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Distal Radius Fractures

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With the wide array of treatment options now available, this is an exciting era for the treatment of fractures of the distal radius. An improved understanding of kinematics, bone quality, and muscle forces acting across the fracture has led to increased awareness of a fracture's relative stability, as well as the development of innovative devices to counteract these forces and restore stability. Innovations have occurred in closed treatment, percutaneous fixation, external fixation, and in particular, implants for internal fixation. However, new devices and techniques require careful assessment of efficacy, risk, and benefit as they are applied in practice, especially since the incidence of this fracture is likely to rise in an aging population. At this time, there are few published studies that definitively demonstrate the superiority of one technique or implant over another, as long as the anatomy of the distal radius is restored.

Distal radius fractures are the most common fractures seen in the emergency department; they represent approximately 3% of all upper extremity injuries, with an incidence of greater than 640,000 annually in the United States alone.[20] There is a bimodal distribution of these injuries, with a peak in the 5- to 24-year-old, predominantly male population who sustain athletic and high-energy injuries and a second peak in the elderly, predominantly female population characterized by lower-energy or "fragility" fractures. U.S. census data indicate that the percentage of persons aged 65 and older in the United States will rise from 12% to 19% over the next quarter century. Osteoporosis may be contributing to fractures in the elderly, and therefore improved attention to care of this condition may reduce the incidence of such fractures.[102]

The goals of this chapter are to provide the surgeon with a detailed understanding of fracture types, better knowledge of wrist and fracture mechanics, improved recognition of individual fracture fragments in complex fractures, and an understanding of expectations of fracture treatment. Using a case-based approach, it is hoped that the reader will have a better appreciation of the factors influencing the results of treatment and enable the surgeon to develop an effective approach to this injury.

THE RATIONALE FOR MODERN TREATMENT

Beginning with Pouteau (1783), Colles (1814), and Dupuytren (1847), early reports of fractures of the distal radius considered these fractures to be a group of injuries with a relatively good prognosis irrespective of the treatment given. Until the mid-1900s, nearly all fractures of the distal radius were treated in closed fashion, with or without reduction of alignment. Patients' expectations of treatment were in line with the treatment tools available at the time, and certainly other public health issues outflanked the wrist in importance to a patient's long-term productivity. Since then, hundreds of clinical and basic publications have contributed to our improved understanding of fracture complexity, stability, and prognosis and have consequently driven the development of modern techniques and technology to optimize patient outcomes. A brief summary of the evolution of modern fracture fixation follows, with the sentinel publications and techniques that fundamentally changed our treatment of these challenging injuries being highlighted.

Although closed reduction with cast treatment of distal radius fractures continues to be the mainstay of treatment of stable fractures, operative methods have evolved over the past century to treat fractures that defy cast management. Casting in acute wrist flexion and ulnar deviation, or the so-called Cotton-Loder position, even though thought to be beneficial for maintenance of reduction of unstable fractures, seemed to result in more stiffness in the digits and the potential for median nerve compression. The "pins and plaster" technique, attributed to Bohler in 1929,[12] was the predecessor of modern external fixation and consisted of the incorporation of percutaneous pins in the mid-radius and metacarpals into a circumferential plaster cast. Although the technique yielded initial improvements, it fell from favor because external fixation devices were easier to apply and seemed to maintain the reduction with fewer complications.[17] The use of external fixation began in the 1940s, and the principles were best summarized by Anderson and O'Neil[3]:

- Strong forearm muscular forces oppose fracture fixation.
- Loss of radial length is secondary to crushed metaphyseal bone.
- Distraction should be maintained for 8 to 12 weeks until the metaphysis is reconstituted.
- Open reduction of impacted articular fragments is necessary.
- Bone grafting is required to support the crushed articular surface.
- "Immediate use of the fingers and arm is the keynote to near perfect functional restoration."

Despite relative improvements in fracture fixation stability, there remained no hard data for surgeons to link patient function or outcome with treatment variables. Surgeons used a variety of techniques ranging from casting with or without Kirschner wire fixation to pins and plaster or external fixation, without comparative studies or a means to judge results. In 1951, Gartland and Werley published a series of 60 patients treated by plaster immobilization and devised a demerit point system to score subjective and objective function that continues to be used today.[35] The authors defined the anatomic indices of normal volar tilt, radial length, and radial inclination and demonstrated that *60%* of treated fractures *assume their prereduction alignment* at final follow-up despite adequate cast treatment. In their series, all fractures lost some component of the initial reduction of dorsal tilt. For the first time, the authors showed that poor functional outcomes are associated with failure to restore and maintain bony alignment. In this and many subsequent series over the next several decades,[27,63,85,121] compelling evidence has been presented to link restoration of anatomy to restoration of function, a principle that is the basis of modern fracture treatment.

The popularity of external fixation for the treatment of wrist fractures was catapulted forward by the concept of "ligamentotaxis" by Jacques Vidal in 1979, who advocated its use for comminuted articular fractures, including those of the hip, knee, ankle, spine, and wrist. The principle of ligamentotaxis involved the application of tension "by means of distraction forces working through capsule-ligamentous structures" to obtain reduction.[117] Though not substantially different in concept from pins and plaster or the Roger Anderson frame, the spanning external fixator enabled the surgeon to adjust ligament tension via distraction and tensioning devices. Although the author described its use for highly comminuted fractures that were otherwise not suited for internal fixation, advocates of the technique championed it widely for virtually all fractures of the distal radius, and industry responded with a plethora of external fixation devices in the 1980s and 1990s. Within 10 years of Vidal's publication, multiple centers reported extensive complications related to overdistraction of articular injuries, including severe digital stiffness, reflex sympathetic dystrophy, and nerve dysfunction, as well as an inability to maintain reduction of articular fragments and radial length with traction alone.[23,58,87,120] Over the ensuing 2 decades, the technique of external fixation evolved to include "augmentation" of fixation with supplemental Kirschner wires, mini-open or arthroscopic reduction (or both), and bone grafting, with a concomitant reduction in traction-related complications.

Frykman called our attention to the importance of injuries on the ulnar side of the wrist to outcome of distal radius fractures.[34] Pivotal work by Palmer and colleagues in the early 1980s unveiled the complex anatomy and the critical importance of the triangular fibrocartilage complex (TFCC) to stability of the radioulnar joint and hand function after distal radial fractures.[93,107] Through mechanical loading experiments, the investigators provided fundamental scientific evidence to explain the relationship between dorsal malalignment of the radius and increased ulnar load transmission, as well as the compounding effect of increased ulnar variance as a result of radial settling. Concurrently, Taleisnik and Watson demonstrated changes in resting carpal posture and aberrations in carpal kinematics caused by dorsal malunion of the radius and advocated realignment osteotomy to restore the radiocarpal and midcarpal relationships.[112] Reports of excellent results after osteotomy and bone grafting of painful malunions by Fernandez and others provided further evidence to underscore the link between bony alignment and function.[31] These important clinical and benchtop advances helped us understand how critical the articular relationships of displaced distal radial fragments are to upper extremity function and solidified the tenet that there is a narrow tolerance of these joints for changes in radial angulation, tilt, and variance in young, active patients.

Although Scheck and others had drawn attention to the presence and importance of impacted articular fragments as a prognostic indicator,[105] Knirk and Jupiter focused attention on the need for longer-term functional studies, particularly in young adults with a high-energy articular fractures.[65] Their long-term follow-up study documented a 91% rate of degenerative arthritis, as judged by plain radiographs, in patients with *any* degree of residual articular incongruity and a 100% rate in patients with 2-mm or greater incongruity. However, a multivariate analysis was not performed to eliminate the potential confounding effects of radial malalignment. The study did draw attention to the need for restoration of joint congruity and ignited a surge of interest in precision realignment of the articular surface. Some studies would support their observation by linking residual articular incongruency directly with the early onset of degenerative changes.[29,68]

With the primary goal of restoration of joint congruity, several authors advocated meticulous restoration of the articular surface through an open dorsal or combined dorsal/volar approach, rigid internal fixation, and cancellous bone graft.[5,33] Although these techniques generally attained the goal of accurate reduction of the articular surface, a high rate of complications was reported, primarily extensor tendon irritation and rupture. This caused many to reconsider the use of dorsal plates. Surgeons and manufacturers teamed to design novel dorsal plate fixation systems that combined improved material strength with lower-profile plates and screws, which seemed to decrease the incidence of extensor tendonopathy.

