Pediatric Orthopedic Trauma

An Evidence-Based Approach

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KEYWORDS

• Supracondylar humerus fracture • Medial epicondyle fracture • Femoral shaft fracture
• Clavicle fracture • Evidence-based medicine • Open fracture

KEY POINTS

- Displaced supracondylar humerus fractures should be managed with closed reduction and pin fixation. Pin placement, size, and surgical timing should be selected based on fracture and patient characteristics.
- Femoral shaft fracture management can be guided by patient age, size, and fracture type. Guidelines are available, but have not yet demonstrated that they streamline how patients receive care.
- Grade 1 open fractures can potentially be treated with local wound debridement, antibiotics, and closed reduction, but this method needs to be proven in randomized studies.
- Although there is strong evidence to suggest that anatomic reduction of specific clavicle fractures in adults improves outcomes, this has not been proven in pediatric patients.

INTRODUCTION

Historically, many pediatric injuries were managed nonsurgically. However, with changes in implant selection and outcomes, studies of operative versus nonoperative treatment, orthopedists have moved toward surgical intervention for certain fractures. To streamline surgical decision making and patient care, the American Academy of Orthopaedic Surgeons (AAOS) has developed clinical guidelines for the management of pediatric diaphyseal femur fractures[1,2] and supracondylar humerus fractures.[3] Although helpful, the guidelines are limited by the lack of high-level evidence relating to certain aspects of these injures. Also, there are currently no other guidelines available for other types of pediatric fractures. The growing body of literature regarding grade 1 open fractures, medial epicondyle fractures, and clavicle fractures has made management of these injuries three of the most controversial topics in pediatric orthopedics today. This article analyzes the available evidence to help guide the management of each of these injury patterns and highlights areas where additional research is needed.

SUPRACONDYLAR HUMERUS FRACTURES

Supracondylar humerus fractures are the most common fractures involving the elbow in pediatric patients.[4] Given the frequency of these injuries, it is important for both pediatric and general orthopedic surgeons to understand the treatment recommendations for different types of supracondylar humerus fractures.

Nonoperative treatment with either splint or cast immobilization is recommended for Gartland type 1 (nondisplaced) supracondylar

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humerus fractures.[3] Studies comparing methods of immobilization have shown that the use of a posterior splint leads to decreased duration of pain, decreased analgesic use, and faster return to normal activity than collar and cuff immobilization.[5,6]

Treatment for type 2 supracondylar humerus fractures is difficult to discern from the current literature. According to the AAOS guidelines, closed reduction and pin fixation is recommended.[3] However, none the studies used to make these recommendations specifically analyzed Gartland type 2 supracondylar humerus fractures in isolation. Five focused only on type 3 supracondylar fractures[7–11] and the remaining included patients with both type 2 and type 3 fractures.[12–17] Moraleda and colleagues[18] specifically analyzed outcomes of patients who sustained type 2 fractures who were treated without attempted reduction or surgery. Compared with the nonoperative side, the total arc of elbow motion was unchanged, but the affected elbows had significantly more extension and significantly less flexion (8° and 7°, respectively).[18] According to the Flynn criteria, results were deemed satisfactory in 80% of patients.[18] This finding would suggest that not all type 2 supracondylar humerus fractures require operative treatment to ensure a satisfactory outcome. However, the increased risk of cubits varus and the altered arc of elbow motion that is seen with unreduced type 2 supracondylar fractures should be discussed with patients and families when considering nonoperative treatment without reduction for these injuries.[18]

The AAOS recommends that type 3 supracondylar humerus fractures be treated with closed reduction and pin fixation.[3] This method is supported by a wide range of studies that examine type 3 supracondylar humerus fractures alone as well as in combination with other types of fractures.[7–17] However, the urgency of closed reduction and pin fixation of type 3 fractures in patients who are neurovascularly intact upon presentation is not well-defined. There are studies that suggest that delayed operative intervention in this setting can increase the need for open reduction and potentially increase the risk of compartment syndrome.[19–21] However, multiple studies have reported no correlation between surgical timing and the need for open reduction or perioperative complications.[22–26] Therefore, surgical timing is left to the discretion of the surgeon. Important considerations include the patient's degree of swelling, status of the soft tissues, the time interval between injury and patient presentation, and access to an operating room in the morning should treatment be deferred. It is also important to consider that patients left unreduced can have continued swelling, which can cause the neurovascular status to change over time. Ho and colleagues[27] found that 8% of patients who presented to a level 1 pediatric hospital with a neurovascular injury in the setting of a supracondylar humerus fracture had evidence of progressive decline in their neurovascular status between the initial evaluation in the emergency department and the evaluation in the preoperative holding area.

