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Operative Techniques in
Orthopaedics

The Pediatric Floating Elbow

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The pediatric floating elbow involves fractures of the humerus and forearm. Majority of these injuries include supracondylar humerus fractures with ipsilateral forearm fractures. These fractures should be managed with great caution as they often result from higher energy injuries and have increased risks of nerve palsies, open fractures, loss of forearm fracture reduction, and compartment syndrome. Previous literature has advocated for operative fixation of ipsilateral forearm fractures in addition to stabilization of the supracondylar humerus fracture, to allow for noncircumferential immobilization to decrease the risk of compartment syndrome. However, recent studies have questioned the universal need for forearm fixation in patients with these injuries. This paper will discuss the pediatric floating elbow, review the available literature, and describe our technique for managing these injuries.
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Introduction

Pediatric elbow fractures are commonplace and represent approximately 12% of all fractures in children. Of these fractures, the majority are supracondylar humerus fractures, which are the most common pediatric fracture to require surgical intervention. These fractures most often occur from a fall onto an outstretched hand. In isolation, the treatment of supracondylar humerus fractures is not typically urgent or emergent except in the setting of neurovascular compromise, significant swelling, puckering or ecchymosis of the antecubital fossa, or open fractures. Distal forearm fractures represent 23.3% of all fractures in children and are the most common fracture seen. Majority of isolated forearm fractures in children can be managed with closed reduction and casting without surgical stabilization. As with isolated supracondylar humerus fractures, isolated fractures of the forearm often do not require urgent or emergent surgical intervention.

The combination, however, of forearm fractures and humerus fractures, most commonly supracondylar humerus fractures, requires great caution by the treating provider. These injuries are referred to as a "floating elbow" and are associated in up to 5% of supracondylar humerus fractures.[3,14] These injuries have been hypothesized to result from a higher energy mechanism with the force being transmitted through the bone rather than dissipated through a single fracture. The soft tissue envelope, in turn, sustains significant trauma most often resulting in a greater degree of swelling. Although these fractures have been classically thought of as high-energy injuries, the vast majority of these injuries result from falls, and majority involve falls from playground equipment as would be seen with isolated extremity fractures.[12,13] The floating elbow, in conjunction with greater degree of soft tissue injury, place patients with these injuries at higher risk of complications including open fractures, compartment syndrome,[3,12,13] neurovascular injury,[7,14,18] and loss of reduction following treatment.[12]

Of these complications, compartment syndrome is potentially the most devastating. A recent review of the National Trauma Data Bank examining the incidence of compartment syndrome in the presence of a supracondylar humerus fracture found that in the presence of a concomitant forearm fracture there is a 0.8% incidence of compartment syndrome and an odds ratio (OR) of 3.2.[13]

Compartment syndrome is one of the true orthopaedic emergencies regardless of age. The combination of trauma and increasing soft tissue swelling within a closed osteofascial compartment can lead to devastating neurovascular

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compromise as well as skeletal muscle ischemia due to decreasing perfusion pressure. Irreversible nerve functional loss occurs after 12-24 hours of continued ischemia while reversible functional loss occurring as early as 2 hours, highlighting
the importance of prevention and diagnosis.[5,10,15] Mild muscle necrosis can occur within 2-3 hours of ischemia time, while moderate to severe necrosis results from ischemia upwards of 5 hours.[9] The presence of circumferential immobilization, degree of elbow flexion, and extent of arm elevation can all influence compartment pressures and can contribute to the ischemia that leads to elevated compartment pressures.

The purpose of this paper will be to review the literature on the pediatric floating elbow, discuss current treatment algorithms, and describe our institutional techniques for managing these injuries.