Advances in the understanding of external fixation also led to improvements in clinical outcomes by using combined techniques of limited open reduction,[9,38] arthroscopic indirect reduction,[29,37,123] and percutaneous "augmented" external fixation. The complications of digital stiffness and overdistraction were reduced by using the external fixator as a neutralization device and using percutaneous Kirschner wires and bone graft to support impacted articular fragments.[106] Use of bone graft was also thought to enable earlier removal of the fixator[77] while providing structural support for the articular surface and improvements in radial length and alignment. "Nonspanning" external fixation in selected patients was reported to lead to improvements in early and late functional and radiographic outcomes,[84] and the technique and indications for this procedure continue to be refined.

Despite the ability to improve articular congruity, a prospective assessment of displaced intra-articular fractures with computed tomography (CT) documented progressive arthrosis of the radiocarpal joint in a high percentage of patients.[43] Interestingly, there was little correlation between patients' functional outcome and the presence or severity of arthrosis. This finding suggests that despite the best effort to restore articular alignment, post-traumatic arthrosis (perhaps asymptomatic) may be unavoidable. In a randomized study in which patients with unstable fractures were treated by either closed reduction, external fixation, or open reduction, improved functional results were directly related to restoration of carpal alignment in the sagittal plane (restoration of volar tilt), and no technique proved superior in this regard.[86]

The last decade has witnessed an unprecedented interest in internal fixation techniques: (1) columnar fixation with miniature or "fragment-specific" fixation[74,99] and (2) fixation of a wide variety of fractures with fixed-angle devices through a single volar approach.[91] Improvements in imaging and recognition of unstable fracture fragments have enabled surgeons to customize their approach and identify and rigidly fix highly comminuted fractures with internal fixation, thereby enabling earlier resumption of wrist motion. Enthusiasm for the new wave of implants and techniques has been tempered by reports of tendon rupture, hardware malposition, and loss of fixation, as well as by two prospective studies that demonstrated better patient outcomes with percutaneous techniques than with open reduction and plate fixation.[45,68] Yet with each new technique comes an expansion of our understanding of fracture behavior and an improved ability to treat a multitude of fracture patterns in a widely diverse group of patients.

The evidence on treatment of wrist fractures accumulated in the last century suggests four principal goals of intervention (ARMS). There is both general consensus and scientific evidence that restoration of the anatomy of the distal radius is closely linked to restoration of function. Consequently, closed or operative management should seek to restore:

1. *A*rticular congruity (to reduce the wear of articular cartilage and degenerative changes)
2. *R*adial alignment and length (to restore kinematics of the carpus and radioulnar joint)
3. *M*otion (digits, wrist, and forearm to optimize return to functional activities)
4. *S*tability (to preserve length and alignment until healing of the fracture)

We may modify our treatment based on the level of patient understanding, bone quality, compliance issues, or expectations. When we speak of "accepting" less than full attainment of these goals, we generally do so because of patient factors (systemic illness, age, activity level) rather than fracture pattern.

What is clear from an analysis of the evolution of wrist fracture treatment is that no single technique or method will yield results superior to those of all other treatment methods, given the wide divergence in fracture subtypes, energy associated with the injury, age, activity level, and related injuries. The indiscriminate use of one method to treat all fractures of the distal radius will predictably lead to cases of fixation failure, soft tissue injury, and inability to achieve the goals of intervention.

FRACTURE EVALUATION

PERTINENT ANATOMY

The distal radius functions as an articular plateau on which the carpus rests (Figures 17.1 and 17.2) and from which the radially based supporting ligaments of the wrist arise (Figure 17.3). The hand and radius, as a unit, articulate with and rotate about the ulnar head via the sigmoid notch of the radius (Figure 17.4). This latter relationship is maintained primarily by the ulnar-based supporting ligaments of the wrist: the TFCC.

The distal radius has three concave articular surfaces—the scaphoid fossa, the lunate fossa, and the sigmoid notch—for articulation with the scaphoid, lunate, and ulnar head, respectively (Figures 17.5 and 17.6). The sigmoid notch is concave, with a poorly defined proximal margin and well-defined dorsal, palmar, and distal margins (see Figure 17.6).

The distal articular surface of the radius has a radial inclination, or slope, averaging 23 degrees and tilts palmarly an average of 11 degrees (Figure 17.7A). Radial inclination is measured by the angle formed by a line drawn tangential to the distal radial articular surface on a posteroanterior (PA) radiograph and one perpendicular to the shaft of the radius. Palmar tilt is measured by the angle created by a line drawn between the dorsal and palmar lips of the lunate facet and the longitudinal axis of the radius. This angle is probably best appreciated on a *facet lateral* radiograph, performed with the beam inclined approximately 10 to 15 degrees distal to proximal, to profile the articular surface of the lunate facet and eliminate the bony overlap of the radial styloid (see Figure 17.7B). Ulnar variance averages just under 1 mm negative[88] and ranges widely; variance is the axial difference between the subchondral bone of the lunate facet at the distal margin of the sigmoid notch and the most distal articular surface of the ulna, measured along the longitudinal axis of the forearm (see Figure 17.7A).

The dorsal aspect of the distal radius is convex and acts as a fulcrum for extensor tendon function (see Figure 17.5). The radial styloid area may have a groove for the tendon of the first dorsal compartment, and ulnar to this is a dorsal longitudinal prominence, Lister's tubercle, which acts as a fulcrum for the extensor pollicis longus (EPL) tendon.

RADIOGRAPHIC PATHOANATOMY

When evaluating fracture radiographs, it is important to appreciate several relationships and bony landmarks that may have subtle but important aberrations because of the malposition of fracture fragments. Perhaps the most important of these bony landmarks of the distal radius is the “teardrop,”[88] which represents the volar projection of the lunate facet of the distal radius and the mechanical buttress for subluxation of the lunate (see Figure 17.5D). The teardrop projects 3 mm palmarward from the flat surface of the radial diaphysis, or 16% of the anterior to posterior height of the lunate facet.[1] A line drawn tangent to the subchondral bone of the articular surface through the tip of the teardrop normally subtends an angle of 70 degrees with the longitudinal axis of the radius (Figure 17.8A)[88]; consequently, subtle dorsal rotation of an extra-articular fractured radius will alter this relationship and decrease the teardrop angle. Similarly, an impaction injury that splits the lunate facet may drive the lunate into the metaphysis of the radius and rotate the teardrop relationship (see Figure 17.8B to D). The teardrop measures just 5 mm at its greatest width, thus making it difficult to gain rigid fixation with traditional volar implants.[53]

Another useful measurement on the facet lateral film is the anteroposterior (AP) distance, and it is measured between the distal apex of the dorsal and volar rims of the lunate facet (Figure 17.9A and B). The average AP distance is 20 mm in males and 18 mm in females, but for improved accuracy, the AP distance on the injured side should be compared with that on the uninjured side. An appreciably widened (or narrowed) AP distance, in relation to the opposite side, represents an alteration in the contour of the lunate facet secondary to impaction or articular split. Because contralateral films are not always available and radiographs may be magnified, a useful comparative (and scalable) landmark on a lateral film of the injured side is the lunate itself. In a normal wrist, the curvature of the lunate facet of the radius and the curvature of the lunate itself are well visualized on a facet lateral projection and virtually concentric. In an uninjured wrist, the AP distance is essentially equal to the diameter of a circle that represents the best fit to the proximal articular surface of the lunate (1.04 ± 0.09) (see Figure 17.9A). Fitting of a circle to the lunate articular contour is easily performed by using the digital toolbox on most modern picture-archiving and communication systems (PACSs). Nonconcentric articular contours or an altered AP/lunate diameter ratio suggests a sagittal split of the lunate facet, nonanatomic radiocarpal alignment, or both (see Figure 17.9B).

On the normal PA view, the dorsal rim of the radius projects 3 to 5 mm beyond the dense subchondral bone of the volar rim of the radius (Figure 17.10). Displaced fractures may increase, reduce, or invert this relationship, depending on the degree of sagittal plane rotation of the distal fragment. Breaks in the dense subchondral bone on the PA view can be recognized as step-offs or articular gaps, and impacted articular fragments can be identified as linear densities within the metaphyseal bone on either the PA or lateral view.

