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Operative Techniques in
Orthopaedics

Monteggia Fractures: Pearls and Pitfalls

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The entity of Monteggia fractures describes a spectrum of fracture-dislocations in which the radiocapitellar joint becomes disrupted in association with an ulnar shaft fracture. While these injuries are relatively uncommon in the pediatric population, they pose both a diagnostic and therapeutic challenge, as the constellation of these injuries can be subtle and difficult to identify. As such, they are often missed or neglected in the setting of a minimally displaced ulnar shaft fracture in which the radiocapitellar dislocation goes unrecognized. There is a wide spectrum of treatment strategies for pediatric Monteggia fractures, from closed reduction and immobilization in the acute setting to extensile open reconstructive techniques for chronic cases. Outcomes can be variable depending on the time of treatment and age of the patient. The most important principle for management of these injuries is early recognition and close follow-up to prevent poor outcomes.
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Introduction

Giovanni Monteggia first described in 1814 two cases with a combined a proximal third ulna fracture and an associated anterior radiocapitellar dislocation.[1] It was not until the 1960s that José Bado coined the eponym known today as the *Monteggia lesion;* in his seminal manuscript, he observed other variants of the Monteggia lesion, describing ulna fractures in locations other than the proximal third and describing posterior and lateral radial head dislocations.[2,3] His classification is still used today.

As multiple variants of Monteggia fractures exist, it is most accurately described as a forearm fracture with dislocation of the proximal radioulnar joint.[4] Subtle bowing of the ulna shaft with an asssociated radiocapitellar dislocation may be missed by the inexperienced clinician who is looking for a forearm fracture and therefore under-recognizes plastic deformation (Fig. 1). It is critical to restore this anatomical relationship between the proximal radius and ulna to the distal humerus when treating Monteggia fractures. In the pediatric population, this relationship is most often driven by the character of the ulna; however, other soft tissue structures may impede the restoration of the normal anatomical architecture.

Epidemiology

Pediatric Monteggia fractures are relatively uncommon. Their true incidence is likely unknown, but Letts et al reported only 33 cases over the course of 5 years at their children's hospital in Winnipeg, Canada.[5] The peak incidence in their series was in children aged 7-10. More recently, Joeris et al performed a comprehensive pediatric classification of long bone fractures out of Switzerland over a 2-year period. Out of 2292 upper extremity fractures in children, 26 were Monteggia fractures, comprising 1.1% of cases.[6] Ninety-six percent of these were children younger than 11 years old.

Anatomy

The anatomical relationship of the radius and ulna is crucial for proper rotational motion. They are held together along

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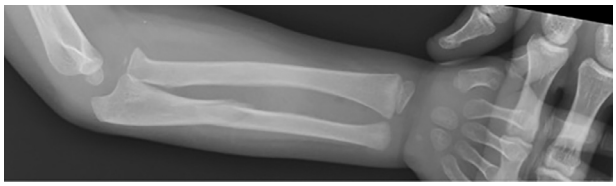

Figure 1 Anteroposterior (AP) forearm radiographic view of an 18-month-old child who fell from the couch. Note the subtle apex anterior bow of the ulna with radiocapitellar dislocation; this Bado Type I Monteggia lesion is easily underappreciated.

their length, distally by the distal radioulnar ligamentous complex, by the interosseous membrane along their shafts, and the proximal radioulnar joint (PRUJ) at the level of the elbow (Fig. 2). Altering the osseous structure or any of their connections along the length of the forearm can be detrimental to regaining functional arcs of motion. Specifically for cases of Monteggia fractures, the quadrate and annular ligaments are crucial structures for maintaining reduction of the PRUJ and radiocapitellar joint.[7] Some even argue that the diastasis of the PRUJ, in addition to radiocapitellar incongruence, is necessary to diagnose a Monteggia fracture.[8,9]

