Pediatric Hand Fractures

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Summary: Hand fractures in children are a common injury. Early recognition and prompt diagnosis is necessary to achieve satisfactory outcome. A thorough history and physical examination along with adequate radiographic imaging are essential. The goal of treatment is to have children return quickly to their daily leisure and academic activities. In the pediatric population, most hand injuries can be treated nonoperatively. Modalities for nonoperative treatment include buddy taping, mallet splinting, intrinsic plus splinting, casting or observation. Several fractures, however, require prompt surgical intervention. These include Seymour fractures and any injury that cannot be suitably managed in a splint or cast, including those with residual deformity, intraarticular extension, displacement, and unacceptable alignment in the coronal, sagittal and rotational plane. In general, most surgical interventions consist of closed reduction and percutaneous pinning. With the thick periosteum and high remodeling potential that makes the pediatric population unique, rarely is anatomic reduction and rigid internal fixation ever needed. Early range of motion after reduction and stable fixation is a cornerstone to postoperative rehabilitation.

Key Words: Hand fractures—Finger injuries—Phalangeal fractures.

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The hand is the most frequently injured part of the body in the pediatric and adolescent age group. The border rays, i.e. the little finger and the thumb, are the most commonly injured fingers (52.2% and 23.4%, respectively in one study).[1] The little finger, which plays a major role in grip power, has the highest number of fractures in all age groups. As children start to mature, thumb and index finger fractures increase in incidence. Children less than 10 years of age had a low incidence of thumb fracture, but a steep rise was noted after the age of 10, as the thumb became the second most common ray to be fractured after the little finger in adolescents.[2]

Crush injuries are very common in the toddler age group.[3,4] This most commonly occurs when a hand gets caught in a closing door.[3] In the older child, the fracture is usually secondary to recreational sports. An overwhelming majority of these fractures, when appropriately treated, heal without complications.

A poorly treated hand fracture, when displaced or unstable can have significant functional consequences and may result in chronic pain, stiffness, or deformity. It is not uncommon for stable fractures to be over treated and unstable fractures to be neglected, both potentially resulting in permanent dysfunction. Complications resulting from pediatric hand injuries are often a result of failure to identify and treat an injury requiring surgery. Accurate diagnosis and timely management of these injuries continues to be the cornerstone of optimal hand care.

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GENERAL PRINCIPLES OF TREATMENT

Most pediatric hand fractures may be managed nonoperatively with excellent functional results. In general, it is a good rule of thumb that patients under one year of age avoid any unnecessary surgery as the risks of anesthesia may outweigh the benefits of fracture care procedures. In addition, infants have the surprising ability to remodel nearly any fracture deformity, especially in the hand. However, in the older pediatric population, there is a subset of fractures that benefit from prompt recognition and surgical intervention.

The goal of any treatment is to have children return quickly to their daily leisure and academic activities. Restoration of bony anatomy is the basis for returning normal function; however, an anatomic reduction is not always necessary to achieve this goal, especially if it comes at the cost of soft tissue scarring and loss of motion. To initiate early hand motion, fracture stability must be present either through the inherent stability of the fracture, splinting, or internal fixation. Early motion prevents formation of adhesions of the gliding soft tissues of the extensor and flexor tendon systems and prevents joint capsule contracture. Immobilization of fingers well beyond four weeks may lead to long-term stiffness because of extensor tendon and joint capsular scarring.

Closed, nondisplaced or minimally displaced fractures with acceptable alignment that are the result of a low-energy trauma usually have sufficient supporting tissues remaining intact making them stable and amenable to treatment by protected mobilization, either with local splinting of the fracture or buddy taping to adjacent fingers. Fractures with rotational or angular mal-alignment may be amenable to closed reduction and splinting, but these fractures are at risk for incomplete reduction and recurrent deformity. These more unstable fractures require careful and frequent clinical and radiographic follow-up. Surgical treatment is indicated for displaced fractures of the articular surface, open fractures, fractures with significant shortening or malrotation, and fractures which are unstable after closed reduction and splinting. Delayed treatment of surgically indicated fractures presents a clinical challenge, with worse functional outcomes because of stiffness, deformity, and even posttraumatic arthritis.

DIAGNOSIS

The signs of injury include pain, swelling, tenderness, ecchymosis, deformity, and/or skin abrasions. The differential diagnosis for hand injuries includes fracture, dislocation, collateral ligament rupture, and tendon laceration or avulsion. A careful examination of the flexor tendons, extensor tendons, and neurovascular function must be performed. At a minimum, three radiographic views of the injured hand should be obtained with the imaging beam centered over the metacarpophalangeal (MCP) joint of the long finger. The posterior–anterior (PA), lateral, and oblique views screen for trauma. PA and lateral views of the injured digit centered on the proximal interphalangeal (PIP) joint should be obtained when a particular digit is of concern.

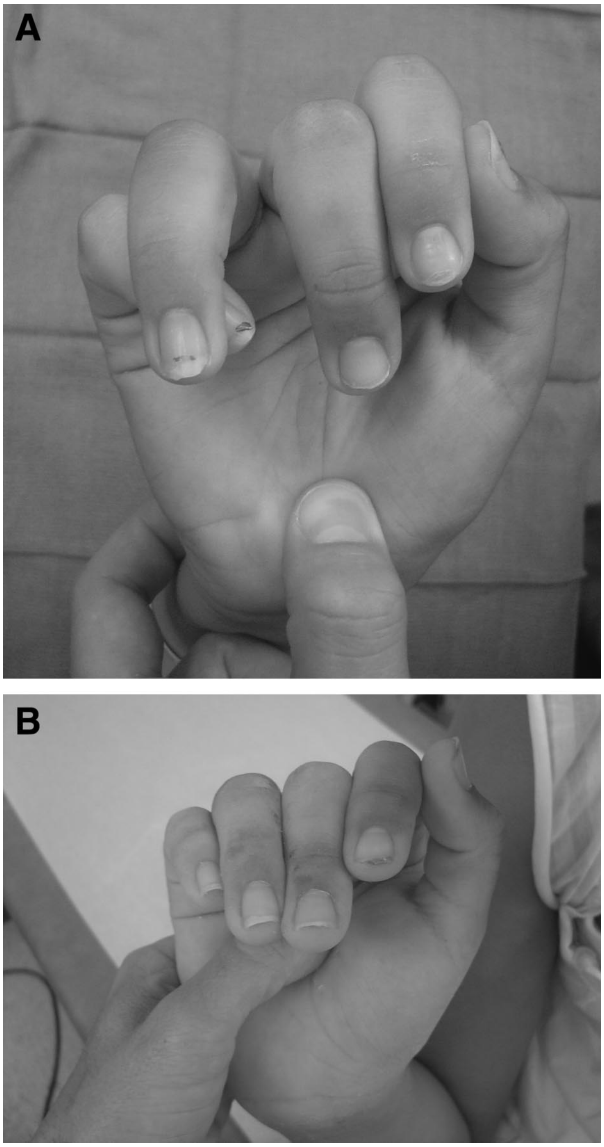

FIGURE 1. **A,** A rotationally mal-aligned hand. **B,** A rotationally aligned hand after operative correction (Oetgen et al.).

