HAND: FRACTURES AND DISLOCATIONS,
THE WRIST, CONGENITAL DIFFERENCES,
AND RHEUMATOID ARTHRITIS

Shelby Richard Lies, MD
Kathlyn J. Drexler, MD
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FRACTURES AND DISLOCATIONS

Understanding the intricate anatomy of the hand is key to determining the patterns of deforming forces associated with fractures and dislocations and how to correct them. A review of the bony and ligamentous architecture of the hand is presented herein.\(^1\)-\(^4\)

Functional Anatomy

The distal carpal row is composed of four bones: the trapezium, trapezoid, capitate, and hamate. These carpal bones articulate with the metacarpals. The trapeziometacarpal joint has a unique “saddle joint” configuration that allows excellent mobility for thumb opposition.\(^5\) The second and third metacarpals behave as a fixed osteoligamentous unit. The carpometacarpal (CMC) joints of the fourth and fifth metacarpals are relatively mobile.

Strong intrinsic muscle insertions contribute greatly to the stability of the thumb metacarpophalangeal (MP) joint (Fig. 1).\(^6\)-\(^8\) Arc of joint motion in the sagittal plane averages 75 degrees.

The collateral ligaments (CL) of the MP joints are quadrangular. They originate from the lateral aspect of the metacarpal condyle dorsal to the axes of rotation and insert into the volar base of the proximal phalanx and into a portion of the distal margin of the volar plate. The CL of the MP joints are lax in extension and tighten in flexion; this is a function of their eccentric origin and of the cam shape of the metacarpal condyle (Fig. 2).\(^6\) At the MP joint level, the CL are twice as strong as the CL of the proximal interphalangeal (IP) joints.

The accessory CL (ACL) originate just volar to the proper CL. The ACL are triangular and insert into the lateral borders of the volar plates (Fig. 2).\(^6\) The radial sesamoid is the primary insertion for the abductor pollicis brevis, and the ulnar sesamoid is the insertion for the oblique head of the adductor pollicis.

**Figure 1.** Medial aspect of the normal MP joint of the thumb shows the origin and insertion of the proper (Pr) and accessory (Ac) ulnar collateral ligaments. The ulnar sesamoid (S) is seen within the volar plate (VP), and the tendon of the adductor pollicis (AP) is inserting onto it. (Modified from Masson et al.\(^9\))
Figure 2. Collateral ligaments (CL) tighten with flexion of the MP joint because of their eccentric origin. As a result, little lateral movement is possible. M, metacarpus; ACL, accessory collateral ligament; VP, volar plate; P, phalanx. (Modified from Eaton.9)
The MP joints of the digits serve as the prime axes for finger movement. The articular surfaces are unique in that they are condyloid (ball-and-socket). The metacarpal head has a volar flare on cross section, and this configuration allows both excellent stability and mobility of the MP joints. The volar plates are continuous laterally with the deep transverse metacarpal (intervolalar plate) ligament, a strong structure that connects the volar plates to each other and reinforces the linked ligament-box support of the joint.

In contrast to the MP joints, the IP joints are hinge joints (ginglymus) that rotate only in the sagittal plane and have excellent stability against angular stress. The proximal IP (PIP) joint has a greater range of motion than does the distal IP (DIP) joint. From full extension, flexion to 105 degrees is normally obtainable in the PIP joint whereas 80 degrees is obtainable in the DIP joint. The proximal articular surface is bicondylar and its transverse dimension is approximately twice its vertical dimension, which provides additional stability against lateral stress.

The proper CL arises from a concentric concavity on the lateral aspect of the condyles and inserts into the volar base of the more distal phalanx and also into a portion of the volar plate. The ACL are triangular and suspend the volar plate and the flexor tendon sheath in much the same way that the CL suspend the phalanx. The ACL are contiguous with the CL and complete the sides of the joint “box.” The floor of the box is the volar plate. The integrity of the box is the key to stability of the IP joints. Dislocation of the IP joints requires disruption of one or more components.

The volar plate is a unique structure in that its dorsal surface is contiguous with the intra-articular portion of the IP joint, whereas its volar surface forms a gliding surface for the flexor tendons as they cross the IP joint. The thickened lateral portions of the volar plate constitute the checkrein ligaments, which are anchored to the volar periosteum. The checkrein ligaments form at the confluence of a portion of the dorsal flexor sheath, the horizontal reflexion of the ACL, and the lateral margin of the volar plate. The ligaments protect a transverse branch of the digital artery as it passes into the retrocondylar space to arborize into the vincula at each joint. The checkrein ligaments normally prevent IP hyperextension yet are sufficiently flexible to flow beneath the articular condyles during flexion of the joint. The volar plate attachment is strongest at the proximal phalanx (avulsion off the middle phalanx at the PIP joint and off the metacarpal at the MP joint), and entrapment of the avulsed end can preclude closed reduction.
Fractures

Epidemiology
In a survey conducted by Chung and Spilson,15 hand and forearm fractures accounted for 1.5% of all emergency department cases in the United States. The fractures that constituted the largest proportion of fractures were those of the radius and/or ulna. The age group that was most affected was from 5 to 14 years (26%).

Pathophysiology
The direction and magnitude of the injuring force determine whether a fracture is characterized into greenstick, transverse, oblique, spiral, or comminuted patterns. Transverse fractures result from a direct blow to the bone, whereas oblique fractures result from direct axial loading. The greater the degree of axial loading is, the more oblique the fracture will be. Spiral fractures result from excessive rotational stress during axial loading.

In general, the degree of bony injury is proportional to the traumatizing force; as the force of injury rises, so does the comminution. Increasing degrees of comminution and displacement have a corresponding disruption of bony circulation and instability of fragments.

Fracture angulation in the metacarpals almost always occurs in a dorsal apex direction, whereas fracture angulation in the phalanges usually occurs volarly. This can be explained by the direction of the force alone16 or by the insertions of tendons, ligaments, or intrinsic bands relative to the fracture geometry.17,18

Radiographic Examination
Radiographic examination should include anteroposterior, oblique, and lateral views. In addition, a Brewerton’s view can be obtained for suspected metacarpal head fracture and a Roberts’ view for thumb injuries.17

The advent of minifluoroscopy has been a notable advantage to the hand surgeon. The smaller, more mobile minifluoroscopy units allow the hand surgeon to perform imaging for both diagnosis and treatment with less radiation exposure. Stern19 found this modality particularly useful for closed reductions and percutaneous pinning. It is a time-saving modality that has allowed greater precision and accuracy in fracture reduction and stabilization.19

Classification
Fractures of the proximal and middle phalanges can occur at the neck, shaft, or base and become articular with any involvement of the joint. Metacarpal fractures are likewise subdivided by anatomic area. Management varies according to displacement tolerated in a particular digit.

Management
Inappropriate management of hand fractures can cause joint deformity, stiffness, and disability.20 Many authors17,21–26 agree that the majority of hand fractures are best treated conservatively with limited immobilization. Stable, nondisplaced fractures can be mobilized.27 Three-fourths of all phalangeal fractures are not significantly displaced, and treatment consists of “buddy” taping and early motion.21,22 Barton21,22 recommended ignoring any displacement of less than 50 degrees in the metacarpal neck, based on studies that showed good recovery of function despite considerable angulation.28,29

Reduction is performed with the patient under satisfactory local, regional, or general anesthesia. Fractures are preferentially manipulated from mobile to immobile fragments. After debridement, cortical key patterns frequently denote proper alignment. Intraoperative radiographs with adequate orthogonal views are used to confirm adequacy of the reduction. Tenodesis allows assessment of rotation in the asleep patient.

When closed reduction methods are unsuccessful, open reduction must be considered. Precise correction of any rotational deformity is essential in the hand. Malrotation is very difficult to correct secondarily and usually requires osteotomy.30 Errors in axis alignment are amplified in the distal end of the finger, especially during flexion: 5 degrees of deviation in a metacarpal bone reflects as 1.5 cm superimposition of that finger over another during full flexion.16,17,31

Pun et al.24 defined “acceptable alignment” as follows:
- no rotational deformity
- maximum 10 degrees of angulation in both sagittal and coronal planes
- in the metaphyseal region, maximum 20
degrees of angulation in the sagittal plane
• in fractures of the neck of the fifth metacarpal, maximum 45 degrees of angulation in the sagittal plane
• at least 50% apposition of fragments at the fracture site.

Burkhalter reported that regardless of the radiographic findings, closed reduction is indicated for extra-articular fractures of the proximal phalanges and metacarpals when full digital flexion is present with no rotational deformity. Considerable osseous malalignment can be tolerated under such circumstances. Closed functional treatment is based on the principle of proper external positioning combined with active joint motion.

Multiple fractures with more than 3 to 4 mm of shortening are highly suspect for associated tendon or nerve injury, and open reduction might be the safest course of action in such cases. Moreover, unstable fractures, fractures involving an articular surface, and those with loss of bony substance or severe disruption of the soft tissues require fixation to maintain adequate alignment after reduction.

External immobilization appliances (splints or casts) should adequately support the proximal and distal bony fragments while freeing those elements that will not affect the fracture site if moved. Internal fixation is indicated for the following reasons:

1. to maintain reduction of unstable fractures (e.g., oblique or spiral fractures of the phalanges) or any fracture after failed closed manipulation
2. for precise positioning of fragments with fractures that involve a joint or are close to a joint
3. in open, complex hand injuries with multiple fractures, segmental bone loss, or compromised soft tissue.

Occasionally, such as for fractures associated with joint or tendon disruptions and for finger replantations, internal fixation is used to facilitate early motion.

Kirschner wires (K-wires) are most commonly used for skeletal fixation in the hand. Tension-band wiring involves crossed or parallel K-wires and monofilament stainless steel suture. "Tension-band wiring is recommended for unstable fractures of the midshaft and for arthrodesis."

Gingrass et al. recommended intrasosseous wiring of complex periarticular fractures, even those that have some degree of comminution. Active assisted motion is begun in a few days, and little or no splinting is required. Lister noted some compression and control of rotation with a single intrasosseous wire but added K-wire(s) to counteract the tendency for angulation.

Small-fragment plates and screws have been developed for use in the hand, but they require extensive periosteal stripping and are difficult to properly place. Barton cautioned that plates should not be used in the fingers because of tendon adherence, but Dabezies and Schutte obtained 90% or better average range of motion with miniplate fixation of unstable metacarpal and phalangeal fractures. The authors stressed meticulous technique in drilling holes and the need to elevate the periosteum to avoid violating the gliding space between the extensor tendon apparatus and the periosteum.

Active range-of-motion exercises are begun the morning after surgery. The Association for the Study of Internal Fixation manual recommends removing K-wires after 1 to 2 months and screws and plates at 4 to 6 months postoperatively, yet Dabezies and Schutte reported no ill effects in patients whose fixation devises were still in place long after surgery. The follow-up duration in that report ranged from 9 to 24 months.

In a study conducted by Omokawa et al. on 51 consecutive patients with periarticular metacarpal and phalangeal fractures treated with a titanium plate system, bone union was successfully achieved in all patients during an average period of 2.6 months. The final range of total active motion was excellent for 26 patients, good for 17, fair for five, and poor for three.

Ouellette and Freland studied 68 mini condylar plate applications in the metacarpals and phalanges. They found that approximately one-third of patients had excellent final range of motion, one-third had good or fair range of motion, and one-third had poor range of motion. The complication rate was significantly higher with open fractures, fractures with associated soft-tissue injury, and fractures requiring bone grafting.
Cortical screws can be used to treat Bennett fractures (intra-articular fracture-dislocations at the base of the first metacarpal), oblique condylar fractures of the phalanges with large fragments in unstable configurations, spiral and oblique metaphyseal fractures of the metacarpals (and rarely of the phalanges), and displaced fractures of the metacarpal bases.\textsuperscript{48,49} Hastings\textsuperscript{49} reviewed the management of metacarpal and phalangeal fractures with screws and plates. According to the author, screw fixation might be indicated for unstable, long, oblique, or spiral fractures of metacarpals and phalanges and for intra-articular fractures with more than 25\% articular surface involvement. Conditions that require plating include metacarpal fractures with segmental defects, extremely comminuted fractures, and unstable diaphyseal fractures.

Vanik et al.\textsuperscript{50} compared the strength of various internal fixation techniques in the treatment of metacarpal fractures. They concluded that plate or plate-and-screw fixation was sufficiently stable to withstand functional use of the hand, but neither a single K-wire nor crossed K-wires provide solid fixation when measured against intraosseous wire, plating, and combination intraosseous wire and K-wire.

A recent study compared the biomechanics of the hand after application of either microplates or miniplates to fractures of the metacarpals or phalanges. The authors concluded that dorsally applied miniplates provided the greatest rigidity across a fracture to a dorsal load.\textsuperscript{51} Freeland and Lindley\textsuperscript{48} discussed the advantages and disadvantages of rigid internal fixation in the hand. Screws and plates are said to enhance stability of the reduction while freeing the hand for early mobilization. When properly used, rigid fixation devices are stress-shielding because the load is applied to the implant rather than to the fracture site.\textsuperscript{48,52-55}

O’Sullivan et al.\textsuperscript{56} studied the use of low-profile, titanium maxillofacial plating systems in hand surgery. The authors reviewed the use of the plates in 57 consecutive patients. They noted that 17 patients (30\%) experienced postoperative morbidity and that 10 (18\%) required secondary surgery. The range of motion was more restricted for patients who received plate fixation of phalangeal fractures than for those who received plate fixation of metacarpal fractures. The authors concluded that the low-profile plates do have a role in hand fractures but are better used for metacarpal fractures than for phalangeal fractures because of the range-of-motion results.

The incidence of infection after open fracture of the hand is less than 10\%,\textsuperscript{36,58-62} and routine use of antibiotics is not recommended.\textsuperscript{36,58-62} Vigorous irrigation and débridement are sufficient to stave off infection in most cases. The most common pathogen is \textit{Staphylococcus aureus}.

External fixation is useful for open fractures that have concomitant soft-tissue injury. In such cases, wound care and subsequent soft-tissue procedures might be necessary. External fixation to provide adequate bony stability for bone healing allows adequate soft-tissue management. The advantages of external fixation have been reported by several authors\textsuperscript{19,63} and include the following:

- limited devascularization of bone
- adequate stability
- soft-tissue access
- ability to perform secondary adjustments if fracture displacement occurs.

### Metacarpal Fractures

Metacarpal shaft fractures typically are caused by axial compression, occasionally with a rotational component. Long oblique and spiral fractures are inherently unstable and often result in shortening. Internal fixation with K-wires or screws is frequently required to maintain reduction; if the fracture is comminuted, the use of transverse K-wires or an external fixator might be indicated to maintain length.

Distal metacarpal fractures usually are the result of direct blows to the area, typically a closed-fist injury exerting axial compression on the head of the metacarpus.\textsuperscript{64} Fractures of the metacarpal neck are called \textit{boxer’s fractures}, and are among the most common of hand injuries.\textsuperscript{65} The distal fragment often is displaced volarly. Failure to properly reduce an angulated fracture can result in a painful metacarpal head in the palm with an associated extensor lag.\textsuperscript{66} Closed reduction of such fractures is accomplished by performing the method presented by Jahss\textsuperscript{67} with placement of a gutter splint.
Comminuted fractures are best treated by molding and splinting or external traction. Postreduction angulation more than 10 degrees at the index and middle finger neck, 20 to 30 degrees at the ring finger, and 40 degrees at the small finger is an indication for surgery; however, substantially more angulation has been tolerated with acceptable functional outcomes. Malrotation with scissoring is an indication for surgery. Be sure to compare the injured hand with the contralateral hand for asymmetry. Clinical examination and patient factors should guide management decision.

Metacarpal base fractures occur mostly on the ulnar side of the hand, usually as a result of direct crush injuries. Unrecognized or untreated fractures are evidenced by a painful power grip. In the fifth metacarpal, fracture-dislocations at the base—also known as reverse Bennett fractures—tend to be unstable and often require open reduction and pin fixation for correction.