Careful analysis of fracture radiographs, thorough understanding of common fracture patterns, and an appreciation of the mechanism of the injury will allow the examining physician to classify the fracture and begin to formulate a treatment plan. Generally, standard radiographic views (PA, facet lateral, oblique) are sufficient to understand a fracture’s pathoanatomy. However, special imaging techniques, such as traction views after reduction, tomograms, or CT scans, provide a more accurate diagnosis of the displacement pattern, number of fragments, and degree of joint involvement at both the radiocarpal and radioulnar levels (Figure 17.11A to D). Though adding significantly to cost, three-dimensional reconstructions of CT scans of articular fractures more accurately define the number and presence of articular fragments and increase the probability of a combined approach for treatment.[53] Three-dimensional imaging also positively influences the number of patients treated operatively, but whether improved fracture visualization and changes in operative planning result in improved patient outcome will require further study.

RECOGNITION OF FRACTURE PATTERNS

Distal radius fractures tend to cluster in recognizable patterns, and it is important that the treating physician be familiar with the multiple fracture variants to recognize a fracture’s “personality,” that is, its behavioral characteristics, energy of injury, relative stability, associated soft tissue injuries, radioulnar involvement, and prognosis. The ideal fracture classification should provide reproducible anatomic, diagnostic, and prognostic considerations, assess the associated soft tissue lesions, and infer appropriate treatment. Physicians dealing with distal radius fractures should adopt a classification scheme that fulfills their own needs for clinical and scientific purposes. When reporting outcomes or designing a multicenter study, however, it is important that a system with a high degree of intraobserver and interobserver reproducibility be chosen.

The nature of many of the classifications mentioned later in the section “Classification” has been analyzed with regard to both interobserver and intraobserver reliability and reproducibility.[2,69] Observer agreement was considered adequate for the main types of the AO classification but was suboptimal when analyzing groups and subgroups. Interobserver agreement was rated moderate for the Mayo and fair for the Frykman, Melone, and AO classifications. Two studies concluded that these classifications lack the capacity for predicting outcome or comparing results among different studies.

COMMONLY USED EPONYMS

There are few areas of skeletal trauma in which eponymic descriptions are so commonly used; contemporary authors have purposely avoided assigning their name to a particular fracture type and instead have preferred to base classification of them on a variety of measurements, observations, and characteristics of the injury.

Colles’ Fracture

Figure 17.12 illustrates the typical features of a Colles’ fracture, or a distal radius fracture with dorsal comminution, dorsal angulation, dorsal displacement, radial shortening, and an associated fracture of the ulnar styloid.[22]

Smith’s Fracture

Figure 17.13 illustrates three types of fractures of the distal radius with volar displacement, classified as Smith's types I, II, and III by Thomas in 1957.[95,113]

Barton's Fracture

Barton's fracture is a displaced, unstable, articular fracture-subluxation of the distal radius with displacement of the carpus along with the articular fracture fragment.[8] Barton's fracture may be either dorsal or volar, as shown in Figure 17.13, and may also be classified as a Smith type II variant.

Chauffeur's or Backfire Fracture

Figure 17.14 illustrates a shear fracture with displacement of the carpus and avulsion of the attached radial styloid. The fracture earned its now antiquated name because of the propensity for the chauffeur to be struck by the backfire recoil of a starter crank on an early automobile engine. Despite its seemingly innocuous name, this fracture is notorious for concomitant injuries to the intercarpal and extrinsic radiocarpal ligaments.

Lunate Load, Die Punch, or Medial Cuneiform Fracture

Figure 17.14 illustrates this fracture, which classically represents a depression of the dorsal aspect of the lunate fossa; a portion of the lunate articular surface may also be impacted into the subchondral bone.[105]

CLASSIFICATIONS

Frykman's Classification

In 1967, Frykman proposed a classification that distinguished between extra-articular and intra-articular fractures of the radiocarpal and radioulnar joints and the presence or absence of an associated distal ulnar fracture (Figure 17.15).[34] This classification is useful; it is easy to learn and to communicate with colleagues, but it does not readily translate into prognostic or treatment utility.

Melone's Classification

In 1984, Melone introduced a classification of distal radial fractures in which he identified four major components of the distal radius: (1) the shaft, (2) the radial styloid area, (3) the dorsal medial facet, and (4) the volar medial facet (Figure 17.16).[89] This classification focused much needed attention on the important medial (lunate) facet of the distal radius (i.e., the "medial complex," the intermediate column, and the teardrop).

The AO Classification

In 1986, the Swiss Association for the Study of Internal Fixation (ASIF/AO) accepted a new classification of fractures that was further revised in 1990. In this classification system, applicable to all long bones, different fractures are broken down into three major types: type A (extra-articular), type B (partial articular), and type C (complete articular). This classification considers the severity of the fracture according to the extent of intra-articular involvement and metaphyseal comminution. It is important to understand the distinction between type B fractures, in which some portion of the articular surface remains in continuity with the metaphysis, and type C fractures, in which no portion of the articular surface is in continuity with the metaphysis (Figure 17.17). The three basic types are further subdivided into groups and subgroups to ultimately produce 27 different fracture patterns at the distal end of the forearm. Unfortunately, despite its ability to categorize virtually each variation of fracture, there is little interobserver agreement when the subdivisions are made; acceptable agreement is reached only when the three major subgroups are chosen.[2]

Mayo Clinic Classification

The classification system advocated by the Mayo Clinic group allows subclassification within types 1 to 4 based on whether the fracture is extra-articular or articular and whether the fracture is reducible or irreducible (Figure 17.18).

"Fragment-Specific" Classification

Robert Medoff developed a simplified intra-articular fracture classification by recognizing five major fragments, namely, the radial styloid, the dorsal wall, impacted articular fragments, the dorsal ulnar corner ("die punch" fragment[89,105]), and the volar rim fragment (Figure 17.19).[74] Articular fractures can be described by identifying their component fragments, either alone or in combination. To more fully understand a fracture and use this understanding to plan treatment, the surgeon should also identify (1) the primary direction of the fracture angulation (dorsal/volar) and (2) the mechanism of the injury (see the Fernandez classification later). The fragment-specific classification is treatment oriented because specific fixation with modular implants for each fracture component can be chosen.

Columnar Classification

Daniel Rikli and Pietro Regazzoni introduced an important conceptual framework for the understanding and treatment of articular fractures by recognizing the three columns of the wrist (Figure 17.20).[99] The radial column, or *lateral* column, is composed of the radial styloid and scaphoid facet of the radius; restoration of this column re-establishes both length and alignment of the articular surface in the frontal and sagittal planes. The intermediate column includes the lunate facet and is the primary load-bearing column of the radius. Fractures of the intermediate column include the dorsal "die punch" fragment, impacted articular fragments, and the volar ulnar corner fragment. Importantly, fractures of this column also disrupt the sigmoid notch of the radius and consequently the radioulnar joint. The medial column constitutes the rotational column of the wrist and includes the distal ulna, the triangular fibrocartilage, and the radioulnar ligaments. It is critical that one assess and treat instability of this column when treating fractures of the radius to restore normal rotation of the forearm. This, too, is a treatment-oriented classification system; Rikli and Regazzoni recommended orthogonally placed microplates to treat dual-column fractures of the radius and demonstrated the biomechanical and clinical efficacy of the concept.[98,99]

Fernandez' Classification

The author prefers the descriptive fracture classification developed by Diego Fernandez,[32] which is based on the *mechanism of injury* (Figure 17.21A).[11] In addition to the obvious bony injury to the radius, the associated ligamentous lesions, fractures of the neighboring carpal bones, and concomitant soft tissue damage are directly related to the direction and degree of trauma sustained. An understanding of the mechanism of the injury facilitates manual reduction through the application of a force opposite that produced by the injury and guides definitive treatment based on the direction and magnitude of impact, as well as the nature of associated soft tissue injuries. Fractures of the distal radius may be divided into the following five types, recognizable on standard PA, facet lateral, and oblique radiographs:

Type I fractures are extra-articular *bending fractures of the metaphysis* in which one cortex fails with tensile stress and the opposite one undergoes a variable degree of comminution (Colles' or Smith's type I fractures, AO type A1-3).

Type II fractures are *shearing fractures of the joint surface* (Barton's, reversed Barton's, and chauffeur's fractures, AO type B1-3).

Type III fractures are *compression fractures of the joint surface* with impaction of subchondral and metaphyseal cancellous bone. These are generally high-energy injuries and usually involve disruption of both the radial and intermediate columns (Mayo type III, medial complex, die punch, AO type C1-2).

Type IV, or *avulsion fractures of ligament attachments*, includes dorsal rim and radial styloid fractures associated with radiocarpal fracture-dislocations.