PRINCIPLES OF CLOSED TREATMENT

Closed reduction may be performed by re-creation of the injury force to unhinge neighboring periosteum, axial traction of the digit, followed by reversal of the deformity. For finger fractures, it is often helpful to decrease muscle forces contributing to the fracture deformity. For example, the intrinsic muscles can be relaxed by flexion of the MCP joints. Once a reduction is performed, the digit is examined to determine the alignment and the stability of the reduction. Rotational alignment is checked by active finger flexion, observing the planes of the nail beds, and assessing for digital overlap. The fingers should all point toward the scaphoid tubercle (Fig. 1). If pain limits active flexion, use of the tenodesis effect (with gentle wrist extension resulting in passive finger flexion and wrist flexion leading to passive finger extension) can be helpful.

A radial or ulnar gutter type splint with the MCP joints flexed and the interphalangeal joints extended (the intrinsic plus position) will hold the digits aligned while relaxing the intrinsics and preventing collateral ligament contracture. Although splinting at 90 degrees of MCP flexion is preferable, as little as 60 degrees of MCP flexion is likely adequate to place the collateral ligaments under sufficient strain, and may be easier to achieve. In the case of a stable, nondisplaced fracture, "buddy taping" the injured digit to an adjacent uninjured digit may be a very acceptable option. Postreduction radiographs should be obtained in two planes. Analysis of sagittal alignment on the lateral view is often difficult, particularly in plaster, and a series of oblique radiographs may be needed to confirm that correct alignment has been achieved. Follow-up at 1 week after initial reduction with new radiographs is optimal to confirm the maintenance of alignment. Delay of follow-up beyond 1 week can make salvage of a lost reduction more difficult as callus develops quickly in the pediatric population.

Early motion is important in the management of hand injuries. For example, nonarticular phalangeal fractures treated with closed reduction and splinting should be mobilized after 3 to 4 weeks, as soon as the fractured phalanx is less tender. Even if splinting of one joint is needed, splints should be made small enough to allow early motion of uninjured joints, if possible.

The following are described indications and techniques in the application of appropriate buddy taping, mallet splinting, and intrinsic-plus splinting.

Buddy Taping

Buddy taping is useful for fractures of the phalanges and metacarpals, particularly stable ones (i.e., nondisplaced, transverse, extraarticular). It can also be useful for >3 week old unstable (i.e., spiral) fractures that are minimally displaced and have demonstrated (by decreasing tenderness and early callus formation on radiographs) that it will unlikely displace further. Treatment of boxer's fractures with buddy taping has shown good results,[5] although a well applied ulnar gutter splint can maintain a reduction and minimize patient discomfort in the acute post-fracture period.

The main purpose of buddy taping is to use an adjacent finger to act as a splint for the injured finger. It is ideal to buddy tape to a digit that is generally longer than the injured digit. In this fashion, the longer digit also acts to protect from minor, inadvertent axial trauma.

A nonreactive skin tape should be used and the tape should be circumferentially wrapped over the proximal and middle phalanges, taking care to avoid the PIP and DIP joint creases both volarly and dorsally (Fig. 2). Tape immobilization is not required over the distal phalanx for several reasons: (1) there is usually enough proximal support that DIP motion will be already limited, (2) irritation of the nail folds by the taping can potentially lead to infection, (3) it adds little to the stability of the injured digit. If necessary, a thin, dry gauze can be inserted between the fingers to keep this area dry as well as pad the PIP and DIP joint prominences.

Mallet Splint

Mallet splints are indicated for mallet injuries, both soft tissue and bony mallets. Splinting using a dorsal, volar, or prefabricated Stack type splint are all reasonable treatment methods. Care must be taken to avoid dorsal skin ischemia and potential breakdown seen in cases of extension splinting of the DIP joint. Ischemia can occur from direct pressure on the skin by a splint that is applied too tightly or by hyperextension of the DIP joint. Hyperextension will completely blanch the dorsal skin making it avascular. When increased external pressure and

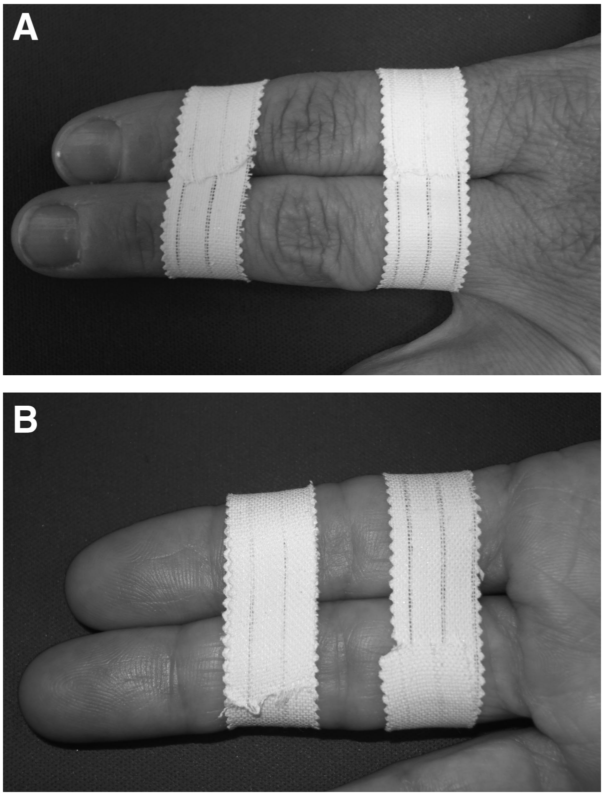

FIGURE 2. Buddy taping between index and long finger: **A,** Dorsal View; **B,** Volar View. [½] inch cloth tape is used. The tape is brought over the middle and proximal phalanges, avoiding the PIP and DIP joints.

hyperextension are combined, the risk of skin necrosis is potentially very high and should be avoided.

The following materials are our preference in making a mallet splint:

1. Aluminum foam splint.
2. Moleskin.
3. [½] inch cloth tape.

A properly sized aluminum splint should be selected that spans the width of the finger. The length of the splint should ideally be crafted to cover the whole distal length of the finger, just stopping short of the PIP joint proximally. The PIP joint should be spared to allow for joint motion. The foam on the aluminum splint is removed. The reason for this is to provide better stability to the DIP joint, but great care must be taken to avoid excess pressure on the dorsal skin with the foam removed. Moleskin should be applied to the side of the splint that was denuded of the foam.

The splint should be positioned dorsally, centered over the DIP joint. Ensure that the DIP joint is fully extended. Hyperextension of even 5 degrees may be unacceptable. Cloth tape should then be applied over the distal phalanx as well as the middle phalanx, ensuring that the DIP joint is free from tape. The tape should be applied such that the splint is snug, but not tight on the finger.

