Current Concepts Review

Supracondylar Humeral Fractures in Children

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Operative fixation is indicated for most type-II and III supracondylar humeral fractures in order to prevent malunion.

Medial comminution is a subtle finding that, if treated nonoperatively, is likely to lead to unacceptable varus malunion.

Angiography is not indicated for a pulseless limb, as it delays fracture reduction, which usually corrects the vascular problem.

A high index of suspicion is necessary to avoid missing an impending compartment syndrome, especially when there is a concomitant forearm fracture or when there is a median nerve injury, which may mask symptoms of compartment syndrome.

Lateral entry pins have been shown, in biomechanical and clinical studies, to be as stable as cross pinning if they are well spaced at the fracture line, and they are not associated with the risk of iatrogenic ulnar nerve injury.

Supracondylar humeral fractures are the most common elbow fractures seen in children\(^1\). Modern techniques for their treatment have dramatically decreased the rates of malunion and compartment syndrome. There still remain several controversial topics with regard to the treatment of these injuries, including the urgency of operative treatment, pin placement configuration, whether type-II supracondylar fractures should be treated operatively or nonoperatively, and management of dysvascular limbs.

Epidemiology
Two-thirds of children hospitalized because of an elbow injury have a supracondylar humeral fracture\(^4\). The age range in which most supracondylar fractures occur is between five and seven years old. Traditionally, boys have had a higher incidence of this type of fracture, but the difference in rates between girls and boys seems to be equalizing, and higher rates in girls have actually been reported in some series\(^5,6\). The injuries have predominantly involved the left, or nondominant side, in almost all studies\(^5,8\).

Mechanism of Injury and Anatomy
Supracondylar fractures are divided into extension and flexion types. Extension-type fractures, which account for approximately 97% to 99% of supracondylar humeral fractures\(^5,9\), are usually due to a fall onto the outstretched hand with the elbow in full extension, and they are the focus of this review. The medial and lateral columns of the distal part of the humerus are connected by a thin segment of bone between the olecranon fossa posteriorly and the coronoid fossa anteriorly, resulting in a high risk of fracture to this area. With elbow extension, the olecranon engages the olecranon fossa and acts as a fulcrum, while the anterior aspect of the capsule simultaneously provides a tensile force on the distal part of the humerus proximal to its insertion. The resulting injury is an extension-type supracondylar humeral fracture.

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With extension-type injuries, the anterior periosteum is torn. The intact posterior periosteal hinge provides stability to the fracture and facilitates reduction. Abraham et al. described the different types of periosteal changes seen with extension-type supracondylar humeral fractures in immature monkeys. They reported that the position of maximum stability for reduction was full flexion and pronation as opposed to supination. Subsequently, many authors have also described using pronation to assist in reduction, but this should not be automatic. The direction of fracture displacement often indicates whether the medial or lateral periosteum remains intact. The most common posteromedially displaced fracture is usually associated with an intact medial periosteum. Pronation places the medial periosteum on tension, thus closing the hinge and correcting varus malalignment (Fig. 1). However, the medial periosteum is often torn in patients with a posterolaterally displaced fracture, in which case pronation may be counterproductive. Instead, supination may be better, especially when the lateral periosteum is intact, which it usually is with this injury. If the posterior periosteal hinge is also disrupted, the fracture becomes unstable in both flexion and extension; such an injury has been recently described as a multidirectionally unstable, modified Gartland type-IV fracture.

**Classification**

The modified Gartland classification of supracondylar humeral fractures is the most commonly accepted and used system. The kappa values for the intraobserver and interobserver variability of this classification were higher than those for previously assessed fracture-classification systems, according to a report by Barton et al.

**Type I**

A Gartland type-I supracondylar fracture is nondisplaced or minimally displaced (by <2 mm) and is associated with an intact anterior humeral line. There may or may not be evidence of osseous injury; the posterior fat-pad sign may be the only evidence of the fracture (Fig. 2). These fractures are very stable because the periosteum is intact circumferentially.

**Type II**

A Gartland type-II supracondylar fracture is displaced (by >2 mm), and the posterior cortex is presumably intact, but hinged. On a true lateral radiograph of the elbow, the anterior humeral line does not go through the middle third of the capitellum (Fig. 2). Generally, no rotational deformity is seen on an anteroposterior radiograph because of the intact posterior hinge. With common usage of the classification, any
rotational deformity noted on an anteroposterior radiograph would qualify the fracture as type III.