Pin construct for supracondylar fractures has been a point of interest in the literature. Multiple studies support the use of crossed pins for biomechanical strength, especially against torsional stress.[16,28–33] However, 3 well-placed lateral entry pins that have bicortical purchase and adequate spread across the fracture site have been shown to be biomechanically equivalent to 2 crossed pins.[34,35] Increasing the pin size from 1.6 to 2.0 mm also increases construct strength for lateral entry pins.[36–38] An advantage of all lateral entry pins is that they minimize the risk of iatrogenic ulnar nerve injury.[39] The decreased incidence of iatrogenic nerve injury reported in the literature is one reason why the AAOS recommends that all lateral entry pins be placed when possible for supracondylar fractures.[3] However, the actual incidence of ulnar nerve injury in the setting of medial pin placement is highly variable in the literature and fractures with medial comminution are more stable and have less chance of loss of reduction when a medial pin is placed.[34,40] Making an incision has not been shown to be protective against iatrogenic nerve injury during pin placement, but elbow extension during pin placement is protective.[39] When possible, all lateral entry pins are the preferred method of fixation. However, because medial pins are sometimes essential to maintain fracture reduction, we support using a medial pin when it is necessary. In this setting, we recommend placing 1 or 2 lateral pins first with the elbow flexed to obtain control of the fracture, followed by elbow extension for medial pin placement to minimize the risk of nerve injury.

Patients who present with a cool pulseless extremity in the setting of a supracondylar fracture should ideally undergo emergent closed reduction to try to restore perfusion to the extremity.[3] Preoperative angiography is not recommended in this scenario, because it has only been shown to delay time to surgery with no appreciable patient benefit.[41–43] Fracture reduction has been shown to restore perfusion in 53% to 72% of cases.[42,44–46] It is helpful to have access to a vascular surgeon if there is an arterial injury and pulses are not restored after anatomic fracture reduction. Consideration can be given to proceeding toward open reduction in this scenario, but there are no high-level studies to support this decision and the AAOS clinical guidelines are unable to offer any recommendations in this setting.[3] The surgeon must weigh his or her own personal experience with this injury pattern, access to a vascular team, and the effect that a surgical delay would have on the patient outcome if the decision is made to transfer the patient to a higher level of care before proceeding with reduction.

The "pink pulseless hand" remains a point of controversy in the literature. This term refers to those extremities that are pink with good capillary refill but lack a palpable radial pulse after fracture reduction. Some sources argue for immediate vascular exploration in this scenario.[45,47–49] However, there are studies that support careful observation of these patients after fracture reduction and pinning. Scannell and colleagues[50] reviewed the outcomes of 20 patients who presented with type 3 supracondylar humerus fractures and perfused pulseless extremities. Patients were taken to surgery an average of 7 hours after injury (range, 2–15 hours). Five patients had a palpable radial pulse in the operating room after closed reduction and pinning; 2 additional patients had a palpable pulse at the time of discharge. The remaining 13 patients had perfused extremities but no palpable radial pulse at discharge. All patients had a palpable pulse at the time of final follow-up, although the date of the return of the pulse varied from 0 to 233 days postoperatively. None of the patients required vascular reconstruction.[50] Weller and colleagues[51] found that most patients with a pink pulseless extremity after fracture reduction and pinning had a pulse that could be detected using Doppler imaging. The 5% of patients who had neither a palpable or apparent pulse on Doppler imaging required vascular reconstruction owing to brachial artery injuries. These authors recommended using the patient's capillary refill and the presence of a radial artery signal detectable by Doppler imaging after closed reduction and pinning when deciding whether a patient requires emergent surgical exploration.[51] Sabharwal and colleagues[52] demonstrated that early revascularization procedures in this circumstance have a high rate of reocclusion and subsequently recommended that close observation with multiple neurovascular checks should be performed before going forward with vascular reconstruction. The AAOS handles this discrepancy in the literature through 2 separate recommendations. The guidelines support emergent closed reduction in the setting of a supracondylar humerus fracture with decreased perfusion to the hand. This description includes the spectrum of "pink pulseless hand" to the cool and pulseless hand. However, the guidelines then indicate that, based on the current literature, they cannot recommend for or against open exploration of the antecubital fossa when a patient has absent wrist pulses but a perfused hand after closed reduction and pinning.[3] The current literature suggests that a hand that is perfused but has absent palpable pulses after closed reduction and pinning needs to be observed closely in the postoperative period with frequent neurovascular checks after surgery if the surgeon decides to not explore the antecubital fossa immediately.

The AAOS guidelines do not offer any recommendations regarding the timing of treatment in patients who present with isolated neurologic injury. Barrett and colleagues[53] found that urgent closed reduction and percutaneous pin fixation did not result in faster neurologic recovery among patients who presented with an isolated anterior interosseous nerve palsy. However, only 35 patients from an initial pool of 4409 met inclusion criteria for the study, giving them an overall incidence of less than 1% of anterior interosseous nerve palsy, which is lower than what has been reported in other studies.[26,27,54] It has been shown that the presence of a neurologic injury upon presentation with a supracondylar humerus fracture is associated with more severe soft tissue injury.[27] Based on the current evidence, we cannot offer a recommendation regarding the urgency of surgical timing when a patient presents with an isolated neurologic injury and a palpable pulse. It is important to remember that a percentage of these patients will have progressive loss of neurologic function between emergency department admission and operative treatment, and this factor should be considered when deciding when to take a patient to the operating room.[27]