An assistant to help in taping makes the process easier as it is important that the DIP not be flexed during the entire 8 weeks treatment period. This most commonly occurs during splint changes. It is prudent to rest the tip of the finger at the end of a table to keep the DIP extended while the splint is being changed (Fig. 3). The splint should be changed daily to check for dorsal skin breakdown. Should this occur, the splint should be applied to the volar aspect of the finger surface until the dorsal skin has healed sufficiently.

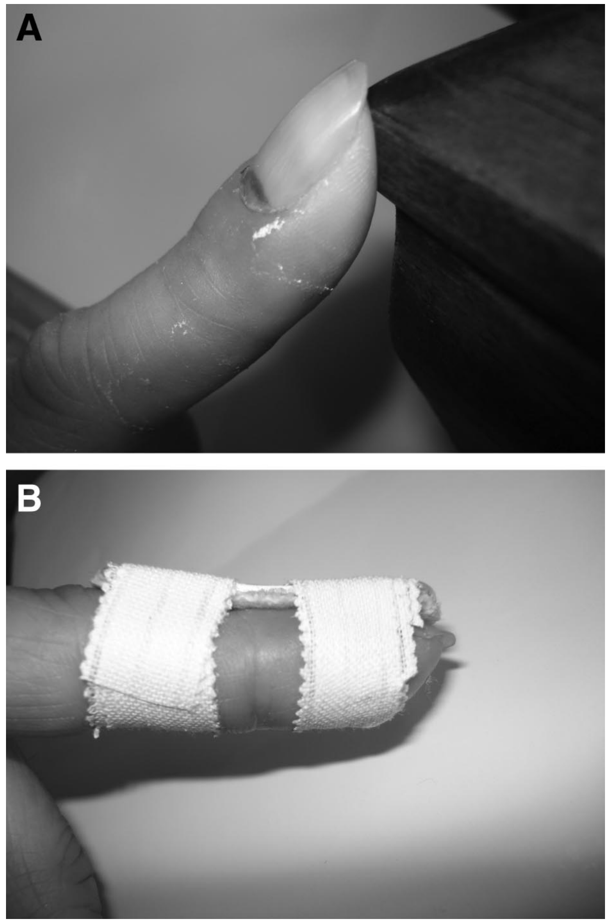

FIGURE 3. **A,** The finger is kept extended by resting at the edge of a surface such as a table. **B,** A properly applied mallet splint.

Intrinsic-Plus Splint

Intrinsic-plus splinting can be used for acute immobilization of nearly any hand fracture. Some or all of the fingers can be incorporated depending on the location of the injury, i.e., ulnar gutter splint typically including just the ring and small fingers. This type of splinting is considered a "safe" position because the MCP joints recover well from flexion and the interphalangeal (IP) joints recover well from extension based on their unique articular and ligamentous anatomy, specifically the MCP joint collateral ligaments are maintained in a stretched position when flexed and the PIP joint collateral ligaments are maintained in a stretched position when extended.

The standard intrinsic-plus splint is volarly based from the fingertips to the forearm with the IP joints in full extension, the MCP joints in flexion, and the wrist slightly extended. Unless there is an associated thumb ray injury, the thumb is not immobilized. Sometimes, a dorsal and volar splint is required to completely immobilize these joints in a satisfactory position.

FIGURE 4. Intrinsic-Plus Splinting–the wrist is extended 30 degree, the MCPs at 90 degrees, IP joints at 0 degrees extension, with the thumb free.

We prefer plaster over fiberglass as it is easier to mold in the acute setting. Once an elastic bandage has been wrapped over the splint, position is held by using one hand to keep the patient's fingers extended and the metacarpal heads flexed (with axial pressure into the metacarpal heads) and the other hand used to hold counter-pressure over the dorsum of the patient's hand (Fig. 4). Placement of one or two tongue depressors volar to the fingers may aid in holding the intrinsic-plus position while the splint is drying.

PRINCIPLES OF SURGICAL TREATMENT

It will be stressed here again that the majority of pediatric hand and finger fractures are best treated conservatively. There are instances, however, where surgical treatment is indicated. Correct recognition of finger injuries that require operative intervention for optimal outcome is as important as proper treatment of stable finger fractures to maintain function. Attempted nonoperative treatment of these injuries will result in the delay of appropriate care, which in most instances will negatively affect the ultimate outcome. Persistent rotational deformity after finger or hand fracture will result in poor aesthetic and functional outcomes (Fig. 1). Fractures at risk for this deformity include oblique and spiral fractures and fractures with comminution preventing bony interdigitation of the fracture fragments after closed reduction.

Two salient points will be highlighted in the discussion of these problematic fractures: certain phalanx fractures can be distinctly different from other fractures in children, and phalanx fractures in children differ considerably from those in adults.[6] No randomized, prospective trials have been performed regarding outcomes of surgical treatment of hand fractures specifically in children, and the literature largely is limited to retrospective case reports and series.

In general, most surgical interventions for pediatric hand and finger fractures consist of closed reduction and percutaneous pinning with at worst, an open reduction if necessary. With the thick periosteum and high remodeling potential that makes the pediatric population unique, rarely is anatomic reduction and rigid internal fixation (i.e., plating) ever required.

We use a mini fluoroscopic device to obtain our closed reduction in the operating room. We always supplement the anesthesia with local anesthesia either with a digital block or a hematoma block, preferring a combination of 1% lidocaine and 0.5% marcaine without epinephrine.

When percutaneously pinning a fracture, we prefer 0.045 inch smooth K-wires strategically placed and bent so as to not irritate other parts of the hand. Depending on the size of the fragment and the size of the patient, 0.035 inch or 0.062 inch K-wires can also be used. Threaded K-wires are usually not used as it complicates pin removal. A battery-powered hand drill improves surgeon freedom when placing these pins.

As described above, diligent assessment of the rotational profile of any injured finger is of utmost importance to avoid this difficult deformity. Due to the need for stable anatomic reduction and fixation, as well as the need for early supervised physical therapy to avoid long-term stiffness, these injuries should be referred to a hand specialist comfortable with their management as soon as they are diagnosed or even suspected. Intraarticular injuries involving the IP joints and the MCP joints are also known to be associated with residual stiffness, often leading to long-term functional deficits of the injured joint. Similar to intraarticular fractures in other parts of the body, intraarticular injuries in the pediatric hand often benefit from an anatomic reduction with internal fixation to allow for early range of motion.