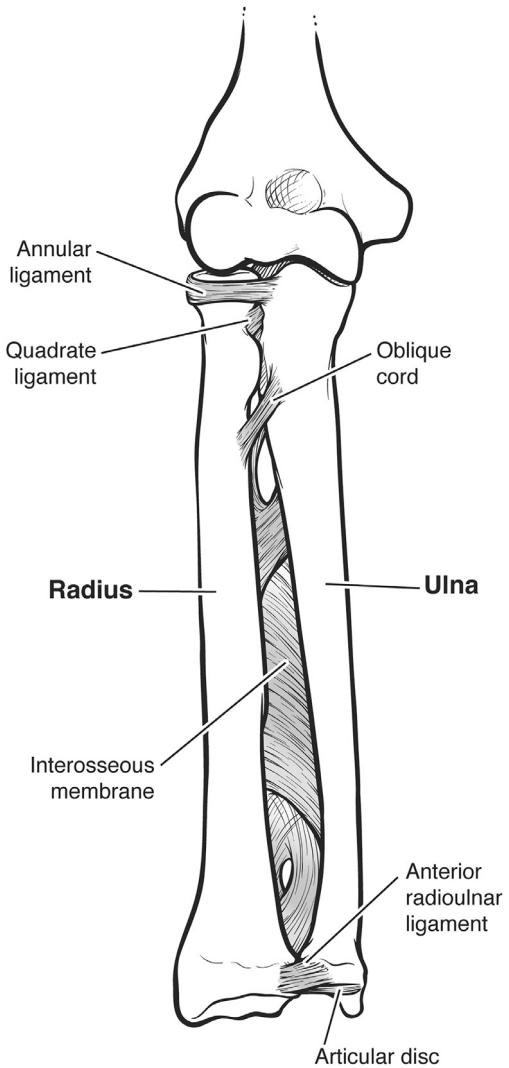

Figure 2 Volar view of the multiple ligamentous structures connecting the radius and ulna.

Because of their intimate association, displaced proximal or midshaft forearm fractures of one bone frequently result in a fracture or dislocation of the other due to the nature of the high energy mechanism.[4]

The muscular anatomy contributes to the deforming forces of Monteggia fractures. In hyperextension mechanisms, the biceps brachii acts to pull the proximal radius anterior relative to the capitellum, which is the most common Monteggia fracture-dislocation, a Bado Type I.[7]

Surrounding neurovascular structures may also experience either compression or traction injuries after Monteggia fractures, which usually result in a transient neurapraxia. Because of its relatively closer proximity to the radial head and neck, the posterior interosseous nerve is at particular risk.

Classification

Originally described as a proximal third ulna fracture with anterior dislocation of the radial head,[1] Bado was the first to thoroughly describe the 4 distinguished types of Monteggia fracture-dislocations in the series of 40 patients that he treated.[2,3] In his description, the type was defined by the direction of the radial head dislocation, which is always in the direction of the apex ulnar deformity (Table 1).

In Bado's series (which included both adults and children), type I was the most common at 60%, followed by type III (20%), then type II (15%), and lastly type II. In children, the majority (>60%) are type I,[6,10] followed by type III; types II and IV are relatively rare in children.[10,11]

Bado also described several Monteggia type I equivalents; the most common of these include a fracture of the ulnar shaft associated with a fracture of the proximal radial epiphysis or radial neck[12]; and another is a pure anterior dislocation of the radial head, which likely is associated with plastic ulnar deformation.[7]

Mechanism of Injury

Each Bado type is associated with a different type of mechanism of injury. Type I Monteggia fractures alone have multiple proposed mechanism: a direct posterior blow to ulna,[1,13] body rotation around a fixed and hyperpronated forearm,[3] and hyperextension during which the biceps pulls the radial

Table 1 Bado's Classification of Monteggia Fracture-Dislocations

Type I	**Radial head is dislocated anteriorly**
Type II	**Radial head is dislocated posteriorly**
Type III	**Radial head is dislocated laterally; the ulna fracture is often a proximal metaphyseal greenstick fracture**
Type IV	**Radial head is dislocated anteriorly, but both the radius and ulna are fractured**

head anteriorly and the ulna fractures from bearing the full weight of the body.[14]

Type II fracture-dislocations occur after a flexed elbow is longitudinally loaded.[12] Type III result from a varus extension force at the elbow.[3,9]

Diagnosis

Evaluation of children with Monteggia fractures usually reveal an obvious deformity about the proximal forearm and elbow.[7] The child will likely have limited range of motion in both flexion-extension and pronation-supination. Depending on the amount of radiocapitellar dissociation, there may be a palpable radial head. It is important to have a high index of suspicion for associated ipsilateral upper extremity injuries, especially in children with Bado type II lesions.[15,16] Examination of skin should be thorough to rule out possible open fractures, and prereduction neurovascular status is important to compare to postreduction or postoperative findings. Pediatric patients with missed or neglected Monteggia fractures may not present until they are adults. In such cases, there may be obvious elbow deformities and neurologic deficits, such as cubitus valgus and tardy ulnar nerve palsy.[17]

Radiographic Findings

Obtaining high quality radiographs of both the elbow and the forearm is critical for appropriate interpretation and subsequent management of pediatric Monteggia fractures. Poor radiographic quality and interpretation is the most common problem faced in treating these children because it may lead to missed or delayed diagnosis.[9,10] This is true both in the acute setting as well as during the follow-up period. Weisman et al described 2 delayed diagnoses of Monteggia fractures: initially both were isolated ulnar fractures with congruent radiocapitellar joints, but as the ulna angulated in the cast, the radial head followed and dislocated from the radiocapitellar joint.[18]

While some Monteggia patterns may show obviously displaced ulnar fractures and radiocapitellar dislocations, care should be taken when assessing for subtle dissociation of the proximal radioulnar joint or incongruity of the radiocapitellar joint.