Review of the Literature

Early reports on the treatment of pediatric floating elbows recommended either olecranon traction or percutaneous pin fixation of the supracondylar humerus fracture as a means of avoiding neurovascular complications, including compartment syndrome.[11,17] Universally, current literature supports the use of closed reduction and percutaneous pinning for type 2 and 3 supracondylar humerus fractures in the setting of a floating elbow. However, the literature is not as clear with regards to management of the ipsilateral forearm fracture.

Ring et al retrospectively reviewed their patients with extension type supracondylar humerus fractures with ipsilateral displaced distal forearm fractures over a 9-year period at a tertiary children's hospital. Despite these fractures being associated with higher energy injuries, all 14 patients were a result from a fall, majority from playground equipment. Of the 14 patients, 1 had an open fracture of the distal forearm and 3 had preoperative nerve injuries. A total of 10 patients underwent closed reduction of the distal forearm fracture with percutaneous pinning of the supracondylar humerus fracture and application of circumferential casting. Of those 10 patients, 2 went on to develop compartment syndrome, 4 had impending compartment syndrome requiring splitting of the cast, which resulted in loss of forearm reduction in 3 of the 4 patients. The 6 patients who underwent percutaneous pinning of both the distal forearm fracture and supracondylar fracture with application of noncircumferential splinting did not develop compartment syndrome or loss of reduction.

Blakemore et al retrospectively reviewed 978 upper extremity fractures over a 13-year period and found 4.4% of those fractures involved ipsilateral fractures of the humerus and forearm, with only 9 patients (0.9%) involving displaced forearm fractures with extension type supracondylar humerus fractures. Of those 9 patients, 3 required fasciotomies for compartment syndrome (33% or 0.3% of all upper extremity fractures).[3] These 2 studies helped lead to the recommendation that displaced forearm fractures in the setting of operative supracondylar humerus fractures undergo closed reduction and pinning to minimize the need for circumferential casting and decrease the risk of compartment syndrome.

Recent literature has questioned the notion that all forearm fractures in the setting of a floating elbow need to be managed with operative fixation. Muchow et al compared 150 patients with floating elbow injuries to 1228 isolated supracondylar humerus fractures requiring surgical stabilization. Of the 150 patients with a floating elbow, 95 patients required forearm fracture reduction. Thirty-nine of the 95 displaced fractures underwent closed reduction and immobilization without surgical fixation. They found that 18/95 (18.9%) had nerve palsies compared to only 7.3% of floating elbows with forearm fractures not requiring reduction and 7.8% for isolated supracondylar fractures. Their study found no significant difference in vascular compromise in floating elbows and no cases of compartment syndrome. Blumberg et al retrospectively reviewed 47 cases of floating elbows requiring operative fixation of a type 2 or 3 supracondylar humerus fracture over a 7-year period. Of the 47 floating elbows, 21 had displaced forearm fractures. Of those 21 displaced forearm fractures, 17 underwent closed reduction and noncircumferential splinting or fiberglass casting. In their series they had no cases of compartment syndrome and none of the forearm fractures lost reduction or required further surgical intervention.[4] In their cohort 28.6% of the displaced forearm fractures had a preoperative nerve palsy and all resolved within 3 months of injury. As with the study by Ring et al[12] all injuries were from falls and 49% were from falls from the monkey bars.

To date, there are no prospective studies evaluating the treatment of floating elbow fractures in the pediatric population.

Authors Technique

Pediatric patients who are suspected of having floating elbow injuries are assessed in the emergency room with a thorough history and physical examination as well as orthogonal views of the humerus and forearm. Regardless of the potential forearm fracture, supracondylar humerus fractures that involve preoperative median nerve palsies, vascular compromise, open fractures, antecubital fossa puckering, or concern for significant soft tissue swelling are taken to the operating room in an urgent or emergent fashion. Patients with isolated anterior interosseous nerve palsies are not consider urgent or emergent.[2] Given the higher incidence of preoperative nerve palsies and potential for compartment syndrome in floating elbows, fractures with operative supracondylar humerus fractures are treated with significant caution and urgency.