SPECIFIC FRACTURES

Gamekeeper's/Skier's Thumb

The terms "gamekeeper's" and "skier's" thumbs have essentially the same meaning and can be used interchangeably. However, a gamekeeper's thumb implies chronicity to the injury because gamekeepers acquire this injury over time whereas a skier's thumb is more acute in nature. It makes sense then, that given the very active and unpredictable nature of the pediatric population, kids usually acquire a "skier's thumb." In adults, this injury represents an acute rupture of the ulnar collateral ligament (UCL) of the thumb from forced abduction of the proximal phalanx. The UCL rarely ruptures in isolation in children, though cases have been reported in the literature.[7] The more typical pediatric skier's thumb involves a fracture of the base of the proximal phalanx of the thumb (Fig. 5A, B). These are Salter III intraarticular fractures that avulse the UCL insertion at the base of the proximal phalanx of the thumb and destabilize the MCP joint. Displaced fractures should be treated

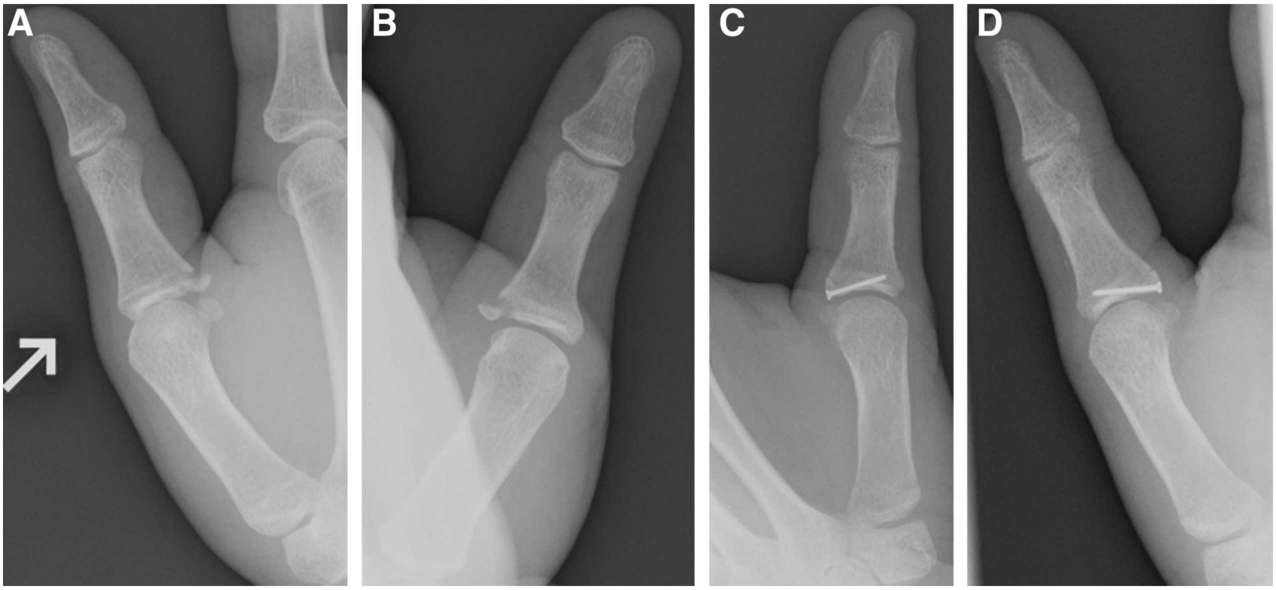

FIGURE 5. Pediatric Skier's Thumb. **A, B,** represent different radiographic views of this UCL avulsion injury. There was a large portion of articular cartilage present on the fracture fragment. **C, D,** are postoperative views of the fracture reduced and fixed with a mini screw.

with open reduction and internal fixation to restore joint congruity and UCL stability (Figs. 5C, D).[8] Suture anchors can be used for fixation for pure ligamentous injuries and for small avulsion fragments as long as injury to an open physis is avoided and the avulsion fragment does not have articular cartilage on it. The risk of a Stener lesion exists, even in the pediatric population.[9] A Stener lesion exists when the adductor tendon lies between the UCL and its insertion, effectively prohibiting closed re-approximation of the injured ligament and subsequent healing. Surgery is recommended in cases of gross collateral ligament instability because of the high association with Stener lesions. When the diagnosis of a Stener lesion is in question, an ultrasound or MRI of the thumb can be diagnostic.

In younger children, Salter I and II fractures of the thumb are more common than Salter III fractures and may present as a pseudo skier's thumb injury because of apparent instability at the MCP joint on clinical examination caused by the displacement through the fractured physis while the UCL remains intact. There is a report in the literature, however, of a true skier's thumb injury in a 7-year-old girl with rupture of the UCL after sustaining a Salter II fracture of the proximal phalanx.[10]

Mallet Fractures

The majority of distal phalangeal base fractures are "mallet injuries," occurring because of an axial load. A sudden eccentric load applied to a contracting extensor tendon occurs at the time of injury causing disruption of the terminal extensor mechanism. Mallet injuries with and without a bony fragment may be effectively treated by splinting the DIP joint in extension for 8 weeks, followed by 1 month of night splinting (Fig. 3).[11]

When a bone fragment has been retained with the extensor tendon, the opportunity to heal is enhanced because of the greater healing potential of bone compared with tendon, but radiographs should be taken in the splint to ensure a concentric joint has been maintained, especially on the lateral view (Fig. 6). The PIP should be left free, as immobilization of the PIP joint and its resultant stiffness may cause more morbidity than the original injury. Patients are counseled to expect a slight extensor lag (5°–10°) under the best circumstances, with a mild loss of total motion. A dorsal bump from the fracture site may also be present after treatment. If, after splinting, there is >20° of recurrent mallet deformity, the splinting program is reinstituted for an additional 6 weeks. Chronic mallet injuries do well with splinting as late as 3 months.[12]

A major issue with nonoperative treatment of mallet fractures that is unique to children is patient compliance with splinting. If splinting is chosen for treatment of a pediatric mallet fracture, compliance should be checked early in the treatment course, and then regularly (every 2–3 weeks), to ensure proper fit and position of the splint. Often, young children are not able to maintain the splint, either for behavioral reasons or for improper fit on a short, plump digit. In these situations, a smooth Kirschner wire across the DIP joint may be used to immobilize the joint in extension.

Surgical treatment of mallet fingers is recommended in cases of volar subluxation of the distal phalanx with significant joint incongruity.[13] Open reduction has a significant risk of complications, so percutaneous internal fixation using Kirschner wires for reduction and fixation is the preferred technique if possible. Reduction of the fracture fragment or of the DIP subluxation may involve multiple pins to reduce the fracture and the DIP joint. The end result should be that the DIP is

FIGURE 6. Lateral radiograph of a bony mallet injury in a splint.

pinned in full extension. Extension block pinning can be used to percutaneously reduce and stabilize the fracture and DIP joint.[14,15] A variety of wire configurations have been shown to be safe and effective, as long as a congruent reduction of the DIP joint is confirmed on the lateral radiograph.[16,13]

The results from a large review of adult and pediatric mallet finger injuries and mallet fractures demonstrated uniformly good results, with surgical treatment offering no advantage over nonoperative treatment.[17] The authors of this review recommended splinting of mallet fractures in nearly all cases as many subluxated mallet fractures will heal and remodel the DIP joint surface. Surgery is certainly best indicated for irreducible or open epiphyseal-physeal injuries occasionally seen in the pediatric population.[17]

Central Slip and Volar Lip Avulsion Fractures

The epiphysis of the middle phalanx is the site of insertion of the volar plate and extensor tendon central slip. Epiphyseal fractures of the base of the middle phalanx can therefore signify avulsions of these structures. It is important to distinguish between these two injuries because treatment can differ considerably.