FEMORAL SHAFT FRACTURES

Femoral shaft fractures account for 1.6% of all fractures in pediatric patients and are among the most common reasons for hospital admissions in this population.[4] In 2009, the AAOS first released clinical guidelines to aid in treatment decisions for these patients; the guidelines were then updated in 2015.[1,2,55] Although studies have shown that clinical practice guidelines can help to standardize patient care based on the best available evidence,[56–58] reviews of the clinical guidelines for femoral shaft fracture management in children have not demonstrated similar effects.[59] A recent multicenter review demonstrated an increase in the use of rigid locked intramedullary nails in adolescents younger than age 11 and increased surgical management of femoral shaft fractures in children younger than 5.[60] These trends counter recommendations made in the clinical guidelines.[55,60] This is potentially due to the limited high-level evidence available for these injuries. Ultimately, of the 14 recommendations listed, only one had sufficient evidence to be truly "recommended" by the committee. Of the remaining recommendations, 50% were either "suggested" or "optional" based on the available evidence and 6 did not have enough supporting evidence to guide treatment.[1–3]

The AAOS recommends that children younger than 36 months who present with a femoral shaft fracture be evaluated for nonaccidental trauma (NAT).[1] This recommendation is based on multiple population studies that have found 12% to 14% of all femoral shaft fractures in children younger than age 3 are related to NAT.[61–63] Studies also suggest that femoral shaft fractures in children who are not ambulatory have a strong association with NAT, with 30% of femoral shaft fractures in children less than 1 year of age attributable to abuse.[64] Orthopedic injuries are among the most common ways for pediatric victims of NAT to present to the emergency department, so orthopedic surgeons need to have a high level of suspicion to ensure the safety of our patients.[64]

Children who sustain femoral shaft fractures between 0 and 6 months of age can be treated in either a Pavlik harness or spica cast.[1] Podeszwa and colleagues[65] found that patients had 100% fracture union with no clinical evidence of malalignment, regardless of whether they were treated in a Pavlik or a spica. However, the spica group did have a greater number of minor complications relating to skin irritation and breakdown in the cast.[65] Stannard and colleagues[66] evaluated 16 patients treated in a Pavlik harness for isolated femoral shaft fractures and all went on to fracture union after an average of 5 weeks of treatment in the brace. Because a Pavlik harness can be applied in a nonsurgical setting, does not require sedation or a general anesthetic, and has been shown to significantly reduce skin complications in this population, we feel that this age group can reliably be treated in a Pavlik harness.

Although many investigators recommend that children ages 6 months to 5 years be treated in a spica cast, the AAOS clinical guidelines do not offer any recommendations for or against spica casting in this age group.[1,4,67] Some authors have examined whether flexible nails would be a better option in this population. Heffernan and colleagues[68] compared 141 preschool aged patients treated with closed reduction and spica casting for femoral shaft fractures with 74 patients of similar ages treated with titanium elastic intramedullary nails (TENs). Although both groups had similar time to radiographic union with acceptable coronal and sagittal alignment,[69] these authors found that the TENs group returned to walking and full function after injury faster than the spica patients.[68] Complication rates were low in both groups, but the authors did not divulge the number of TENs patients who required a second surgical procedure for implant removal. Also, the study did not differentiate between polytrauma patients and those with isolated femoral shaft fractures. More than one-third of the patients in the TENs group had other associated injuries (32% vs 13% in the spica group; $P = .002$), which potentially influenced the surgeon's decision to treat these patients with TENs rather than a spica cast.[68] Bopst and colleagues[70] also found that preschool children treated with TENs were able to weight bear and mobilize faster than those who were treated with spica casts. However, 12% of this cohort required an early return to the operating room for revision surgery owing to nail migration through the skin. The authors did not state whether any patients treated with casting required a repeat anesthetic. They also did not report the number of patients who underwent another anesthetic for removal of the TENs nails after fracture union.[70] It has previously been shown that elective implant removal after flexible nail placement for a femur fracture has an infrequent but real risk of complications, and this factor is important to consider when weighing treatment options in this population.[71]

Studies have highlighted the potential burden that a spica cast can place on a family. Parents are more likely to report needing to take time off work because daycare facilities and schools are unable to provide care for this patients during the day.[72] A percentage of patients also require alternate modes of transportation owing to the cast, such as the use of an ambulance to get to and from clinic appointments.[69] Leu and colleagues[73] compared single versus double leg spica casting for patients with femoral shaft fractures. Patient in the single leg group were more likely to fit into car seat and chairs, and care givers were able to take less time off work during the treatment period, with no difference in union rates, fracture alignment, or shortening between the groups.[73] Flynn and colleagues[69] have shown that placing a child in a walking spica cast allows children to crawl, stand, and walk faster than patients treated in a traditional spica. Although almost 1 in 4 patients in the walking spica required an in-clinic cast wedge early in the treatment course, fewer of these patients required a second anesthetic for cast revision than the traditional group and there were no differences in the ultimate coronal or sagittal plane alignment between the groups. Family members of the walking spica group reported a reduced care burden compared with the traditional spica group, and none of the patients treated in a walking spica required an ambulance for transportation.[69]