Type V fractures are *high-velocity injuries* that involve combinations of bending, compression, shearing, and avulsion mechanisms or bone loss. Typically, there is diaphyseal as well as severe metaphyseal and articular disruption (AO type C3).

This classification scheme details frequent associated soft tissue injuries and suggests a treatment algorithm for displaced fractures that incorporates each fracture category (see Figure 17.21A). Type I displaced bending fractures are best treated by a counterforce that will exert tension on the concave side of the angulation. In stable fractures, this force can be applied with a well-molded, three-point contact cast. Unstable fractures may be treated by either percutaneous or rigid internal fixation. Type II shearing fractures are highly unstable because of the obliquity of the fracture line and are therefore suitable for internal fixation. Restoration of the joint surface in type III compression fractures can be achieved acutely by applying tension to the joint capsule with finger traps, external fixators, or pins and plaster techniques. Unstable or impacted articular fragments require open reduction; percutaneous or internal fixation and subchondral support with bone graft are generally necessary. Type IV avulsion fractures are a constant component of radiocarpal dislocations caused by a combination of rotation and shear in predominantly young, healthy bone. Stabilization of large avulsion fragments with screw, wireform, or tension band fixation generally restores ligament stability. Finally, in the type V combined fracture or high-velocity injury, the fracture combines articular, metaphyseal, and diaphyseal disruption and may require a combination approach, including internal fixation, spanning external fixation, or spanning internal fixation (distraction or "bridge" plate).

The treating physician should not lose sight of the purposes of fracture stratification when confronted by the multitude of eponyms and classifications that have been developed. The purpose of a classification should be to both (1) catalog fracture types for subsequent reporting and comparison of outcome and (2) understand fracture anatomy and guide treatment. A useful initial approach is to simultaneously appreciate the complexity, mechanism, and relative energy of the injury by using the Fernandez system. For extra-articular fractures, the primary determinant of treatment becomes the relative stability of the fracture. For articular fractures, in addition to an understanding of relative stability, the physician must obtain the necessary radiographs or advanced imaging studies (or both) to determine the location, number, and displacement of the articular fragments, as well as the integrity of the radial, intermediate, and ulnar columns. Careful consideration of these factors should enable the physician to develop an appropriate treatment plan and, when indicated, the optimal surgical approach and fixation strategy.

Classification of Associated Injuries to the Distal Radioulnar Joint

Outcomes of treatment of distal radius fractures can adversely and seriously be affected by residual incongruity or instability of the radioulnar joint. Figure 17.21B illustrates a useful classification of concomitant ulnar injuries and guidelines for treatment. After satisfactory realignment of the radioulnar relationship is attained by restoring radial length and sagittal and coronal tilt, stability of the radioulnar joint depends on two factors:

- Restoration of the mechanical integrity of the sigmoid notch
- Continuity of the dorsal and volar radioulnar ligament components of the TFCC, which attach at the ulnar fovea (see Chapter 16)

Type I consists of *stable distal radioulnar joint* (*DRUJ*) *lesions*, which means that adequate reduction of the radius will render the joint clinically stable without disruption of the articular surface. Such lesions include

1. Avulsion of the tip of the ulnar styloid
2. Stable fracture of the neck of the ulna

In both, the primary stabilizers of the joint (foveal attachment of the TFCC) are intact.

Type II consists of *unstable DRUJ lesions*. Despite satisfactory reduction of the radius, the ulna is unstable as a result of

1. A massive tear of the TFCC
2. An avulsion fracture of the ulnar styloid through or below the fovea

These injuries usually require supination casting, repair of the TFCC, fixation of the avulsed ulnar styloid, or temporary cross-pinning of the radius and ulna to restore stability.

Type III includes *comminuted articular injuries* of either the sigmoid notch or the ulnar head, and these injuries require reduction and stabilization to restore articular congruency and prevent degenerative changes.

Fracture Stability

Certain fractures are unstable by definition or require surgical management in healthy adults and include:

- Open fractures
- Displaced shear fractures (type II)
- Comminuted and displaced articular fractures with articular impaction (type III)
- Fracture-dislocations (type IV)
- Combined injuries with metaphyseal-diaphyseal comminution (type V)
- Fractures complicated by nerve compression, compartment syndrome, or multiple injuries

The majority of fractures, including extra-articular and simple articular fractures, are not easily sorted into operative and nonoperative treatment regimens, and determination of fracture stability becomes a critical crossroad for fracture treatment. Treatment of inherently unstable fractures with casting will fail and result in loss of radial length, carpal alignment, or articular incongruity. Unnecessary casting in this scenario will prolong overall treatment time and cost, may lead to digital stiffness and trophic changes, and might require subacute surgical intervention or corrective osteotomy to restore alignment and function, depending on the particular patient needs. What is not immediately evident is how to identify stable and unstable fractures early to optimize patient outcome and minimize unnecessary surgery or ineffective cast immobilization.

In a cohort of 32 patients treated nonoperatively for unstable Colles' fractures, Bickerstaff and Bell demonstrated that the two best predictors of poor functional, subjective, and objective outcomes were residual dorsal tilt of the radial articular surface and the associated nondissociative dorsal lunate instability.[11] In a group of patients who required operative treatment of unstable fractures that failed closed reduction, McQueen and colleagues also demonstrated that failure to restore carpal alignment in the sagittal plane, as demonstrated on lateral radiographs at 1 year, was the single most predictive factor of worsening functional outcomes and objective measures of strength.[86] Failure to restore radial length was significantly associated with diminution in grip and pinch strength. The authors delineated a useful parameter of carpal malalignment on neutral-positioned lateral radiographs by defining intersecting lines of the capitate axis and the longitudinal axis of the radius. Carpal malalignment is defined when the two lines intersect outside the boundaries of the carpus (Figure 17.22).[86] In a perfect lateral radiograph, these two lines may be parallel and thus this method may not be accurate. I consider the carpus malaligned if the center of the capitate proximal pole does not lie within a "radial box" defined by the dorsal or volar cortical confines of the radius (Figure 17.23).

Numerous authors have attempted to determine parameters that are predictive of radial instability in the acute setting. Lafontaine and colleagues defined five "instability parameters" and demonstrated a linear relationship between the number of instability parameters present on displaced fracture films and ultimate fracture collapse with closed treatment[72]:

1. Dorsal angulation greater than 20 degrees
2. Dorsal comminution
3. Intra-articular radiocarpal fracture
4. Ulnar fracture
5. Age older than 60 years

The authors recommended that patients with three or more of the five parameters be considered for surgical intervention at an early stage of management. Although inclusion of all five factors is the subject of some controversy, subsequent authors have confirmed that age, loss of radial length, and initial dorsal angulation are the most important predictors of collapse with cast treatment. MacKenney and colleagues produced a quantitative, weighted formulaic approach to determination of fracture instability in a prospective study of 3559 patients with displaced and nondisplaced extra-articular fractures and demonstrated a surprising 60% malunion rate had all displaced fractures been treated by closed reduction.[82] Advanced age was the most predictive factor, and the nature of the fracture on the initial fracture films was also predictive of instability and malalignment at healing. Specifically, in addition to a “relentless” association of instability and malalignment with *age*, *dorsal comminution* and *increased ulnar variance* (>3 mm) were important predictors of subsequent loss of reduction in plaster. Initial dorsal angulation was not predictive because it was confounded by the presence of dorsal comminution in the multivariate analysis.

Taken together, though not infallible, it is evident that patient age and the position and comminution of the fracture on initial trauma films can be vital predictive tools for assessment and formulation of treatment plans. Patients with a constellation of instability factors should be advised of the relative probability of loss of reduction, and physiologically young or active patients should be counseled concerning the option of early operative intervention. Patients with initial radial shortening and dorsal comminution, particularly if older than 60 years, who elect to not undergo surgical stabilization should be observed weekly for radiographic evidence of fracture settling. Understanding that malunion and carpal malalignment are important predictors of diminished strength and function in otherwise healthy adults should enable the physician to tailor the treatment expeditiously.

TREATMENT OPTIONS

Closed Reduction

The greatest challenge of closed treatment of a dorsally angulated fracture is to reduce the fracture and maintain the position without excessive flexion of the wrist joint. Inherently unstable fractures with initially acceptable closed reduction will often redisplace and shorten secondary to the resting muscular tension, occasional involuntary contraction, and the load transmitted from normal digital motion. Although *extreme* palmar flexion and ulnar deviation (the so-called Cotton-Loder position[24]) may be mechanically effective in restoring volar tilt, this position cannot be maintained because a fully flexed wrist may cause compression of the median nerve and is mechanically disadvantageous to the digital flexors.