Gunshot wounds to the hand that are treated in civilian emergency departments are typically of the low-velocity type. Chappell et al. studied 121 fractures in 90 patients with low-velocity gunshot wounds to the hand. The cases were managed with immediate irrigation and débridement, intravenously administered antibiotics, and early fracture stabilization. The authors had a low threshold for performing internal fixation; 60 fractures were treated by either rigid internal or external fixation and 56 by closed reduction. Associated complications included one infection and two late amputations. The authors recommended this regimen of immediate irrigation and débridement, antibiotic administration, and early fracture stabilization. The authors had a low threshold for performing internal fixation; 60 fractures were treated by either rigid internal or external fixation and 56 by closed reduction. Associated complications included one infection and two late amputations. The authors recommended this regimen of immediate irrigation and débridement, antibiotic administration, and early fracture stabilization for low-velocity gunshot wounds to the hand. However, the urgency of treatment for a gunshot wound depends on the caliber of the projectile, type of firearm, and extent of injury. A review of selecting appropriate surgical technique with percutaneous pinning, lag screw, or plate fixation emphasized minimizing soft-tissue disruption and allowing early motion when possible.

Phalangeal Fractures

Proximal Phalanx

Fractures at either end of the phalanx occur in predominantly cancellous bone and consequently heal faster than do fractures of the shaft. Proximal third fractures are most common on the ulnar side of the hand. If the reduction is stable, immobilization with a short arm cast or splint is indicated. Distal third fractures are fairly common and often unstable. Fractures of the condyles of the proximal phalanx can be unicondylar or bicondylar, can be with or without displacement, and can vary greatly in their presentation, severity, prognosis, and treatment. Internal fixation with K-wires or compression screws usually is needed, but prolonged immobilization is not necessary.

Schenck emphasized the use of a dynamic traction splinting method for treatment of complex, comminuted, intra-articular fractures at the PIP joint. This method relies on the principle of ligamentotaxis, which allows motion at the joint through dynamic traction while maintaining reduction and promoting joint remodeling. Good functional results have been achieved through use of this method, which can also be applied to similar complex, comminuted, intra-articular fractures at the MP joint level. Ruland et al. and Suzuki et al. achieved good results with dynamic external fixation of the proximal phalanx in 34 patients. Volar plate and hemi-hamate arthroplasty should be considered when joint involvement exceeds 50%.

Middle third fractures tend to be spiral, oblique, or transverse and are therefore generally unstable with volar apex angulation of the fragments. Agee reported that progressive palmar angulation of the fracture results in loss of skeletal length that is more marked dorsally, with a simultaneous loss of IP extension and secondary flexion contractures. To prevent bony shortening, the phalangeal length needed for extensor tendon competence must be restored by accurately realigning the bone ends. Fixation can be achieved with K-wires or miniscrews placed in such a manner that allows active, unrestricted gliding of the extensor and flexor tendons during fracture healing. Exposure for open reduction is through a dorsal or midaxial approach.

Distal Phalanx

Fractures of the distal phalanx usually are the result of crush injuries with corresponding destruction of the soft tissues. They commonly occur in the long finger of
children, and car doors are the usual agent. Injuries to the nail bed must be carefully evaluated by nail plate removal when subungual hematomas encompass more than 25% to 50% of the plate. Repair should be performed with fine suture and loupe magnification. The trimmed nail plate or a foil pack should be replaced in the eponychial fold as a stent to prevent synchia.  

A Seymour fracture is a Salter-Harris I or II or juxta-epiphysyeal fractures of the distal phalanx of the hand with associated nailbed laceration. Al-Qattan studied 25 patients with Seymour fractures, 18 of whom were treated with closed reduction and splinting and five of whom were treated with K-wire fixation. Open Seymour fractures are susceptible to infection, progressing to osteomyelitis when not managed appropriately.  

The mallet deformity is caused by extension of the proximal fragment by the extensor tendon and flexion of the distal fragment by the attachment of the flexor digitorum profundus tendon. Intra-articular fractures involving more than 30% of the joint surface or subluxation of the distal phalanx require precise reduction and internal fixation. When less than 30% of the joint is involved, immobilization with the DIP joint in neutral position or slight hyperextension is indicated.  

Kang et al. studied 59 mallet fractures that were treated by open reduction and internal fixation (ORIF). The authors noted a very high rate of postoperative complications: 24 cases (41%) had complications, including marginal skin necrosis on the dorsal aspect of the distal phalanx, recurrent extensor lag, permanent nail deformities, and transient infections of the K-wires and pullout steel wires. Osteomyelitis was also observed.  

In contrast, Takami et al. treated 33 patients with ORIF of mallet fractures. They noted good results with only one complication. Their patients experienced an average of only 4 degrees of loss of extension of the distal phalanx. The average flexion of the DIP joint was 67 degrees.

Middle Phalanx

Nondisplaced fractures of the middle phalanx should be immobilized to block the final 30 degrees of extension. Motion is gradually increased until full extension is permitted approximately 4 to 8 weeks after injury.

When the fracture involves the shaft, even minor angulation of fragments disrupt the floor of the flexor mechanism and interfere with tendon excursion. Agee noted that with middle phalangeal shortening, a fixed length of extensor mechanism between its insertion into the middle and distal phalanges results in loss of distal joint extension and PIP joint hyperextension. The biomechanics that produce the swan neck deformity that occurs secondary to injury to the distal joint extensor tendon are the same as those that produce swim neck deformity secondary to middle phalangeal shortening. Comminuted fractures often cannot be properly reduced, in which case molding and splinting, and occasionally skeletal traction, are treatment options.

Articular Fractures of the Phalanges

Indications for ORIF of intra-articular fractures are greater than 25% involvement of the articular surface or more than 2 mm of articular step-off or joint subluxation or dislocation.

Fractures of the Thumb

The most common type of bony injury in the thumb is an intra-articular fracture-dislocation at the base of the first metacarpal, called Bennett fracture. Reduction of a Bennett fracture involves traction, pronation, abduction, and internal fixation with K-wires driven across the metacarpal base and into the trapezium and/or into the base of the second metacarpal. This technique succeeds in 80% to 90% of cases. The goal of reduction is to reduce the metacarpal to the fractured fragment to which the anterior oblique ligament is attached. Should the reduction fail to hold, small AO plates or lag screws and oblique traction are indicated.

In a useful review of fractures of the base of the first metacarpal in children with open growth plates, Jehanno et al. subdivided the fractures into three groups. Group A consisted of pure metaphyseal fractures. Group B consisted of Salter type II epiphysyeal detachment fractures with a medial metaphyseal-epiphysyeal corner. Group C was made up of Salter type II epiphysyeal detachment fractures with a lateral metaphyseal-epiphysyeal corner. In reviewing the treatment and the outcomes in 30 cases, the authors noted that none of the Group B fractures that were treated with
simple immobilization in a splint or cast experienced secondary displacement. In contrast, half of Group A and Group C fractures that were treated with a splint or cast became secondarily displaced and required surgical revision. The authors concluded that Group B lesions can be adequately treated by casting or immobilization, whereas Group A and Group C fractures should be treated by immediate surgical stabilization.

Rolando fracture results from a larger applied force and has both dorsal and palmar fragments, which often are comminuted (Fig. 5). The degree of comminution and the size and position of the fragments (whether T- or Y-shaped) dictate the management of Rolando fractures. When the fragments are large enough, exact reconstruction of the joint surface by ORIF is preferable, but when the fragments are minute or comminution is severe, longitudinal traction on the metacarpus and early mobilization are indicated.

The thumb has a greater margin of tolerance for both angular and rotatory misalignment compared with the fingers. According to Stern, malrotation rarely is a problem. Angulatory deformities of less than 15 to 20 degrees in the frontal plane are functionally acceptable. Similarly, angulation of less than 20 to 30 degrees in the lateral plane usually causes no functional deficit.

Fractures of the first metacarpal shaft without intra-articular extension usually are successfully treated by closed reduction and casting. Phalangeal fractures are potentially unstable and should be stabilized with K-wires inserted percutaneously. If open reduction is required, the fracture is exposed through a dorsal incision, leaving the extensor pollicis longus intact.

**Functional Results**

After fracture reduction and fixation of most metacarpal and phalangeal shaft fractures, the hand is immobilized for approximately 3 to 4 weeks. Proper placement of the joints is essential to prevent contracture of the periarticular structures. James described a “safe position” for splinting that keeps the MP joint flexed 70 degrees and the PIP joints in 20 degrees of flexion (Fig. 6). However, PIP joints are routinely immobilized in extension to prevent flexion contracture. The wrist should be included in the immobilization.

Remobilization after hand fractures typically begins earlier than for fractures in other anatomic sites. Active exercises should begin as soon as skeletal stability is clinically evident, which for most bones of the hand is in 3 to 5 weeks. Wright found little difference in functional recovery after fracture of the metacarpals or phalanges when motion was begun at any time up to 3 weeks, but if the joints were immobilized beyond that time, a significant increase in stiffness and contractures and a corresponding reduction in hand function were noted.
According to Huffaker et al., the following factors are implicated in decreased range of motion associated with hand fractures:

- associated joint injury
- more than one fracture per finger
- crush injury
- flexor or extensor tendon injury
- skin loss.

Pun et al. added the following:

- functionally unstable fractures
- open fractures
- comminuted fractures
- associated significant soft-tissue injuries.

Complications and Sequelae

Stern et al. studied 258 patients who underwent internal fixation for metacarpal and phalangeal fractures. Complications developed more frequently when associated bone and soft-tissue injuries were present than after isolated fractures. The complication rate after plating was 42% overall and 67% in the phalanges. Hand function was measured by the total active motion criteria and was judged to be poor in 24% of the patients in that study.

Swanson et al. tracked the course of 200 open hand fractures and reported nine wound infections, 18 malunions, 17 delayed unions or nonunions, 23 fixation problems, and two late amputations. The infection rate rose in the event of wound contamination, delay in treatment for longer than 24 hours, or systemic illness and was unrelated to type of fixation, wound size or severity, or mechanism of injury. On the basis of their analysis, the authors recommended immediate wound closure for clean wounds in otherwise healthy patients and delayed closure of contaminated wounds in cases of delayed treatment for 24 hours or more or for patients with systemic illness.

The first step in the correction of tendon adherence is tenolysis. The joint should be put through the full range of motion while the patient is still on the operating table. For severe flexor tendon scarring, interpositional paratenon, polyethylene film, or Silastic sheeting has been suggested. Adherent extensor tendons are more difficult to correct than are flexor tendons because of the relative lack of soft-tissue padding between the tendon(s) and the bone. Regardless of the technique used, early postoperative mobilization is essential. Continuous passive motion machines have been used with varying success. However, their use is controversial.

Joint stiffness is the expected outcome of inadequate, inappropriate, or prolonged immobilization of the hand after a fracture. The most common manifestations of a stiff joint are extension contractures at the MP level, which are managed by dorsal capsulectomy, and flexion contractures of the PIP joint, which respond to checkrein ligament release.

Fractures in Children

Hand fractures in children are not only relatively rare but also tend to show less displacement and comminution compared with hand fractures in adults. Two reasons for this are that a child’s bones are more malleable and less growth. Surgical correction by osteotomy is indicated when the deformity impairs hand function or is cosmetically unacceptable.

The incidence of nonunion after hand fractures averages less than 1%. Phalangeal fractures of all types show radiographic evidence of healing in approximately 5 months, although clinical signs can predate radiographic confirmation by many weeks. True nonunion, therefore, cannot be assumed until at least 1 year after reduction. Treatment of the nonunited hand fracture might include external fixation, sculpted bone grafting, and internal fixation. Surgery for septic delayed union must be staged, first removing the infected bone and later placing the autogenous bone graft.

Bone shortening of up to 5 mm causes no functional or cosmetic impairment. Deficits larger than 5 mm need to be bridged with bone grafts, K-wire spacers, external fixators, or other distraction devices. Simultaneous soft-tissue coverage often is required.

The most common complication associated with phalangeal and metacarpal fractures is malunion. The usual causes of malunion are initial misalignment during reduction, subsequent distraction of the fragments, and epiphyseal plate injury producing asymmetrical growth. Surgical correction by osteotomy is indicated when the deformity impairs hand function or is cosmetically unacceptable.

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brittle than an adult’s bones and that the periosteum in a child is tougher and thicker and has a better blood supply. Fractures near but not involving the growth plate are extremely rare in children. This is because the epiphyses represent weak areas along the bone that coupled with the strong resilient ligaments of a child, are prone to fracture in response to sudden stresses that in an adult would manifest as ruptured ligaments.

Salter and Harris\textsuperscript{105} identified five types of epiphyseal fracture (Fig. 7).\textsuperscript{106} Type II is most common overall, including in the hand.

Hand fractures in children heal twice as fast as hand fractures in adults\textsuperscript{31} because of accelerated osteogenesis from the active epiphyses. The epiphyses also help correct any remaining angular deformity, especially in the plane of motion.\textsuperscript{107} Growth deformities as sequelae of malunited epiphyseal fractures in the hands of children occur infrequently. The exception is mallet finger, which results when the extensor apparatus inserts into the epiphysis and the flexors into the shaft of the distal phalanx, pulling the fracture segments in opposite directions. The nail plate occasionally interposes between the epiphyseal and phalangeal fragments, preventing union. This is also known as Seymour fracture. It is important to recognize this injury because it requires careful reduction.

Fractures that occur through the neck of the proximal and middle phalanges occur primarily in children. The largest series of such fractures was reported by Al-Qattan,\textsuperscript{108} who presented 67 phalangeal neck fractures. Fractures were classified into types I, II, and III. Type I fractures were nondisplaced and were treated with a splint in all cases, with excellent results. Type II fractures were displaced fractures that still had some bone-to-bone contact. Type III fractures were displaced fractures that had no bone-to-bone contact (Fig. 8).\textsuperscript{108}

Both type II and type III fractures required K-wire fixation. Fractures treated without K-wire fixation had significantly worse outcomes. The most common fracture type was type II, which accounted for approximately 70% of fractures. Al-Qattan\textsuperscript{108} discussed important points about the potential for remodeling and correction of deformity associated with phalangeal fractures in children. For example, the epiphyses of the phalanges are only at the proximal end, and the potential for remodeling distally with a phalangeal neck fracture is therefore limited. In addition, based on the author’s experience, lateral angulation in swan neck deformity can occur when fractures are untreated or improperly treated and do not improve with time. Overall, K-wire fixation is recommended for displaced phalangeal neck fractures in children.
Leclercq and Korn\textsuperscript{109} presented a comprehensive review of articular fractures of the fingers in children. The authors noted that the remodeling of bone malunions occurs primarily in the sagittal plane with anteroposterior angulations and less so in the frontal plane with lateral angulations. Remodeling does not occur with rotational deformities. In addition, the remodeling is most effective in the metaphyseal area and less effective in the epiphyseal area. As children get older, the remodeling potential of the bone decreases. Based on the authors’ experience, remodeling of the articular cartilage occurs effectively only in children younger than 2 years. Overall, the authors recommended surgical treatment of displaced articular fractures in children. Because the size of the fragments often is small, the authors recommended performing ORIF and using miniaturized wires or screws or periosteal sutures for fixation, combined with perioperative splinting or casting.

Leclercq and Korn\textsuperscript{109} also noted some of the common sequelae that result from inadequate treatment of hand fractures in children, including malunion with clinodactyly, malrotation, growth arrest, and stiffness. In some cases, the sequelae require secondary surgical intervention.

Dislocations

Because the thumb and digits have significant structural differences at their joints, they are considered separately in this section on dislocations.

Dislocations of the Thumb

\textit{CMC Joint}

The CMC (basal) joint of the thumb has a wide range of movement but is also able to withstand considerable stress. The most important capsular reinforcement at this level is the volar beak (anterior oblique) ligament, which passes from the trapezium tuberosity to the volar peak of the thumb metacarpal. The volar ligament is a short reflection of the transverse carpal ligament and is responsible for the stability that is necessary during the dorsal subluxation force associated with pinch. Dorsal support of the CMC joint of the thumb is provided by the posterior oblique (dorsoradial) CMC ligament, which is thin and contributes little to capsular stability. Because of the strong volar oblique ligament, pure dislocations at this level are uncommon.

The usual mechanism of trauma is a blow that transmits a longitudinal force down the metacarpal shaft while the basal joint is in a partially flexed position. The resulting injury is an intra-articular fracture-dislocation at the base of the first metacarpal, called the \textit{Bennett fracture}.\textsuperscript{85-90} Diagnosis can be very difficult in that partial ruptures might exhibit only minimal joint displacement. Stress radiographs aid in the diagnosis.