Volar plate avulsion fractures result from hyperextension injuries and are more common than central slip avulsions (Fig. 7). They should be treated with early motion after a short period (up to 1 week) of splinting. Bony union is not always achieved, but a fibrous nonunion confers adequate joint stability. The primary problem after this injury is joint stiffness; cast or prolonged splint treatment can lead to permanent joint contracture. Even with early motion, however, swelling and stiffness often persist for a long time with these injuries, and it is important to advise the patient and parents of this early on in the treatment.

Central slip avulsion fractures are rarer, but must be differentiated from volar plate avulsion fractures. Small flecks avulsed from the dorsal rim of the middle phalanx (Fig. 8) can be treated like volar plate avulsion fractures as long as central slip function is maintained. This can be assessed with an Elson test. In the Elson test, the patient's finger is placed over the edge of a table, with the PIP joint flexed to 90 degree. The patient is then instructed to extend the DIP joint against resistance. Active extension of the DIP joint against resistance (with the PIP joint held in flexion) indicates rupture of the central slip at the PIP joint. Central slip ruptures or larger, nondisplaced fragments should be treated with splint or cast immobilization to keep the PIP joint extended, thus allowing bony healing and restoration of the central slip insertion. Displaced fractures or those associated with PIP joint subluxation benefit from open reduction and internal fixation.

Distal Tuft Fractures

Distal phalanx fractures are quite common as it extends most distally during hand use, especially in the thumb, index, and middle fingers. Because there are few deforming forces about the distal phalanx, these fractures can usually be treated in a closed manner with simple splinting, closed reduction and splinting, or closed reduction and percutaneous fixation. Tuft fractures and a majority of distal phalangeal shaft fractures can be treated with immobilization using a clam-shell type splint. Open or significantly unstable shaft fractures may be ideally managed with operative fixation consisting of a longitudinal Kirschner wire.[18]

Regardless of the treatment selected for the underlying bony injury, the commonly associated soft tissue and nail bed injury cannot be ignored and must be addressed. Many of these are open injuries that require adherence to the principles of treatment of open fractures including: a course of antibiotic therapy along with a thorough debridement of any devitalized tissue. Conscious sedation in the emergency room setting may

FIGURE 7. A lateral radiograph shows a typical volar plate avulsion fracture (arrow) (Cornwall et al.).

FIGURE 8. A lateral radiograph of a central slip avulsion fracture (arrow) (Cornwall et al.).

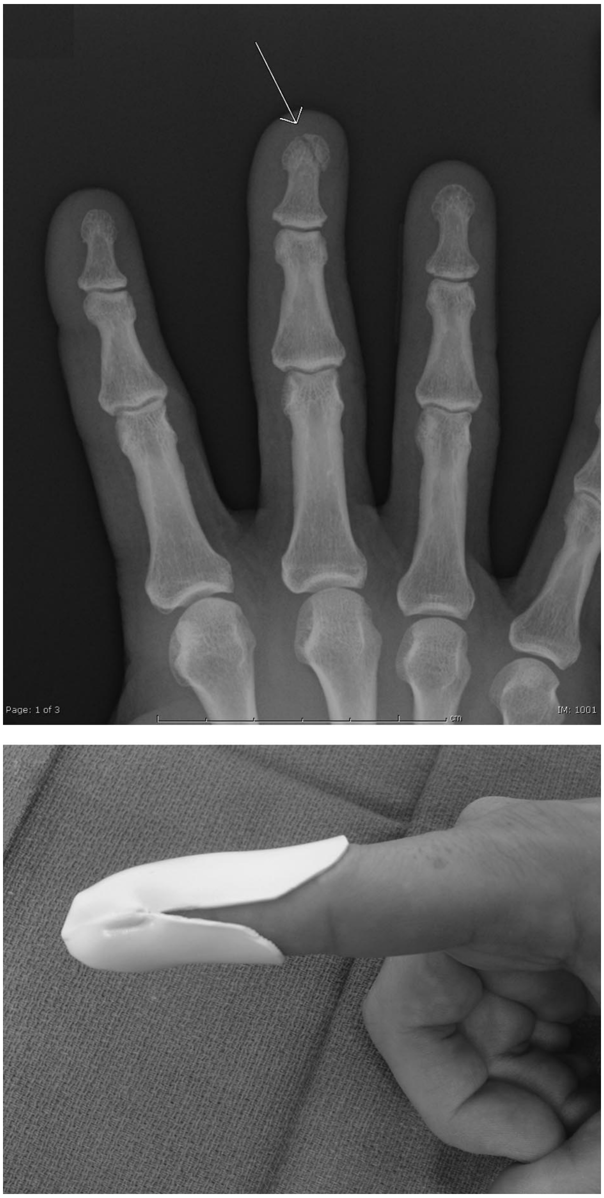

FIGURE 9. Distal tuft fracture and clam-shell splint (from Oetgen et al.).

be required depending on the age and disposition of the patient. Significant nail bed injuries should be treated with subungual hematoma decompression and reapproximation of nail bed lacerations with fine absorbable sutures (e.g., 6–0 suture). The use of absorbable sutures anywhere about the hand is especially critical in the pediatric population as removing these sutures several weeks later in the office can prove very difficult. One may ensure the proximal nail fold remains open by avoiding injury to this structure and by placing a temporary spacer in situations requiring complete removal of the native nail plate.[19]

Most tuft fractures can be protected by 2 to 3 weeks of simple splinting including the DIP joint, but leaving the PIP free (Fig. 9). Motion of the DIP is begun at 2 to 3 weeks, with continued protection during active use until pain resolves. Because of the injury to the finger tip, which is the terminal sensory organ, patients must be warned that they will often have decreased function caused by hyperesthesia, cold intolerance, and numbness even 6 months after the injury.[18] Although more common in adults, a fibrous nonunion of the fracture may result. Nevertheless, this does not usually result in any noticeable functional consequences.

Seymour Fractures

Seymour fractures are Salter I or II fractures of the distal phalanx physis, with avulsion of the proximal edge of the nail from the eponychial fold. It is a flexion injury that results in a physeal separation between the extensor tendon dorsally and the FDP insertion volarly with an avulsed nail. This is an open fracture of the proximal physis of the distal phalanx where the nail plate is avulsed and the germinal matrix is disrupted. The flexed digit on presentation can easily be misinterpreted as a mallet finger and incorrectly treated with dorsal splinting alone. Seymour fractures mimic true mallet injuries in children because of the insertion of the extensor and flexor tendons. The terminal extensor tendon inserts into the epiphysis, while the flexor digitorum profundus tendon inserts onto the metaphysis–diaphysis.[20] Some, including Seymour,[21] have suggested this fracture can also occur in a juxtaepiphyseal position, 1 to 2 mm distal to the physis in the metaphysis.