Classic dogma has taught that a line drawn down the longitudinal axis of the radius should pass through the center of the capitellum in all views regardless of the amount of flexion or extension of the elbow.[13,18] This has been described as the radiocapitellar line, or RCL. However, the RCL may not be as reliable as originally thought to predict the congruence of the radiocapitellar joint and define a Monteggia fracture or an equivalent thereof. Silberstein et al state that the RCL may miss the capitellum completely on the anteroposterior (AP) view in young child.[19] Likewise, Miles and Finlay recommend caution in using the RCL as they identified 5 normal pediatric elbows in which this line did not intersect the capitellum.[20] These authors recommend limiting the use of the RCL to the lateral radiograph. Also, there is a controversy on how best to draw this line: through the axis of the radial shaft or the radial neck?

More recently, Ramirez et al evaluated the RCL in 116 children with normal elbows and found that it fell outside the middle third of the capitellum 50% of the time, and 8.6% missed the capitellum completely (Fig. 3). In their

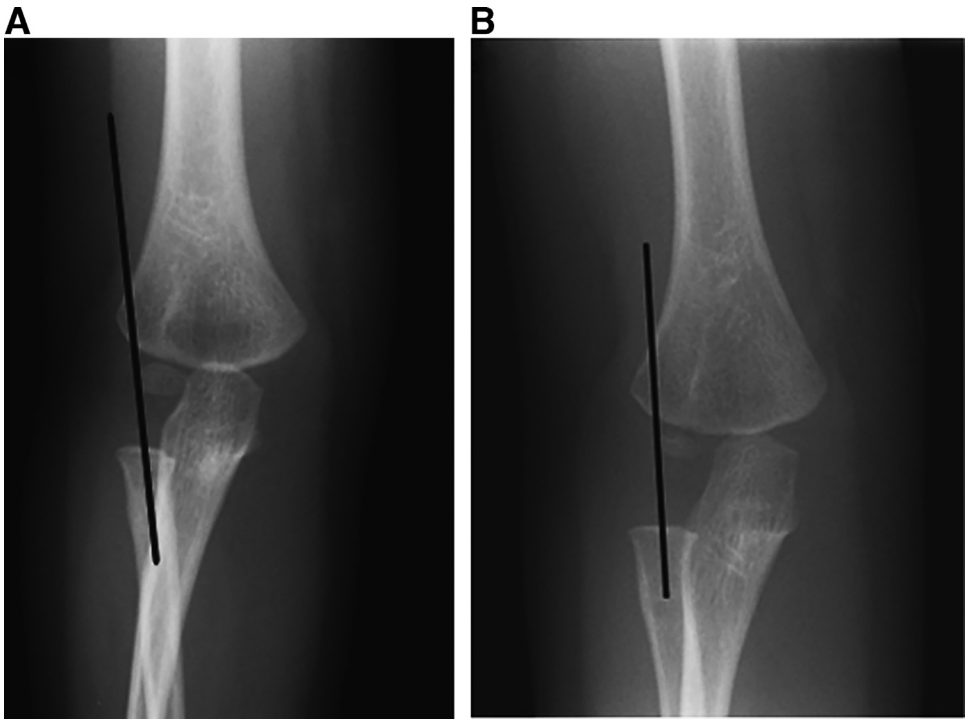

Figure 3 The radiocapitellar line (RCL) misses the capitellum on the AP view in both of these toddler-aged patients.[21]