Ramo and colleagues[74] specifically compared outcomes of children ages 4 to 5 years treated with either spica casting or flexible nails. This study examined 262 patients, 158 of whom were treated with immediate spica casting and 104 who were treated with flexible nails. The flexible nail patients were older, weighed more, and more likely to have sustained a high-energy injury compared with the spica group. Four patients in the spica group returned to surgery for cast removal and nail placement owing to either malalignment (n = 3) or family request (n = 1), and 4 patients in the nail group required early implant removal and spica casting owing to nail migration through the skin. There was no difference between the groups with regards to coronal or sagittal angulation or fracture shortening greater than 20 mm at the time of fracture union.[74] A greater percentage of patients treated with flexible nails had complications (16.3% vs 7.6%; $P = .04$) and 89% underwent a subsequent surgery versus only 5.1% in the spica group ($P<.001$), mostly for implant removal.[74] Given the high rates of fracture union and acceptable femoral alignment after treatment, this study suggests that spica casting is the preferred treatment for this age group in the setting of an isolated femoral shaft fracture owing to the significantly lower rates of complications and secondary surgeries.

The AAOS states that flexible intramedullary nails are an option when determining the treatment of femoral shaft fractures in children age 5 to 11 years. This approach has become a generally accepted treatment, with benefits including earlier mobilization, return to walking, return to school, and return to full function in this age group compared with other treatment modalities.[75,76] The studies referenced in the guidelines focused specifically on the use of titanium nails and the guidelines highlight reports of malunion and implant failure when TENs nails are used in children who weigh more than 47 kg and/or are greater than 11 years of age.[77–79] The complication rates seen in this subgroup population treated with TENs have led surgeons to try other treatment modalities for this group, including submuscular plating and rigid intramedullary nail placement in older and heavier patients.[80]

Although are popular in the United States, there are multiple studies comparing stainless steel flexible nails with TENs that suggest that the stainless steel implants are a superior choice from both a strength and a cost perspective. Wall and colleagues[81] demonstrated that the malunion rate was 4 times greater and the major complication rate was more than 2 times greater in patients treated with TENs compared with stainless steel implants, whereas the cost of the stainless steel implant was 3 to 6 times lower. Since the publication of these guidelines, Shaha and colleagues[82] have shown that stainless steel flexible nails can be used in patients who weigh more than 100 lbs without any significant increased risk of nonunion, malunion, or implant. Length unstable fractures have less risk of fracture shortening, implant prominence, and minor perioperative complications when treated with locked stainless steel flexible nails.[83] Although studies of TENs have suggested that 80% canal fill needs to be achieved for maximum fracture stability,[84,85] stainless steel implants can have as little as 60% canal fill with no significant effects on fracture union, shortening, or ultimate alignment.[86] The current guidelines do not address whether titanium or stainless steel implants should be used when considering flexible intramedullary nail placement.[1]

Patients 11 years and older are candidates for either flexible or rigid intramedullary fixation.[1] Studies of TENS nails in this group have shown higher rates of complications, although this is potentially related to the weight rather than the age of these patients.[77,78] Garner and colleagues[87] reported reduced operative time, blood loss, and implant-related complications in length stable femur fractures treated with TENs nails with no increased risk for malunion or limb length discrepancy, although their 66% rate of implant-related complications with rigid nails is higher than what has been reported in other studies.[88–90] The superior biomechanical properties of stainless steel over titanium also makes stainless steel flexible intramedullary nails a reasonable treatment option in this patient population, even in length unstable fractures, although the clinical guidelines do not address this issue.[82,83] The guidelines do state that a piriformis start point should be avoided in this population owing to the risk of avascular necrosis.[1]

GRADE 1 OPEN FRACTURES

Surgical treatment of open fractures to remove contamination and devitalized tissue from the wound is well-established in the literature. Work by Gustilo and Anderson has helped to promote this aggressive treatment of open fractures, and has given orthopedics one of the most widely used classification schemes to help guide the treatment of open fractures.[91–97] Studies have suggested that all open fractures should be managed with antibiotics and surgical debridement, and that both antibiotic administration and debridement should occur within a few hours of injury.