Type III
A Gartland type-III fracture is a displaced supracondylar fracture with no meaningful cortical contact. There is usually extension in the sagittal plane and rotation in the frontal and/or transverse planes. The periosteum is extensively torn, and soft-tissue and neurovascular injuries often accompany this fracture. A potential pitfall is to underappreciate the extent of loss of normal alignment in fractures with comminution and collapse of the medial column. Involvement of the medial column in this way signifies malrotation in the frontal plane and thus defines the injury as type III.

Type IV
Leitch et al. retrospectively reviewed the characteristics of 297 displaced extension-type supracondylar fractures and described nine (3%) with multidirectional instability\(^\text{11}\). These fractures are characterized by an incompetent periosteal hinge circumferentially and are defined by instability in both flexion and extension. This multidirectional instability is usually determined with the patient under anesthesia at the time of the operation. The instability pattern may be due to the initial injury, or it may occur iatrogenically during attempted reduction. Classifying this fracture as a separate type may be warranted as multidirectional instability has treatment implications; however, time will tell if others find this addition to the Gartland classification system useful.

Clinical Evaluation
When a child with elbow pain is examined, it is essential that the entire extremity be evaluated, as forearm fractures can occur in association with supracondylar fractures and can substantially increase the risk of compartment syndrome\(^\text{14}\). The examiner must take note of soft-tissue swelling, ecchymosis, and skin puckering. Skin puckering results from the proximal segment piercing the brachialis muscle and engaging the deep dermis. This is a sign of considerable soft-tissue damage. Any bleeding from a punctate wound should be considered to indicate an open fracture. Assessment of the vascular status is essential. The prevalence of displaced supracondylar humeral fractures presenting with vascular compromise has been reported to be up to 20% (10% [twenty-three of 230] in the study by Pirone et al.\(^\text{15}\), 12% [seventeen of 143] in that by Shaw et al.\(^\text{16}\), and 19% [eleven of fifty-nine] in that by Campbell et al.\(^\text{17}\)). The vascular status may be classified into one of three categories: class I, which indicates that the hand is well perfused (warm and red) and a radial pulse is present; class II, which indicates that the hand is well perfused but the radial pulse is absent; and class III, which indicates that the hand is poorly perfused (cool and blue or blanched) and the radial pulse is absent.

The neurologic examination must be performed carefully because of the high prevalence of neurologic injury. Preoperative assessment of the ulnar nerve in particular may be challenging, as young children in pain may not be able to cross their fingers. However, even young children will usually pinch an examiner’s finger and allow the examiner to palpate contraction of the first dorsal intersosseous muscle and confirm ulnar motor function. As a last resort, the hand can be wrapped in a wet cloth. In this test, any area of skin not exhibiting the normal wrinkling response is presumed to have an injury to the nerve innervating that area. During the physical examination, a very high index of suspicion is needed to avoid missing a developing compartment syndrome; considerable swelling and/or ecchymosis, anterior skin puckering, and an absent pulse are indications of this complication.

Radiographic Diagnosis
Radiographic examination begins with a true anteroposterior view of the distal part of the humerus, rather than an anteroposterior radiograph of the elbow, and a true lateral radiograph of the elbow. Initial radiographs may show no evidence of a fracture except for a posterior fat-pad sign. In a series of thirty-four patients with traumatic elbow pain and a posterior fat-pad sign but no visible fracture, one of us (D.L.S.) and Mirzayan found that 53% (eighteen) had a supracondylar humeral fracture, 26% (nine) had a fracture of the proximal part of the ulna, 12% (four) had a fracture of the lateral condyle, and 9% (three) had a fracture of the radial neck\(^\text{18}\). When an osseous injury is present, two main radiographic parameters are used to evaluate these fractures. On a true lateral radiograph of a normal elbow, the anterior humeral line should cross the capitellum through its middle third (Fig. 3). In an extension-type supracondylar fracture, the capitellum is posterior to this line. The Baumann angle, or humeral capitellar angle, is the angle between the long axis of the humeral shaft and the physeal line of the lateral condyle; the normal range for this angle is about 9° to 26°. A decrease in the Baumann angle is a sign that a fracture is in varus angulation and may be seen with subtle comminution of the medial column (Fig. 4).