Patients with operative supracondylar humerus fractures with nondisplaced forearm fractures or buckle fractures of the distal third of the forearm can be observed and taken to the operating room in a nonurgent fashion if the supracondylar humerus fracture allows. Our typical construct for supracondylar humerus fractures are 2 lateral pins for type 2 fractures and 3 lateral pins for type 3 fractures. Depending on fracture pattern a medial pin is used if needed for construct stability. If the forearm fracture is inherently stable and does not need a reduction the patient can be placed in a long

arm cast. At our institution, we use sterile foam padding in the antecubital fossa underneath the fiberglass cast to allow for postoperative swelling while maintaining the strength of a circumferential cast.[16] In addition, careful attention is paid to the position of the elbow and casted between 45 and 60° of flexion to decrease the chance of postoperative swelling.

Patients who have displaced fractures of the forearm and operative supracondylar humerus fractures are treated urgently with operative intervention (Fig. 1). We currently recommend operative stabilization of both the forearm fracture and supracondylar humerus fracture. The forearm fractures are addressed first and typically involve closed reduction and percutaneous pinning for displaced distal third forearm fractures (Fig. 2). Often only the radius needs to be percutaneously stabilized if there is a displaced both bone forearm fracture. Diaphyseal fractures are treated individually depending on the patient's age, with the most common form of stabilization being flexible intramedullary nails. Given the concern for postoperative swelling and potential for compartment syndrome, noncircumferential casting or splinting is preferred. A circumferential cast or splint does not allow for adequate monitoring of the soft tissue envelope for the potential development of compartment syndrome.

Surgical technique OR setup: The operating room setup for floating elbows is the same as our standard setup for all operative supracondylar humerus fractures. The patient is placed supine on the operating room table and a pediatric sized arm board is used. The patient's head is appropriately positioned at the edge of the bed, typically in the most superior crease of the arm board and operating room table. Depending on the size of the patient, a small gel foam donut can help secure the position of the head and ease the fear of our anesthesia colleagues from the potential for pulling the patients head off the table during the surgical procedure. Care is taken to ensure that fluoroscopic imaging can be adequately obtained without superimposed metal from the operating room bed and/or arm board clamps. The bed is placed at a 90-° angle from anesthesia in order to allow for the C-arm to be brought in parallel to the bed, from the patient's feet. The C-arm