Treatment of a Bennett fracture can be through a closed or an open approach. If no gross instability is noted in the joint, closed treatment with immobilization of the metacarpal in abduction and extension for 4 weeks is a reasonable option.\textsuperscript{80,83,84} Anatomic reduction is essential. Otherwise, various degrees of hypermobility and joint instability ensue, leading to progressive degenerative changes within the joint. If gross instability or complete dislocation is noted initially, reduction and follow-up radiographs in 1 week are indicated. If at that time, reduction is maintained, cast immobilization can be continued. However, if reduction is not well maintained, K-wire fixation might be required.\textsuperscript{85,86,110}

The results of casting are highly unpredictable, and many patients require open treatment. Closed reduction with percutaneous pinning is the most common procedure to treat Bennett fractures.\textsuperscript{5,14} The principle of reduction is to reduce the metacarpal to the fractured fragment to which the anterior oblique ligament is attached.

The most common operation to treat chronic dislocation and unstable CMC joint of the thumb involves reconstruction of the ruptured volar ligament with a strip of flexor carpi radialis that is rerouted to the base of the thumb metacarpal near the site of original ligament rupture, as depicted by Eaton and Littler.\textsuperscript{5,14} Direct repair seldom is possible.

\textit{MP Joint}

Dislocations of the MP joint are five times more common in the thumb than in the other digits.\textsuperscript{111} Injuries at that level tend to be either dorsal dislocations or lateral dislocations. Dorsal dislocations usually result from injury to some portion of the volar plate, whereas lateral
dislocations result from injury to the CL complex. Hyperextension is the usual mechanism of injury with dorsal dislocations. The degree of dislocation depends on the severity of injury to the volar plate, ACL, and CL. With severe injuries, the characteristic bayonet deformity is present, with the proximal phalanx overriding dorsally and parallel to the metacarpal. In most cases, the positions of the sesamoid and proximal phalanx on radiographs are clues to the degree of injury and dislocation.

Dislocations of the thumb MP joint usually are reducible but occasionally necessitate regional or general anesthesia to bring the joint into alignment. The thumb is then splinted in slight flexion for 3 weeks. Open reduction is necessary in the event of an irreducible dislocation, an incomplete reduction, a reduced but unstable joint, or a dislocation with a lateral (collateral) injury and a volar component.

With lateral dislocations, the CL complex is disrupted, most often on the ulnar side. This is 10 times more common than radial CL disruption. The diagnosis is made using the stress test with the thumb in extension: if more than 40 degrees of angulation is present, a major disruption has occurred. On the ulnar side, the ligament disrupts at its distal attachment more commonly than at the proximal attachment. On the radial side, disruption of CL occurs with the same frequency at the proximal and distal attachments. The mechanism of injury is as follows. The ulnar CL complex tears, and subsequent displacement occurs. The adductor aponeurosis then stretches across the site of rupture and prevents healing (Stener lesion). The torn ligament comes to lie superficial to the aponeurosis or might become folded on itself. Classic examples of lateral dislocation of the thumb MP joint are the so-called skier’s thumb (acute) and gamekeeper’s thumb (chronic) (Fig. 9).

Although closed treatment for this injury has been reported, surgery is generally considered to be necessary to prevent posttraumatic MP joint instability. Smith listed the following criteria for an unstable MP joint: 1) lateral deviation of more than 45 degrees, 2) displaced articular fracture of the proximal phalanx, and 3) volar subluxation of the proximal phalanx.

If the patient is treated soon after injury, reattachment of the CL, either by traditional suture repair or the recent Mitek technique, usually is sufficient treatment. If the injury is chronic, it is possible that significant attenuation of the ligament occurred and reconstruction with tendon graft might be necessary. Breek et al. reported that 92% of patients who received tendon graft were satisfied, even though one-third of the group had some loss in the flexion-extension arc.

Although surgical treatment has been recommended for displaced or rotated fractures of the ulnar base of the proximal phalanx, a recent study by Kuz et al. noted good results with nonsurgical treatment of avulsion fractures of the ulnar base of the proximal phalanx of the thumb. The authors studied 30 patients who had avulsion fractures of the ulnar CL of the thumb MCP joint; 24 of the patients had displaced or rotated and displaced fracture fragments. Patients with bony Stener lesion—which is displacement of the fracture fragment proximal to the adductor hood—were excluded. In addition, patients with fractures involving more than 30% of the articular surface were excluded. These patients were treated with a thumb spica cast or forearm-based thumb spica splint for 4 weeks of continuous immobilization. The results indicated that the patients, at an average follow-up interval of 3.1 years, were pain-free and very functional. However, a 25%
nonunion rate was noted, and three patients were shown by clinical stress testing to have instability. Despite the problems, all patients were satisfied with the treatment.

Acute injuries to the radial CL can be adequately managed with 3 weeks of complete immobilization. Open reduction usually is unnecessary.112,123

IP Joint
The IP joint of the thumb is a simple hinge joint and moves in the sagittal plane alone. With dorsal dislocations, the volar plate ruptures off the proximal phalanx but remains attached to the distal phalanx. The dislocations typically are easy to reduce, and the joint is then immobilized in slight flexion for 3 weeks.

Dislocations of the Fingers
MP Joint
Dislocations at the level of the MP joint are much rarer in the fingers than they are in the thumb. The index finger MP joint is most commonly dislocated, the little finger less often, and the long and ring fingers seldom. The joint can be either subluxated or dislocated. With subluxation, the proximal phalanx is locked in 60 to 90 degrees of hyperextension and the injury usually is reducible. With true dorsal dislocations, the volar plate becomes wedged between the joint surfaces, with the metacarpal neck lying between the lumbrical on the radial side and the flexor tendon on the ulnar side. This is known as buttonholing. The joint cannot be easily realigned by closed methods because attempts at reduction further constrict the metacarpal neck (Fig. 8).108,124-129 Open reduction is needed to extricate the interposed volar plate.

This scenario is classically described for the index finger, but little finger dislocations also tend to be irreducible.129 Again, the metacarpal head lies between the abductor digiti quinti and the flexor tendons. In contrast, injuries to the long and ring fingers typically are subluxations rather than dislocations.

Volar dislocations are extremely rare and tend to be irreducible except by surgical exploration with removal of the trapped dorsal joint capsule.130 It is very important to protect the digital nerves when attempting surgical reduction from a volar approach for MP joint dislocation because they are very superficial and can be easily damaged.

Patients who have isolated injury to the CL complex at the MP joint present with severe pain and swelling of both the volar and dorsal surfaces of the hand. Roentgenographic findings usually are negative. Treatment with immobilization in MP joint flexion for 2 to 3 weeks usually is adequate.129 A special situation might occur in the little finger, where damage to the radial CL leaves the finger subject to the unopposed pull of the adductor digiti quinti. This is a severe injury that presents as ulnar deviation of the proximal phalanx.131 Treatment usually includes K-wire fixation of the proximal phalanx in an overcorrected position to allow capsular healing and prevent ulnar shift. If the joint is markedly unstable, the radial CL and volar plate might also need to be repaired or reconstructed.

PIP Joint
Stability of the PIP joint depends on its box-like configuration; two sides of the box must be disrupted before significant joint displacement can occur.9 In dorsal dislocation, the volar plate usually ruptures off the middle phalanx with an accompanying injury to the CL. The volar plate is either avulsed from the middle phalanx or is attached to a triangular fragment of bone from the middle phalanx in a fracture-dislocation.129 Schenck71 identified four degrees of fracture-dislocation of the PIP joint that can occur when the articular surface of the middle phalanx is fractured. The degrees are those involving less than 25% of the joint surface (grade A) to total involvement (grade D) in increments of 25%.

Hastings49 classified IP fracture-dislocations into three groups: stable, tenuous, and unstable. Stable dislocations involve less than 30% of the joint surface and usually are stable throughout the full range of motion. They can be reduced by closed means, and early motion can be instituted.132 Tenuous fracture-dislocations involve 30% to 50% of the joint surface. Closed reduction should be attempted, and splinting should then be applied with the PIP joint in 30 degrees of flexion.129 Unstable fracture-dislocations involve more than 50% of the joint surface. The dislocations are unstable, and open treatment
generally is recommended.\textsuperscript{133,134} The surgical approach to an unstable or chronic dislocation usually consists of volar plate arthroplasty, as advocated by Eaton and colleagues.\textsuperscript{129,135,136} Surgery is most successful—average motion 95 degrees at the PIP joint—when performed within 6 weeks of injury, but even patients treated up to 2 years after injury regain an average 87 degrees of motion at the PIP level.

An alternative method of treatment for dorsal fracture-dislocations of the PIP joint has been advocated by Newington et al.\textsuperscript{137} The authors presented a review of 10 patients with 11 unstable dorsal fracture-dislocations of PIP joints, with a mean follow-up of 16 years. The patients had fractures that involved 30\% to 60\% of the articular surface of the PIP joint. All patients were treated with closed reduction and transarticular K-wire fixation of the PIP joint without attempt to reduce the fracture at the base of the middle phalanx. During long-term follow-up, seven of 10 patients had no complaints of pain or stiffness and none had severe pain. The patients were noted to have a mean fixed flexion deformity of 8 degrees at the PIP joint. The PIP joint had a mean arc of movement of 85 degrees. No severe degenerative changes were noted on radiographs. The authors concluded that this technique is a reliable and safe method of treatment that has proved to be satisfactory over the long term for dorsal fracture-dislocations of the PIP joint.

A dynamic external fixator can also be used in the treatment of fracture-dislocations and pilon-type injuries.\textsuperscript{74} It has the advantage that early motion can be started. However, it is difficult to apply to the middle and ring fingers. Ruland et al.\textsuperscript{73} reported achieving good results with dynamic external fixation in 34 armed services patients.

Volar dislocations occasionally are difficult to reduce because the proximal phalanx becomes buttonholed through the extensor mechanism between the central slip and one lateral band. Attempts at reduction further constrict the proximal phalanx. A regional anesthetic block sometimes can overcome the muscle spasm sufficiently to allow closed reduction, but open treatment should be planned for.\textsuperscript{129} Reducible volar dislocations of the PIP joint likely have injury to the central slip, and it is important to recognize this injury because it will necessitate splinting of the PIP joint in extension for 5 to 6 weeks.

To check for central slip injury is difficult in cases of acute injury because of pain and swelling. Useful tests for assessing the presence of central slip injury are active PIP extension, resisted PIP extension, and Elson tests.\textsuperscript{138}

Lateral dislocations with rupture of the CL complex are also possible and occur six times more often on the radial side than on the ulnar aspect. Lateral dislocations can be reduced and immobilized for 2 to 3 weeks. If reduction and immobilization fail, open treatment might be required.\textsuperscript{129}

Early mobilization of the PIP joint is important because the joint has tendency to develop contracture. It is important to inform the patient that PIP joint swelling takes a long time to resolve.

\textbf{DIP Joint}

Dislocation of the DIP joint is relatively infrequent because of the stability afforded by the adjacent flexor and extensor tendon insertions and the strong CL.\textsuperscript{139} Nevertheless, dislocation can occur in either the dorsal or lateral plane, typically in conjunction with an open wound, and is easily managed with reduction and splinting in slight flexion for 3 weeks.\textsuperscript{129} Good joint stability and adequate joint motion are the expected results.

\textbf{THE WRIST}

\textbf{Functional Anatomy}

The wrist is a complex joint connecting the distal forearm to the hand. Eight carpal bones are connected to each other and to adjacent structures by an array of ligaments. The proximal carpal row includes the scaphoid, lunate, triquetrum, and pisiform. The distal row includes the trapezium, trapezoid, capitate, and hamate (Fig. 10).\textsuperscript{140} The pisiform is the only carpal bone to have a tendon insertion for a muscle, the flexor carpi ulnaris.\textsuperscript{141–145} The carpal bones have both intrinsic and extrinsic ligaments (Fig. 11A).\textsuperscript{145} The intrinsic ligaments originate on the carpal bones and are referred to as short, intermediate, and long. The extrinsic ligamentous system includes the radial CL and the important radioscaphocapitate, radiolunate, and radioscapopholunate ligaments on the radial aspect (Fig. 11B).\textsuperscript{146}
The ulnar side contains the ulnar CL, meniscus, ulnolunate ligament, and important triangular fibrocartilage complex (TFCC). The space of Poirier is an area of weakness at the volar wrist capsule caused by the absence of a volar lunocapitate ligament.

Considerable dynamic change takes place with wrist motion, emphasizing that the carpal bones are not static. Taleisnik proposed the double-V ligamentous system to explain the complex mechanism of carpal mobility (Fig. 12).

The apex of one V is the capitate, on which converge fibers originating proximally and laterally from the radius and scaphoid and proximally and medially from the triquetrum. The second V is contained within the first and is made up of the radiolunate and ulnolunate ligaments, which converge into an insertion on the volar aspect of the lunate. Ulnar or radial deviation of the wrist is not the result of pure angular displacement of the carpus but rather the consequence of rotation around three axes, and the double-V ligamentous structures are well suited to the task.

The scaphoid bridges the proximal and distal carpal rows and is the key to wrist motion. During ulnar deviation of the wrist, the scaphoid is in a fully extended position, whereas during radial deviation, the scaphoid flexes to allow rotation. Wrist rotation and lateral deviation are functions of the articulation of the scaphoid with five bones: the radius, trapezium, trapezoid, capitate, and lunate. The scaphoid has three well-defined ligamentous zones. The central zone comprises the radioscaphocapitate ligament, also called the sling ligament, around which the scaphoid rotates. The proximal zone is the radioscapholunate ligament, which along with the radioscaphocapitate ligament anchors the scaphoid to the volar radius. This proximal ligament is important because it is tense at both ends of scaphoid rotation, thereby preventing rotary subluxation. The distal zone of the scaphoid contains ligamentous insertions of the radial CL and the volar intercarpal V ligament.

The carpal bones have multiple articular surfaces and ligamentous attachments but no tendon insertions (except for the previously mentioned pisiform). Wrist joint movements take place at the radiocarpal articulation (mostly flexion and ulnar deviation) and midcarpal level (primarily extension and radial deviation). Motion of the carpal bones is constrained by the capsular ligaments. Navarro introduced the concept of vertical carpal columns (Fig. 13) to explain the mechanics of the wrist joint. The central (flexion-extension) column is formed by the lunate, capitate, and hamate. The lateral (mobile) column is composed of the scaphoid, trapezium, and trapezoid, and the medial (rotation) column is composed of the triquetrum and pisiform. Taleisnik proposed two modifications to this concept: 1) eliminate the pisiform, considering it does not actually participate in carpal motion; and 2) include the trapezium and trapezoid as part of the central column, considering they are integral parts of the distal carpal row.

Gelberman et al. and Panagis et al. studied the vascularity of the carpus. The extraosseus blood supply of the wrist is from the ulnar and radial arteries, which form an anastomotic network of three dorsal and three palmar arches (Fig. 14). The most distal palmar arch is formed by the radial artery and the deep palmar branch of the ulnar artery. The arch gives off a radial and an ulnar recurrent artery that anastomose with a terminal branch of the anterior interosseous artery. Together they form the major collateral circulation of the carpus.

Figure 10. Carpus. 1 through 5, first through fifth metacarpals; Tm, trapezium; Td, trapezoid; C, capitate, H, hamate; P, pisiform; Tl, triquetral; L, lunate; S, scaphoid; U, ulna; R, radius; AD, articular disc. (Modified from Snell.)
The carpal bones themselves are grouped according to the size and location of the nutrient vessels. Group I is composed of the scaphoid, capitate, and lunate in 20% of the population. Bones in group I have large osseous areas that are dependent on a single intraosseous vessel and are therefore at high risk of incurring vascular necrosis after a fracture. Group II comprises the trapezoid and hamate, which have two distinct areas of vessel entry but do not have intraosseous anastomoses. Group III consists of the trapezium, triquetrum, and pisiform along with the lunate in 80% of the population. Bones in group III receive two distinct nutrient arteries through nonarticular surfaces.

Intraosseous anastomoses are numerous, and no single large area of bone is dependent on any one vessel.\textsuperscript{155,156}

Carpal injuries in children are very unusual. Because the carpus is primarily cartilaginous in infants and young children, it is less susceptible to injury. However, as ossification begins, the carpus becomes more vulnerable to fractures and injuries of the intracarpal ligaments. In adolescents, the carpus is nearly completely ossified and the injury patterns are similar to those in adults.