Treatment
Initial Management
Displaced supracondylar fractures requiring a reduction should be initially treated with a splint, with the elbow in a comfortable position of approximately 20° to 40° of flexion and avoidance of tight bandaging or splinting. Excessive flexion or extension may compromise the limb’s vascularity and increase compartment pressure\(^\text{9,20}\). The arm should then be gently elevated.

Treatment with Traction
Fracture as definitive treatment for supracondylar fractures in children is largely of historic interest in modern centers. Rates of cubitus varus ranging from 9% to 33% have been reported in some series\(^\text{19,22}\), whereas excellent results have been reported in others\(^\text{23-25}\). Nevertheless, fourteen to twenty-two days of in-hospital traction are difficult to justify given the excellent results with closed reduction and pin fixation, which usually
requires no more than one night of hospitalization and is associated with a low rate of intraoperative complications.

Closed Reduction and Pin Fixation
This is the most common operative treatment of supracondylar fractures. An initial attempt at closed reduction is indicated for almost all displaced supracondylar fractures that are not open. With the patient under general anesthesia, the fracture is first reduced in the frontal plane with fluoroscopic verification. The elbow is then flexed while the olecranon is pushed anteriorly to correct the sagittal deformity and reduce the fracture. Criteria for an acceptable reduction include restoration of the Baumann angle (which is generally >10°) on the anteroposterior radiograph, intact medial and lateral columns as seen on the oblique radiographs, and the anterior humeral line passing through the middle third of the capitellum on the lateral radiograph. As there is considerable rotation at the shoulder, a certain amount of rotational malalignment in the axial plane can be tolerated at the fracture site. Any rotational malalignment is detrimental to fracture stability, so, if it is present, one must be especially careful in assessing the stability of the reduction and probably use a third fixation pin.

The fracture reduction is held with two or three Kirschner wires, as will be discussed later in this review. The elbow is immobilized in 40° to 60° of flexion, depending on the amount of swelling and the vascular status. If there is a considerable gap in the fracture site or the fracture is irreducible with a so-called rubbery feeling on attempted reduction, the median nerve and/or brachial artery may be trapped in the fracture site and one should proceed to an open reduction. A detailed description of this operative technique is available in the literature.

Open Reduction
Open reduction is indicated in cases of failed closed reduction, a dysvascular limb, and open fractures. In the past, open reduction led to concerns regarding elbow stiffness, myositis ossificans, unsightly scarring, and iatrogenic neurovascular injury. However, several studies have demonstrated a low rate of complications associated with open reduction. In a study of fifty-two displaced fractures treated with open reduction through a lateral approach, Weiland et al. reported a moderate loss of motion of 10% (five) of the elbows but no cases of infection, nonunion, or myositis ossificans. Fleuriau-Chateau et al. reported that, of thirty-four patients treated with open reduction through an anterior approach, 6% (two) had an unsatisfactory loss of motion but none had infection, myositis ossificans, malunion, or a Volkmann contracture. Reitman et al. reported that 78% (fifty-one) of sixty-five patients treated with open reduction (through either a medial or a lateral approach) had an excellent or good result according to the criteria of Flynn et al. Loss of motion was reported in four cases. In a prospective, randomized controlled study of twenty-eight children, Kaewpornsawan compared closed reduction and percutaneous pin fixation with open reduction (through a lateral approach); the patients treated with percutaneous pin fixation showed no differences with regard to

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Fig. 3
The anterior humeral line should cross the capitellum through the middle third on a true lateral radiograph of a normal elbow. (Reprinted, with permission, from: Skaggs DL, Flynn JM. Staying out of trouble in pediatric orthopaedics. Philadelphia: Lippincott, Williams and Wilkins; 2006.)

Fig. 4
The Baumann angle is formed by the line perpendicular to the long axis of the humeral shaft and the physeal line of the lateral condyle. A decrease in the Baumann angle may indicate medial comminution. (Reprinted, with permission, from: Skaggs DL, Flynn JM. Staying out of trouble in pediatric orthopaedics. Philadelphia: Lippincott, Williams and Wilkins; 2006.)
cubitus varus, neurovascular injury, the range of motion, the infection rate, the union rate, or the criteria of Flynn et al.