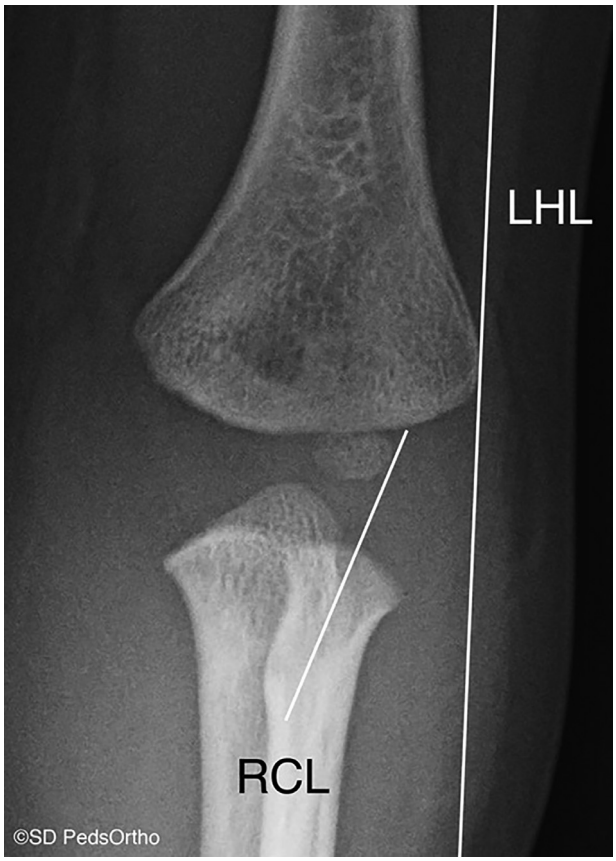

Figure 4 While the RCL does not bisect the ossified capitellum, the radial neck lies medial to the lateral humeral line (LHL), signifying no lateral subluxation of the radial head.[22]

work, an RCL drawn along the neck (instead of the shaft) was more likely to pass through the central third of the capitellum and less likely to miss it altogether. The RCL was also more accurate in the lateral radiograph compared to the AP. Younger patients less than 5 years of age were also less likely to have the RCL bisect the capitellum.[21]

Souder et al recommend an additional radiographic marker to assess the congruency of the radiocapitellar joint: the lateral humeral line (Fig. 4).[22] This line is drawn on an AP radiograph of the elbow along the lateral edge of the most lateral ossified aspect of the lateral condyle, or epicondyle if present, parallel to the long axis of the distal humerus. They hypothesize that the lateral extent of the radial neck would lie medial or tangential to the lateral humeral line in the normal pediatric elbow. Conversely, the lateral extent of the radial neck would be lateral to the lateral humeral line in cases of radiocapitellar dissociation. They advocate this marker because it offers more consistent evaluation of the radiocapitellar joint in the coronal plane compared to the RCL, and it avoids relying on the eccentric nature of the capitellar ossification all together.

Chronic cases of radiocapitellar malalignment may be obvious on plain film radiography, but one should also look for associated findings. Jarrett et al assessed 118 elbows with radial head subluxation or dislocation looking for capitellar osteochondritis dissecans lesions. Most of their cases originated from congenital or developmental causes, but of the 14 osteochondritis dissecans found, 5 were in children with missed or neglected Monteggia fractures.[23]

Treatment

In both operative and nonoperative treatment of Monteggia fractures, whether acute or chronic, the goal is to maintain an anatomically reduced radial head even if there is a nonanatomic reduction of the ulna. However, it should be recognized that the reduction of the radial head typically follows a more satisfactory reduction of the ulna in the acute setting, as long as there is no soft tissue interposition.[7] Furthermore, both operative and nonoperative treatment require close follow-up, as small losses of reduction can lead to treatment failure and the more difficult management of a chronic Monteggia fracture.

Closed Reduction and Cast Immobilization

Many acute Monteggia fractures can usually be managed with closed reduction and cast immobilization performed in the emergency department under sedation.[10,12,13,24-26] The different Bado types typically require different methods of reduction and positions of immobilization. As long as the radial head is reduced, one can usually accept up to 10° ulnar angulation.[7] For type I fractures, the maneuver is through longitudinal traction and reduction of the ulnar fracture followed by elbow flexion and gentle pressure on the radial head. The elbow is then immobilized in 90° flexion in the neutral or slightly supinated rotation.[14] Type II fractures are reduced by traction and elbow extension, and they are immobilized in extension and neutral rotation.[7] Type III fractures are reduced with elbow extension, traction, and pressure on the ulna and radial head with a slight valgus force. These are casted in 90° flexion and in the supinated position.[3,9,26] Type IV fractures typically require surgical treatment.[3]

In all cases of nonoperative treatment, it is recommended that reduction is assessed weekly for 3 weeks with radiographs of the elbow and forearm with close attention paid to any losses of reduction in the ulna and radial head. If this is maintained, then follow-up can be extended to the 6 week mark to have the immobilization discontinued.[7,18] It has been reported that up to 20% of Monteggia fractures can have a recurrence of radial head dislocation,[9] so this must be caught early to avoid development of a chronic lesion (Fig. 5).