Because of the cartilaginous nature of the developing carpus, diagnosis can be more difficult in children than in
adults.\textsuperscript{157} Serial carpal injuries might not be apparent on plain radiographs. In addition, because the scaphoid bone ossifies from distal to proximal, an apparent increased distance is present between the ossified scaphoid and the ossified lunate, which is known as the pseudo-Terry-Thomas sign. The gap varies from approximately an average of 9 mm in 7-year-old children to 3 mm in 15-year-old adolescents. The gap between the ossified centers is filled by unossified and articular cartilage. This is not indicative of scapholunate dissociation. Hand surgeons treating children should be aware of this developmental pattern. Magnetic resonance imaging (MRI) studies can be extremely helpful in diagnosing injuries to the cartilaginous carpus.

**Radiographic Evaluation**

Radiographic evaluation of a suspected wrist injury is crucial in making a diagnosis. Three radiographic views are currently standard: anteroposterior, lateral, and oblique views.\textsuperscript{153} The hand must be in neutral position for the anteroposterior and lateral projections. On lateral view images, the palmar tilt of the distal articular surface of the radius averages +11 degrees. On anteroposterior view images, the radial inclination of the distal radius averages 22 degrees.

Gilula and Weeks\textsuperscript{158} and Gilula\textsuperscript{159} defined three major radiographic features that should be surveyed sequentially in cases of suspected wrist injury. First are the carpal arcs, which are drawn to check normal carpal relationships. Arc 1 is traced along the convex proximal surface of the scaphoid, lunate, and triquetrum. Arc 2 outlines the concave curvature of these bones, and Arc 3 is drawn on the condylar surfaces of the capitate and hamate. A break in any of these smooth lines reflects distortion of joint integrity.\textsuperscript{158}

The second criterion presented by Gilula and Weeks\textsuperscript{158} and Gilula\textsuperscript{159} was the width and symmetry of joint spaces, and third was the shape of the individual carpal bones. Again, it should be remembered that the shape of the carpal bones depends on the position of the wrist: the lunate becomes triangular with extreme volar flexion or dorsiflexion, and the scaphoid adopts a different shape on anteroposterior view radiographs according to whether the wrist is in ulnar or radial deviation.\textsuperscript{159}
Figure 14. Palmar pericarpal arterial network. (Modified from Taleisnik.145)
Another important measurement was described by McMurtry et al.\textsuperscript{160} The authors defined carpal height as the distance from the base of the third metacarpal to the distal articular surface divided by the length of the third metacarpal. The ratio was $0.54 \pm 0.03$ and was found to be constant throughout radioulnar deviation in normal wrists (Fig. 15).\textsuperscript{160} They also noted a constant value of $0.30 \pm 0.03$ for the ratio of ulnocarpal distance to third metacarpal length.\textsuperscript{149} Carpal height measurements are obtained with the hand and wrist in neutral position, the elbow flexed 90 degrees, and the shoulder abducted 90 degrees.\textsuperscript{161} These measurements are extremely helpful in the evaluation of patients who have both rheumatoid arthritis and Kienböck disease.

Lateral view radiographs of the wrist are beneficial in assessing radiolunate and radioscaphoid alignment. On a radiograph of a normal wrist, the head of the capitate fits within the distal concavity of the lunate, which then fits into the concavity of the distal radius. The colinear relationship is continued to the third metacarpal. The normal scapholunate angle averages 47 degrees (range, 30–60 degrees) (Fig. 16).\textsuperscript{162} Any scapholunate angle larger than 70 degrees or smaller than 20 degrees indicates some form of carpal instability with scapholunate dissociation.\textsuperscript{145} A true lateral view radiograph shows scaphoid, pisiform, and capitate in a volar to dorsal alignment.

Mann et al.\textsuperscript{161} reviewed the radiographic features of dissociated and nondissociated carpal instability, scapholunate advanced collapse (SLAC), ulnar translocation, ulnocarpal impaction, and ulnoradial impingement. The authors also provided normal ranges for carpal height, ulnar variance, radial inclination, radial length, palmar tilt, and radial shift. The measurements are important in the radiographic diagnosis of many pathological conditions of the wrist.

MRI is a useful tool for diagnosing carpal injuries, both acute and chronic, and both osseous and ligamentous.\textsuperscript{163,164} Proper MRI studies of the wrist require a high field strength magnet and a dedicated wrist coil. Detailed images of both cartilaginous and ligamentous structures can be obtained (e.g., the triangular fibrocartilage and the extrinsic and intrinsic ligaments of the wrist can be imaged). In addition, special sequences allow the detection of acute osseous injuries that often are radiographically occult.
MRI is also very helpful in diagnosing and evaluating conditions in skeletally immature patients whose wrists are largely cartilaginous. Finally, magnetic resonance angiography can be used to evaluate the vascular system of the wrist, sometimes obviating the need for invasive arteriography.

Lohman et al. studied 67 patients with acute wrist trauma and compared the findings of MRI versus plain radiography. The images were studied by three senior radiologists in a blinded and random fashion. The authors found that one-third of the 37 fractures that were diagnosed with the use of MRI were missed on plain radiographs. Based on those results, the authors concluded that clinicians should consider using MRI in the evaluation of acute wrist trauma under the following circumstances: 1) in the cases in which a clear discrepancy exists between the clinical status and negative radiographic findings and splint treatment would increase costs by causing occupational restriction; and 2) in cases in which traumatic injury diagnosed as contusion or distention does not heal during the expected time period.

Intercarpal Dislocations
Pathophysiology

Wrist injuries are largely the result of hyperextension, ulnar deviation, and supination of the hand on a fixed, pronated radius (intercarpal supination). Carpal dislocations occur most often between the lunate and capitate, but any combination of fracture-dislocation is possible. The exact pathology depends on the degree of extension and ulnar deviation and on the magnitude of the supination force that is exerted on the articular complex. With increasing traumatic force to push the wrist into greater and greater extension, the following injury continuum is noted: the scaphoid either fractures or the scapholunate ligament ruptures; the lunate extends and allows the capitate to shift dorsally, either completely dislocating or fracturing the tail of the hamate; and the triquetrum is fractured or dislocated.

Carpal instability patterns can be defined in relation to the lunate. Linscheid et al. described the posttraumatic intercarpal instability-collapse deformity and identified two patterns: dorsal intercalary segment instability (DISI) and volar intercalated segmental instability (VISI) (Fig. 17). The diagnosis is based on the capitolunate angle, as seen on lateral view radiographs.

The DISI deformity is far more common and can be caused by rotatory subluxation of the scaphoid or scapholunate dissociation. The scaphoid assumes a more palmar, flexed position, and the lunate slips toward the palm such that its concave surface points dorsally. The VISI deformity is characterized by the lunate tipping over toward the palm (“spilled teacup” sign) and a decreased scapholunate angle.

A less common, nontraumatic type of carpal subluxation occasionally occurs in people with congenitally lax ligaments. No ligamentous rupture is involved, but rather stretching of the capsules occurs with dislocation and collapse of the lunate, scaphoid, and occasionally other carpal bones. This condition is called carpal instability nondissociative or CIND.

Hodge suggested a classification scheme for carpal instabilities that is based on analysis of the wrist images and limited patient histories. Clinical application of the system combines radiographic features with the elements of chronicity, constancy, cause, location, direction, and pattern of the instability to arrive at a diagnosis.

Figure 17. Scapholunate and lunotriquetral dissociation are shown. DISI, dorsal intercalated segment instability. VISI, volar intercalated segment instability. R, radius; L, lunate; C, capitate. (Modified from Linscheid et al.)
The following factors play a role in the epidemiology of carpal injuries:

- The weakest ligaments of the wrist are on the radial side.
- The radiocapitate ligament is maximally taut in maximum extension and ulnar deviation.
- The proximal carpal row is stabilized by five ligaments in the distal forearm, whereas the distal carpal row is stabilized by only one, the radiocapitate ligament.
- The weakest link between the distal carpal row and the distal forearm is the radiocapitate ligament.

In a cadaver study, Mayfield noted varying degrees of perilunar instability according to the loading force of extension, intercarpal supination, and ulnar deviation. The scaphoid, capitate, and triquetrum are progressively dislocated from the lunate, producing gradually more severe carpal instability. The author classified perilunar instability into four stages based on the degree of carpal dislocation and ligamentous damage (Fig. 18).

Stage I: scaphoid dislocation or instability with scapholunate, interosseous, and radioscaphoid ligament injury
Stage II: capitate dislocation and opening of the space of Poirier
Stage III: triquetral dislocation and radiotriquetral ligament failure
Stage IV: radiocapitolunate, radiotriquetrolunate, and dorsoradiocarpal ligament failure with lunate dislocation.

With stages I and II of perilunar instability, spontaneous reduction of the capitolunate and triquetrolunate joints frequently occurs; scapholunate diastasis might be the only persistent manifestation. With lunate dislocation (stage IV), roentgenographic findings usually are more obvious than with other stages. These perilunar instability patterns can also be observed with fractures of the scaphoid, capitate, radial and ulnar styloids, and triquetrum. Johnson referred to these conditions as the greater arc injuries (Fig. 19), whereas lesser arc injuries are purely ligamentous. Green noted reports of concomitant scaphoid fractures and scapholunate dissociation, attesting to the possibility of many combinations and variants of these “pure” injury patterns.

Yaghoubian et al. presented a discussion of two major categories of acute fracture-dislocation of the carpus: 1) perilunate fracture-dislocations, as described above; and 2) axial fracture-dislocations of the wrist. The authors reviewed the classification of perilunate fracture-dislocations and axial fracture-dislocations of the wrist. In terms of treatment, the authors emphasized that such injuries involve major disruption of key ligamentous structures and therefore require accurate anatomic ORIF with repair of the disrupted ligamentous structures. This usually is best accomplished by a combined volar and dorsal approach. In addition, the authors noted that with axial fracture-dislocations, the associated injuries usually determine the outcome.

Diagnosis
Radiographic findings can be subtle and easily overlooked. Therefore, before ruling out pathological findings, it is helpful to compare the injured wrist with the noninjured wrist. For example, in the event of a widened scapholunate distance, examination of the opposite wrist might reveal the condition to be a normal variant for that person. As noted earlier, MRI can be extremely useful for diagnosing ligamentous and acute osseous injuries in the carpus. Use of a dedicated wrist coil can provide extremely accurate anatomic information in the evaluation of such injuries.

Obtaining a detailed history that includes the mechanism of injury is important for accurate diagnosis. As stated above, most wrist injuries occur with hyperextension and supination forces. Palmar flexion and pronation forces also are significant and tend to affect the ulnar side of the wrist. Any information obtained from the patient regarding the appearance of swelling or abnormal clicks or clunks should be documented. Any previous treatments, including medications, must be recorded.

During physical examination, the range of motion should be measured and tender spots noted. Tenderness in the “anatomic snuffbox” indicates a possible scaphoid
fracture. Positive findings of a scaphoid shift test (Watson test) identify scapholunate dissociation. Tenderness on the ulnar side of the wrist, which might be accompanied by clicking in the wrist, can signify either injury to the TFCC that separates the distal radioulnar joint from the radiocarpal joint or injury to the ulnocarpal abutment. When patients who have significant midcarpal instability move the wrist from neutral to ulnar deviation, a clunk can occur, which means reduction of the midcarpal subluxation at the triquetrohamate joint (nondissociative carpal instability).

Management

Taleisnik and Taleisnik et al. offered a comprehensive review of carpal instability disorders, mechanisms, and management. Initial treatment measures for hyperextension injuries of the wrist are as follows:

1. anesthesia to completely relax the muscles
2. closed reduction (Watson-Jones technique of dorsiflexion and then gradual palmar flexion under longitudinal traction
3. cast immobilization with the wrist in 30 degrees of palmar flexion for 3 weeks and then an additional 3 weeks of immobilization with the wrist in neutral position
4. radiographic confirmation of the reduction.

When a perilunate dislocation includes a scaphoid fracture, open reduction of the scaphoid fracture in anatomic position is necessary. Persistence of intercarpal collapse predisposes to nonunion of scaphoid fractures and degenerative changes of carpal articulations.

Hee et al. presented a study of 16 cases of dorsal transscaphoid perilunate fracture-dislocations in 15 patients. The authors reported the results of open treatment with reduction and internal fixation through a volar approach. Fixation was obtained with Herbert screws in 13 cases and with K-wires only in three cases. Results were excellent to good in 10 cases and fair in six. Nonunion requiring subsequent bone grafting occurred in two cases. The authors concluded that this treatment regimen resulted in acceptable relief of pain and functional motion and grip strength in the majority of their patients.

The treatment of unreduced perilunate dislocations in a delayed fashion is more complex. Inoue and Shionoya studied 28 patients with perilunate dislocations that were untreated for at least 6 weeks after injury. Treatment then included proximal row carpectomy in 16 cases, open reduction with or without internal fixation of the scaphoid in six cases, total excision of the lunate in four cases, and carpal tunnel release with partial

Figure 18. Stages of progressive perilunar instability. I, scapholunate failure; II, capitolunate failure; III, triquetrolunate failure; IV, dorsal radiocarpal ligament failure, allowing lunate rotation and lunate dislocation. (Modified from Mayfield.)

Figure 19. The area in which most carpal fracture-dislocations occur (shaded area) is called the greater arc of the carpus. GA, greater arc injuries; LA, lesser arc injuries. (Modified from Moneim.)
excision of the lunate in two cases. The mean follow-up duration was 6.8 years. The authors found that in patients whose injury was less than 2 months old, open reduction was satisfactory. For injuries that are more than 2 months old, the authors recommended that partial row carpectomy should be considered if the proximal pole of the capitate has healthy cartilage. Lunate excision was not recommended.

In another study of chronic perilunate dislocations, Rettig and Raskin\textsuperscript{184} treated 12 patients with chronic stage III or IV perilunate dislocations with proximal row carpectomy. All injuries were initially untreated and were at last 8 weeks old. The range of time of injury to definitive treatment was 8 weeks to 6 months. Treatment consisted of a dual dorsal and volar approach involving median nerve decompression, lunate excision, and capsuloligamentous repair performed volarly while scaphoid and triquetrum carpectomy was performed dorsally. The authors found that marked relief of wrist pain and median nerve dysesthesia was routinely achieved and that effective wrist range of motion and grip strength were restored. The results of the study by Rettig and Raskin are similar to those of the study by Inoue and Shionoya\textsuperscript{183} in that all authors concluded that injuries older than approximately 2 months are better treated with proximal row carpectomy.

Injuries associated with poor prognoses include transscaphoid fractures, comminuted radial styloid fractures, extensive osteochondral fractures, and untreated scapholunate dissociations. Untreated scapholunate dissociations can lead to SLAC wrist deformity. Patients for whom initial treatment fails typically show chronic pain, carpal instability, nonunion, and aseptic necrosis.\textsuperscript{185} Management includes bone grafting,\textsuperscript{186} partial or total arthrodesis,\textsuperscript{187-190} total wrist arthroplasty,\textsuperscript{191} and proximal row carpectomy.\textsuperscript{192} Blatt\textsuperscript{193} recommended soft-tissue ligamentous reconstruction as an alternative to fusion in patients who have scapholunate dissociation with rotary subluxation of the carpal scaphoid. The author described techniques of dorsal capsulodesis and construction of a volar restraining ligament after excision of the distal ulna. Table 1 shows the stages of scapholunate instability.\textsuperscript{194}

Slater et al.\textsuperscript{195} described another method of capsulodesis for scapholunate dissociation with rotatory subluxation of the scaphoid. The authors presented the anatomy of the dorsal intercarpal ligament and proposed its use for capsulodesis. The method has since been somewhat modified, as described below.

Walsh et al.\textsuperscript{196} discussed the current treatment of scapholunate dissociation. They reviewed the anatomy of the scapholunate interosseous ligament, the dorsal intercarpal ligament, and the dorsal radiocarpal ligament, which can be used in treating scapholunate dissociation injuries with rotatory subluxation of the scaphoid. Scapholunate injuries are classified as either subacute or acute and late or chronic. An algorithm has been devised for their surgical treatment (Table 2).\textsuperscript{196}

Routine anteroposterior, lateral, and oblique view radiography and dynamic stress views of the wrist are important in the diagnosis of scapholunate ligament injury. It is important to obtain radiographs of the unaffected wrist for comparison. Various stress views have been described in the literature. Grip views and the clenched pencil view\textsuperscript{197} are useful in identifying scapholunate injuries in cases in which the scapholunate gap appears normal on routine radiographs of the wrist.