Although the direct anterior approach to the elbow is not commonly used by many orthopaedists, it is our preferred approach, particularly in cases of neurovascular compromise. The anterior approach has the advantages of allowing direct visualization of the brachial artery and median nerve as well as the fracture fragments. When the operation is performed through a relatively small (5-cm) transverse incision along the cubital fossa, the resulting scar is much more cosmetic than is the scar resulting from the lateral approach, and scar contraction limiting elbow extension is not an issue. In a series of twenty-six patients treated with the anterior approach, Koudstaal et al. found the results to be equivalent to those of the traditional lateral or combined lateral and medial approach in terms of malunion, the criteria of Flynn et al., and the range of motion.

The posterior approach is generally not recommended because of the high rate of loss of motion and, more importantly, the risk of osteonecrosis secondary to disruption of the posterior end arterial supply to the trochlea of the humerus.

**Treatment by Fracture Type**

**Type-I Fractures**

It is generally agreed that these fractures should be managed in a long arm cast with the elbow in approximately 60° to 90° of flexion for approximately three weeks. It is recommended that follow-up radiographs be made at one and two weeks to identify any fracture displacement.

**Type-II Fractures**

The optimal treatment of type-II fractures has evolved into the current trend of operative intervention rather than cast immobilization. The distal part of the humerus provides 20% of the growth of the humerus and thus has little remodeling potential. The upper limb grows approximately 10 cm during the first year of life, 6 cm during the second year, 5 cm during the third year, 3.5 cm during the fourth year, and 3 cm during the fifth year. Toddlers (less than three years old) have some remodeling potential so the surgeon may accept nonoperative treatment of a type-II fracture in which the capitellum abuts the anterior humeral line but does not cross it. However, a child who is eight to ten years old has only 10% of growth of the distal part of the humerus remaining, so an adequate reduction is essential to prevent malunion.

The results of two studies support the initial treatment of type-II fractures with closed reduction and a cast. Hadlow et al. made the point that pin fixation of all type-II fractures in their series would have meant that 77% (thirty-seven) of the forty-eight patients would have undergone an unnecessary operative procedure. However, 23% (eleven) of the forty-eight patients in that series lost reduction following closed reduction and underwent a delayed operation. Two of fourteen patients who were followed had a poor outcome on the basis of the criteria of Flynn et al. In a retrospective study of twenty-five elbows treated with closed reduction and a cast, Parikh et al. reported that 28% (seven) had a loss of reduction, 20% (five) had delayed surgery, and 8% (two) had an unsatisfactory outcome according to the criteria of Flynn et al.

In contrast, in a consecutive series of sixty-nine children with a type-II fracture treated with closed reduction and pin fixation, there was no radiographic or clinical loss of reduction, no cubitus varus, no hyperextension, no loss of motion, no iatrogenic nerve palsies, and no need for additional surgery.

In a study of 191 consecutive type-II fractures treated with closed reduction and percutaneous pin fixation, there were four pin track infections (2%), three of which were treated successfully with oral antibiotics and pin removal. In the fourth case, operative irrigation and debridement was performed for a wound infection not involving the joint. There were no nerve or vascular injuries and no loss of reduction, delayed union, or malunion.

Another reason for advocating operative treatment of these injuries is that the amount of hyperflexion needed to maintain reduction of type-II fractures without pin fixation would predispose these patients to increased compartment pressures. In a study by Mapes and Hennrikus, who used Doppler examination, positions of pronation and increased flexion were found to decrease flow in the brachial artery. The authors recommended a position of flexion and supination for “vascular safety.” Pin fixation of these fractures obviates the need for immobilization with considerable elbow flexion. The basic concept is that, in any case requiring elbow flexion of >90° to hold reduction, the reduction should instead be held by pins and the arm should be immobilized with the elbow in less flexion (usually about 45° to 70°).

**Type-III Fractures**

If the child presents to the emergency department with the extremity in either extreme flexion or extreme extension, the arm should be carefully placed in 30° of flexion to minimize vascular insult and compartment pressure. The standard of care in most centers for the treatment of type-III fractures is operative reduction and pin fixation.

The Special Case of Comminution of the Medial Column

Fractures with medial comminution may not have the dramatic displacement of most type-III fractures, but they must be treated with operative reduction because collapse of the medial column will lead to varus deformity in an arm with an otherwise minimally displaced supracondylar fracture (Fig. 5). De Boeck et al. recommended closed reduction with percutaneous pin fixation when a fracture has medial comminution, even if it is otherwise minimally displaced, in order to prevent cubitus varus. In their retrospective review, cubitus varus did not develop in any of six patients with medial comminution who had undergone operative fixation whereas it developed in four of seven patients who had been treated nonoperatively.