Open Reduction and Fixation

Open treatment is required when there is a failure to obtain and maintain reduction of either the ulna fracture, the

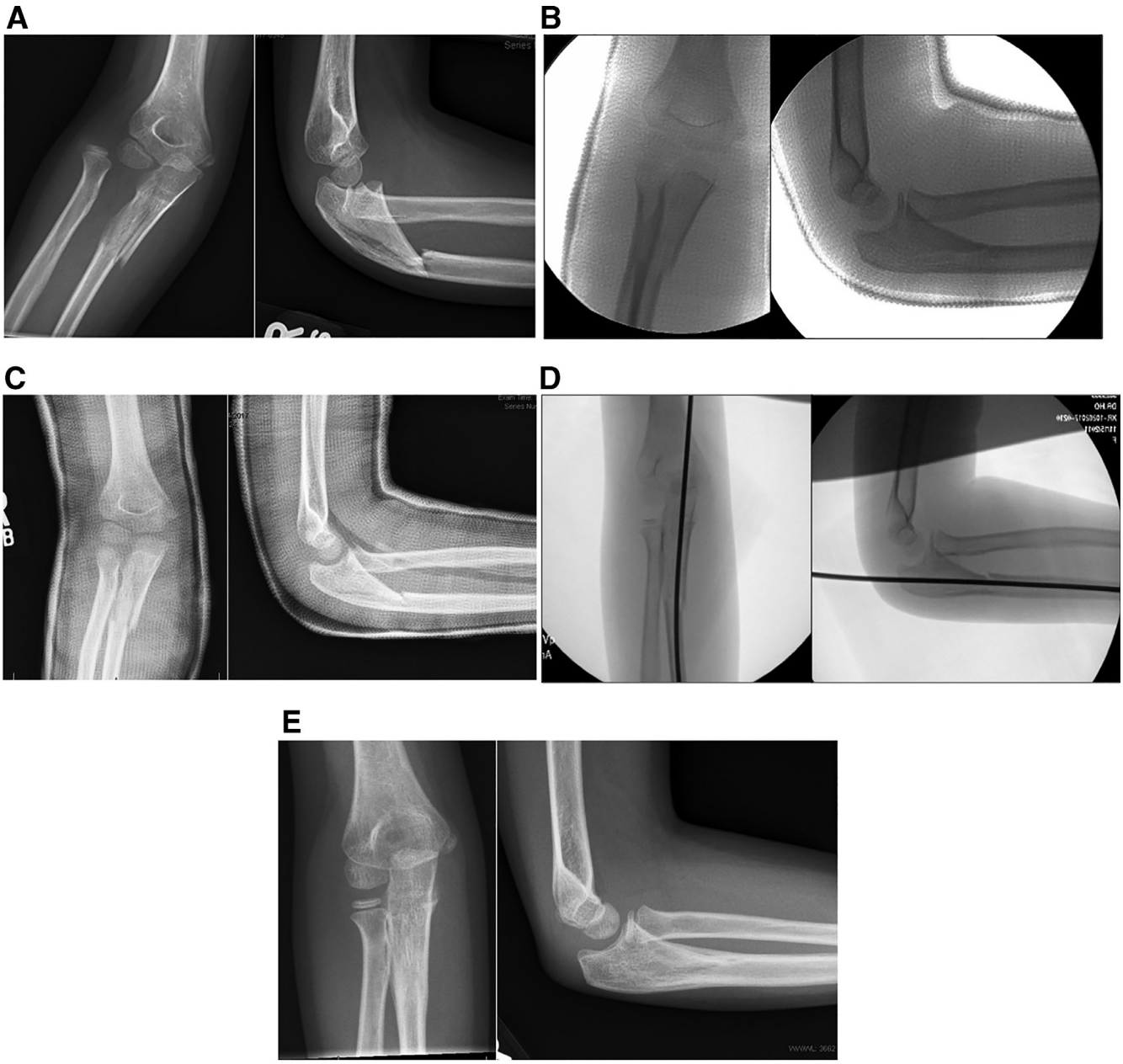

Figure 5 (**A**) AP and lateral elbow radiographs of 5-year-old boy sustained a Bado II Monteggia fracture after falling off a swing. (**B**) Sedated closed reduction in the emergency department achieved reduction of both the ulna fracture and radial head dislocation. (**C**) Repeat AP and lateral radiographs and 1 week follow-up demonstrate reangulation of the ulna fracture and posterior resubluxation of the radial head. (**D**) Intraoperative AP and lateral fluoroscopy demonstrated reduction of the radial head after closed reduction and intramedullary stabilization of the ulna fracture. (**E**) 3 months postoperative AP and lateral radiographs with complete healing of the ulna fracture and maintained reduction of the radiocapitellar joint. The patient had full rotation as well as flexion-extension arc.

radiocapitellar joint, or both.[11] As stated previously, the quality of the ulnar reduction will drive the reduction of the radiocapitellar joint, and this relationship can be used to the surgeon's advantage during operative fixation as obtaining ulnar reduction often reduces the radiocapitellar joint. Multiple stabilization methods can be utilized, most of which involve fixation of the ulna. Techniques are usually different in acute vs chronic cases. In cases of Bado IV injuries, fixation of the radial head or neck may be required as well.[7]