Physical examination findings include a mallet posture of the involved finger with an exposed proximal nail plate (Fig. 10). Sometimes the nail bed or germinal matrix laceration is not visible. One must do a very careful examination of the nail bed in all mallet-like injuries. Hints that the nail is injured is checking the total length of the nail itself—if the visible nail appears too long, usually there is an injury proximally and on careful inspection, one can see that the proximal edge of the nail sits atop of the eponychial fold. In some cases, the nail is not actually avulsed from the eponychial fold, but the nail bed underneath is torn and the cuticle seal is broken, creating an open fracture. Another tip to diagnose this fracture is to look for signs of trace bleeding around the nail bed, which will confirm that the fracture is actually open. Radiographs should be examined closely for physeal injury. Dorsal physeal widening is common, as is flexion of the distal segment. When in doubt, nail removal will reveal the open physis.

This is a problem fracture that can lead to substantial complications if missed. Incomplete fracture reduction because of interposition of the proximal edge of the torn nail matrix or nail fold in the open physis has been reported in the literature.[20,6] Complete reduction is possible only after removal of this tissue. Fracture instability tends to occur if the nail plate is completely removed and not replaced, and therefore, the avulsed nail should always be replaced.[6] Malunion with residual pseudo-mallet or flexion deformity can occur in fractures treated without fixation. In two studies, 3 of 18[20] and 3 of 4[22] Seymour fractures treated with closed reduction and splinting healed with mild residual flexion deformity. It is likely that the results are due to a combination of incomplete initial reduction, redisplacement after reduction, and poor patient compliance with splinting. Conservative therapy may be tried, but it is imperative that weekly office visits for clinical inspection of the wound and radiographs be done to ensure that the injury is progressing satisfactorily. Conservative therapy is probably not a good treatment option in those who are likely to be noncompliant as a high rate of infection has been reported.[21,20,23] Seymour fractures are open injuries, and infection is a concern if the injury is not treated as such. Because of these poor results with conservative therapy and the potential problems with

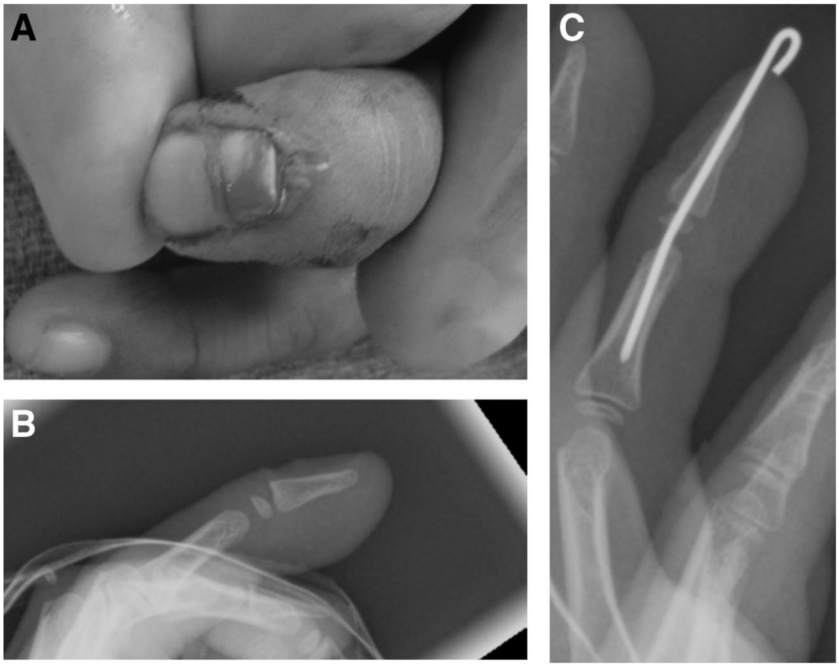

FIGURE 10. **A,** Clinical Presentation of Seymor Fracture – This is an open injury as the proximal nail is off the eponychial fold, revealing bone underneath. **B,** Lateral Radiograph of a Seymour Fracture. **C,** Radiograph of a Reduced and Pinned Seymour Fracture.

reduction, we prefer to take these patients to the operating room to do a formal irrigation and debridement with proper reduction and fixation with a smooth Kirschner wire. The steps in the operation are listed as follows:

1. Removal of the nail.
2. Thorough debridement of the open fracture.
3. Removal of tissue such as incarcerated nail bed from fracture site.
4. Reduction of fracture.
5. Fixation of fracture with a K-wire.
6. Repair of nail bed (if a substantial proximal flap exists).
7. Replacement of nail underneath eponychial fold.
8. Splinting or casting.

Complications from this injury include premature growth plate closure because of direct physeal injury, but this may also be secondary to infection. Dorsal rotation of the epiphysis can occur in Salter I Seymour fractures.[24] This is a rare complication, but if unrecognized, can lead to extensor mechanism dysfunction, distal phalanx deformity, and articular surface deformity. Finally, nail bed deformity or absence may result from the associated nail bed injury in these fractures.

Metacarpal Fractures

Although shaft fractures are more common, metacarpal fractures in children are often articular or periarticular.[25] In the thumb, for example, the base of the metacarpal is the most common fracture. The metacarpal neck fracture, specifically of the small finger, has been listed as the most common location, the so-called "Boxer's fracture."[26] In another series, this fracture represented 80% of metacarpal injuries in children (Fig. 11).[27]

Stable, minimally displaced fractures of the metacarpals can usually be treated with simple closed reduction and splinting. The intermetacarpal ligaments are stout ligaments that span between each metacarpal head and resist displacement of low-energy fractures. Metacarpal neck fractures may be treated with the Jahss maneuver (application of a dorsally directed force to the 90 degree-flexed proximal phalanx and palmar-directed counterpressure to the fracture site).[28] Traditional teaching allows for conservative management of metacarpal neck fractures with the following acceptable degree of apex dorsal angulation: small finger: 50 to 60 degrees, ring finger: 30 degrees, middle finger: 20 degrees, index finger: 10 degrees.[29] The degree of apex dorsal or volar angulation at the fracture site is more accurately assessed with a lateral radiograph of the hand. Oblique views have been shown in a cadaveric study to be misleading, often amplifying the actual angle of the fracture.[30] Apex dorsal angulation, if left unreduced will lead to a change in the appearance of the cascade of MCP joints on the dorsum of the hand. It is important to note that these deformities are only acceptable if there is no significant rotational deformity (any rotation of >5 degrees). Small finger rotation should be carefully assessed as fracture site swelling within the fourth web space can exaggerate a perceived rotational deformity. In addition, recent literature has demonstrated with cadaveric testing that metacarpal shortening of up to 1 cm may lead to nearly 50% decreased grip strength.[31]

Immobilization after reduction should be performed, however, the type of splint or cast used is not as important. A retrospective review evaluated 3 different casting techniques for closed management of extraarticular metacarpal fractures: 1 group was casted with the MCP joint in flexion with full IP joint motion permitted, another group was casted with the MCP joint in extension and full IP joint motion permitted, and the last group was casted with the MCP joint flexed and the IP joints extended without motion. The authors found no differences between groups in terms of maintenance of fracture reduction, finger range of motion, or grip strength.[32]

Inability to achieve the alignment or rotation within the acceptable degrees as stated above is an indication for surgery. Closed reduction and percutaneous pinning with K-wires offer the simplest, least invasive technique to maintain reduction of

FIGURE 11. Lateral Radiograph of a Boxer's fracture (arrow) (Oetgen et al.).