Technique of Closed Reduction

In preparation for closed reduction, the first step is gentle surgical preparation of the dorsal surface of the wrist. The hematoma associated with the fracture is then sterilely infiltrated with 1% lidocaine without epinephrine, and the anesthetic is allowed to diffuse about the fracture site for approximately 5 minutes. If the fracture is seen late and there is significant soft tissue swelling, a regional nerve block (axillary) or general anesthesia may be necessary. The arm is gently suspended with finger traps attached to the thumb, index, and long fingers (Figure 17.24) and 5 to 10 lb of countertraction across the upper part of the arm.

The patient is asked to relax. After allowing the arm to hang from the finger traps for 5 to 10 minutes, pressure is applied by the treating physician’s thumb to the distal fracture fragment in a direction that will reduce the displacement (see Figure 17.24D). For a dorsally displaced fracture, the distal fragment is rotated with the treating physician’s thumb into a slightly flexed position with a palmarly directed force. Care should be taken to avoid overpronation of the fracture fragment on the radial shaft. When the distal fragment is translated dorsally as well as angulated, I find it helpful to simultaneously distract and hyperextend the fracture first to disimpact the fracture fragments before subsequently reducing the deformity with a traction/flexion maneuver. A stable reduction will generally hold its position with the wrist only slightly flexed and ulnarly deviated. A sugar tong splint is applied to maintain the position (some prefer to apply the splint while still suspended in finger traps), and the fracture reduction can be fine-tuned as necessary with the splint in place (Figure 17.25). Molding over the index metacarpal, with a countermold over the palmar apex of the fracture site, is helpful to maintain fracture position. The recommended position of immobilization for a dorsally angulated metaphyseal fracture is neutral to slight flexion, 20 to 30 degrees of ulnar deviation, and neutral forearm rotation (Figure 17.26). Radiographs are obtained to confirm reduction. Although palmarly displaced, extra-articular Smith’s fractures are generally unstable, the flexion-pronation deformity of Smith’s fractures can be reduced and occasionally stabilized effectively in extension and supination (45 to 60 degrees) with a sugar tong splint.

Depending on the type and stability of the fracture, patients should initially be examined weekly with cast checks and serial radiographs. Patients with stable fractures can be changed to a well-molded short arm cast at 2 or 3 weeks. The principles of three-point bending should be used to help maintain reduction; dorsal molds are applied over the metacarpals and the mid-diaphysis of the radius and a third palmar countermold over the apex of the fracture. “Six-pack” digital exercises are begun immediately to reduce edema and prevent contractures and disuse atrophy (Figure 17.27). If displacement in the cast occurs, skeletal fixation should be strongly considered for young or physiologically active patients.

Percutaneous Pin Fixation

Gartland and Werley warned us that upward of 60% of distal radial fractures will displace in plaster and assume their pre-reduction position.[35] Percutaneous pinning, supplemented by an external fiberglass cast, is a relatively simple and effective method of fixation that is applicable for reducible extra-articular fractures and simple intra-articular fractures without metaphyseal comminution but with good bone quality.

A variety of different techniques have been described, and the most commonly used methods are shown in Figure 17.28. These include pins placed through the radial styloid alone, crossed radial styloid and dorsal ulnar corner pins, intrafocal pinning *within* the fracture site, transulnar oblique pinning without transfixation of the DRUJ, one radial styloid pin and a second across the DRUJ, and multiple transulnar-to-radius pins, including the DRUJ.[97]

The procedure is done in the operating room, usually under brachial block anesthesia with fluoroscopic guidance. The hand is prepared and suspended in finger traps with 5 to 10 lb of countertraction applied across the upper part of the arm. Closed reduction is performed and the adequacy of reduction confirmed fluoroscopically. Pinning of the fracture may be done while traction is maintained, or the hand may be removed for ease of manipulation, with 0.0625-inch Kirschner wires being preferred. The pins can be inserted with a minidriver by using only one hand so that the surgeon's other hand is left free to manipulate and stabilize the fracture. Care must be taken to avoid injury to the dorsal sensory nerves, particularly when transfixing the radial styloid. The styloid pin is inserted first to simultaneously restore length and inclination of the distal fragment. At the tip of the styloid, the surgeon brackets the tendons of the first dorsal compartment with his fingers and identifies the starting point of the styloid pin immediately dorsal to the tendons. A 0.062-inch Kirschner wire is placed by hand through the skin to engage the tip of the styloid and the position checked with fluoroscopy. The pin is directed obliquely to engage the stout diaphyseal bone of the opposing cortex at the metaphyseal flare. Position of the fracture is assessed, and a few additional degrees of volar tilt can be "dialed in" by rotating the fragment around the styloid wire. The second 0.062-inch Kirschner wire is placed at the dorsal ulnar corner of the radius, just radial to the sigmoid notch, and between the fourth and fifth extensor compartment tendons. It is easiest if a free Kirschner wire is placed percutaneously and its position checked before engaging the wire driver. The ideal starting position is just ulnar to the fourth dorsal compartment tendons in the "soft spot" of the 4-5 arthroscopy portal. The wire is gently navigated through the subcutaneous tissues to engage the bone and its position confirmed with fluoroscopy. The Kirschner wire is then drilled at 45-degree angles to the frontal and sagittal planes to engage the opposing stout volar bone well *proximal* to the fracture line. After confirmation of reduction, a second styloid wire will increase the stability of the construct. For simple articular fractures, a fourth wire can be placed as necessary between the third and fourth dorsal compartments to stabilize the scaphoid facet fragment, but this is rarely necessary. Before completion of the procedure, the extensor tendons are checked by passive flexion of the digits and wrist flexion tenodesis to be certain that tendons have not been tethered. Any skin tethering is relieved with a No. 11 scalpel blade. The pins are bent and cut off 1 cm above the skin and pin caps or petroleum gauze applied. A well-padded sugar tong splint in supination is applied for 3 weeks, followed by a short arm cast for an additional 3 weeks. Full forearm rotation is allowed after 2 weeks. The cast and pins are removed 5 to 6 weeks after reduction (Figure 17.29).

Kapandji has popularized the technique of "double intrafocal wire fixation" to both reduce and maintain distal radial fractures (Figure 17.30).[60] This technique is best reserved for simple extra-articular fractures and is not without complication. Under fluoroscopic guidance, one Kirschner wire is inserted into the fracture site in a radial to ulnar direction until the ulnar cortex of the radius is felt. The wire driver and wire are then moved distally to "lever" the distal radial fragment to regain normal radial inclination. The wire is then advanced through the ulnar cortex. A second wire is next inserted into the fracture 90 degrees to the first wire in a dorsal to palmar direction. The wire is advanced until the palmar cortex of the radius is contacted. Next the wire and wire driver are moved distally to "lever" the fragment into its normal position of 12 to 15 degrees of palmar inclination. This second wire is then advanced through the palmar cortex of the radius.

External Fixation

Since the original idea of Roger Anderson of applying skeletal traction with a "portable" external fixation device for the treatment of comminuted distal radial fractures,[3] there has been constant evolution in both technique and design technology. One of the two most important developments has been the recognition that excessive distraction was harmful and associated with multiple complications and poor outcomes.[58] The second development was that distraction alone (ligamentotaxis) could not reduce displaced and impacted articular fragments. Modern techniques include limited open or arthroscopic reduction of the articular surface, subchondral support with bone graft or bone graft substitute, and "augmentation" with supplemental pin fixation. Augmentation of fixation allows the fixator to be placed in a neutralization mode with only minimal distraction, thereby enabling immediate use of the fingers for light activity. Early controlled motion of the wrist is sometimes possible between 4 and 6 weeks after the injury by removing the fixator and leaving the pins in place for several additional weeks (Figure 17.31).

Several studies have demonstrated the efficacy of these combined procedures. Seitz and coauthors reported satisfactory results in 92% of 51 patients with an average age of 50 years.[106] Jakim and associates produced excellent results in 83% of a series of 132 patients with a combination of external fixation, limited open reduction, and internal fixation with Kirschner wires.[55] Leung and associates combined external fixation with autogenous bone grafting in 100 fractures; the frame was removed as early as 3 weeks after the operation, and functional bracing was used for another 3 weeks.[76] Patients were rated good or excellent in nearly all cases. In a number of recent articles reporting the use of combined techniques and a relatively short period of static external fixation, final wrist motion averaged 120 degrees of flexion-extension and 140 to 150 degrees of forearm rotation.[38,124]

Technique of External Fixation

Under brachial block or general anesthesia, the anesthetized upper extremity is prepared sterilely in the operating room from the fingertips to the lower part of the arm, just below a pneumatic tourniquet that has been applied to the arm. Sterile finger traps and a traction device may be used if preferred. Manual reduction is performed to grossly align the fracture fragments and approximate normal length, alignment, and tilt (see Figure 17.24).