Most irreducible acute Monteggia fractures can be managed by simple intramedullary pin and/or nail or plate fixation of the ulna. An advantage of intramedullary fixation is that it avoids large incisions and, after pin or nail removal, there is no retained hardware.[7] Kruppa et al intramedullary nail fixation in 202 pediatric forearm fractures, 10 of which were Monteggia fractures or Monteggia equivalents that were treated with elastic nails with or without k-wire fixation.[27] Of these 10 cases, only 1 complication was seen. They

conclude that acute Monteggia fractures can be reasonably treated with elastic intramedullary nail fixation.

In cases of acute Monteggia fractures, Ring and Waters proposed a treatment strategy based on the fracture pattern of the ulna.[10] They recommend that all complete fractures undergo operative fixation. They recommend that length stable (transverse and short oblique) ulnar fractures be treated with intramedullary nail fixation, and that length unstable (long oblique or comminuted) ulnar fractures be treated with plate fixation. Ramski et al performed a retrospective analysis of 112 consecutive patients to assess the efficacy of this treatment algorithm.[28] The primary outcome was treatment failure, defined by subsequent radial head dislocation or subluxation or loss of ulnar reduction of greater than 10° requiring revision reduction. They separated patients into 3 treatment groups according to Ring and Water's recommendations: those treated according to the recommendations, those treated more rigorously than the recommendations, and those treated less rigorously than the recommendations. They identified 6 treatment failures, all of which were in the group treated less rigorously than the treatment recommendations. All 6 were complete fractures that underwent attempted closed reduction. Their conclusion was that nonoperative treatment of complete ulnar fractures in Monteggia fractures was the only risk factor for failure identified.

Conversely, Foran et al propose a more conservative approach.[29] They retrospectively reviewed 94 pediatric Monteggia fractures, 59 of which were complete fractures, treated conservatively by closed reduction and immobilization with close follow-up. Approximately 76% of these complete fractures were successfully treated nonoperatively. In their series, the most predictive factor for casting failure was an initial ulnar angulation of >36.5 degrees. They conclude that, with a conservative approach, they avoided 59 primary surgeries by not implementing the more aggressive protocol discussed by Ramski and colleagues. Of note, in both series, there were similar percentages of complications, which included transient neuropraxia, ulnar refracture or nonunion, and compartment syndrome. Given the low incidence of complications and relative simplicity when surgically treating acute Monteggia fractures and the difficulty in reconstruction a chronic Monteggia lesion, it is the authors' preference to follow the treatment strategy outlined by Ring and Waters.

Some cases of acute Monteggia fractures may demonstrate a block to reduction of the radial head after operative reduction of the ulna. In these cases, the annular ligament may be ruptured or interposed, requiring formal open reduction of the radial head.[7,14] This can be done through a posterolateral approach splitting the anconeus and extensor carpi ulnaris, or through a more extensile Boyd approach, which allows for further exposure of the PRUJ and annular ligament.[24,30] If the annular ligament is found to be intact, direct reduction can be attempted; if this is not possible, then it can be incised with a Z-step cut followed by repair. Similarly, if it is found to be ruptured, it can often be repaired.[7]

After reduction is confirmed in multiple planes and throughout elbow range of motion (flexion and/or extension and pronation and/or supination), a splint or cast immobilization is applied. Follow up is typically at 1 week postoperatively, and if reduction is maintained, then the next follow-up can be at 6 weeks postoperatively.[7] The authors do not advocate use of a transcapitellar pin into the radial head to aid acute reduction due to problems such as implant failure, postoperative stiffness, and osteonecrosis of the radial head.

Complications

Chronic Monteggia Fracture

The most common complication of an acute Monteggia fractures is a missed or delayed diagnosis, leading to a chronic Monteggia fracture.[7] This is typically defined as a fracture-dislocation that stays unreduced for greater than 4 weeks.[31] Some reports have shown minimal sequelae in the short term.[32,33] Historically, however, long-standing neglected or missed Monteggia fractures have been associated with pain, instability, limited range of motion,[34] and tardy nerve palsies.[35-38]

Because chronic Monteggia fractures tend to be refractory to closed reduction, surgical reconstruction is usually recommended. Reconstruction can be technically demanding, and they are associated with better results if performed within 3 years of the injury or in children younger than 12 years old.[39] Di Gennaro et al reviewed outcomes after surgical treatment of 22 missed pediatric Monteggia fractures.[31] Of these, 15 remained reduced, and 14 had excellent Kim Elbow Scores[40] at a mean follow-up of 5.5 years.