FIGURE 12. AP radiograph of a long, oblique fracture of the proximal phalanx. The inherent instability of this fracture pattern will likely lead to suboptimal finger function if treated nonoperatively (from Oetgen et al.).

these fractures. However, open reduction and internal fixation is a reasonable alternative if closed reduction is unsuccessful. Postoperative problems for any metacarpal fracture by closed reduction and percutaneous pinning or open reduction and internal fixation include adhesions of overlying extensor tendons. To minimize the impact of extensor tendon adhesions, sufficient fixation should be achieved to allow for early digital motion.

Other notable metacarpal injuries include intracapsular fractures of the MCP joint, which carries the additional risk of avascular necrosis. Aspiration of the joint at the time of reduction and treatment may decrease this risk.[33] Fractures of the base of the thumb metacarpal are often SH III fractures that can be viewed as Bennett fracture equivalents.[34] Most of these fractures will require surgical treatment to reduce and pin the fracture accurately. Poor reduction of the articular surface may lead to posttraumatic degenerative arthritis, although this result is rare.[35]

Proximal Phalanx Fractures

Proximal phalangeal fractures are best understood in regards to the location of the fracture. Like any long bone fractures throughout the body, phalangeal fracture care should adhere to the same principles of anatomic restoration for articular or periarticular injuries and good alignment for extraarticular injuries.

Shaft Fractures

Treatment of closed, extraarticular shaft fractures of the proximal phalanx can be guided first by separating these injuries into nondisplaced and displaced fractures. These fractures also tend to cause rotation that can be misdiagnosed in the acute phase if alignment during active or passive motion of the fingers is not examined. Most nondisplaced extraarticular fractures can be treated with buddy-taping and early motion for 3 to 4 weeks. For displaced fractures, stability following closed reduction should be assessed. As for spiral fractures or others with potential for instability, splinting may be attempted; however, vigilant follow-up is a must to monitor for subsequent displacement (Fig. 12). Displaced fractures may be unstable, even if reduced, and can be difficult to hold reduced. Among shaft fractures, the oblique, spiral, or comminuted fractures tend to be unstable, whereas transverse fractures or Salter II metaphyseal fractures tend to be stable after reduction.

Base of Phalanx Fractures

Proximal phalanx base fractures tend to occur as a transverse fracture pattern. The pull of both intrinsic and extrinsic muscles extends the finger, causing an apex volar, extension type deformity at the fracture site. Most phalangeal fractures in children are articular or periarticular. Radiographic studies of patients with suspected proximal phalanx injuries should include PA, lateral, and oblique films of the suspected digit. The most common injury is the Salter-Harris II fracture of the base of the proximal phalanx.[25,36] Some have suggested the fracture line may actually be entirely metaphyseal, 1 to 2 mm distal to the physis, and are more appropriately termed juxtaepiphyseal fractures.[22,37,38]

Substantial remodeling can occur with these fractures, because of the proximity to the physis and the multiplanar motion of the MCP joints. Growth arrest is rare. Oftentimes, conservative treatment with closed reduction and casting or splinting is successful and the results are good,[37] but open reduction may be needed for significantly displaced fractures with soft tissue interposition[39–41] or unstable fractures. It is therefore important to recognize the possible need for open reduction in severely displaced proximal phalanx base fractures.

In the little finger, base fractures are known as "extra octave" fractures because of the typical abduction deformity related to ulnar angulation. These can be reduced with counter force applied to the digit using a pencil as a lever in the fourth web space. Buddy tape and an ulnar gutter splint in an intrinsic plus position is applied if reduced and stable.

Phalangeal Neck Fractures

Fractures of the neck of the proximal phalanx occur almost exclusively in children. Distal periarticular fractures or "neck" fractures may be missed in young children secondary to the purely cartilaginous distal fracture fragment (Fig. 13). The injury frequently results when a child's finger is closed in a car door or window and forcibly extracted. These fractures usually present as a dorsal dislocation of the distal fragment and extension angulation (Fig. 14). This leaves the adjacent interphalangeal joint in hyperextension and the subcondylar fossa obliterated by the volar spike of the proximal fragment, forming a block to flexion at the adjacent interphalangeal joint. Radial or ulnar deviation and malrotation can also occur and radiographs can underestimate the degree of clinical deformity (Fig. 15).

Displaced phalangeal neck fractures may be missed because the fracture may be confused with a distal physis, a minor avulsion fracture, or even a nondisplaced fracture if adequate lateral and oblique films are not obtained.[8] True lateral radiographs with isolation views of the affected digit can be diagnostic and should be performed to evaluate for these injuries. Also, because the distal cap may be radiolucent, normal anterior-posterior radiographs in children with this history should be viewed with caution.

In general, most of these fractures in children do well with conservative treatment, i.e., closed reduction, buddy taping, splinting. Closed reduction usually is successful in acute fractures (fewer than 7–10 days after injury). Close follow-up should be instituted to ensure that no deviation of alignment occurs.

Operative treatment is reserved for articular and displaced, unstable injuries that are unlikely to remodel (e.g., in adolescents). Closed reduction and percutaneous fixation with K-wires or a percutaneous reduction with K-wires used as joysticks to manipulate the distal fragment into a reduced position are typically successful ways to manage this injury without opening the PIP joint. Percutaneous reduction can often be achieved in the subacute period (1–3 weeks after injury).[42] Pins are usually left in place for 3 to 4 weeks to allow for healing of the fracture in a reduced position. The hand and involved finger(s) are immobilized in a cast while the pins are in place. It should be mentioned that open reduction is associated with a risk of extensor tendon adhesions, avascular necrosis of the condyles, and considerable PIP joint stiffness—especially in children.[43]

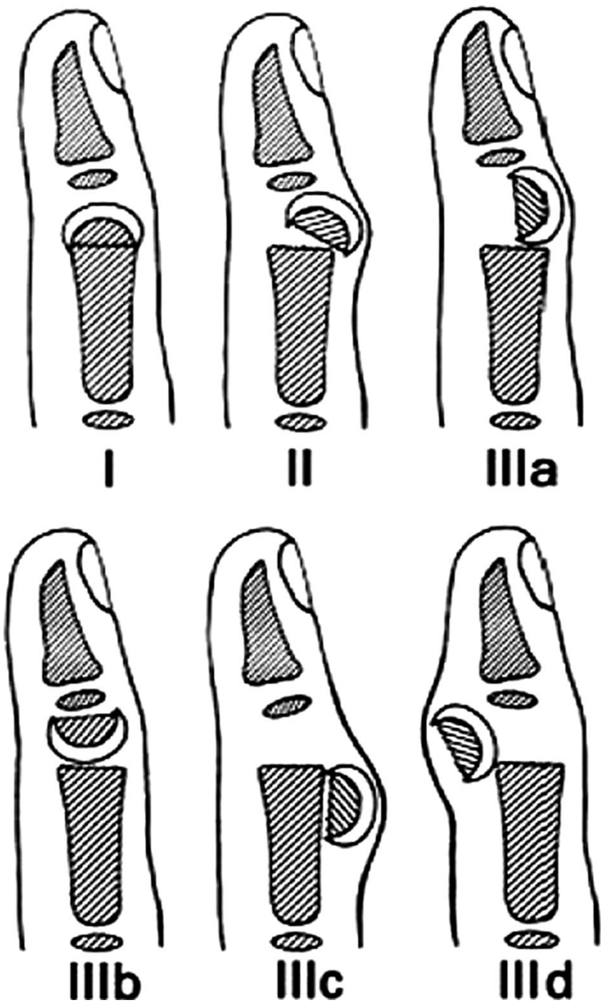

FIGURE 13. Cartilaginous cap of distal phalanx (Nofsinger et al.).