Walsh et al.\textsuperscript{196} described the various techniques of repair of scapholunate injuries. The techniques include direct scapholunate interosseous ligament repair, Blatt type or dorsal intercarpal ligament type dorsal capsulodesis, ligament augmentation techniques that use strips of the extensor carpi radialis longus tendon or the flexor carpi radialis tendon to augment the ligament reconstruction,\textsuperscript{198,199} and bone-ligament-bone reconstruction of the scapholunate interosseous ligament (Figs. 20–28).\textsuperscript{196} The bone-ligament-bone reconstructions essentially consist of using a small bone graft from either side of a small joint, either in the hand or the foot, together with the ligament that connects the two pieces of bone, and transplanting that as a composite graft and an intact unit to replace the disrupted scapholunate interosseous ligament complex.\textsuperscript{200} Newer devices consist of tendon graft configurations inserted with bone anchors that act as an internal brace and intercarpal screws.

For the SLAC wrist, arthrosis of the wrist after scapholunate ligament injury consists of the following stages:

- **Stage 1:** radial styloid-scaphoid arthrosis
- **Stage 2:** radioscaphoid arthrosis
Stage 3: radioscaphoid arthrosis + lunocapitate arthrosis.

For advanced arthritis (stage 3), salvage procedures such as proximal row carpectomy and scaphoid excision with four-corner fusion are the only options. Proximal row carpectomy offers greater wrist motion; however, the grip strength is decreased. Scaphoid excision with four-corner fusion offers better grip strength; however, wrist motion is decreased compared with proximal row carpectomy.

Arthroscopy of the wrist plays a role in the diagnosis and management of scapholunate instability. Many authors consider wrist arthroscopy to be the gold standard for diagnosis of intracarpal ligamentous injuries. In addition, arthroscopic management of partial scapholunate ligament injuries might be beneficial. Kozin201 outlined indications for arthroscopy in scapholunate dissociation, subdividing them into acute and chronic injuries. The author classified scapholunate ligament injuries according to the arthroscopic findings.

Geissler et al.202 presented arthroscopic grading of scapholunate ligament injury, as follows.

- Grade I: attenuation or hemorrhage of interosseous ligament as seen from radiocarpal space; no incongruity of carpal alignment in midcarpal space
- Grade II: attenuation or hemorrhage of interosseous ligament as seen from radiocarpal space; incongruity or step-off of carpal space; slight gap (less than width of probe) might be present between carpal bones
- Grade III: incongruity or step-off of carpal alignment as seen from both radiocarpal and midcarpal spaces; probe might be passed through gap between carpal bones
- Grade IV (static): incongruity or step-off of carpal alignment as seen from both

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**Table 1**

<table>
<thead>
<tr>
<th>Stages</th>
<th>Occult</th>
<th>Dynamic</th>
<th>SLD</th>
<th>DISI</th>
<th>SLAC</th>
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<tbody>
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<td>Injured ligaments</td>
<td>Partial</td>
<td>Complete SLIL</td>
<td>Complete SLIL and extrinsics</td>
<td>SLIL, extrinsics, secondary changes</td>
<td>Arthrosis</td>
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<td>Normal</td>
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<td>RL &gt; 15 degrees</td>
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<td>Stress views</td>
<td>Normal</td>
<td>Abnormal</td>
<td>Grossly abnormal</td>
<td>Not necessary</td>
<td>Arthrosis</td>
</tr>
</tbody>
</table>

SLD, scapholunate dissociations; DISI, dorsal intercalary segment instability; SLAC, scapholunate advanced collapse; SLIL, scapholunate interosseous ligament; SL, scapholunate; RL, radiolunate; CL, capitolunate.

**Table 2**

<table>
<thead>
<tr>
<th>Type</th>
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<th>Treatment</th>
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<tbody>
<tr>
<td>Subacute</td>
<td>Dynamic deformity*</td>
<td>Conservative (splinting), arthroscopic pinning, capsulodesis</td>
</tr>
<tr>
<td>Acute</td>
<td>Static deformity</td>
<td>Open repair of SLIL</td>
</tr>
<tr>
<td>Late (chronic)</td>
<td>Static deformity</td>
<td>Open repair of SLIL and capsulodesis alone, tenodesis alone, intercarpal fusion scaphotrapezial-trapezoid or scaphocapitate</td>
</tr>
</tbody>
</table>

SLIL, scapholunate interosseous ligament.

*Dynamic deformity = present on stress (motion) radiographs, positive findings of clinical stress testing, positive findings of arthroscopy but negative findings of arthrography and normal findings of static radiography.
**Figure 20.** Scapholunate interosseous ligament as seen from proximal radial side with scaphoid removed. (*Modified from Walsh et al.*\textsuperscript{196})

**Figure 21.** Dorsal radiocarpal and intercarpal ligaments from distal scaphoid. \(V\), fifth metacarpal; \(I\), first metacarpal; \(S\), scaphoid; \(C\), capitate; \(T\), triquetrum; \(LT\), Lister tubercle. (*Modified from Walsh et al.*\textsuperscript{196})
Figure 22. Dorsal fiber-splitting capsulotomy. (Modified from Walsh et al.196)

Figure 23. Illustration shows direct scapholunate interosseous ligament repair. A and B, two views of joysticks plus retrograde K-wire drilling of proximal scaphoid. C, Ligament repair through waist of scaphoid, with emphasis on dorsal scapholunate interosseous ligament repair. D, Completed repair. (Modified from Walsh et al.196)
Figure 24. Blatt dorsal capsulodesis. A, Proximally based capsular flap is attached to scaphoid to create derotation (indicated by arrows). B, Tightening of capsulodesis applies pressure to distal scaphoid (arrows). (Modified from Walsh et al.196)

Figure 25. Illustration shows intercarpal ligament capsulodesis with use of proximal half of dorsal intercarpal ligament (DIC) to link distal scaphoid to distal radius. A, Scaphoid is rotated into extension by capsulodesis of proximal half of dorsal intercarpal ligament (arrow), which is attached to dorsal rim of distal radius. B, Lateral view of dorsal intercarpal ligament shows derotation (arrow) of scaphoid. Td, trapezoid; S, scaphoid; T, triquetrum; DRC, dorsal radiocarpal ligament; R, radius. (Modified from Walsh et al.196)
Figure 26. Ligament augmentation technique presented by Linscheid is illustrated. 

A, Strip of detached extensor carpi radialis longus tendon with K-wire joysticks inserted into the scaphoid and lunate. 

B, Tendon pulled through drill hole. 

C, Tendon passed across dorsal part of scapholunate interval to triquetrum and through ulnar wrist capsule. 

D, Tendon can be used to reinforce dorsal portion of scapholunate interosseous ligament. (Modified from Walsh et al.196)
Figure 27. Ligament augmentation technique presented by Brunelli is illustrated. A, Half of flexor carpi radialis (FCR) tendon is passed through distal pole of scaphoid. B, Dorsal view shows flexor carpi radialis sling attached to either distal radius (original Brunelli technique) or to dorsal lunate (modified technique). T, triquetrum; S, scaphoid; R, radius; L, lunate. (Modified from Walsh et al.196)

Figure 28. Bone-ligament-bone graft technique is illustrated. A, Preparation of bed for placement of bone-ligament-bone graft into dorsal scapholunate interval. B, K-wire fixation. Dotted line rectangles, areas of resection of bone-retinaculum-bone graft site. (Modified from Walsh et al.196)
radiocarpal and midcarpal spaces; gross instability observed with manipulation; 2.7-mm arthroscope can be passed through the gap between carpal bones (“drive-through sign”).

Barnaby\textsuperscript{185} presented an algorithm for treatment of scapholunate ligament injuries (Fig. 29). The author offered a concise but thorough review of fractures and dislocations of the wrist, including diagnosis, management, and likely outcome.

Lunotriquetral injuries are less common than scapholunate injuries but can also be a cause of chronic wrist pain and wrist deformity (the VISI deformity). As is the case with scapholunate injuries, division of the lunotriquetral ligament alone is not enough to create a static deformity. Injury to other either volar or dorsal supporting ligaments also is required to create the static VISI deformity.

In a study of 57 patients who had isolated lunotriquetral injuries, Shin et al.\textsuperscript{203} reported the results of arthrodesis, direct ligament repair, and ligament reconstruction. Injuries were classified as either subacute or chronic in 98\% of the patients. The mean follow-up duration was 9.5 years. The probability of remaining free of complications 5 years after surgery was 68.6\% for reconstruction, 13.5\% for repair, and less than 1\% for arthrodesis. Improvements in strength and movement and subjective indicators of pain relief and patient satisfaction were significantly better (strength, $P = 0.007$; movement, $P = 0.041$; pain, $P = 0.038$) for patients who underwent lunotriquetral repair and reconstruction than for those who underwent arthrodesis.

Shin et al.\textsuperscript{204} offered a thoughtful review of lunotriquetral instability. The authors discussed the differential diagnosis of lunotriquetral injuries and the various causes of ulnar-sided wrist pain. The lesions causing ulnar-sided wrist pain are as follows:\textsuperscript{204}

- distal radioulnar joint subluxation or arthrosis
- ulnar head chondromalacia
- triangular fibrocartilage injury
- triquetrohamate instability
- hamate fractures

Shin et al.\textsuperscript{204} described the technique for examining the lunotriquetral and pisotriquetral articulations and presented an algorithm for the treatment of lunotriquetral injuries (Fig. 30). The techniques for direct lunotriquetral ligament repair, lunotriquetral ligament reconstruction, and lunotriquetral arthrodesis are illustrated. The direct repair and ligament reconstruction techniques can be thought of as analogous to the corresponding techniques in scapholunate dissociation.\textsuperscript{204}

As is the case with injuries of the scapholunate ligament complex, injuries to the lunotriquetral complex also can be evaluated and treated to some extent with arthroscopic techniques. Arthroscopy can be particularly useful for diagnosing injuries to the lunotriquetral ligament complex and associated injuries, particularly to the TFCC. Once the nature of the injury and the degree of instability have been diagnosed, a treatment plan can be formulated and can consist either of arthroscopic or open treatment of the injury.\textsuperscript{205}

Scaphoid

Fractures of the scaphoid account for approximately half of all wrist injuries.\textsuperscript{174} Scaphoid fractures typically occur in young men between the ages of 15 and 30 who have a history of falling on an outstretched hand. Increasing force produces a spectrum of injuries: scaphoid fracture, scapholunate dissociation, perilunate dislocation, and triquetal fracture—not always in that sequence. The most common type of greater arc injury is a transscaphoid perilunate fracture-dislocation.\textsuperscript{153}

Pathophysiology

Weber and Chao\textsuperscript{206} showed that the degree of dorsiflexion is important in the pathogenesis of scaphoid fractures. In an experimental approach, the authors showed that with intermittent loading and the wrist in 40 to 90 degrees
Figure 29. Algorithm for treatment of scapholunate ligament injuries. SLAC, scapholunate advanced collapse. (Modified from Barnaby.185)
Figure 30. Algorithm for treatment of lunotriquetral (LT) ligament injuries. VISI, volar intercalated segmental instability; *, initial relief defined as transient relief secondary to anesthetic, and relief defined as lasting relief secondary to effects of corticosteroid administration. (Modified from Shin et al.204)
of dorsiflexion, fractures of the distal radius occurred. With a load on the radial half of the palm and the wrist in 95 to 100 degrees of dorsiflexion, scaphoid fractures were consistently produced. The authors explained the underlying mechanism. Although the proximal half of the scaphoid is stabilized between the radius, capitate, and volar capsular ligaments, bending loads applied to the distal half of the scaphoid cause fracture between the supported and unsupported zones. Thus, the most frequent site of scaphoid fracture is the waist (70%). Much less common are fractures of the proximal pole (20%) and distal third (10%).

**Diagnosis**

Typically, a case of scaphoid fracture includes a history of a fall onto an outstretched hand. Examination elicits significant tenderness in the anatomic snuffbox, and pain might be present in the wrist with supination against resistance. The scaphoid compression test consists of applying pressure along the thumb metacarpal toward the scaphoid. If pain is elicited, the test is positive and a scaphoid fracture is likely. The patient must be assumed to have fracture of the scaphoid unless radiographic examination proves negative beyond doubt.

Scaphoid fractures can be difficult to diagnose and might require special views; up to 20% of initial anteroposterior and lateral view radiograph findings can be falsely negative. If a scaphoid fracture is suspected during clinical examination, an additional navicular series should be obtained with the wrist in ulnar deviation and the fist clenched. If radiographic evaluation fails to show a fracture, advanced imaging should be considered.

In a cost-effective analysis, Karl et al. found that advanced imaging had lower costs and its health outcomes were projected to be better than those of empiric cast immobilization. The decision to use computed tomography MRI is a function of institutional availability and sensitivity.

Dorsal tipping of the lunate with misalignment of the radius, lunate, and capitate is pathognomonic of a DISI and occurs in cases of scapholunate dissociations or scaphoid fracture with fracture displacement. VISI is less common and occurs with injury along the lunotriquetral region. Displacement of more than 1 mm shown on anteroposterior view radiographs and angulation of more than 15 degrees at the lunocapitate or 45 degrees at the scapholunate shown on lateral view radiographs indicate an unstable fracture unless the opposite wrist shows similar findings, in which case they represent a normal variant.

**Management**

The optimum management of scaphoid fractures is highly debatable. A suggested treatment algorithm is presented in Figure 31.

Because the blood supply of the scaphoid comes from distal to proximal, the more proximal the fracture is, the longer the healing time will be. It is also said that the more vertical the fracture is, the more likely it is that the proximal pole is avascular. Nondisplaced distal fractures tend to heal with cast support because the blood supply to the area usually is satisfactory.

Regarding patients with acute fractures that are to be treated with casting, some surgeons prefer a short thumb spica cast and others opt for a long thumb spica cast including the fingers and elbow. Gellman et al. found that long thumb spica casts were superior for the treatment of patients with nondisplaced fractures of the scaphoid regarding decreased times to union and reduced rates of delayed union and nonunion. However, studies have shown no difference in outcome with various casting techniques. Nonunion rates varied from 5% to 12% in a series of nondisplaced scaphoid fractures managed by casting.

ORIF of nondisplaced fractures offers advantages, including early motion and shorter time in a cast. The presence of DISI with rotatory subluxation as revealed by initial radiographic evaluation is an indication for open reduction. Radiographic signs include foreshortening of the scaphoid, a cortical ring shadow, a wide scapholunate gap, and an increased scapholunate angle. The fracture is reduced using a dorsal or volar approach, and a compression screw is used for fixation. Alternatively, the fracture can be reduced through a combined dorsal and volar approach and stabilized with pins. Fixation is maintained for at least 8 weeks.

Headless compression screws have been designed...
Figure 31. Left, stages of perilunate fracture-dislocations. Right, top row, axioradial disruptions. Right, bottom row, axiolunar disruptions. (Modified from Yaghoubian et al.172)
with a fully threaded variable pitch to optimize compression with scaphoid fracture fixation. Because a headless compression screw is a cannulated screw, it can be inserted percutaneously or with a mini-open technique over a central, axially placed guidewire. Adolfsson et al.\textsuperscript{218} presented a report of 53 patients with scaphoid waist fractures who were treated with percutaneous insertion of an Acutrak screw (Acumed, Hillsboro, OR) for acute nondisplaced fractures at the waist of the scaphoid.

Patients were randomized into two groups: 28 were treated by immobilization in a below-elbow plaster cast for 10 weeks, and 25 were treated with percutaneous insertion of the Acutrak screw. No differences were observed between groups regarding the rate of union or the time to union. However, patients treated surgically had better range of motion at 16 weeks. The authors concluded that for nondisplaced scaphoid waist fractures, rigid fixation with percutaneous insertion of an Acutrak screw allows early mobilization without any adverse effects on fracture healing.

Percutaneous fixation techniques, such as use of the Acutrak screw, make the surgical treatment of nondisplaced fractures more attractive. Not only is early mobilization achieved but the disruption of the capsuloligamentous structures of the wrist that occurs with open techniques is avoided.

Displaced fractures are prone to nonunion (nearly 50\% in some series),\textsuperscript{219} and open reduction is indicated. Even when healing has occurred, the incidence of malposition and late collapse is high enough to prompt some authors to advocate ORIF for all unstable fractures of the scaphoid.\textsuperscript{220} A Herbert screw might not generate sufficient interfragmentary compressive force—4.4 kg, compared with 17.0 kg for the Association for the Study of Internal Fixation 4-mm cancellous screw—and Gelberman et al.\textsuperscript{215} recommended continued immobilization in a short thumb spica cast until union of the fracture has been confirmed radiographically and clinically.