Operative techniques typically involve ulnar osteotomy with or without reconstruction of the annular ligament. If there is even a subtle ulnar malunion or bow that precludes maintenance of radial head reduction, an ulnar osteotomy is necessary.[7,41] Such deformity can be assessed on plain lateral forearm radiographs by evaluating lateral bow deviation. This is done by drawing a straight line from the proximal to distal posterior border of the ulna. If the true contour of the ulna deviates at all from a straight line, then it should be assumed that the deformity will be a block to reduction of the radiocapitellar joint, and an ulnar osteotomy should be planned.[42,43] It can be performed through an extensile posterolateral approach which will allow exposure for triceps tendon harvest if necessary for annular ligament reconstruction.[44] Distraction through a dorsal opening wedge at the apex of the deformity is followed by plate fixation with or without bone graft.[7,45] Obtaining sufficient ulnar length via distraction and overcorrection of the malangulation is crucial for success (Fig. 6). Alternatively, restoring the ulnar anatomy can be accomplished by external fixation or by gradual reduction with an Ilizarov technique, both of which have been shown to be effective in obtaining and maintaining radiocapitellar reduction.[41,46-48]

In chronic cases in which the radiocapitellar joint cannot be reduced with ulnar osteotomy alone, the radiocapitellar joint should be exposed. There is typically joint debris and fibrosis blocking reduction. After joint debridement and removal of any interposed annular ligament, another