The results of phalangeal neck fracture care in children have been reported. In one study,[44] outcomes of treatment based on displacement were performed on a series of 67 phalangeal neck fractures in 66 children. Nondisplaced fractures were almost all treated with splinting and had excellent results in nearly all cases. Displaced fractures, including those that were only minimally displaced, in general had better outcomes if treated with K-wire fixation than if simply closed reduced, including a decreased risk of malunion and nonunion.

Phalangeal Condyle Fractures

Fractures of the phalangeal condyles are complex lesions as they are intraarticular fractures that can involve one or both condyles. Fracture patterns include lateral avulsion fractures, unicondylar or intracondylar fractures, bicondylar or transcondylar fractures, and a shearing fracture that separates the articular surface and subchondral bone from the remaining phalanx. As

FIGURE 14. Phalangeal Neck Fracture. These **A,** AP, and **B,** lateral radiographs show a proximal phalangeal neck fracture with the typical displacement pattern of extension and ulnar deviation angulation. On the lateral radiograph, note the volar spike (arrow) on the proximal fragment obliterating the subcondylar fossa (Cornwall et al.).

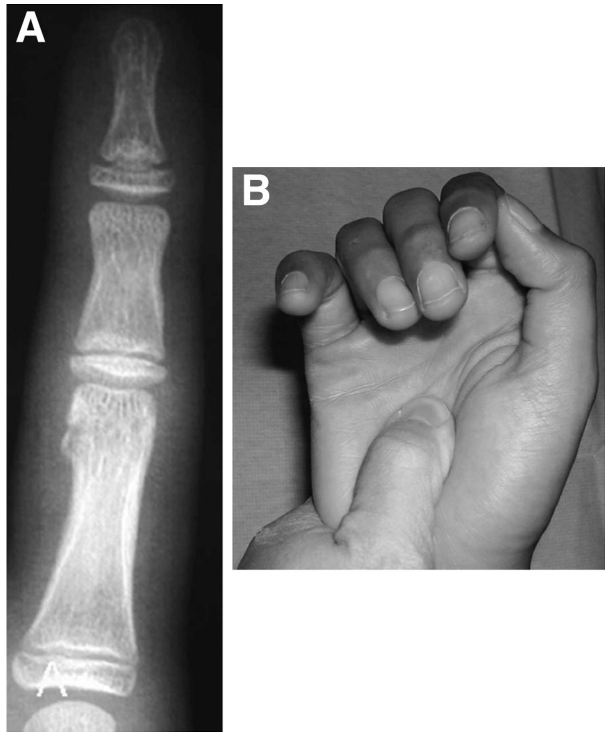

FIGURE 15. Phalangeal Neck Fracture and Resultant Clinical Deformity. **A,** A seemingly nondisplaced phalangeal neck fracture, may have, **B,** considerably clinical rotational deformity (Cornwall et al.).

with any axial impaction fracture, phalangeal condyle fractures may be associated with joint subluxation or dislocation.

Condyle fractures can be a challenge to identify and difficult to treat. Recognition of the true extent of this injury on the original radiographs is important. The anteroposterior radiographic view may look normal, but lateral radiographs can often show the double density sign, representing the offset of a displaced, fractured condyle (Fig. 16). Oblique views are also helpful. A CT scan can be considered if radiographs do not provide enough information about the location and extent of the injury.

Frequently, these fractures are displaced and an anatomic reduction may be needed to restore proper joint alignment. These fractures can evolve to nonunion, pseudarthrosis, and osteonecrosis. The goal of treatment is to maintain articular congruity to optimize long-term outcome. This is established by reduction, stable fixation, and early mobilization. Reduction options include closed or percutaneous reduction using carefully placed instruments such as a pointed bone reduction forceps or a smooth pin. During open reductions, it is important to check that the subcondylar fossa is cleared of bone, because failure to do so may result in a block to flexion despite anatomic reduction.[6] In addition, excessive soft tissue stripping from the condyle fragment should be avoided to minimize the potential risk of avascular necrosis, which has been reported in open reduction of phalangeal neck fractures.[43] Fixation is obtained using mini screws or smooth K-wires. K-wire or screw placement through the collateral ligaments should be avoided to prevent tethering on these structures that may limit motion.[6] An intrinsic-plus forearm-based cast is usually done for 2 to 3 weeks before instituting range of motion exercises. Pins are usually pulled at the 3 to 4 week mark.

As with phalangeal neck fractures, phalangeal condyle fractures must be treated promptly. Delaying reduction and fixation even into the second week postfracture can create great difficulty in achieving an anatomic reduction and may lead to finger stiffness. Remodeling does not occur as routinely with these articular fractures and malunion may result in clinical deformity.[45]

Middle Phalanx Fractures

Middle phalanx fractures act very similarly to proximal phalanx fractures and principles of diagnosis, physical examination, and treatment are essentially identical to that of the proximal phalanx. One difference is the insertion of the flexor superficialis tendon on the middle phalanx. Fractures of the middle phalanx distal to the insertion of the flexor superficialis tendon will deform in an apex volar manner, whereas fractures proximal to the insertion of this tendon will deform with an apex dorsal angulation. Understanding the deforming forces of a middle phalanx fracture facilitates the planned reduction maneuver and splint application for these fractures.

SUMMARY

Fractures of the hand and phalanges are common injuries in children. The initial evaluation of these injuries requires a good history and physical examination along with quality radiographs to determine an appropriate treatment plan. Most

FIGURE 16. Preoperative and postoperative radiographic view of a unicondylar fracture of the proximal phalanx is shown. **A,** The preoperative radiographic view is shown. **B,** The postoperative radiograph shows reduction and percutaneous pinning.

pediatric hand fractures can be treated nonoperatively. Stable fractures without rotational deformity or intraarticular extension are best treated nonoperatively with gentle reduction, appropriate splinting, and early motion to provide an environment for fracture healing without excessive residual stiffness. Fractures that cannot be suitably managed in a splint or cast, including those with residual deformity, intraarticular extension, displacement, and unacceptable alignment in the coronal, sagittal, and rotational plane are best handled by an open reduction with internal fixation.

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