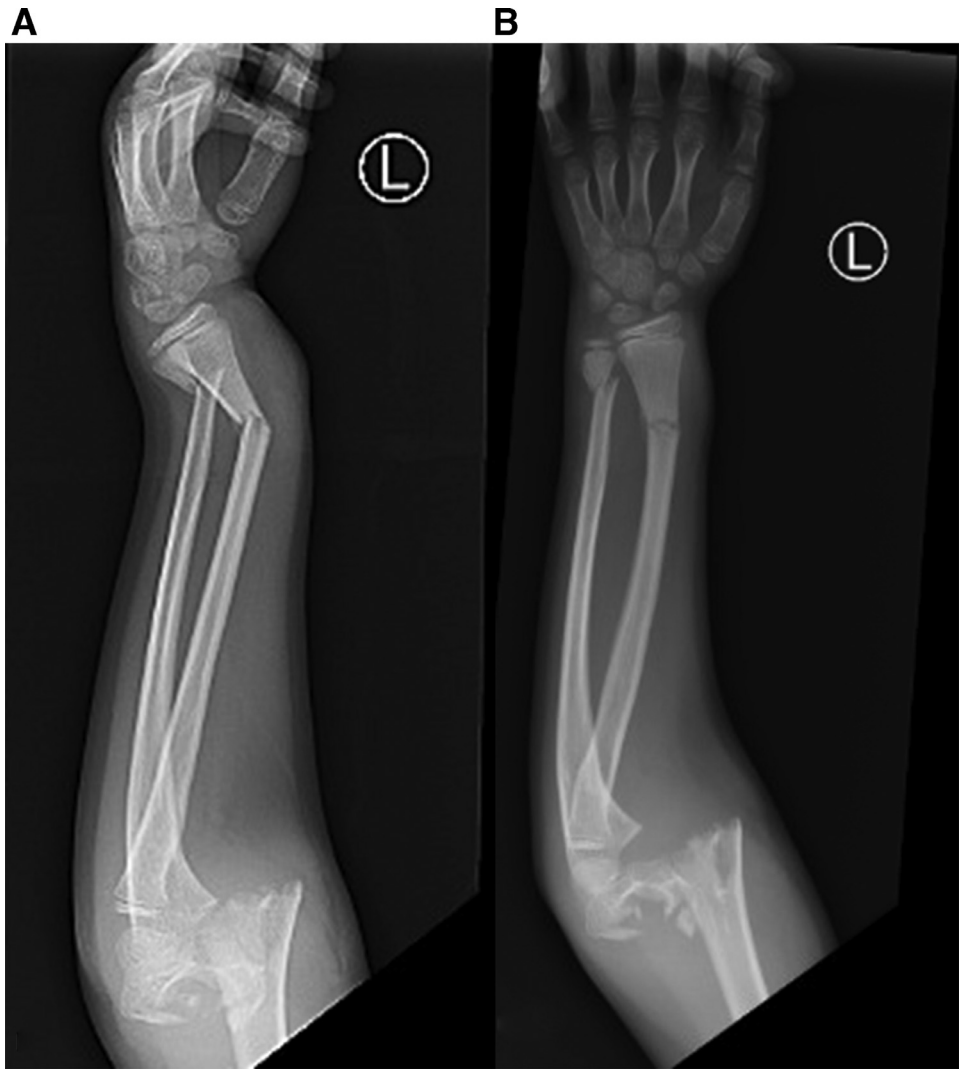

Figure 1 Floating elbow with (A) significant dorsal angulation of both bone forearm fracture with (A/B) ipsilateral type 3 supracondylar humerus fracture.