Rettig et al.\textsuperscript{221} reviewed the results of treatment with ORIF of acute displaced scaphoid fractures in 14 consecutive patients. The patients were treated with anatomic reduction of the displaced fracture, correction of carpal instability, bone grafting for comminution, and internal fixation with either K-wires or a Herbert screw. The average follow-up duration was 26 months after surgery. Fracture union was achieved in 93\% of the cases. On average, union occurred 11.5 weeks after surgery. The authors noted that functional range of wrist motion and grip strength were achieved in all patients and recommended ORIF of acute displaced scaphoid waist fractures to avoid malunion and carpal instability that can occur with inadequate treatment.

Fractures of the proximal pole of the scaphoid can be difficult to manage because of the small size of the fracture fragment and the compromised blood supply to the proximal pole of the scaphoid. A dorsal approach usually is required to treat the fractures surgically. Rettig and Raskin\textsuperscript{222} presented a report of 17 consecutive patients with acute unstable proximal pole scaphoid fractures who were treated with a dorsal approach to the scaphoid, radius bone grafting, and freehand retrograde Herbert bone screw fixation. The average follow-up duration was 27 months, and all fractures healed within 13 weeks (average healing time, 10 weeks). Functional wrist range of motion and grip strength were noted in all patients. The authors concluded that ORIF is a better alternative than primary casting for decreasing potential complications of delayed union, nonunion, and irreparable osteonecrosis that often are the sequelae of acute proximal pole scaphoid fractures treated with cast immobilization.

Complications and Sequelae

The most severe complications associated with scaphoid fractures are delayed union and nonunion. Delayed union is said to exist if bony union is incomplete or if symptoms persist after 4 months of adequate immobilization.\textsuperscript{223} Factors predisposing to delayed union are delayed diagnosis,\textsuperscript{224,225} failure to maintain uninterrupted immobilization, and displaced or inadequately reduced fragments.\textsuperscript{224–226}

The management of delayed union of scaphoid fractures is controversial. Up to 4 months after acute scaphoid fracture, most patients are treated successfully with cast immobilization. Between 4 and 12 months after fracture, some authors prefer immobilization whereas others recommend early bone grafting. Russe\textsuperscript{207} achieved 100\% success with cast immobilization for 5 months in 27 patients, but Dobyns et al.\textsuperscript{227} cautioned that radiographic evidence of sclerosis or displacement of the proximal fragments after 4 months of casting

\textsuperscript{36}
dictates more aggressive treatment. Conyers advocated palmar posterior carpal reduction stabilization and palmar ligament reconstruction.

Nonunion is defined as failure of trabeculation across the fracture site where the ends have become sclerotic. Cooney et al. were able to diagnose scaphoid nonunion based on routine radiographs supplemented with trispiral tomography in 90% of cases. Subsequently, Perlik and Guilford used MRI to predict the vascular status of nonunited scaphoid fragments. Preoperative knowledge of the healing potential of a fracture aids the surgeon in selecting the most appropriate treatment.

Various approaches have been advocated for the management of nonunions. In cases with prolonged cast immobilization (≥12 months) and no radiographic evidence of bony union, most authors have recommended surgical intervention. Surgery is also the first choice for patients with untreated scaphoid fractures that have progressed to nonunion. In such cases, most authors advocate bone grafting and then another 12 to 16 weeks of casting. Dooley warned against bone grafting and internal fixation in the event of avascular necrosis of the proximal fragment, but others have not considered this condition to be a contraindication to bone grafting.

Green noted that poor operative results correspond to increasing degrees of avascularity in the proximal pole of the scaphoid. The rate of union in his series dropped from 92% when the proximal fragment had good vascularity, to 71% when vascularity was spotty, and to 0% when the proximal pole was completely avascular.

In 1984, Herbert and Fisher designed a double-action screw for use in scaphoid nonunion that could be combined with bone grafting to allow early mobilization in 2 to 3 weeks, without protracted external support. The volar approach is preferred to lessen the risk of further injury to the vessels.

Robbins presented a report of 26 patients with nonunion of the scaphoid and avascular proximal pole who were treated with iliac crest bone grafting and Herbert screw fixation plus immobilization in a short-arm thumb spica cast for 3 months. Of the 17 patients followed for 1 year or longer after surgery (average follow-up duration, 31 months), six were judged to have excellent functional results, five good, four fair, and two poor. This outcome is much improved over previously published series.

Muzaffar and Carter described a technique consisting of vascularized bone grafting and Herbert screw fixation of scaphoid nonunions with avascular proximal poles. The vascularized bone graft is harvested from the dorsum of the distal radius and transferred in a modified Zaidemberg technique pedicled on the 1,2-intercompartmental supraretinacular artery. Rigid fixation is obtained by insertion of a miniscrew from a dorsal approach. Very small proximal pole fracture fragments can be successfully treated with this procedure.

Amadio et al. stated that bony union alone is not the sole criterion of successful treatment. A good outcome, in the opinion of the authors, is when the axes of the bony poles are properly aligned. In their series, an angle of more than 45 degrees between the proximal and distal poles of the scaphoid was associated with a “humpback” deformity and residual functional impairment, regardless of bony union.

Tomaino et al. corrected lunate malalignment when bone grafting a scaphoid nonunion with humpback deformity. The authors used palmar wedge bone graft combined with reduction of the lunate to correct DISI deformity (Fig. 32) and reported lunate realignment and union of the scaphoid with restoration of scaphoid length. The authors emphasized accurate correction of the lunate malalignment by initial reduction and pin fixation to the radius before inserting the scaphoid bone graft and performing internal fixation of the scaphoid fracture.

Another choice is a Russe graft, which involves a bone graft inlaid into the scaphoid itself. Takami et al. treated 43 patients with scaphoid nonunion with a modified Russe bone grafting technique and fixation with K-wires. The authors used longer corticocancellous bone grafts in cases with carpal instability to obtain a more normal alignment of the scaphoid by opening up the volar cortex. All except one wrist achieved bony union, and the single failure was subsequently successfully treated with a second inlay bone graft. Other options for the management of scaphoid nonunion include soft-tissue arthroplasty, proximal pole resection, radial styloidectomy, partial or total arthrodesis, proximal row carpectomy, and wrist denervation. Arthrodesis, carpectomy, and denervation usually are advocated for wrist salvage after other techniques have failed.
Figure 32. Surgical technique to correct dorsal intercalary segment instability deformity is shown. A, Lunate extension (dorsal intercalated segment instability deformity) accompanies scaphoid nonunion with humpback deformity because of carpal collapse. B, Wrist is passively flexed to bring lunate into neutral alignment, and K-wire is placed percutaneously through radius into lunate to maintain correction. C, Tricortical iliac crest graft is harvested. D and E, Wrist is extended, radiolunate joint is pinned, and scaphoid will open at nonunion site. Microsagittal saw smooths ends of bone at nonunion. Iliac crest graft is tamped into place with inner surface apposed to capitate. F, Graft is pinned in place before insertion of Herbert bone screw. Lunate transfixion pin is removed before screw placement to facilitate accurate imaging of scaphoid and guidewire. (Modified from Tomaino et al.241)
Insertion of Herbert bone screws through a volar approach is not without potential complications. In particular, this technique of Herbert screw insertion requires some mobilization of the scaphotrapezial joint and insertion of the screw through the distal scaphoid articular surface. Overdissection in the joint or excessive manipulation of the distal pole of the scaphoid could damage the articular cartilage and might predispose to arthritis or osteophyte formation.

Nicholl and Buckland-Wright\textsuperscript{247} studied three groups of patients. One group (28 patients) had symptomatic primary osteoarthritis of the hands. A second group (23 patients) had scaphoid fractures successfully treated nonsurgically. A third group (18 patients) had scaphoid fractures treated with a Herbert bone screw. The authors found that patients who had primary osteoarthritis of the hands had more narrowing of the scaphotrapezial joint compared with the other two groups. However, patients who were treated with a Herbert bone screw had a significantly higher incidence of osteophytosis on the distal aspect of the scaphoid than did the other two groups. The authors cautioned that this can be a cause of painful sequelae after Herbert screw fixation of scaphoid fractures. It is recommended that dissection in the scaphotrapezial joint be very carefully performed and that repeated manipulation of the distal pole of the scaphoid be avoided when using this technique of Herbert bone screw insertion.

Another potential complication of scaphoid nonunion is rupture of the flexor pollicis longus tendon. Saitoh et al.\textsuperscript{248} presented a report of four patients with long-standing scaphoid nonunions who sustained rupture of the flexor pollicis longus tendon. Preoperative radiographic examinations and intraoperative findings indicated the volarly protruding distal scaphoid segment as the cause of the flexor pollicis longus tendon rupture. Three patients had DISI deformity. Three patients were treated with iliac crest bone grafting, osteosynthesis, and palmaris longus tendon graft for the ruptured tendon, and all had successful outcomes from surgery.

Other Carpal Bones

Isolated fractures of wrist bones other than the scaphoid are rare.\textsuperscript{145,174,207,249–252} Occasionally, however, a surgeon might be faced with a complex fracture-dislocation of another carpal bone.

The triquetrum can be injured as part of a severe perilunate dislocation. For dorsal triquetral fractures, immobilization of the wrist for 6 weeks is indicated. For triquetral body fractures, reduction might be necessary.

For pisiform fractures, the usual treatment consists of immobilization and short-arm cast. If chronic pain develops, it might be a sign of posttraumatic arthritis in the pisotriquetral joint requiring pisiform excision.

Hamate fractures account for 2\% to 4\% of carpal bone fractures. Most commonly, the hamate hook fractures, typically during sports involving racquets or clubs. A hamate fracture can be difficult to identify on standard radiographs, and special views (e.g., carpal tunnel view) or computed tomography might be necessary for diagnosis. Some minimally displaced hamate hook fractures heal with immobilization; many others require hamate hook excision for proper treatment. A patient with a hamate fracture might complain of tingling and numbness in ulnar nerve distribution caused by proximity of the hook to the ulnar nerve. Tendon irritation and rupture in the small and ring fingers have been reported to be caused by hook fracture.

Capitate fractures occur as a result of high-energy injuries. If the fracture is nondisplaced, immobilization alone usually suffices. Careful evaluation to rule out scaphocapitate syndrome must be conducted at the onset. If rotation of the proximal capitate with concomitant fracture through the scaphoid and capitate is present, ORIF is necessary for treatment.

Fractures of the trapezoid also usually result from high-energy axial forces. Reduction and pin fixation often are required for treatment. Fractures of the trapezium must be managed with ORIF if the articular surface of the thumb CMC joint is involved.

**Kienböck Disease**

Kienböck disease is the eponym for avascular necrosis of the lunate. The exact cause of Kienböck disease is unknown. One theory for the origin of Kienböck disease is founded on the observation presented by Linscheid\textsuperscript{253} that approximately 55\% of the joint compressive force
is transmitted across the lunate. The theory postulates a nutcracker effect on the lunate from the capitate and the radius present in patients with ulnar-minus wrist variant. Other authors think that repeated minor trauma leads to avascular necrosis on the basis of a common patient history of multiple episodes of minor trauma rather than a single major event. The fracture theory fails to explain why all fractures of the lunate do not go on to develop Kienböck disease. Other theories about the cause of Kienböck disease involve differences in the shape of the lunate, the vascular supply of the lunate, or the inherent trabecular network of the lunate.

Lichtman et al. identified four grades of severity of Kienböck disease on the basis of roentgenographic and clinical findings, as follows.

Stage I: lunate has normal architecture and density; fracture line might be evident; indistinguishable from wrist sprain
Stage II: lunate exhibits definite density change but no other alterations; intercarpal relations are normal
Stage IIIA: lunate has collapsed; no fixed intercarpal rotation
Stage IIIB: entire lunate has collapsed; proximal migration of capitate and disruption of carpal architecture with fixed intercarpal rotation
Stage IV: generalized degenerative changes are evident in addition to pathological alterations described for Stage III

Treatment of Kienböck disease is difficult. In the past, prolonged cast immobilization was recommended but that method fails to prevent further degeneration of the lunate. To further complicate the treatment decision-making process, some long-term studies of cases of Kienböck disease that were untreated reported resolution of the associated pain after 24 months, perhaps reflecting a self-limiting process.

A number of treatments have been proposed, including lunate excision with or without replacement arthroplasty, joint-leveling procedures, wrist denervation, limited arthrodesis, proximal carpectomy, wrist arthrodeses, and lunate revascularization. One interesting technique of lunate revascularization uses vascularized bone grafts from the distal radius. Biomechanical studies on cadavers have shown maximum unloading of the lunate in joint-leveling procedures (radial shortening or ulnar lengthening).

The most common limited carpal arthrodesis performed is the scaphotrapezial-trapezoid procedure advocated by Watson et al. Capitohamate arthrodesis was recommended by Chuinard and Zeman and was further studied by Oishi et al. Although consistent unloading of the lunate has not been observed, patients who undergo this limited arthrodesis obtain excellent pain relief.

Oishi et al. and Inglis and Jones published the results they achieved by using capitohamate arthrodesis to treat Kienböck disease. The authors studied 45 consecutive wrists with Lichtman stage I, II, or III Kienböck disease treated with capitohamate arthrodesis. The average follow-up duration was 32 months. All arthrodeses healed in approximately 2 months. Forty-two patients (93%) had either no pain or significantly less pain postoperatively. In addition, all patients had preserved range of motion and increased grip strength. The authors concluded that capitohamate arthrodesis is a safe and effective treatment for Lichtman stage I, II, and III Kienböck disease.

Once stage IV disease is reached, salvage procedures such as proximal carpectomy and total wrist arthrodesis become necessary. Proximal carpectomy is possible only when the distal radial articulating surface of the lunate fossa and the articular surface of the capitate are intact. Lunate revascularization procedures have shown fair to good results during stages II and IIIA. However, during stages IIIB and IV, revascularization procedures have shown poor results.

Vascularized Bone Grafts

Vascularized bone grafts from the distal radius are useful in the treatment of Kienböck disease and in the treatment of scaphoid nonunions. The vascular anatomy of the distal radius has been described by various authors who outline the potential of vascularized pedicled bone grafts from the distal radius in the hand and wrist. The grafts are particularly useful in the treatment of scaphoid nonunion with avascular proximal poles and in cases of Kienböck disease.
Pedicled bone grafts from the dorsum of the distal radius can be based on either two superficial arteries, which are known as the 1,2-intercompartmental supraretinacular artery and the 2,3-intercompartmental supraretinacular artery, or on two deep arteries, which are known as the fourth extensor compartment artery and the fifth extensor compartment artery. These vessels have a communicating blood supply via the three dorsal arterial arches, known as the dorsal intercarpal arch, the dorsal radiocarpal arch, and the dorsal supraretinacular arch.197,260 Medial femoral condyle transfers have also been used for proximal pole nonunions and avascular necrosis with success.266,267

CONGENITAL DIFFERENCES

Most hand surgeons will, at some point, be called upon to care for a patient with a congenital hand condition. The incidence of all upper extremity anomalies is estimated to be between 1 of 600 and 1 of 500 live births.268–270 Although many hand differences occur in isolation, up to half present with abnormalities of other systems.268 When a patient presents early in infancy, the initial evaluation can be very stressful for parents and families. It is the duty of the hand surgeon to have basic knowledge of hand development and embryology to educate families and to recognize associations between certain hand differences and underlying syndromes, which can have a much greater impact on the patient’s overall well-being. The goal of this section is to review the current state of understanding about hand developmental biology, to provide the hand surgeon with a basis for classifying congenital hand differences, and to introduce treatment approaches to some of the more common congenital hand differences.

Development and Embryology

The current paradigm aims to understand and describe upper limb embryology at the molecular level. In the most basic layout, each event in embryological development can be reduced to four steps: a cell secretes a protein that then binds to a receptor to instigate intracellular signaling, which is conveyed to the cell nucleus where transcription factors bind to deoxyribonucleic acid and ultimately lead to the expression of target genes.271 Although our understanding of all the molecular pathways in upper limb development is incomplete, the following are some widely accepted fundamental pathways.