**Type-IV Fractures**

While this extremely unstable fracture could be treated with open reduction, Leitch et al. described a treatment protocol
Medial comminution is a subtle radiographic finding and indicates a more unstable fracture variant, which may collapse into varus if it is not treated appropriately. (Reprinted, with permission, from: Skaggs DL, Flynn JM. Staying out of trouble in pediatric orthopedics. Philadelphia: Lippincott, Williams and Wilkins; 2006.)

utilizing closed reduction in nine patients. Their recommended technique is to first place two Kirschner wires into the distal fragment. Next, the fracture is reduced in the anteroposterior plane, and the reduction is verified by imaging. At this point, rather than the arm being rotated for a lateral image, as is commonly done for more stable fracture patterns, the fluoroscopy unit is rotated into the lateral view. The fracture is then reduced in the sagittal plane, and the Kirschner wires are driven across the fracture site. All nine fractures treated with this technique united; there were no cases of cubitus varus, malunion, or loss of motion; and no additional operative treatment was required. Because of the limited number of these uncommon yet potentially problematic fractures, the need for open reduction as well as the true complication rate cannot be predicted.

Complications

Vascular Injury

Approximately 10% to 20% of patients with a type-III supracondylar fracture present with an absent pulse. An absent radial pulse is not in itself an emergency, as collateral circulation may keep the limb well perfused. Urgent, but nonemergent, reduction with pin fixation in the operating room is indicated. An arm that is pulseless with signs of poor perfusion is an emergency. When a patient with a severely displaced supracondylar fracture and compromised vascularity to the limb presents to the emergency department, the arm should be splinted with the elbow in approximately 20° to 40° of flexion.

Fracture reduction should not be delayed by waiting for an angiographic study, as reduction of the fracture usually restores the pulse. Several reports have shown angiography to be an unnecessary test that has no bearing on treatment. Shaw et al. reported on a series of 143 type-III supracondylar fractures, seventeen of which were associated with vascular compromise. All underwent reduction and percutaneous pin fixation without a preoperative angiogram. Blood flow to the hand was not restored after the reduction in three of the seventeen patients, and open exploration was required. In fourteen of the seventeen patients, blood flow to the hand was restored without complications. The authors concluded that prereduction angiography adds nothing to the management of these injuries. In another study, angiography was utilized for four of seventeen dysvascular limbs with a supracondylar humeral fracture; the angiogram did not alter the course of management in any of the cases.

If anatomic reduction cannot be obtained by closed reduction in the setting of an absent pulse, open reduction through an anterior approach is indicated in order to allow evaluation of all vital structures at risk for incarceration between the fracture fragments. Once the artery has been freed from the fracture site, arterial spasm may be relieved by application of lidocaine, warming, and ten to fifteen minutes of observation. If, following fracture reduction in a pulseless limb, the pulse does not return and the hand remains poorly perfused, vascular reconstruction (usually by a vascular surgeon) is indicated.

There is controversy about what constitutes the best treatment if the pulse does not return but the hand is well perfused. Our practice is to admit the child to the hospital, elevate the limb slightly, and observe him or her for at least forty-eight hours. Loss of perfusion can occur during this time and necessitate emergent treatment. Alternatively, vascular reconstruction may be performed. However, Sabharwal et al. found that early repair of the brachial artery is associated with a high rate of symptomatic reclosure and residual stenosis, and they recommended a period of close observation with frequent neurovascular checks before more invasive correction of this problem is contemplated. If a pulse was present preoperatively but is absent following reduction and pin fixation, immediate rereduction, which in most cases should be open, is indicated, as the artery or adjacent tissue is presumed to be entrapped in the fracture site.