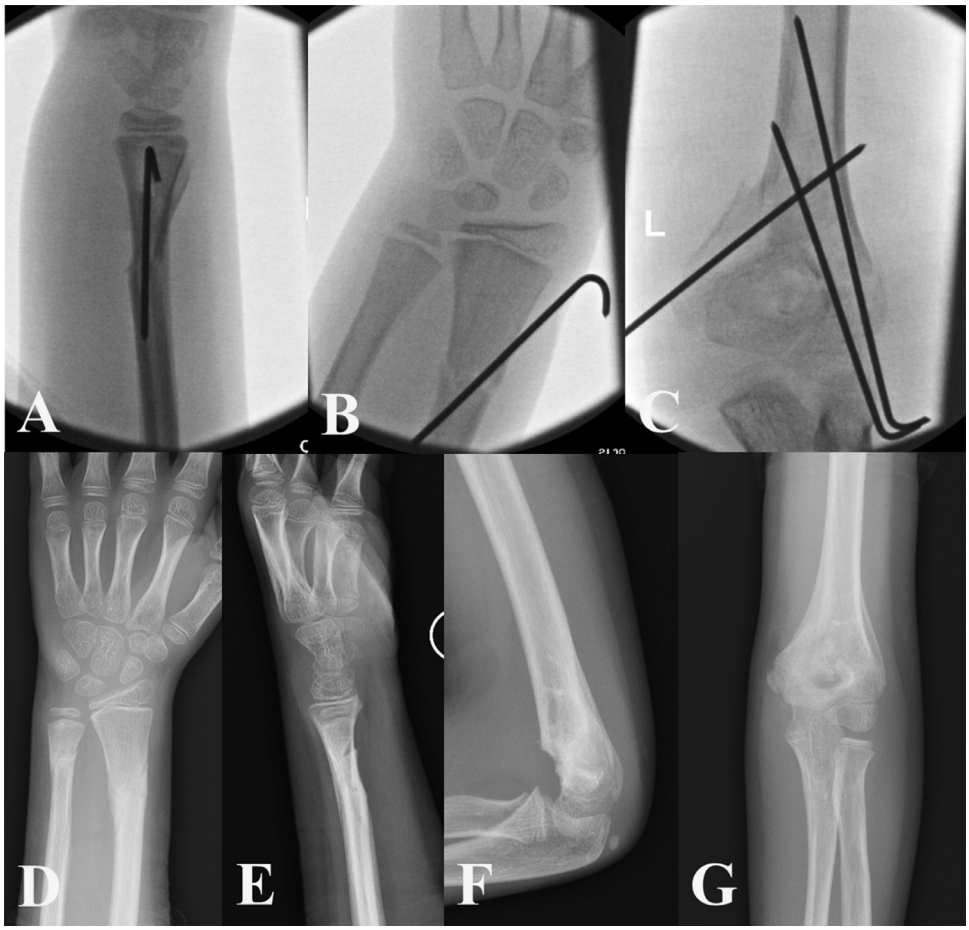

Figure 2 (A/B) Closed reduction of both bone forearm fracture with percutaneous pining of distal radius fracture. (C) Closed reduction and percutaneous pinning of type 3 supracondylar humerus fracture. A medial pin was necessary secondary to the medial column comminution. (D-G) Healed distal both bone forearm fracture and supracondylar humerus fracture.

Figure 3 Missed compartment syndrome in a pediatric patient with upper extremity fractures. There has been significant necrosis of the volar compartment.

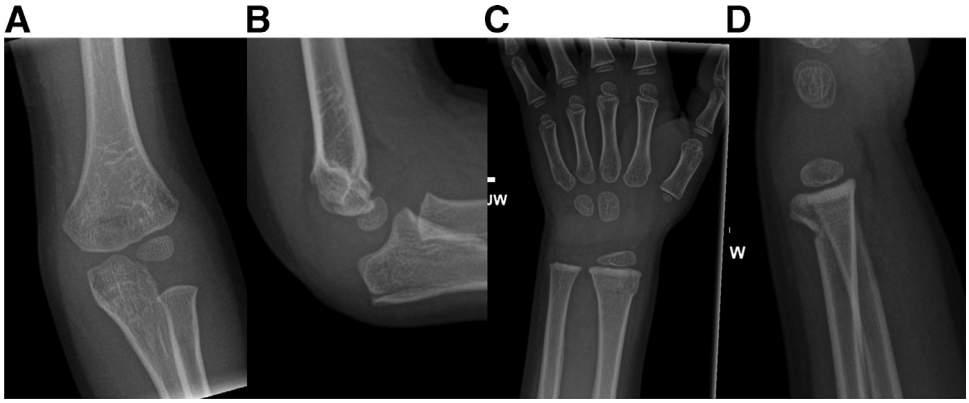

Figure 4 (A) Nondisplaced supracondylar humerus fracture (type 1) and minimally displaced olecranon fracture. (B) Positive anterior fat pad sign. (C) Buckle fracture of the distal radius. (D) Buckle fracture of the distal radius without significant angulation.

monitor should be placed close to anesthesia on the opposite side of the bed so that the monitor is in direct line of site of the operating surgeon who will be performing the percutaneous pinning (Fig. 3). *This allows efficient use of imaging and patient positioning for both the supracondylar humerus fracture and the forearm fracture, in the event that they need surgical stabilization.*

We recognize that no surgical procedure is without potential risks and complications. Surgical stabilization of distal forearm fractures with percutaneous pinning can result in iatrogenic nerve injuries, such as injury to the superficial radial nerve and pin tract infections. Flexible intramedullary nails can result in prominent hardware and often result in a secondary procedure to have the nails removed. In our experience these complications are uncommon and the potential devastating consequences of developing compartment syndrome far outweigh the risks of operative forearm fixation in the majority of cases.