The more recent literature has called the timing and need for operative intervention into question for some types of open fractures. Skaggs and colleagues[98] first reported a retrospective review of 104 open fractures in pediatric patients treated at a single center. All patients underwent operative debridement with an overall infection rate of 1.9%. There was no difference in the infection rate between those treated within 6 hours and those treated either 6 to 12 hours or more than 12 hours after injury. A subsequent multicenter study reviewed surgical timing and rate of infection among 544 open fractures in pediatric patients.[99] Fractures involved a wide variety of anatomic locations, with 178 involving the radius and ulna. Just more than 50% of injuries were classified as grade 1, 28% as grade 2%, and 17% as grade 3. Overall, 62% of all fractures were surgically debrided within 6 hours of injury. Timing to surgery did not vary by fracture grade, although there was a trend toward more rapid surgical intervention in the grade 2 and grade 3 injuries compared with the grade 1 fractures. Surgery was delayed more than 6 hours in more than 40% of grade 1 injuries, 25% of grade 2 injuries, and 36% of grade 3 injuries. Despite this delay, there was no difference in the overall rate of infection (3% among those who underwent surgery within 6 hours vs 2% in those in whom surgery was delayed more than 6 hours; $P = .43$).[99] This study calls into question the significance of early surgical debridement of open fractures.

Antibiotic timing for the treatment of open fractures in pediatric patients has not been well-reviewed. Patzakis and Wilson cited an infection rate of 4.7% when patients received antibiotics within 3 hours of injury, compared with a 7.2% infection rate when antibiotic administration was delayed by more than 3 hours.[100] Although there is no level 1 evidence to support a strict time interval during which antibiotics need to be given, there is universal agreement that antibiotics should be administered as quickly as possible upon patient arrival to the emergency department.

The treatment of grade 1 open fractures has garnered increasing amounts of attention over the past 20 years. Multiple studies promote the maxim that all open fractures be treated operatively. Studies of grade 1 open forearm fractures treated with antibiotics and surgical debridement consistently report high rates of good to excellent outcomes with high rates of healing and very low rates of infection.[101,102] However, some authors have called into question the need for surgical debridement of type 1 open fractures. By definition, these fractures retain their periosteal coverage, which is thicker in children than in adults. The wounds are not grossly contaminated and the muscle layer is intact. These anatomic factors support the idea that there is adequate blood supply to the fracture site to deliver antibiotics to prevent infection and promote fracture healing.

Yang and colleagues[103] first reviewed the treatment of 91 grade 1 open fractures in adult and pediatric patients. All injuries were irrigated urgently in the emergency department but only one-third of patients underwent formal surgical intervention. Cefazolin was administered within 6 hours of the injury and patients were admitted for an additional 48 hours of intravenous antibiotics. There was a 0% incidence of infection, leading the authors to argue that operative intervention may not be indicated for grade 1 open injuries as long as antibiotics, appropriate wound care, and fracture stabilization are performed in a timely manner.[103]

Subsequently, multiple studies specifically analyzing management of grade 1 open fractures in pediatric patients have been performed. Iobst and colleagues[104] reported on 40 pediatric patients with grade 1 open injuries who presented between 1998 and 2003. Patients received intravenous antibiotics in the emergency department and were subsequently admitted for another 48 to 72 hours for additional antibiotics. Only 4 patients received oral antibiotics after discharge and the overall deep infection rate was 2.5%.[104] Doak and colleagues[105] subsequently reviewed their own experience with 25 pediatric patients, 11 of whom were treated exclusively in the emergency department with a single dose of intravenous antibiotics. The discharge protocol was variable, with 20 patients receiving a prescription for oral antibiotics after discharge; the drug type and duration of treatment was also variable. Only 1 patient developed an infection, although this was not culture proven and symptoms resolved with an additional 48 hours of intravenous antibiotics; surgical debridement was not performed. Bazzi and colleagues[106] similarly found no cases of deep infection after nonoperative management of 40 patients with grade 1 open fractures of the forearm or tibia. Godfrey and colleagues[107] compared the outcomes of 49 patients with grade 1 open fractures treated nonoperatively with 170 patients who underwent surgical debridement and reported only 1 deep infection in the nonoperative group. In addition to the single case of infection, 1 patient who was managed nonoperatively had a loss of reduction after initial management. However, 9 patients in the operative group experienced complications, which included compartment syndrome, acute carpal tunnel syndrome, and a delayed fracture union. As with the prior studies, there was no consistency regarding the type of antibiotic chosen, duration of intravenous treatment, decision to administer oral antibiotics after discharge, or duration of antibiotic administration after discharge.

To minimize inconsistency, Iobst and colleagues[108] developed an institutional protocol for the management of grade 1 open forearm fractures in pediatric patients. All patients receive 1 dose of an intravenous cephalosporin in the emergency department and undergo wound irrigation with saline and betadine. Patients subsequently undergo closed reduction and casting, with a window created in the cast to monitor the wound. Patients are then admitted for an additional 3 doses of intravenous antibiotics and discharged home without further medical treatment. Wound checks and in cast radiographs are obtained 1 week after discharge. In reviewing their experience with 45 patients with open forearm fractures, they had no deep infections, and only 3 of 45 patients lost reduction in the cast and required surgery for repeat reduction.[108] The duration of admission ranged from 26 to 41 hours, and the average time to radiographic fracture healing was 50.5 days. Patients were followed for a minimum of 5 years and there were no known delayed infections.