Neurologic Injury

The rate of associated neurologic injury has been reported to be as high as 49%, but in most modern series it has ranged between 10% and 20%. Previously, investigators reported that the radial nerve is injured most often, but, as first noted by Spinner and Schreiber, the anterior interosseous nerve actually appears to be the most commonly injured with extension-type supracondylar fractures of the humerus.
This condition presents as paralysis of the long flexors of the thumb and index finger without sensory changes. Complete median nerve injury, due to contusion or transection of the nerve at the level of the fracture, has also been described with these fractures and presents with sensory loss in the median nerve distribution as well as motor loss of all muscles innervated by the median nerve.\textsuperscript{30,54}

Open reduction of the fracture and exploration of the injured nerve is not necessarily indicated when a nerve injury is associated with a closed fracture. Neural recovery, regardless of which nerve is injured, generally occurs after two to 2.5 months of observation, but it may take up to six months.\textsuperscript{4,55} Nerve transections are rare and almost exclusively involve the radial nerve.\textsuperscript{32,56-58}

There is a lack of information in the literature on which to base treatment of an iatrogenic ulnar nerve injury that occurs following placement of a medial pin. Lyons et al. reported on seventeen patients with an iatrogenic ulnar nerve injury that was presumably due to a medial pin.\textsuperscript{41} All seventeen patients had a complete return of function, although many did not have it until four months later. Only four of the seventeen patients had removal of the medial pins. This study demonstrates that ulnar nerve function can eventually return without pin removal.

Rasool demonstrated, with operative exploration, that the pin rarely directly impales the ulnar nerve but more commonly constricts the nerve within the cubital tunnel by tethering adjacent soft tissue.\textsuperscript{61} These findings were later confirmed by an ultrasonographic study by Karakurt et al.\textsuperscript{62} Common sense suggests that removal of the causative factor (the medial pin) earlier rather than later may lead to a quicker recovery of the nerve. However, routine surgical exploration of the ulnar nerve is not recommended.\textsuperscript{30,55,60,62}

Compartment Syndrome

The rate of compartment syndrome in the setting of a supracondylar fracture is estimated to be 0.1% to 0.3%.\textsuperscript{19} Blakemore et al. found the prevalence of forearm compartment syndrome to be three of thirty-three in association with the combined injury of a supracondylar fracture and a radial fracture.\textsuperscript{14} Battaglia et al. showed that the threshold position for increased forearm pressures is between 90° and 120° of elbow flexion.\textsuperscript{17} This highlights the importance of immobilization of the elbow in a position well below 90° of flexion. In what we believe is the largest reported retrospective study of compartment syndrome following supracondylar humeral fractures in children, Skaggs et al. showed that ecchymosis and severe swelling even in the presence of an intact radial pulse with good capillary refill should alert the treating physician to the possibility of a compartment syndrome.\textsuperscript{63} Special attention must be paid to supracondylar fractures with median nerve injury, as the patient will not feel pain in the volar compartment.\textsuperscript{64}

Cubitus Varus

Some authors have proposed that unequal growth in the distal part of the humerus causes cubitus varus deformity.\textsuperscript{55,65} However, this is unlikely as there is not enough residual growth left in this area to cause cubitus varus within the time in which it is recognized. The most common reason for cubitus varus in patients with a supracondylar fracture is therefore malunion rather than growth arrest.\textsuperscript{22,23,27,30,66} Cubitus varus can be prevented by making certain that the Baumann angle is intact at the time of reduction and remains so during healing. Pirone et al. reported cubitus varus deformity in eight (8%) of 101 patients treated with cast immobilization compared with two (2%) of 105 patients treated with pin fixation, with ages ranging from 1.5 to fourteen years (mean, 6.4 years).\textsuperscript{15}

Treatment for cubitus varus has in the past been considered for cosmetic reasons only. However, there are several consequences of cubitus varus such as an increased risk of lateral condyle fractures, pain, and tardy posterolateral rotatory instability, which may be indications for an operative reconstruction with a supracondylar humeral osteotomy.\textsuperscript{67-72}

Pin Track Infections

The rate of pin track infections in children treated with percutaneous Kirschner wire fixation of a fracture has ranged from <1% to 21%.\textsuperscript{73} The reported rates of pin track infections in association with supracondylar humeral fractures range from <1% to 6.6%.\textsuperscript{6,8,37,74,75} Battle and Carmichael evaluated a series of 202 fractures, 92.6% (187) of which involved the upper extremity, and reported an infection rate of 7.9% (sixteen of 202).\textsuperscript{15} Twelve of the sixteen infections required oral antibiotics and local pin care, one required intravenous antibiotics, and three required an operative incision and débridement. One of us (D.L.S.) and colleagues noted only one pin track infection in a series of 124 supracondylar humeral fractures treated with percutaneous pin fixation. The single pin track infection resolved with administration of oral antibiotics and pin removal.\textsuperscript{76} Gupta et al. reported one pin track infection in a series of 150 fractures; it also resolved with use of oral antibiotics and pin removal.\textsuperscript{77} In a larger series, of 198 fractures, Mehlman et al. identified five pin track infections (2.5%), which were treated with oral antibiotics and resolved without sequelae.\textsuperscript{78}