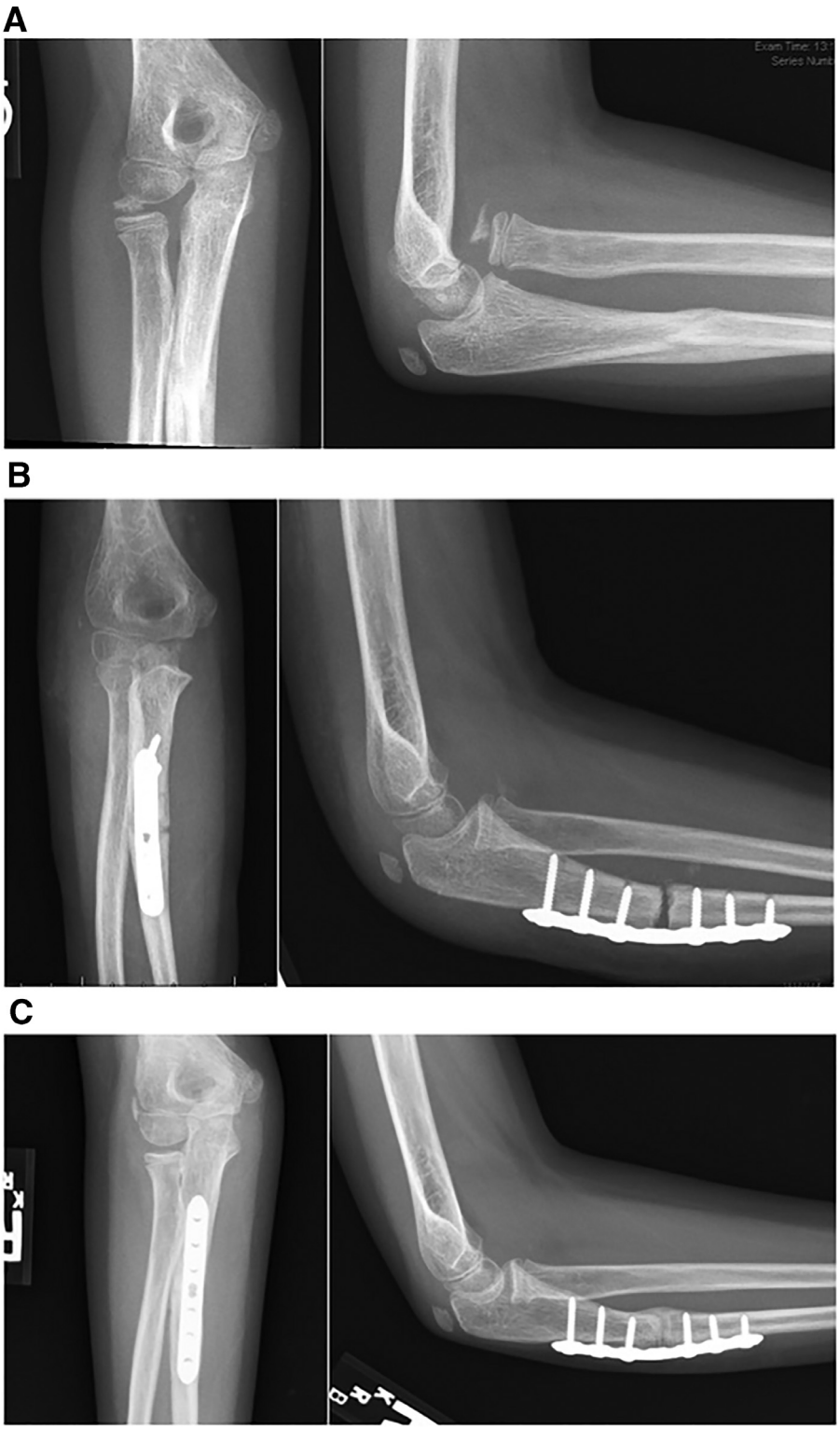

Figure 6 (**A**) AP and lateral elbow radiographs of a 7-year-old female who fell off the balance beam 6 months ago. Calcification of the annular ligament is noted. At the time of injury, she was treated in a long arm cast for an ulna fracture; the radial head dislocation was unrecognized. (**B**) Postoperative radiographs after ulnar lengthening osteotomy with overcorrection of the malangulation; open reduction was necessary to debride the fibrous tissue. The annular ligament was unrepairable, but the radial head was stable after ulnar overcorrection and no annular ligament reconstruction was needed. (**C**) 3 months postoperative AP and lateral radiographs demonstrate a healed osteotomy with maintenance of the radial head reduction; the patient lacked the final 20° of rotation arc but had full flexion extension.

Table 2 Pearls and Pitfalls in the Management of Pediatric Monteggia Fractures

Pearls	Pitfalls
• Early recognition with high quality radiographs. • Achievement and maintenance of ulnar length and alignment is essential for radiocapitellar congruency. • Close radiographic follow-up after closed reduction to identify early loss of radiocapitellar alignment. • Low threshold for surgical treatment with changes in ulnar alignment and/or radiocapitellar congruency.	• Missed or delayed diagnosis. • Failure to restore ulnar length during closed reduction or operative treatment leads to loss of radiocapitellar alignment. • Failure to recognize annular ligament interposition in radiocapitellar joint as cause of radiocapitellar subluxation after ulnar alignment achieved. • Recognition of PIN palsy, especially in Bado III pattern.

reduction is attempted via lengthening and angulation of the ulnar osteotomy. If the radial head remains reduced and is stable, the ulna osteotomy can be plated. However, if it remains unstable then the annular ligament should be repaired. If repair is untenable, then reconstruction should be considered. This can be done with a Lloyd-Roberts modification of the Bell Tawse technique by incorporating a lateral strip of triceps tendon that has already been exposed.[7,49,50] It has been the authors' experience that annual ligament repair and/or reconstruction is insufficient to maintain radial head reduction in the setting of an incomplete correction of ulnar shortening and malangulation.

Malunion

As stated above, ulnar malunion leading to significant angulation may lead to loss of reduction in the radiocapitellar joint. However, if the radiocapitellar joint alignment is maintained, then the minor angulation typically leads to little loss of pronation and supination and can be well-tolerated.[7]

Stiffness

Limited elbow range of motion can be common after any treatment for a Monteggia fracture, and may be related simply to the routine period of immobilization, which usually abates in 1-2 months. Other causes include periarticular ossification which also tends to be self-limited.[33,38,43,49] Proximal radioulnar synostosis, while rare, can be a more severe cause of limitation in pronation and supination, and it may require resection with soft tissue or synthetic interposition.[51]

Nerve Palsy

Most nerve palsies are transient, resolving in 2-3 months. The most common nerve involved is the posterior interosseous nerve because of its location relative to the radial neck. This is most common after Bado I or III injuries and occurs up to 20% of the time.[7,52] However, other nerve palsies have been reported,[53] including tardy ulnar nerve palsies secondary to the deformity and arthritic changes manifested many years later in chronic cases of Monteggia fractures.[17]

Compartment Syndrome

Finally, one of the most feared complications is that of compartment syndrome which may go on to Volkman's ischemic contracture. This is more likely in cases of significant soft tissue disruption or when immobilizing the elbow is greater than 90° flexion.[7] As such, a high index of suspicion should be maintained and treatment not delayed in cases of suspected compartment syndrome.

Summary

Pediatric Monteggia fractures have long been recognized as a difficult injury to manage. The most important principle is early and accurate diagnosis of the acute injury with appropriate treatment. In most acute cases, proper treatment and close follow-up usually lead to good outcomes, and many cases can be treated by closed reduction and casting. Chronic injuries that have been missed are more complex and may require extensive reconstructive procedures to restore the anatomy and range of motion at the elbow. The most important part of treatment, then, is early recognition and close clinical follow-up with high quality radiographs of these fractures (Table 2).

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