Currently, there is no level 1 or 2 evidence to support the nonoperative management of grade 1 open fractures in pediatric patients. However, there are a growing number of level 3 studies that suggest this is a safe treatment approach that spares children from surgery and general anesthetic exposure while being cost effective for both the families and the health care system. The existing level 3 and 4 studies advocating nonoperative management are consistent in that each patient received intravenous antibiotics, usually a cephalosporin, in a timely fashion upon arrival in the emergency department. Patients also underwent local wound debridement in the emergency department and fracture reduction with subsequent casting or splinting. The studies vary on the type and duration of antibiotics subsequently administered and the route of administration. No firm treatment recommendations can be made based on the current evidence, but these studies indicate that larger level 1 and 2 studies need to be performed using firm treatment protocols regarding antibiotic administration.

MEDIAL EPICONDYLE FRACTURES

The treatment of acute medial epicondyle fractures in pediatric patients is potentially one of the most debated trauma topics in the literature today. Classically, this is an injury that has been treated nonoperatively with immobilization in a long arm cast for approximately 4 weeks, regardless of the amount of displacement.[109,110] There is consistent agreement that open fractures and medial epicondyle fractures that are incarcerated in the ulnohumeral joint after an elbow dislocation should be treated operatively.[111–116] Possible surgical indications have been extended to include fractures associated with ulnar neuropathy, citing the concern for possible nerve entrapment in the joint, as well as fractures associated with elbow dislocations or documented valgus instability.[111] More recently, there has been an increasing interest in extending surgical treatment to fractures that are more displaced, with some authors citing as little as 2 mm displacement as an indication for surgery.[117,118] Finally, there is growing interest in treating patients based on their level of physical activity, citing that high-demand and/or overhead athletes require an anatomic reduction of the fracture fragment to impart stability and tension the flexor pronator mass.[119–121]

The medial epicondyle is both the attachment point for the anterior bundle of the ulnar collateral ligament as well as the flexor–pronator mass.[111] Biomechanical studies of the ulnar collateral ligament have shown that it plays a crucial role in resisting valgus stress, acting as a static stabilizer of the ulnohumeral joint.[122,123] The anterior bundle is uniquely important, because it plays a role in stability in elbow flexion and extension.[124] The flexor–pronator mass is a dynamic stabilizer of the elbow and it functions as a protective force for the ulnocollateral ligament when the elbow is exposed to torsional stress.[111] Advocates of surgical treatment for medial epicondyle fractures argue that the resulting displacement of the attachment points of both the anterior bundle of the ulnocollateral ligament and the flexor–pronator mass in nonoperatively treated fractures leave the ulnohumeral joint at risk for valgus instability. Those who care for high-level athletes argue that even slight instability to valgus loads place the athletes at risk for cartilage degeneration and long-term arthritis.[125]

Evidence to guide the treatment of medial epicondyle fractures is limited. Josefsson and Danielsson[110] followed patients with medial epicondyle fractures treated nonoperatively for 35 years. These authors cited a high rate of nonunion, although the patients did well functionally. Farsetti and colleagues[126] offered long-term follow-up of both operatively and nonoperatively treated patients, with an average follow-up of approximately 30 years. Regardless of whether patients were treated nonoperatively or surgically, patients were equally likely to have good or fair outcomes at the final follow-up. Patients treated with anatomic reduction through surgery were significantly more likely to go on to osseous union, whereas 17 of 19 patients treated nonoperatively had documented nonunion at follow-up. However, patients had equal results in terms of strength, muscle mass, and elbow stability.[126] The only patients who had poor results where those who underwent fragment excision with suture repair of the soft tissue structures. Because nonunion was so common in the nonoperative group and also seemingly asymptomatic, the authors argued that this should be seen as an expected outcome rather than a complication and that nonoperative treatment should be the accepted treatment for these injuries.[126] Stepanovich and colleagues[127] reported similar findings in a smaller study of only 12 patients, with no difference in elbow stability or strength regardless of treatment. They also found a higher rate of union among surgically treated patients. However, surgically treated patients were significantly more likely to complain of medial elbow pain, although this was not severe enough to require implant removal.

Because classification schemes have been based on amount of fracture displacement, there is increasing interest on how accurately fracture displacement can be measured on radiographs. Pappas and colleagues[128] showed low rates of interobserver reliability when measuring fracture displacement on routine anteroposterior, lateral, and oblique radiographs. Edmonds[129] supported this finding in 2010, which demonstrated that anteroposterior and lateral radiographs consistently underestimated the degree of fracture displacement compared with computed tomography studies. computed tomography scans of 9 patients with displaced medial epicondyle fractures showed that the maximum trajectory of displacement was anterior, which is difficult to measure on pure anteroposterior or lateral radiographs. These images showed minimal medial fracture displacement, which radiographs typically overestimated. Internal oblique radiographs were slightly, but not significantly, better at assessing the displacement, although only 6 of the 9 patients had this image taken as a part of their initial series.