Just 20 days after fertilization, the cells that are fated to become the upper limb are gathered in position, and the expression of TBX5 determines the identity as a forelimb.272 During development of the normal human upper limb, limb buds first begin to appear on day 26, during the 3rd week after fertilization.271,273,274 Limb bud development takes place and is completed between the 4th and 8th weeks after fertilization.268 Limb buds are elevations off the lateral body wall at the level of the eighth to 12th somites. They consist of undifferentiated mesenchyme with overlying ectoderm: the somatic mesoderm becomes skeletal muscle, and the lateral plate mesoderm becomes cartilage and bone.268 The notocord signals the initiation of limb bud formation through expression of sonic hedgehog, and the limb buds begin to elongate and differentiate under the influence of the apical ectodermal ridge, which is a bulge of ectoderm lying along the junction between the dorsal and ventral ectoderm.271

The sequence of differentiation proceeds from proximal to distal. First, an arm is formed, then a forearm, and then a hand. The limb bud develops in three-dimensional space described in terms of three axes: proximodistal, anteroposterior, and dorsoventral. These three axes are controlled by three separate signaling centers: the apical ectodermal ridge, the zone of polarizing activity, and the dorsal and ventral ectoderm by means of producing Wingless (Wnt7a) proteins and Engrailed-1 (En-1) proteins, respectively.268 The complex interplay between the signaling centers of the three axes makes them interdependent for simultaneous and coordinated limb development. A mutation in gene products recognized in one axis can have downstream effects on the development of the other two axes because of feedback loops.270

Chondrification of the upper extremity begins at the humerus at approximately day 36 and concludes with the proximal aspect of the distal phalanges at approximately day 50.271 Cavitation, the process of joint development, also occurs in a proximal-to-distal direction beginning with the glenohumeral joint and concluding between days 47 and 50 with the joint interzones of the hand.268,271 At 7 weeks, every upper limb muscle is present and can be identified.271 Between days 47 and 53 after fertilization, the most distal aspect of the upper limb—the digital
rays—have been formed. Their separation is completed under the influence of MSX2, BMP4, and HOX7, which are some of the more important factors in the programmed cell death pathway.268,271

The vasculature of the upper extremity begins with the subclavian artery present during the 3rd week after fertilization, and the major vessels are present by day 30 post-fertilization.268 From this develops the brachial artery, which initially gives rise to the median and interosseous arteries to supply the developing hand. Subsequently, the ulnar and radial arteries develop and join to supply the hand through the deep and superficial palmar arches, and the median artery regresses to supply only the median nerve; however, in 10% of the normal population, a persistent median artery is found.271 Neural development of the upper extremity follows the vascular development. Mixed motor and sensory nerves to the upper extremity arise from spinal cord levels C6–T1, with nerves appearing at approximately day 36 post-fertilization; motor nerves originate from the neural crest, and sensory nerves originate from the neural tube.268

Animal models and experience with chemotherapeutic agents have illuminated some important relationships between gene products and transcription factors governing upper limb development. We have learned that sonic hedgehog is a critical link among all three axes, along with a reciprocal feedback loop involving FGF10 signaling, which maintains a population of cells known as the progress zone to promote simultaneous elongation and differentiation along the proximodistal and anteroposterior axes.270 Through sonic hedgehog and FGF10, the apical ectodermal ridge and zone of polarizing activity are linked such that a disturbance in either one has the potential to halt progress in the other. The dorsoventral axis development is the least well understood at present. We have observed that Wnt7a protein is secreted by the dorsal ectoderm and produces a dorsalizing effect on the mesoderm by way of the Lim homeodomain transcription factor LMX1B.270 The hand surgeon should realize that as our understanding of upper limb development has become more sophisticated, our methods of diagnosis, classification, and treatment of upper limb congenital differences has moved toward a genetic and molecular-based system.

### Epidemiology and Causation

Congenital anomalies occur in approximately 3% to 7% of live births, with 20% of these having a skeletal anomaly or dysplasia and one in 626 newborns having an anomaly affecting the upper extremities.272,275 Among those, only one in 10 has a significant functional or cosmetic deformity.276

The causes of birth defects can be classified into three broad categories: 20% to 25% genetic and/or chromosomal, 10% to 12% environmental, and 63% to 70% multifactorial.272 The multifactorial category includes disorders that might be caused by time-sensitive and dose-dependent interactions between genes and the environment. The interactions are currently not well understood. Similarly, Tickle277 estimated that 60% of malformations are caused by multiple-gene disorders, 20% by single-gene disorders, 10% by chromosomal aberrations, and 10% by environmental factors. Among the extraneous agents that have been implicated in known malformations are drugs (Thalidomide, Dilantin [Pfizer, New York, NY], alcohol, Coumadin [Bristol-Myers Squibb, New York, NY]), other chemicals, irradiation, anoxia, and violent infections.

Teratogens in the environment of a developing embryo likely cause damage by fundamentally disrupting the transcription or translation of morphoregulatory genes. The specific molecular targets of some teratological drugs and chemicals are known, and many others likely cause damage by ultimately leading to the formation of reactive oxygen species; because the embryo or fetus has a lower capacity to buffer against oxidative stress, it is much more susceptible to genetic damage and disruption than adult tissues. Furthermore, the appendicular skeleton combines the coordinated and interdependent development of vascular, neural, and skeletal elements over a relatively long period of fetal development, between weeks 4 and 8 of fetal life, rendering the limbs disproportionally susceptible to environmental conditions during critical times of development and differentiation.

The mechanism of teratogenesis has been investigated for many known teratogens; however, because of the complexity of the pathways involved, most are still not completely understood. For example, Thalidomide is now thought to cause its devastating effects on the
fetus by its antiangiogenic regulation, which leads to disruption of the vascularity and resultant truncation of the developing limb. Likewise, some of the teratogenic chemotherapeutic and anticonvulsant medications can exert harmful effects by ultimately disrupting the vascularity of the developing limb. Population data estimate that a staggering one of 300 live births within the United States is affected by fetal exposure to ethanol. The constellation of observed features consistent with fetal alcohol syndrome can include mental retardation, attention deficit, microcephaly, midface hypoplasia, short distal phalanges, and digital separation defects. Although some of these features can be subtle, congenital hand differences are often immediately apparent and receive attention and concern from family and medical personnel. This should emphasize the importance of a complete physical examination of a child referred for a hand difference. During the evaluation of a child with a congenital hand difference, parents might experience inappropriate guilt and inquire whether certain behaviors or exposures during the pregnancy could have been responsible for the harm to their child. This topic should be approached with caution, because although the United States Food and Drug Administration rigorously attempts to protect the United States population from harmful exposures, the international standards of testing using rats and rabbits are estimated to be less than 50% predictive of effects in humans… and Thalidomide passed the tests in rodents.

Classification

For nearly the past 5 decades, the classification system proposed by Swanson and adopted by the American Society for Surgery of the Hand and International Federation of Societies for Surgery of the Hand has been used internationally as the basis for medical communication and research regarding congenital hand differences. The Swanson classification presented seven categories of congenital upper extremity malformations that are as follows:

1. Failure of formation of parts
2. Failure of differentiation (separation) of parts
3. Duplication
4. Overgrowth (gigantism)
5. Undergrowth (hypoplasia)
6. Congenital constriction band syndrome

As was appropriate to the level of understanding during the era, the Swanson classification was based on observational morphology of the limb. It has become apparent, however, that some deformities (e.g., symbrachydactyly) do not fit clearly into any category. Because the seven basic categories were not founded on common molecular etiologies, the system was difficult to adapt and expand as our genetic and molecular understanding of congenital limb differences became more sophisticated.

The Japanese Society for Surgery of the Hand proposed a major modification with the inclusion of a separate category, Abnormal Induction of Digital Rays. However, that system did not prove adequate. An ideal classification system serves as a means of effective communication and should provide information regarding the mechanistic etiology of a condition, guide treatment, and provide an indication of prognosis. Other qualities of an ideal classification system include ease of use, uniform acceptance across specialties, and adaptability to accommodate an ever-changing level of understanding. Because the Swanson classification system was useful for so long, many excellent texts have referred to congenital differences using this system; this is why it is presented herein. However, recently, the Oberg, Manske, and Tonkin (OMT) classification has been accepted by the International Federation of Societies for Surgery of the Hand to replace the Swanson system.

The OMT classification has undergone a number of modifications; however, the fundamental basis allows incredible flexibility as we gain new knowledge about specific conditions. The basic categories of the OMT classification are presented below:

1. Malformations—abnormal formations or differentiations of tissues
2. Deformations—alterations to tissues that have already formed normally
3. Dysplasias—abnormal organization of cells into tissues
4. Syndromes—hand anomalies cross-referenced to the preceding three categories

The first category, malformations, is very large and is organized first according to involvement of the entire upper limb versus only the hand plate and second according to the developmental axis affected. The second category, deformations, is much smaller and is limited to three subcategories: constriction ring sequence, trigger digits, and not otherwise specified. The third category, dysplasias, includes hypertrophy and tumorous conditions.

Management of Common Congenital Hand Differences

Hand surgeons without specialized training in pediatric and congenital hand conditions might find that managing some of the most common conditions best serves their communities when referral to a pediatric hand surgeon is impractical. The following are some of the most frequently encountered conditions and general treatment strategies.

**Syndactyly**

Syndactyly is one of the most common congenital deformities of the hand. It occurs in one of 2000 to 2500 births. Boys are affected twice as often as girls, whites are affected twice as often as blacks, and a positive family history is elicited in approximately one-third of cases. The usual inheritance pattern is dominant, with both variable penetrance and expressivity. Most cases of syndactyly occur in isolation; however, syndactyly is a common feature associated with syndromes, most prominently Apert syndrome, although it has also been described as occurring with other craniosynostoses. Poland syndrome also includes syndactyly.

Syndactyly can be complete or incomplete, simple or complex. Complete syndactyly is said to exist when the interconnection extends to the tips of the involved digits. Incomplete syndactyly refers to any interconnection that is less extensive than complete. Simple syndactyly involves abnormal digital interconnections consisting of skin and fibrous tissue only. Complex syndactyly refers to interconnection involving bone. The most common syndactyly is simple and involves the third web space; the fourth, second, and first web spaces are involved with decreasing frequency, respectively. The condition is frequently found bilaterally and involving the web spaces of the feet. The initial examination should therefore carefully take note of these factors. In a recent study syndactyly was found to be the most commonly imaged congenital hand difference by standard radiographs, and 92% of cases were determined to be simple syndactyly. The median age of patients undergoing radiographic imaging was 12 months, and this was appropriate considering that surgery is unlikely before 12 months of age. Radiographic examination is also important and useful to exclude a diagnosis of synpolydactyly, which includes supernumerary digits incorporated into the syndactylized mass. Synpolydactyly presents a complicated surgical problem, and this spectrum of malformations has recently been radiographically classified into three categories: type 1 with metacarpal involvement, type 2 with proximal phalanx involvement, and type 3 with idle or distal phalanx involvement.

The timing of surgery for the correction of syndactyly is debatable. Patterns of hand function are noted to be established between 6 and 24 months of age, so the digits must be separated within that time frame. Surgery usually is not recommended before age 6 months because of the increased risk of anesthesia, although Raus reported achieving simple syndactyly repair in two newborns who were younger than 72 hours. At the other extreme, Flatt and Wood did not perform surgery until the patients were a minimum age of 18 months. In cases of complex syndromic syndactyly, Barot and Caplan performed the first surgery when the patients were 7 months old unless thumb involvement was present, in which case the first stage of surgery—release of the web space between the long and ring fingers—was performed when the patients were between 3 and 6 months of age. The repair sequence usually is completed by age 2 years. Earlier surgery, between 4 and 6 months of age, has been advocated for involved border digits to prevent tethering and angulation deformity of the longer digit during growth.

Principles of syndactyly surgical correction have historically indicated release of only one border of an involved digit in a single surgical setting. Although this is a sound principle to avoid the devastating complication of vascular compromise to the digit, in the experience of certain experts, this is not always necessary in the case of simple syndactyly. Other surgical considerations center...
on creation of the web space and correction of the skin deficiency. Most current techniques of complete syndactyly release involve zigzag incision and small triangular flaps designed to interdigitate in the sides of the fingers. Skin grafts usually are required for complete resurfacing after separation of the fingers. Ezaki et al. emphasized the importance of meticulous separation of the fingertips with pulp grafts over exposed bone. The most common complications after surgery include graft loss and web creep.

Camptodactyly

Camptodactyly is congenital flexion contracture of the PIP joint. Two forms of camptodactyly have been noted: one that occurs during infancy and one that affects adolescents. In terms of incidence, early camptodactyly affects male and female infants equally whereas camptodactyly that appears during adolescence affects mostly female adolescents. Although most cases are sporadic, an autosomal dominant pattern involving more than one digit can occur.

The pathophysiology of camptodactyly has been explained as an imbalance between the flexion and extension forces acting on a PIP joint. The skin, fascia, FDS, and other structures have all been implicated as causative factors, although a single unifying mechanistic explanation has yet to be described. The insertion of the lumbrical muscle is almost invariably abnormal. McFarlane et al. concluded that the loss of normal lumbrical action is the principal cause of the intrinsic minus deformity seen in camptodactyly of the small finger. Two of every three patients with camptodactyly have fixed flexion contracture of the PIP joint, and in 57% of the cases, the angle of flexion is greater than 45 degrees. Other associated abnormalities include superficialis V tendon adherent to superficialis IV in 47% and various anatomic irregularities revealed by radiographic examination of the PIP joint. These conditions are interdependent and have an adverse effect on surgical outcomes.

Because the results of surgery for camptodactyly are largely unpredictable, a conservative approach with stretching is reasonable for young children. Stretching and night splinting should be used, and surgery should be avoided if possible. Operative treatment is reserved for patients with more than a 60-degree flexion contracture and functional limitation or pain unresponsive to conservative measures. Patients and families must understand that complications are not uncommon and include recurrence, with 11% of surgical patients actually developing worse deformities and/or pain postoperatively.

Clinodactyly

Clinodactyly is a non-traumatic radial or ulnar deviation of a digit as a result of phalangeal dystrophy. The abnormality occurs in the middle phalanx and can be identified by a bracketed epiphysis. The usual deformity is a radial deviation of the little finger observed clinically at the DIP joint. Clinodactyly has been associated with mental retardation. Its incidence in children with Down syndrome ranges from 35% to 79%, whereas in normal children it is between 1% and 19.5%. Clinodactyly can be either sporadic or inherited as a dominant trait with variable expressivity. Most cases present a cosmetic problem rather than a functional one. Surgical correction requires osteotomy, which might have to be repeated as the child grows; however, good results have been obtained with a closing wedge corrective osteotomy for functional deformities with greater than 25 degrees of angulation.

Polydactyly

Polydactyly means digital duplication and is the second most common congenital hand anomaly. With this condition, duplication of digits can be observed on the radial or ulnar border of the hand. Defects range from simple polydactyly to very complex arrangements, with twinning or mirror hands and duplication of skin or skeletal structures. Although polydactylies can seem to be united by the commonality of supernumerary digits, the underlying genetic and molecular factors governing the development of ulnar, radial, or central digit duplication differ greatly.

Preaxial polydactyly refers to duplication of radial border digits. In whites and Asians, the thumb is most commonly duplicated. Central polydactyly involves the index, long, or ring finger and is rare. Postaxial polydactyly includes duplication of the ulnar border digit. Postaxial polydactyly occurs most commonly in blacks,
with an incidence of approximately 1/300 live births.\textsuperscript{287} It is 10 times more common in blacks than in whites.\textsuperscript{306}

Temtamy and McKusick\textsuperscript{306} classified postaxial polydactyly into types A and B. Type A occurs when the extra digit is well formed and articulates with a broadened or bifid fifth metacarpal head. Type B occurs when the extra digit is fully formed and connects to the little finger or ulnar side of the hand by a skin bridge. The treatment for type B polydactyly is simple removal; if discovered in the nursery, Ligaclips (Ethicon Endo-Surgery, Cincinnati, OH) can be applied. Type A postaxial polydactyly poses a more complex problem. After the extra digit is removed, the neurovascular bundles, tendons, and abductor digiti minimi must be exposed for adequate reconstruction.\textsuperscript{307}

Preaxial polydactyly can more accurately be called \textit{split thumb}, because both thumbs are of smaller size and neither alone functions normally. Thumb duplication is a common congenital anomaly accounting for 6.6\% of all hand deformities.\textsuperscript{308} Approximately half the cases of thumb duplication have secondary deformities of the hand, most commonly angulation at the MP or IP joints.\textsuperscript{309} Wassel,\textsuperscript{309} in 1969, classified preaxial polydactyly into seven types, as shown in Figure 33. Type IV, the most common type, represents duplication of both phalanges articulating with the common broadened metacarpal head and is observed in approximately 50\% of patients with preaxial polydactyly.\textsuperscript{305,309} With the exception of type VII (triphalangeal thumbs), which sometimes occurs in association with hematopoietic disorders or Holt-Oram syndrome, split thumbs do not occur in combination with other congenital anomalies.