A 2- to 3-cm-long incision is made over the dorsal radial aspect of the index metacarpal base. Blunt dissection with scissors exposes the metacarpal while carefully preserving and reflecting branches of the dorsal radial sensory nerves. A soft tissue protector is then placed on the metacarpal, and 3-mm self-tapping half-pins are inserted at a 30- to 45-degree angle dorsal to the frontal plane of the hand and forearm. Pin position and length are confirmed with portable fluoroscopy. Next, a 4-cm skin incision is made 8 to 10 cm proximal to the wrist joint and just dorsal to the midline. Blunt dissection exposes superficial branches of the lateral antebrachial cutaneous nerve, the brachioradialis, the two radial wrist extensors, and the radial sensory nerve, which exits in the mid-forearm from the investing fascia between the brachioradialis and the extensor carpi radialis longus (Figure 17.32). Two

3-mm half-pins (1.5 cm apart) are then introduced through a soft tissue protector between the radial wrist extensors at a 30-degree angle dorsal to the frontal plane of the forearm. The pins should just perforate the medial cortex of the radius and should be confirmed fluoroscopically. Both wounds are irrigated and closed with 4-0 nylon sutures before applying the frame. For relatively stable fractures and when performing augmented fixation with Kirschner wires or graft (or both), a simple single-bar external fixation frame is ideal. The particular design or strength of the frame is less important from a mechanical perspective than the degree of stability attained by the supplemental Kirschner wires (Figure 17.33).[122] Some surgeons prefer more complex fixators such as the "Wristjack" external fixator (Hand Biomechanics Lab, Sacramento, CA), which allows independent palmar carpal translation, with which the volar tilt can be adjusted.

If nonbridging external fixation is selected for a minimally comminuted extra-articular or simple articular fracture with good bone stock, proximal pin insertion remains identical but the distal pins are introduced exclusively into the distal fragment. A radial-sided pin is placed through a small dorsal radial incision between the wrist extensors in the radial half of the distal fragment. Its direction is dorsal palmar, parallel to the joint surface in the sagittal plane. A second pin is placed in the ulnar aspect of the distal fragment through a limited incision between the fourth and fifth extensor compartments. Its direction is also dorsal palmar, but it is aimed slightly obliquely from the ulnar to radial side to engage the palmar ulnar cortex of the distal fragment. Having securely fixed the distal pins, closed reduction is performed by using the distal pins as "joysticks" to restore volar tilt.[44,84] The pins are assembled with separate clamps and rods to create a triangular frame (Figure 17.34).

Augmented External Fixation

For all but minimally comminuted extra-articular fractures, augmented external fixation is recommended to provide additional support to individual fracture fragments and increase construct stability.[125] For unstable fractures without depressed articular fragments, 0.045- or 0.0625-inch Kirschner wires are introduced into the fracture fragments in a crossed configuration for maximal stability according to the technique described earlier. One or two pins driven through the radial styloid fragment and one through the dorsal ulnar fragment into the radial shaft combine to produce maximum additional stability.[125] The pins should pierce the ulnar cortex of the radius but not penetrate into the ulnar shaft. The pins are cut off 1 cm external to the skin margin and bent at an acute angle.

Impacted and severely displaced fragments that do not respond to ligamentotaxis or external reduction maneuvers require additional limited open reduction. The concept of limited open reduction is defined as selective surgical exposure of articular fragments that still remain displaced after the application of traction, closed manipulation, or percutaneous manipulation. The main objective of this technique is to achieve anatomic reduction with limited exposure and to minimize the use of implants in an effort to preserve ligament attachments, thereby minimizing iatrogenic soft tissue disruption and preserving the vascular supply of the fragments. This technique is particularly useful for intra-articular four-part fractures of the distal radius without metaphyseal comminution. Articular tilt, radial length, and reduction of the radial styloid fragment can usually be achieved with classic closed reduction maneuvers alone or combined with longitudinal traction. However, the dorsal ulnar and volar ulnar fragments that disrupt the lunate fossa and the sigmoid notch may remain displaced because of either impaction or soft tissue interposition (Figure 17.35). The technique of limited open reduction addresses the anatomic restoration of such fragments after percutaneous fixation of the radial styloid fragment.

After grossly aligning the fracture fragments, the external fixator is applied in slight distraction (see earlier), and the wrist joint is approached through a 3- to 4-cm dorsal longitudinal midline incision (Figure 17.36A-B). The extensor retinaculum is opened over Lister's tubercle and the EPL transposed radially. The fourth compartment is opened and a 2-cm section of the posterior interosseous nerve may be excised at the discretion of the surgeon. The EPL is retracted to the radial side and the finger extensors to the ulnar side. The wrist capsule is left intact; rarely is it necessary (or helpful) to perform an open inspection of the articular surface when using modern portable fluoroscopy. If examination of the joint is deemed necessary, the surgeon is afforded a more complete view of all articular surfaces and associated soft tissues with the arthroscope (see the next section). The radial styloid fragment is then reduced anatomically and stabilized with a single 0.062-inch Kirschner wire or cannulated screw as mentioned previously (Figure 17.37). Any traction that has been applied at this point is reduced, and the impacted articular fragments are elevated en bloc with a Freer elevator or a pointed awl by using the apposing articular surfaces of the lunate and scaphoid as a template. The congruency of the reduction is checked with fluoroscopy, and the resultant metaphyseal void beneath the reduced subchondral bone is then packed with autogenous bone graft or structural bone graft substitute (see p. 593). Most advocates of augmented external fixation routinely graft all subchondral bone defects regardless of the size of the defect if the articular surface has been elevated. The bone graft provides mechanical buttressing of small cartilage-bearing fragments and may accelerate fracture healing by providing additional osteogenic potential. A second 0.045- or 0.062-inch Kirschner wire is then directed from the radial styloid transversely across the radius immediately beneath and tangent to the articular surface to engage the cortical bone of the sigmoid notch. Care is taken to avoid protrusion of the wire into the radioulnar joint (see Figure 17.37B).

If there is joint incongruity involving the sigmoid notch of the radius, every attempt is made to achieve anatomic reduction. Usually, this can be accomplished with percutaneous manipulation of the fragment with a Kirschner wire and Kirschner wire fixa-tion of the fragment to the stout volar metaphyseal bone (see earlier). If irreducible by percutaneous means, there may be soft tissue interposition, and limited open reduction is required. To gain access to the fragment, the fourth dorsal compartment tendons are retracted radially, and the extensor digiti mimimi, which lies directly over the DRUJ, is exposed and retracted to the ulnar side. Great care is taken to avoid disruption of the dorsal radioulnar ligament when exposing and realigning this fragment, and the periosteum is left intact to avoid vascular stripping. A 0.045-inch Kirschner wire can be passed at a 45-degree angle to the frontal and sagittal planes to engage the distal and ulnar margin of the dorsal ulnar fragment and secure it to the opposing palmar cortical bone. The reduction and fixation are confirmed with fluoroscopy.

If an unstable volar ulnar fragment is identified, reduction and fixation through a limited volar approach must be performed to prevent subsequent volar displacement of the carpus (see Figure 17.35). Percutaneous fixation of the volar ulnar fragment is not recommended because of the density of neural, vascular, and tendinous structures overlying it.

The fixator is then adjusted to a neutral position in the frontal and sagittal planes, and any excess traction is removed. Full passive flexion and extension of the digits and thumb are ensured at this time to be certain that there is neither residual distraction nor tethering (see Figures 17.33 and 17.35). The wound is closed by reapproximating the extensor retinaculum while leaving the extensor pollicis transposed. DRUJ stability is assessed with a manual “shuck” test of the radioulnar joint. Gross instability must be treated to avoid long-term sequelae (see earlier).