Controversies

Crossed Pins Compared with Lateral Entry Pins

The rate of iatrogenic injury of the ulnar nerve associated with the use of crossed pins has been reported to be as low as 0%, but the rates were 5% (seventeen of 345) and 6% (nineteen of 331) in what we believe to have been the two largest reported series of supracondylar fractures.\textsuperscript{53,59,60,62,77-79} Others have reported that these injuries occur more commonly.\textsuperscript{79,80} In 1977, Arino et al. recommended the placement of two lateral pins in order to avoid injury to the ulnar nerve.\textsuperscript{81} A recent systematic review of thirty-five articles comparing medial and lateral pin fixation with lateral entry pin fixation revealed that iatrogenic ulnar nerve injury occurred in forty (3.4%) of 1171 cases involving medial and lateral crossed pins and five (0.7%) of 738 cases in which only lateral entry pins had been used. Iatrogenic ulnar nerve injuries usually resolve, but there have been several reports of permanent iatrogenic ulnar nerve injuries.\textsuperscript{53,60,77}
Zaltz et al. reported that, when the elbow was flexed >90°, the ulnar nerve migrated over, or even anterior to, the medical epicondyle in most (thirty-two) of fifty-two children less than five years of age. Wind et al. showed that the location of the ulnar nerve cannot be adequately determined by palpation to allow blind medial pin placement. Unfortunately, even making an incision over the medial epicondyle in an effort to ensure that the ulnar nerve is not directly injured by a pin does not guarantee protection of this nerve. In contrast, Weiland et al. reported that fifty-two patients treated with crossed pins and use of a small medial incision had no iatrogenic ulnar nerve injuries. Green et al. reported that, of sixty-five patients treated with two lateral and one medial pin by means of a mini-open technique, one had an iatrogenic nerve injury. In a series in which six iatrogenic ulnar nerve injuries were treated with early exploration, the nerve was directly penetrated by the pin in two cases, constriction of the cubital tunnel occurred in three cases, and the nerve was fixed anterior to the medial epicondyle in one case. Thus, even if direct penetration of the ulnar nerve is avoided, simply placing a medial epicondyle entry pin adjacent to the nerve may cause injury, presumably by constriction of the cubital tunnel.

One of us (D.L.S.) and colleagues reported on a series of 345 supracondylar humeral fractures treated with percutaneous pin fixation and showed that the use of a medial pin was associated with a 4% risk of ulnar nerve injury (six of 149) when the medial pin was placed without elbow hyperflexion and a 15% risk (eleven of seventy-one) when the medial pin was placed with the elbow in hyperflexion. None of the 125 procedures in which the fracture was treated with lateral entry pins alone resulted in iatrogenic ulnar nerve injury. This observation is consistent with the finding of anterior subluxation of the ulnar nerve with elbow flexion beyond 90° in the study by Zaltz et al. Thus, one apparently undeniable conclusion is that, if a medial pin is used, the lateral pin(s) should be placed first, the elbow should then be extended, and the medial pin should be placed without hyperflexion of the elbow. Of course, the simplest way to avoid iatrogenic nerve injuries is to not place a medial pin. No iatrogenic ulnar nerve injuries were reported in a series of 124 consecutive fractures stabilized with lateral entry pins only, regardless of the fracture displacement or stability.