The treatment of split thumbs depends on the specific deformity. For types I and II, either excision of the smaller part or a Bilhaut-Cloquet closure is performed.\textsuperscript{302,303} The Bilhaut-Cloquet procedure as classically described is rarely performed anymore because of persistent deformities and poor aesthetic appearance; however, the Baek modification, which includes a step cut to preserve articular surfaces and physis along with modified nail reconstruction, is now performed with more frequency.\textsuperscript{269} For types III and IV, the radial thumb usually is smaller and should be removed. Reconstruction of the radial CL and careful osteotomies should then be performed.\textsuperscript{310} Rebalancing of tendons usually is necessary. For types V and VI, which infrequently occur, the extrinsic and intrinsic muscles must be explored and rebalanced and the web space can be widened.

Triphalangeal thumbs (type VII) can occur with a duplicated thumb, an absent thumb, or even a normal thumb on the other hand. The condition can be inherited as a dominant familial trait and can be associated with severe cardiac defects, such as transposition of the great vessels, patent ductus arteriosus, atrial septal defect, and ventricular septal defect. In addition, type VII thumbs can be a component of syndromes such as Holt-Oram, Juberg-Heywood, Blackfan-Diamond anemia, and Fanconi pancytopenia.\textsuperscript{302} If the diagnosis of triphalangeal thumbs is made when the patient is very young, excision of the accessory phalanx is all that is necessary. When the triphalangeal component is discovered later in life, a portion of the “middle phalanx” can be removed to allow fusion of the DIP joint into a thumb of proper length. A more complicated approach involves combined longitudinal and transverse osteotomy, with shortening and de-angulation of the thumb achieved by ablation of the extra joint and abnormal epiphysis.\textsuperscript{311}

Ulnar dimelia (mirror hand) is a rare but extreme form of upper limb duplication.\textsuperscript{303,304} The preaxial structures of the hand and wrist are missing, another ulna replaces the radius, and the number of postaxial digits is usually double. Dobyns et al.\textsuperscript{302} and Flatt\textsuperscript{303} listed the functional problems attendant to this condition as limited movement of the elbow, decreased pronation and supination of the forearm, flexion contracture of the wrist with radial deviation, absent or weak extensor tendons, excessive number of digits with no thumb, absent thumb web, weak opposition of the digits, syndactyly, divergent metacarpals, and palmar cleft. The treatment plan involves four operative stages addressing elbow motion, forearm motion, wrist stability, and the hand.\textsuperscript{302,312,313}

Radial Longitudinal Deficiency and Thumb Hypoplasia

Radial deficiencies occur in one of 30,000 live births.\textsuperscript{281} The first step in treating patients who have preaxial deficiencies is a careful evaluation to rule out associated congenital defects. The most common associations are with cardiac anomalies; vertebral pathology, imperforate anus, tracheoesophageal fistula, and renal abnormalities, known as the \textit{VATER syndrome complex}; Fanconi anemia; thrombocytopenia; and cardiovascular malformations (Holt-Oram syndrome). Studies that should be ordered
when one of these syndromes is suspected include radiographs of the spine, echocardiography, renal ultrasound, complete blood count, and chromosomal breakage test.287

Bayne and Klug314 classified radial longitudinal deficiencies into four types according to the severity of the radial deficit as follows:

Type I: short distal radius
Type II: hypoplastic radius

Figure 33. Wassel’s classification of thumb polydactyly. (Modified from Wassel.307)

Type III: partial absence of radius
Type IV: total absence of radius.

The goal of treatment is to achieve a straight stable wrist and to maintain hand function. The hand function is the most important aspect when evaluating these patients, and despite any radial club hand appearance, the patient’s functional needs will guide the decision for surgery. Function must never be sacrificed for cosmetic appearance of the hand and arm. Patients who require
treatment typically lack sufficient radial support for the hand, have thumb and finger deformities, or have radial contractures that cannot be reduced by plaster stretching. Stretching exercises for some months before surgery are recommended. The usual treatment sequence involves centralization during the first stage, which is performed when the infant is age 6 months or older.291

The radial (preaxial) deficiencies span a wide range of deformities from hypoplastic thenar muscles to a short club thumb and radial dysplasia. Buck-Gramcko,315 based on the work of Müller316 and Blauth,317 classified hypoplastic thumbs associated with radial dysplasia into the following five types:

Type I: minimal shortening and narrowing of all structures
Type II: moderate underdevelopment, bones slender and shortened, web space narrowed, hypoplasia of superficial thenar muscles, instability of MP joint
Type III: partial aplasia of the first metacarpal, severe atrophy and instability of first ray, anomalies of muscles and nerves, thenar musculature almost completely absent
Type IV: total or subtotal aplasia of first metacarpal, rudimentary phalanges (aka “floating thumb”)
Type V: complete absence of thumb.

Type I thumbs do not require treatment. Type III was modified and divided into type IIIa having a stable CMC thumb joint and type IIIb having an unstable CMC thumb joint. This distinction is critical because for type IIIa thumbs, surgical reconstruction including a Huber transfer can restore adequate function to the hypoplastic thumb. For type IIIb thumbs, a superior surgical option includes ablation of the unstable hypoplastic thumb and pollicization of the index finger, as described by Buck-Gramcko.315 For type IV and type V thumbs, index pollicization is the usual treatment.278,279,318

However, because it is rarely if ever observed at birth, it is more correct to refer to this entity as “pediatric” rather than “congenital” trigger thumb. Clinical examination reveals obvious flexion of the thumb IP joint and typically a palpable mass at the level of the A1 pulley called Nott’s nodule. It is reasonable to recommend a trial of nonoperative treatment, including stretching exercises performed by the parents and observation of the patient, before recommending surgery.295

Macrodactyly

The overgrowth spectrum of congenital hand and upper extremity differences is relatively rare and is classified in the OMT system as type 3: dysplasias. Overgrowth can involve the entire limb or be limited to the distal aspect of the hand or digits. Static overgrowth is present at birth and grows proportionally with the patient. Progressive overgrowth can be present at birth; however, the rate of enlargement might accelerate during periods of childhood growth such that proportionality is not maintained. Overgrowth can occur in isolation or as part of a syndrome. The most common form seen is isolated overgrowth, which can present as either a nerve territory-oriented distribution or lipomatous macrodactyly. Patients and parents seek treatment for cosmetic improvement, but macrodactyly presents a challenging problem that is not always improved with surgery. Function of the hand and digit must be carefully considered before undertaking any procedure with the potential to compromise protective sensation and render an already inhibited digit more stiff and painful.319

Cutaneous Lesions

Skin lesions affecting the upper extremities of the newborn and infant are typically managed by pediatricians and dermatologists. Occasionally, an infant with cutaneous lesions is referred to a hand surgeon after conservative and medical treatments have failed. This can occur in the case of a large or disfiguring hemangioma on the hand or arm or in the case of various types of vascular malformations that can present with skin discoloration and local tissue enlargement. Surgical treatment of vascular malformations must be carefully undertaken with a thorough preoperative evaluation to fully image the extent of the lesions and
to rule out coagulopathies. A common skin lesion that might be seen first by the hand surgeon is a lobular capillary hemangioma (pyogenic granuloma). These lesions are red, friable, rapidly growing lesions that can occur on the hands and fingers and are often associated with a history of trauma. They can be successfully treated in a number of ways, including shaving, excision, laser therapy, cryotherapy, topical steroids, and silver nitrate. Patient age and lesion location govern choice of treatment strategy.

Summary

Congenital hand differences range from functionally incapacitating deformities to benign, subtle cosmetic variations. Because hand differences can be the most ostensible features of a syndrome, the hand surgeon might be the first specialist to evaluate an infant and must be mindful of underlying disorders that could more significantly impact the health and well-being of the patient. When managing congenital hand differences, the hand surgeon must center the goals of treatment around maximizing the function of the hand and upper extremity. Function must never be sacrificed for appearance.

RHEUMATOID ARTHRITIS

With the advent of disease-modifying antirheumatic drugs, the progression of rheumatoid arthritis has been ameliorated and fewer surgical deformities have been presenting to clinic. However, a significant burden remains for those afflicted with this devastating arthritic process.

Medical optimization is critical for healing. One must remember that rheumatoid arthritis is a systemic inflammatory disorder that affects multiple tissue types. The diagnosis is based on American College of Rheumatology classification criteria. Rheumatoid factor is detected in a majority of patients; anti-cyclic citrullinated peptide, and anti-mutated citrullinated vimentin provide specificity. Rheumatoid nodules can be pathognomonic but should be distinguished from Heberden’s and Bouchard’s nodes at the DIP and PIP joints, respectively.

With rheumatoid arthritis, the MCP and PIP joints tend to be involved. With osteoarthritis, the DIP joint and thumb CMC joint are more commonly affected. Rheumatoid arthritis causes an angry synovitis that attacks joints and destroys articular cartilage and tendons along its way. This leads to ankyloses and tendon rupture more severely than degenerative processes do. The pathogenesis is clearly autoimmune, and medical management with monoclonal antibodies has mounted a more favorable milieu of inflammatory cytokines and helped prevent a typical cascade of progression.

Typical staging begins first with synovitis; because of the success of antirheumatic drugs, subsequent deformity has been greatly decreased. The second stage includes a passively correctable deformity that can involve tendon imbalances. The deformity becomes fixed in its third stage. Soft-tissue reconstruction might improve function; however, the fourth stage includes the very broad ranges of articular destruction. When this occurs, implant arthroplasty and joint fusion might be indicated.

Characteristic hand deformities include ulnar deviation of MP joints, boutonniere deformity of the thumb, and swan neck deformity of the fingers (Fig. 34). In the wrist, synovial hypertrophy destabilizes the triangulofibrocartilage complex and leads to dorsal subluxation of the ulnar head and volar subluxation of the extensor carpi ulnaris. The carpus radially deviates and supinates. Ulnar translocation of the carpus occurs. Radial deviation of the metacarpals and ulnar deviation of the fingers ensues. Inability to extend the digits can be caused by extensor tendon subluxation at the MP joint, rupture (most frequently from a prominent ulnar head, Vaughn-Jackson syndrome), posterior interosseous nerve palsy, and/or carpal dislocation.

Indications for surgery include disabling pain, impaired function, and preventing future deformities. Preoperative workup requires careful assessment. If endotracheal intubation is planned, it is crucial to confirm cervical spine stability. Consult an expert if there is any concern. In addition, the temporomandibular joint can make intubation difficult. A preoperative anesthesia evaluation is prudent. The recommendation for perioperative medication management should be deferred to the prescribing doctor. Fortunately, more frequently, patients have acquired a rheumatologist who has been involved with their care and has a sense of their disease flares and overall status. It is important to develop collaboration with a multi-disciplinary team, including a hand therapist. Coordination of care and precise
documentation in the medical record will better prepare all parties in anticipation of any procedures needed. It is also very helpful to build that relationship when discussing scheduling a surgery date that fits a mutual agreement of when the patient is physically and mentally best prepared.

It can be difficult to strike a delicate balance of altering the patient’s immunotherapy. The surgical risks and complications can be swayed with the proper judgment in timing of dosage modulation which is best assessed from the risk:benefit portfolio from the combined, sometimes competing perspectives of the surgeon and rheumatologist. The risk of holding medication might outweigh the benefits of surgery if doing so creates a flare of previously well-controlled symptoms, whereas the risk of restarting medication might erase the benefits of surgery if it causes substantial wound breakdown or infection. Newer generations of medications are targeted to optimize overall ability to heal and ward off infection. Surgery is indicated for recalcitrant symptoms despite being on a stable regimen, improving function for activities of daily living, and preventing or correcting deformity when medical management cannot do so. Tsai and Borah\textsuperscript{321} published a useful guideline for interruption of immunosuppressants depending on particular drug half-lives. Bear in mind that the patient might require a corticosteroid booster if he or she is typically dependent or if any evidence of adrenal crisis is present, which can be life threatening. Immunosuppressants obviously increase the susceptibility to infection. Proper irrigation, perioperative antibiotic prophylaxis, and judicious choice of implants are therefore critical.

The general categories of surgery for the patient with rheumatoid arthritis fall into either prophylactic or reconstructive procedures of the soft tissue, tendon, or bone. Early tendon transfer, such as extensor carpi radialis longus to extensor carpi ulnaris, can help rebalance wrist dynamics. Tenosynovectomy and removal of inciting osteophytes can decrease the chance of attritional tendon rupture and need for repair or transfer. Flexor or extensor synovectomy can prevent invasion of synovial tissue within the tendon fiber substance, although it is not known to alter the progression of disease. When radical excision is performed, rice bodies consisting of consolidated synovial tissue are frequently noted. When indicated, open carpal tunnel release is recommended with expectant need for flexor tenosynovectomy.

In cases of extensor tendon rupture because of synovial invasion or attritional rupture near the eroded distal ulna, tendon transfers are selected based on available donors. The small finger extensor tendon can be weaved end to side or side to side to the ring. Extensor indicis proprius can be used for ring and small fingers, and the middle finger can be weaved to the extensor digitorum of the index finger when the middle, ring, and small finger tendons are out. When the extensor indicis proprius tendon is unavailable, FDS from the middle and ring fingers can be rerouted. The Mannerfelt lesion involves rupture of the flexor pollicis longus and possibly index flexor digitorum profundus from an eroded distal pole of the scaphoid.

Fusion of the DIP joints stabilizes the terminal finger; however, limited bone stock can preclude the compression screw technique. PIP joint fusion is effective in alleviating pain with sacrifice of motion. Fusion of the PIP joints of the index and middle fingers assists with stability for pinch. Arthroplasty is preferred for the PIP joints of the ring and little fingers to maintain power grip. Operative correction of boutonniere and swan

\begin{figure}[h]
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\includegraphics[width=\textwidth]{rheumatoid_arthritis.png}
\caption{Late stage rheumatoid arthritis.}
\end{figure}
neck deformities has long been attempted and has led to variable results. Boutonniere deformity of the finger is most frequently caused by central slip attenuation, which can be treated by centralization of the lateral bands and/or shortening of the central slip. Distal tenotomy of the lateral conjoined tendon provides improved flexion of the DIPJ. The deformity can successfully be treated nonoperatively by serial casting of the PIPJ or by using a relative motion flexor splint as described by Merritt. Swan neck deformity develops as a result of rupture of the terminal tendon, volar plate laxity, or rupture of the FDS resulting in excessive central slip pull. Tight lateral bands from MCPJ subluxation can be addressed as described by Fowler and Riordan. Regarding the thumb, boutonniere deformity is more common. The insertion of the EPB at the MP joint is attenuated; the EPL migrates volarly, accentuating flexion deformity and hyperextending the distal phalanx. Joint fusion is indicated when nonoperative measures fail. Comparatively swan neck deformity of the thumb develops when CMC joint subluxation leads to hyperextension of the MCPJ. Additionally, chronic ulnar CL stretching from synovial hypertrophy can lead to gamekeeper’s thumb requiring secondary stabilization.

Indicated procedures for the wrist should be performed before or concomitant with those for the hand because they will undoubtedly affect the outcome. Distal ulnar resection by Darrach or Suave-Kapandji procedures are commonly performed. Wrist fusion is highly effective to stabilize end-stage arthritis and alleviate pain. Radioscapholunate fusion can preserve midcarpal motion if the capitolume articular cartilage is preserved. The choice between total wrist fusion and wrist arthroplasty is debatable. A retrospective review comparing the two procedures showed no statistically significant differences, although a trend was shown toward improved personal hygiene ($P < 0.10$) and fastening buttons ($P < 0.09$) with arthroplasty. Improvements of implant design have facilitated selective use. MP joint arthroplasty is indicated for severe destruction and volar subluxation. Silicone implants of appropriate size are suitable spacers allowing an arc of motion that is deemed satisfactory to the patient. Implant fracture rate based on radiographs is highly variable; however, it is not as frequently clinically relevant. Tendon rebalancing, such as the cross-intrinsic transfer, might have a protective effect on the durability of the construct.
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