A major argument for treating displaced but closed and nonincarcerated fractures in adolescent patients is that restoring the normal anatomic alignment of the medial collateral ligament will result in less risk of symptomatic valgus instability and improved overall elbow function. However, the current literature does not consistently support this argument. Biggers and colleagues[130] compared operatively and nonoperatively treated medial epicondyle fractures among 31 adolescent patients and cited equally high functional outcome scores in each group, although patients managed nonoperatively were more likely to have radiographic evidence of fracture nonunion, valgus instability of the elbow, and medial epicondyle hypertrophy. One study comparing operative and nonoperative treatment among athletes found that all patients, regardless of treatment, were able to return to their desired sporting activities at the appropriate level for their age and skill.[131] Seven patients were active in baseball and the 3 nonoperatively treated patients had no issues with valgus instability or elbow pain that limited them from play. All patients were followed for a minimum of 2 years.

Surgical stabilization of displaced medial epicondyle fractures makes anatomic sense when the importance of the medial collateral ligament for elbow stability is considered. However, there are no large, high-level studies that document improved function among pediatric patients who undergo operative intervention for medial epicondyle fractures. At this time, the literature continues to support treating open and/or incarcerated fragments operatively and treating nondisplaced or minimally displaced fractures nonoperatively. There is a trend toward operative intervention for medial epicondyle fractures that are displaced by more than 5 mm, but there is no strong evidence to suggest that this results in improved patient outcomes. An understanding of the ideal treatment for this injury would benefit substantially from a well-designed, large, prospective, randomized study.

CLAVICLE FRACTURES

Clavicle fractures account for anywhere from 10% to 15% of all pediatric fractures.[132,133] Ninety percent of these are middiaphyseal injuries.[134] Historically, these fractures were treated nonoperatively with general agreement they have a high rate of union and patients do well clinically with no significant loss of function.[109] However, there has been an increasing trend toward operative intervention for displaced clavicle fractures in pediatric patients in recent years.[135–137] This trend has coincided with recent literature advocating for more aggressive treatment of adults with certain clavicle fractures.

In 2004, Robinson and colleagues[138] prospectively reviewed 886 adults who sustained closed, acute, traumatic, displaced clavicle fractures that were treated nonoperatively. These investigators reported a 4.5% incidence of nonunion with age, female gender, fracture displacement, and comminution each increasing the risk of nonunion. McKee and colleagues[139] then reported that patients who went on to union but who had shortening of 2 cm or more sustained a significant loss of both maximum and endurance strength of the affected shoulder in abduction, forward flexion, and rotation. These studies helped to pave the way for a large, multicenter, randomized, level 1 trial of operative versus nonoperative management of closed clavicle fractures in adults. This study demonstrated that patients with displaced diaphyseal clavicle fractures who were treated operatively had significantly shorter time to union, a decreased risk of nonunion and symptomatic malunion, improved Disability of Arm Shoulder and Hand scores, and overall increased patient satisfaction compared with those who were treated nonoperatively.[140] To be included in the study, patients were required to have closed fractures that were completely displaced with no cortical contact; patients younger than 16 years of age were not included. These studies have changed acceptable operative criteria for diaphyseal clavicle fractures in adults to include open fractures, threatened skin, presence of an ipsilateral humerus fracture resulting in a floating shoulder, diaphyseal fracture comminution, and/or shortening of 2 cm or more. Relative indications reported include fracture shortening of 15 mm or more and presence of a "z-deformity" in the fracture pattern.[133,141–143]

Because treatment recommendations for management of adults with clavicular fractures have changed, many surgeons are becoming more surgically aggressive in pediatric patients despite the absence of similar high-level studies in this population. Studies of postnatal clavicular growth have shown that females achieve 80% of clavicular growth by age 9 and males achieve 80% of clavicular growth by age 12; neither gender has significant clavicular growth remaining after age 12.[144] This finding suggests that there is limited clavicular remodeling potential in adolescents who are older than 12 years at the time of injury. With this in mind, some surgeons have started to use the operative indications for adult patients in their pediatric population.[142]

Kubiak and Slongo[134] first reported their results on adolescents who underwent operative fixation of their clavicle fractures in 2002. Of 939 patients who presented between 1980 and 2000, only 15 required operative intervention, which accounts for only 1.6% of the affected population in the study period. Indications for surgery included soft tissue impingement with threatened skin, and impingement on surrounding structures, including the trachea. Although there were no major postoperative complications, 13 of the 15 had minor complications, which included numbness at the surgical site, implant prominence, skin irritation, and 1 refracture after healing. Although this study supports the idea that patients can do well postoperatively, surgery is not without risk, the minor complication rate is high, and the authors argue that they continue to treat most of their patients nonoperatively.

