores. In contrast, Farsetti and colleagues reported poor results from fragment excision at 34 years of follow-up. Complications included pain, weakness, paresthesias, and instability. In an effort to decrease hardware-related complications, Shukla and Cohen performed open reduction and internal fixation (ORIF) using a tension-band technique for symptomatic nonunions in 5 patients. They achieved union in all patients and reported high satisfaction and no complaints related to elbow stiffness or prominent hardware.

**STIFFNESS**

Function-limiting stiffness following elbow fractures is uncommon in the pediatric population. Studies uniformly show a rapid gain in range of motion within the first month following discontinuation of immobilization, then gradual improvements for up to a year. Most children have no significant side-to-side difference in elbow range of motion. Factors associated with longer recovery time include increasing patient age, length of immobilization, severity of injury, intra-articular fracture, and need for surgical intervention. In order to optimize treatment, stiffness should be classified based on cause. Intrinsic causes include intra-articular malunion, callus formation, and degenerative changes. Extrinsic causes include heterotopic ossification and soft tissue contracture. Given the potential for improvement in motion over a long time period and data from a large study showing that surgery for elbow stiffness in children is less effective than in adults, splinting and physical therapy should be the first-line treatment. Experienced investigators emphasize unrestricted play (especially swimming) over formal physical therapy. Given the potential for improvement in motion over a long time period and data from a large study showing that surgery for elbow stiffness in children is less effective than in adults, splinting and physical therapy should be the first-line treatment. Experienced investigators emphasize unrestricted play (especially swimming) over formal physical therapy. Indications for surgery are a functional deficit caused by stiffness in a child at least 6 months after injury who has undergone an appropriate trial of nonoperative treatment.

Three studies in the past 20 years have specifically reported outcomes of open surgical release in children with stiff elbows. Common themes include the need to address both intrinsic and extrinsic blocks to motion, release and/or transposition of the ulnar nerve (especially in cases in which flexion is improved), and the use of a continuous passive motion machine with adequate pain control (with either a peripheral nerve block or patient-controlled analgesia) postoperatively. Lateral, medial, and combined approaches have proved successful, and no comparisons have been studied to suggest superiority of a given approach. Each patient was treated individually, and the most common procedures were anterior and posterior capsulotomies; olecranon tip excision; and removal of hardware, osteophytes, and loose bodies.

Mih and Wolf studied 9 patients and showed an increase in arc of motion of 53°; Bae and Waters reported a similar gain of 54°. This finding is consistent with the adult literature, with gains in arc of motion reported around 45° to 50° in large cohorts. However, in their study of 37 patients, Stans and Morrey reported less favorable results, with an average gain in arc of motion of 28°, including 2 patients who lost motion and 1 who gained none. Unlike the previous 2 studies, Stans and colleagues did not perform muscle or tendon lengthening as part of their treatment, which may account for the discrepancy in results.

Only 1 study has reported the results of arthroscopic treatment of elbow stiffness in children, the indications being stiffness recalcitrant to nonoperative treatment in athletic patients. All procedures included joint debridement and release of flexion contracture. Six patients were available for follow-up, with an average improvement of 63° in the arc of motion.

**MISSED INJURIES AND DELAYED DIAGNOSIS**

The complication of delayed diagnosis or missed injury merits special attention. At birth, only the distal humeral metaphysis is ossified with the secondary ossification centers appearing in a well-described manner. This unique and complex developmental anatomy makes interpretation of radiographs difficult at times. An understanding of normal anatomy is a prerequisite for interpreting the radiographs of injured children. The number of missed injuries and delayed diagnoses is minimized by obtaining a thorough history and physical examination followed by high-quality appropriate radiographic views. A low threshold for advanced imaging, including MRI and ultrasonography, must be held.

Waters and colleagues described several of these potentially missed injuries as TRASH (the radiographic appearance seemed harmless) lesions. These injuries include (1) transphyseal distal humerus fractures, (2) displaced medial condyle fracture before ossification of the trochlea, (3) capitellar shear fractures, (4) radial head fracture with subsequent progressive radiocapitellar subluxation, and (5) intra-articular osteochondral fractures.
Recognizing common features of TRASH lesions minimizes missed injuries. TRASH lesions are usually caused by a high-energy mechanism (e.g., a fall from a significant height in a small child). These predominantly osteochondral lesions are commonly the result of a spontaneously reduced elbow dislocation. Swelling is usually more than would be expected for the misinterpreted benign radiographs, and restrictions to range of motion are greater than would be expected for a sprain or contusion. Along with careful scrutiny of quality plain films, providers should have a low threshold for obtaining advanced imaging (MRI or ultrasound) in suspected cases.

Medial epicondyle fracture with the fracture fragment entrapped in the joint has also been recognized as a potentially missed injury (Fig. 3).66–68 This pattern typically occurs following an elbow dislocation, with or without spontaneous reduction, and is associated with up to 18% of medial epicondyle fractures68 and up to 25% of elbow dislocations.66 Clinical findings include a block to motion (especially full extension) and radiographs showing the fracture fragment at the level of the joint. In this scenario, the fragment must be considered to be in the joint until proven otherwise.66 When promptly treated with ORIF, 13 out of 13 patients achieved excellent range of motion and functional outcome scores.68

In addition, although often grouped with forearm injuries, Monteggia injuries (proximal ulna fractures associated with a radial head dislocation)
merit special attention because missed injuries can lead to poor outcomes (Fig. 4). A complete discussion of reconstruction strategies is beyond the scope of this article. What is clear is that clinicians should always assess the radiocapitellar joint in any patient with a forearm fracture. Likewise, clinicians should be wary of a diagnosis of isolated radial head dislocation and ensure there is not a subtle fracture of the ulna, including plastic deformation. Although the radial head may be reducible, the reduction is often lost if the concomitant ulna fracture is not simultaneously reduced. Orthogonal radiographs should show a concentric radiocapitellar joint in all views and the ulna should have no bow in the sagittal plane.

REFERENCES