The second issue with regard to pin configuration is fracture stability. Biomechanical studies of the stability provided by various pin configurations have been somewhat misleading. In two studies evaluating the torsional strength of pin configurations, crossed pins were found to be stronger than two lateral pins. Unfortunately, those studies are of little relevance, as the two lateral pins were placed immediately

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**Fig. 6**
Properly placed divergent lateral entry pins. On the anteroposterior radiograph, there should be maximal pin separation at the fracture site, and the pins should engage both the medial and the lateral column just proximal to the fracture site and should engage an adequate amount of bone proximal and distal to the fragments. On the lateral radiograph, the pins should incline slightly in the anterior-to-posterior direction in accordance with normal anatomy. (Reprinted from: Skaggs DL, Cluck MW, Mostofi A, Flynn JM, Kay RM. Lateral-entry pin fixation in the management of supracondylar fractures in children. J Bone Joint Surg Am. 2004;86:702-7.)
adjacent to each other and were not separated at the fracture site as is recommended. A more relevant biomechanical study by Lee et al. showed that two divergent lateral pins separated at the fracture site were superior to crossed pins with loading in extension and varus but were equivalent with loading in valgus. The greater strength seen with divergence of the pins was attributed to the location of the intersection of the two pins and the fact that the greater amounts of divergence between the two pins allow for some purchase in the medial column as well as the lateral column (Figs. 6 and 7).

Bloom et al. reported that three lateral divergent pins were equivalent to cross-pin fixation and both of these constructs were stronger than two lateral divergent pins. Another study, in which medial comminution was simulated, showed that three lateral divergent pins had torsional stability equivalent to that of standard crossed medial and lateral pins. Thus, contemporary biomechanical studies support the clinical recommendations for use of three lateral entry pins in the treatment of type-III fractures.

One of us (D.L.S.) and colleagues demonstrated no malunions or loss of fixation in a series of 124 consecutive fractures treated with lateral entry pins. They recommended maximal pin separation at the fracture site with engagement of the medial and lateral columns, a low threshold for placement of a third laterally based pin if additional stability is needed, and the use of three pins for type-III fractures. Gordon et al. further validated this point by recommending use of two lateral pins initially for a type-III fracture and then stressing the fracture under fluoroscopy to determine the need for a third lateral pin.

In a study of eight supracondylar humeral fractures that lost reduction, Sankar et al. reported that the loss of fixation in all cases was due to technical errors that were identifiable on the intraoperative fluoroscopic images and could have been prevented with proper technique. They identified three types of pin-fixation errors: (1) failure to engage both fragments with two pins or more, (2) failure to achieve bicortical fixation with two pins or more, and (3) failure to achieve adequate pin separation (>2 mm) at the fracture site. A systematic review of thirty-five articles showed a loss of reduction of zero of 849 fractures treated with crossed pins and four (0.7%) of 606 fractures treated with lateral entry pins.

In a prospective, randomized clinical trial comparing lateral and cross-pin fixation techniques in the treatment of type-III supracondylar humeral fractures, Kocher et al. found...
no significant difference between the two treatment groups with regard to any radiographic or clinical outcome measure. However, because of the lack of power in this study, which had a small sample size of twenty-four patients who had undergone cross-pin fixation, the absence of iatrogenic ulnar nerve injury may have been due to chance alone. Another prospective randomized study, by Blanco et al., showed no significant difference in the radiographic outcomes between lateral entry and cross-pin fixation techniques for the management of type-III supracondylar humeral fractures in children.51

Delayed Treatment
The authors of several studies have concluded that an eight to twenty-one-hour delay before surgery does not have any deleterious effects on the outcomes for children with a supracondylar fracture.7,65-69. These studies were all retrospective and may have demonstrated good results in large part because of the selection bias resulting from experienced pediatric orthopaedic surgeons choosing which fractures required urgent treatment. While we are not aware of any published studies to support our opinion, we believe that, if conditions such as poor perfusion, an associated forearm fracture, firm compartments, skin puckering, antecubital ecchymosis, or very considerable swelling are present, operative treatment should not be delayed.

Overview
The current recommended treatment for Garland type-II and III fractures is operative reduction and pin fixation. When correct technique is used, lateral entry pins alone provide sufficient fixation stability with avoidance of the possibility of iatrogenic ulnar nerve injury. A supracondylar fracture in a pulseless limb should be treated with urgent reduction, which should not be delayed to await an angiogram as fracture reduction usually restores perfusion. Associated nerve injuries normally resolve, and immediate nerve exploration in patients with a closed fracture is generally not indicated.

References
87. Bloom T, Robertson C, Mahar A, Pring M, Newton PO. Comparison of supracondylar humerus fracture pinning when the fracture is not anatomically reduced. Read at the Annual Meeting of the Pediatric Orthopaedic Society of North America; 2007 May 23-26; Hollywood, FL.