Vander Have and colleagues[145] reported on 42 consecutive adolescent patients with closed diaphyseal clavicular fractures, 17 of whom underwent surgical intervention. There was 100% union in the operative group with no reported major complications and only 3 patients went on to have implant removal owing to prominence. In contrast, 5 patients in the nonoperative group reported pain with prolonged overhead activity, easy fatigability, and pain at the fracture union site. Four of these patients underwent surgery for corrective osteotomy and plate fixation with resolution of symptoms. Although the high rate of union and low rate of major complication in the operative group are similar to other studies, the 20% incidence of symptomatic malunion and 16% incidence of corrective osteotomy after union is an outlier in the pediatric literature. Randsborg and colleagues[146] reported on 62 adolescent patients, 9 of whom underwent surgical correction. In contrast with the study by Vander Have and colleagues,[145] 95% of patients in Randsborg's cohort who were treated nonoperatively reported good to excellent long-term results on the Quick Disability of Arm Shoulder and Hand score and the Oxford Shoulder Score. Also unlike the study done by Vander Have and colleagues,[145] 66% of the operative group reported by Randsborg and colleagues required a second surgery for implant removal owing to prominence. Hagstrom and colleagues[147] reported a trend toward better Disability of Arm Shoulder and Hand scores and faster return to play among patients treated nonoperatively, although neither outcome achieved statistical significance. The variability in patient outcomes seen when comparing these studies is likely reflective of the small patient cohort in each study.

One of the driving factors for surgical intervention in adult patients is the increased risk of nonunion when displaced fractures are treated nonoperatively. Extending the adult operative indications to pediatric patients would mean that nonunion could be similarly high in this population when displaced fractures are treated conservatively. However, the current literature does not support this assumption. Hagstrom and colleagues[147] and Vander Have and colleagues[145] reported no nonunions in their nonoperative cohorts, and Randsborg and colleagues[146] reported only 1 nonunion out of 185 patients. Nogi and colleagues[148] submitted a case report of a single nonunion in a 12-year-old patient with a displaced clavicle fracture. The current literature, therefore, suggests that nonunion is uncommon after nonoperative treatment of clavicle fractures in pediatric patients.

Another important consideration in treatment selection is whether pediatric patients have diminished strength or function when displaced fractures are treated nonoperatively. Although Randsborg and colleagues[146] reported a high rate of patient satisfaction and high functional scores in 95% of patients treated nonoperatively, patients with completely displaced or comminuted clavicular fractures reported significantly worse scores with regard to pain and cosmetic results. Fracture shortening had a small but significant negative effect on the Oxford Shoulder Score, as well as patient cosmetic and overall satisfaction scores. Parry and colleagues[149] sought to determine whether patients who sustained clavicle fractures that healed in a shortened position had lasting deficits in strength and function. This study compared 8 patients treated nonoperatively with 8 patients who underwent operative intervention for similar fracture patterns and found no difference in range of motion, strength or self-reported function. One patient from each group reported dissatisfaction with the cosmetic result, reminiscent of the question, "Would you rather have a bump or a scar?" Similarly, Bae and colleagues[150] identified 21 adolescents who had clavicular fractures treated nonoperatively that healed with more than 2 cm of shortening. No significant loss of strength was seen when comparing the affected side with the nonoperative extremity. Patients lost an average of 7.5° of forward flexion and 6.5° of abduction, which was significant although it is unclear if this loss is of actual clinical relevance. No difference was seen regarding strength.

Surgical treatment is not without risk of complication. Li and colleagues[151] reported an 86% postoperative implication rate in 36 adolescent patients treated surgically for clavicle fractures. The majority of the complications were related to implant prominence and/or irritation, but 16% also reported anterior chest wall numbness, 5% had problems with superficial wound dehiscence, and 1 patient sustained a fracture adjacent to the plate. Luo and colleagues[152] reported a 21.7% complication rate among operatively treated adolescents versus a less than 1% complication rate in 130 adolescents treated nonoperatively.

Although high level studies in adult patients support operative intervention for specific fracture patterns, the current literature in pediatric patients does not demonstrate the same risks of nonunion or loss of function when patients are treated nonoperatively.[138–140,149,150] The current literature suggests that pediatric patients do equally well from a healing and functional standpoint when treated nonoperatively, even in the setting of a shortened and/or displaced fracture. However, the literature is lacking in large, high-level studies. At this time, operative treatment for closed, displaced clavicle fractures in the absence of threatened skin cannot be recommended, but further research is needed in this area.

SUMMARY

The number of studies examining treatment options for pediatric fractures have exploded in recent years, perhaps complicating rather than simplifying surgical decision making and patient care. Although clinical guidelines are available in limited circumstances, these also have shortcomings. There is strong evidence to support closed reduction and pinning of type 3 supracondylar fractures, especially in the cool and pulseless extremity, but surgical timing and management recommendations are less well-defined in the setting of severe soft tissue injury, isolated neurologic injury, and the "pink, pulseless" hand. Similarly, whereas strong evidence supports evaluating young children with femoral shaft fractures for NAT, there is limited high-level evidence available for almost every other clinical scenario involving pediatric femoral shaft fractures. Level 1 and level 2 multicenter studies with firm treatment protocols are needed to better understand how grade 1 open fractures, medial epicondyle fractures, and clavicle fractures in pediatric patients should be managed.

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