The external fixator pin clusters are dressed with a compressive wrap to prevent skin shear, the wounds are covered, and the wrist is immobilized in a light compressive bandage with a supportive plaster splint. I prefer to immobilize the wrist in a supinated position with a sugar tong splint for 10 days until the pain and swelling have subsided to promote DRUJ stability and facilitate resumption of full supination postoperatively. The frame is usually removed at 6 weeks and the supplemental pins kept in place for 8 weeks postoperatively. It is recommended that the patient clean the skin-pin interface with peroxide once or twice daily until the wounds have sealed to help prevent pin track infection. Active and passive finger motion is begun as soon as the anesthetic wears off and is encouraged for the entire time that the frame is in place. Supination-pronation of the forearm is begun at the first postoperative visit and its importance re-emphasized throughout the postoperative period. Supervised hand therapy is begun for patients who are unwilling, uncomfortable, or unable to mobilize their fingers and forearm independently.

CRITICAL POINTS: AUGMENTED EXTERNAL FIXATION

Indications

- Unstable extra-articular fractures of the distal radius (type I bending)
- Impacted articular fractures (type III compression)
- Comminuted unstable fractures with articular and metaphyseal involvement

Contraindications

- Severe osteoporosis
- Volar shear fractures (type II, Smith’s type II, volar Barton’s)
- Patient preference, compliance concerns, or inability to care for the external fixation and pins

Technical Points

- Closed reduction with traction, finger traps, or both
- Mini-open placement of proximal and distal fixation pins to the index metacarpal and radius
- Placement of fixator pins in a plane 45 degrees oblique to the sagittal and frontal planes
- Closure of pin cluster incisions before assembly of the fixator
- Gross alignment of the fragments by fixation in moderate traction, flexion, and ulnar deviation
- Mini-open dorsal incision over the third dorsal compartment and transposition of the EPL
- Reduction of traction and elevation of impacted articular fragments with an elevator against the carpus
- Fluoroscopic check of reduction and support of fragments with graft or substitute.
- Percutaneous 0.062- or 0.045-inch Kirschner wire or screw fixation through the radial styloid
- Percutaneous 0.045-inch Kirschner wire fixation transversely below the reduced subchondral bone
- Crossed percutaneous 0.062-inch Kirschner wire through the dorsal ulnar corner
- Assessment of the volar ulnar fragment and performance of limited open reduction and fixation if needed
- Revision of the fixation posture to a neutral wrist angle to facilitate digital mobility and function
- Assessment of the DRUJ for stability and augmentation as needed

Postoperative Care

- Apply a sugar tong splint in supination for 5 to 10 days until suture removal.
- Begin digital range of motion exercises immediately.
- Use peroxide or dry pin care, and apply compressive wraps until the wounds are sealed.
- Begin forearm rotation and gentle active wrist motion exercises at the initial postoperative visit.
- Evaluate with radiographs at the initial postoperative visit and at 2 and 6 weeks postoperatively.
- Remove the fixator at 6 weeks while leaving the Kirschner wires in place for 2 additional weeks.

Arthroscopic Reduction and Percutaneous Fixation

Diagnostic and therapeutic wrist arthroscopy is widely used by many practicing hand surgeons. Its use in conjunction with percutaneous means of fracture fixation offers several advantages in the management of articular fractures of the distal radius.[29,40] Arthroscopy presents a minimally invasive means of monitoring articular reduction, without the additional ligamentous and capsular damage that is inherent with open inspection of the articular surface. In addition, the arthroscope affords an unparalleled diagnostic view of the interosseous carpal ligaments, the carpal articular surfaces, and the TFCC. If indicated, arthroscopic or limited open management of concomitant soft tissue injuries of the carpus or DRUJ may be undertaken simultaneously. Although the addition of arthroscopic inspection and reduction adds additional operating room time and equipment, there is evidence to suggest that outcomes are improved. Doi and associates demonstrated improvements in range of motion and fracture reduction in a prospective cohort of patients treated by arthroscopically assisted percutaneous fixation when compared with a group treated by conventional open reduction and internal fixation (ORIF) for displaced intra-articular fractures of the distal radius.[29]

Technique: Arthroscopic Reduction and Percutaneous Fixation

When considering arthroscopically assisted reduction and fixation of an intra-articular distal radius fracture, it is prudent to reduce and stabilize the fracture in plaster for 3 to 7 days before surgery. Treatment of fractures acutely by arthroscopic means may limit visibility secondary to bleeding and may risk the development of compartment syndrome because of extravasation of fluid into the soft tissues. After 7 days, however, it becomes difficult to elevate impacted articular fragments without a formal open reduction.

The arm is prepared sterilely, draped in the usual manner, and suspended from sterile finger traps attached to the index and long fingers (Figure 17.38). The forearm may be exsanguinated with an Esmarch bandage, which may be left in place from just proximal to the wrist up to the elbow to prevent extravasation of fluid into the soft tissues. Alternatively, an elastic bandage may be wrapped about the hand and forearm to reduce soft tissue swelling. I prefer to perform the arthroscopic portion of the procedure without a tourniquet and save tourniquet time for any open reduction that may be required. The fracture is then evaluated under fluoroscopic guidance and the fracture fragments manually manipulated into position. As an alternative to finger trap or tower traction, an external fixation device may be applied before arthroscopy of the wrist to obviate the need for suspension traction.[123]

The arthroscope is inserted through the 3-4 portal, and an outflow portal is established in either the 4-5 or 6U position. Immediate and copious irrigation is critical to clear clot and debris and improve visualization. Once this is done, continuous irrigation is maintained through the 6U portal, and working portals may be established in the 1-2 or 4-5 positions (or both). Doi and associates demonstrated the additional utility of a volar radial portal created by means of a limited open incision over the flexor carpi radialis (FCR) tendon.[29] Kirschner wires (0.0625 inch) are useful as percutaneous “joysticks” when placed into the radial styloid and other large articular fragments. Reduction of the fragment is then accomplished with the joysticks under fluoroscopic control and the reduction stabilized as mentioned previously with either 0.045- or 0.0625-inch Kirschner wires (see Figure 17.38D and E). Impacted articular fragments can be elevated through a mini-open dorsal approach (see earlier) and supported with bone graft or substitute. Pins can be replaced with cannulated screw fixation at the discretion of the surgeon.[50,68] If using pin fixation alone, the wrist must be supported in a plaster cast until healing. If using augmented external fixation, the wrist posture is returned to neutral, and the forearm is immobilized in a supinated position for 7 to 10 days with a light sugar tong dressing. The cast or fixator is generally removed at 4 to 6 weeks, depending on the fracture and use of bone graft; percutaneous pins are usually removed 2 to 3 weeks later.

Additional Soft Tissue Injuries

Concomitant complete tears of the scapholunate or lunotriquetral ligaments should be reduced anatomically and pinned or treated by limited open reduction, repair, and pin or screw fixation (see Chapter 15). A minimum of two divergent pins or a temporary compression screw should cross the affected intercarpal articulation, and one or two additional pins should be placed to temporarily stabilize the proximal row to the distal carpal row across the midcarpal joint. Intercarpal pins are left in place for at least 8 weeks and a slowly graduated program of range of motion and resistive exercises begun thereafter. If using a temporary scapholunate screw, the device can be left in place while gentle midcarpal motion is begun with a dart thrower’s rehabilitation protocol[25] (see Chapter 15); the screw may be removed 4 to 6 months postoperatively. Complete peripheral detachment of the articular disk of the TFCC can also be treated by arthroscopically guided suture placement at the time of fracture reduction (see Chapter 16).

Technique of Harvesting Iliac Bone Graft

After a rolled towel has been placed under the ipsilateral sacroiliac joint, the iliac crest region is sterilely prepared and draped. A 5-cm-long incision is made over the iliac crest beginning 2 cm posterior to the anterior superior iliac spine and coursing posteriorly. With straight and curved 1-cm osteotomes, a section of the iliac crest 3 cm in length and 1 cm thick is reflected on its medial periosteum. This exposes an abundant area of cancellous bone between the two cortical wings. Cancellous bone is harvested and preserved in a moist saline-soaked sponge. The flap of iliac crest is then turned back down into its bed and sutured in place. (This technique leaves virtually no cosmetic defect to either the eye or touch along the iliac crest.) The wound is then closed in layers over a suction catheter drain. Alternatively, a bone trephine set can be used to harvest one or more bicortical 10- to 12-mm plugs from the iliac wing through a 1- to 2-cm incision. Each harvest site is filled with thrombin-soaked Gelfoam for hemostasis and the area infiltrated with a long-acting anesthetic. This procedure reduces the pain and local morbidity of iliac crest graft harvest, can be performed under local anesthesia with sedation, and generally obviates the need for an overnight stay or ambulatory assistance postoperatively.