Regardless of fracture pattern and treatment, patients should be admitted to the hospital for monitoring of the soft tissues and regular neurovascular checks. We typically admit patients for 24 hours of monitoring. The traditional signs of compartment syndrome, the 5 P's (pain, paresthesias, paralysis, pallor, and pulselessness), are unreliable in the pediatric population.[1] In pediatric patients, an increasing analgesia requirement has been found to be the most sensitive predictor of developing compartment syndrome.[1] Analgesia requirement should be closely monitored and all members of the healthcare team should be educated about the early signs of compartment syndrome in these patients. In patients with suspected forearm compartment syndrome we recommend emergent compartment release as the results of delayed treatment can be devastating (Fig. 4).

Although rare, it is possible to have nondisplaced fractures of the forearm and distal humerus. Fig. 5 shows the radiographs of a 3-year who sustained a fall from the monkey bars and sustained a type 1 supracondylar humerus fracture, nondisplaced olecranon fracture, and buckle fracture of the distal

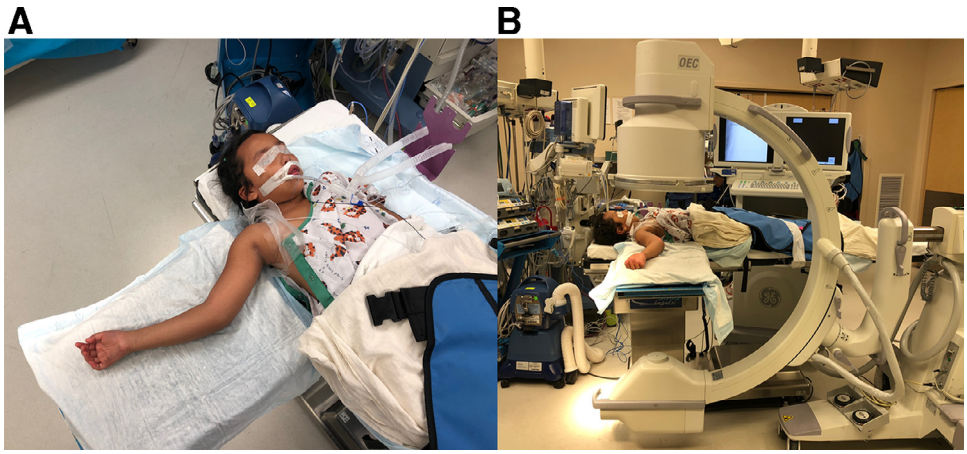

Figure 5 (A) Patient positioning: patient is placed supine on OR bed with pediatric arm board. The elbow should be positioned in the center of the arm board to optimize fluoroscopic imaging. (B) The OR bed is positioned 90° to anesthesia and the fluoroscopy monitor is positioned directly in the line of site of the physician performing the percutaneous pinning. The c-arm is brought in parallel to the bed and from the feet.

radius. The patient had minimal swelling to the forearm and distal humerus, and was managed nonoperatively with treatment in a long arm cast for 3 weeks. Another rare fracture involves humeral shaft or proximal humerus shaft fracture with ipsilateral displaced forearm fractures. In these situations, flexible intramedullary nails can safely be used for both the humerus and forearm fracture without the need for circumferential casting.[6,8]

Conclusion

Although these fractures have been classically thought of as high-energy injuries, the vast majority of these injuries result from falls, and majority involve falls from playground equipment. Regardless of the treatment algorithm for the ipsilateral forearm fracture, patients who present with floating elbows should be managed and cared for with great caution. These patients have a higher rate of preoperative nerve palsies and are at greater risk of developing compartment syndrome. Patients should be monitored closely postoperatively for signs of compartment syndrome, specifically an increasing analgesia requirement.

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