Bone Graft Substitutes

Bone graft substitutes may be used as an alternative to the harvesting of autogenous bone. With acute fractures, the need for structural support of the elevated articular surface generally outweighs the need for osteogenic stimulation of healing (see Figures 17.33 and 17.35). The intact radial metaphysis is normally a potent source of osteogenic cells, growth factors, and osteoinductive cancellous bone, and fractures through this area have a strikingly low rate of delayed union or nonunion. The ability to expedite fracture healing by the addition of biologic products has not been demonstrated, except in situations in which healing potential has been compromised by disease or tobacco use.[71] Thus, bone graft substitutes that demonstrate compressive properties equal to or greater than cancellous bone are of greater utility in the management of comminuted articular fractures than are purely osteogenic or combined osteogenic–moldable putty formulations. For unstable Colles' fractures in elderly or osteoporotic patients, the use of methylmethacrylate bone cement has been attempted, but it has not been widely accepted because of methylmethacrylate's brittle mechanical profile and its exothermic properties. Two prospective studies demonstrated modest improvements with an injectable calcium phosphate cement as an adjunct to percutaneous fixation of distal radius fractures when compared with casting or external fixation alone, but high complication rates and cement extrusion plagued both studies.[16,104] The specific advantages and disadvantages of several common bone graft alternative categories are presented in Table 17.1. Proprietary names and specific commercial formulations are not listed.

Open Reduction and Internal Fixation

Open reduction of articular fractures of the distal radius is indicated in active patients with good bone quality when anatomic restoration of the joint surface cannot be achieved by closed manipulation, ligamentotaxis, or percutaneous reduction maneuvers or as an alternative to percutaneous fixation at the preference of the patient or surgeon. There is increasing evidence to support equivalent functional, clinical, and radiographic outcomes of fixed-angle internal fixation when compared with percutaneous and indirect fixation (Jupiter J, personal communication, 2008),[80,126] and it is an attractive alternative to the bulkiness and pin care issues of external fixation. Open reduction has also been demonstrated to yield improved radiographic alignment when compared with percutaneous and repeat closed reduction for fractures that have lost reduction after a trial of closed reduction and casting.[86] Articular fractures in elderly, inactive patients and in those with massive osteoporosis have traditionally been considered a contraindication to open reduction because in these patients there is a risk for complications, including failure of fixation, nonunion, and reflex sympathetic dystrophy. However, since the recent introduction of "fixed-angle" internal fixation devices, both unstable extra-articular and simple articular fractures in elderly, active osteoporotic patients have increasingly satisfactory outcomes with ORIF.[92] Subchondral buttressing with fixed-angle pins or screws secured to the plate greatly reduce the incidence of settling or secondary articular displacement (Figure 17.39).

General factors limiting surgical reconstruction of the articular surface include the number of fragments, their size, the amount of cancellous bone impaction, and associated traumatic lesions of the articular cartilage. Alternatives to open anatomic restoration should be considered if the articular comminution involves more than four to five fairly sizable fragments. Every effort should be made to improve the anatomic relationship of the radius and ulna and ensure normal alignment of the hand and carpus with the long axis of the forearm by percutaneous and indirect means. If secondary radiocarpal arthritic changes occur, the absence of metaphyseal malunion and shortening will greatly facilitate the performance of secondary reconstructive procedures.

The choice of surgical approach depends on the location and direction of displacement of the fracture fragments. Thus, dorsally or radially displaced fractures have been classically approached through dorsal incisions, whereas volarly displaced fractures (Smith's and reversed Barton's) are classically approached through palmar exposures. There has been increased interest in the management of dorsally displaced nonarticular and articular fractures with volar fixed-angle plate fixation in an attempt to decrease the incidence of extensor tendon irritation associated with dorsally applied implants. Palmar incisions are also appropriate for primary repair of a torn wrist capsule in radiocarpal fracture-dislocations and whenever primary median nerve decompression or fasciotomy of the flexor compartment is indicated. When using multiple plate or "fragment-specific fixation," dorsal, radial palmar, ulnar volar, and ulnar incisions are used in combination, as dictated by the particular fracture configuration.

Dorsal Plate Fixation

Although overall satisfactory outcomes have been reported with dorsal plating systems, the incidence of extensor tendon complications, including irritation, synovitis, attrition, and tendon rupture because of direct contact of these structures with the dorsal plates, is not negligible.[5,15,59] Low-profile and stainless steel plates may have a decreased incidence of dorsal tendinopathy,[108] but with the increased versatility, mechanical strength, and ease of application of fixed-angle volar devices, isolated dorsal plate fixation for distal radius fractures is decidedly less common.

"Universal" Dorsal Approach to the Distal Radius

If a single dorsal plate is used to stabilize an unstable distal radius fracture, the patient should be informed of the risk of tendinopathy and implant removal. A 3- to 10-cm straight dorsal incision is made just ulnar to Lister's tubercle, centered over the radial metaphysis. Full-thickness skin flaps are raised at the retinacular level, including the dorsal sensory branches of the radial and ulnar nerves. An ulnar-based retinacular flap is begun just radial to the second compartment and elevated to expose the EPL and the tendons of the fourth compartment. A 2-cm segment of the posterior interosseous nerve is removed at the discretion of the surgeon. Subperiosteal exposure yields direct visualization of the fracture fragments, and rarely is it necessary to violate the wrist capsule. Direct and indirect reduction of the fracture fragments is performed and confirmed with fluoroscopy, and temporary fixation is performed with Kirschner wires through the styloid and dorsal ulnar corner. Articular reduction is facilitated with the use of a Freer elevator and subchondral elevation, with the carpus being used as a template for reduction. Placement of the plate may be facilitated by removal of Lister's tubercle and insertion of conventional screws or 2.0- and 2.7-mm fixed-angle pegs and screws to support the subchondral bone. The tendons of the second and fourth compartments are replaced over the plate, and a portion of the retinaculum can be used as an interposition flap between the tendons and the distal plate. The EPL tendon is primarily transposed to a subcutaneous position when closing the dorsal retinaculum (Figure 17.40).

When performing conventional dorsal plate fixation of the distal radius, use of autogenous iliac bone graft or an appropriate structural bone graft substitute to support comminuted or impacted articular fragments is important. Bone grafting may biologically compensate for the relatively extensive exposure required for application of the plate. If fixed-angle devices with subchondral buttressing are used, the need for bone grafting is reduced because the chance of secondary displacement of articular fragments is diminished by the increased structural properties of the fixed-angle plate. A compilation of published series of internal fixation since 2000 demonstrated that bone graft was used in 33% of cases when single dorsal plates were used, in 42% of cases in which multiple fragment-specific plates were used, and in only 11% of procedures using volar fixed-angle plates (Table 17.2).

Technique of Volar Plate Fixation

Regardless of the displacement of the distal fragment (dorsal, volar, radial), volar plating of both articular and nonarticular fractures is an effective fixation method that may reduce some of the soft tissue complications associated with dorsal plating. Advantages of palmar exposure and volar plating include the following:

- Minimal volar comminution facilitates reduction of dorsally displaced fractures.
- Anatomic reduction of the volar cortex facilitates restoration of radial length, inclination, and volar tilt.
- Avoidance of additional dorsal dissection helps preserve the vascular supply of comminuted dorsal fragments.
- Because the volar compartment of the wrist has a greater cross-sectional space and the implant is separated from the flexor tendons by the pronator quadratus, the incidence of flexor tendon complications is lessened.
- The use of fixed-angle volar plate designs avoids screw “toggling” in the distal fragment and thus reduces the danger of secondary displacement.
- When stabilized with a fixed-angle internal fixation device that uses subchondral pegs or screws, control of shortening and late displacement of articular fragments are improved and the need for bone grafting reduced (see Figure 17.39).

Fractures are exposed through the distal part of the Henry approach between the FCR and radial artery via an 8- to 9-cm longitudinal incision directly over the distal course of the FCR tendon. The subsheath of the FCR is opened along its radial border to avoid inadvertent injury to the nearby palmar cutaneous branch of the median nerve. The virtual space beneath the flexor tendons is developed and the FCR and flexor tendons are retracted to the ulnar side, thus protecting the median nerve and its palmar branch. The radial vascular bundle is retracted radially to expose the flexor pollicis longus (FPL) and the pronator quadratus. Some distal fibers of the FPL may require release from the radius for adequate exposure of the radial shaft. The brachioradialis tendon is sharply separated from overlying soft tissues and split longitudinally at the level of the pronator quadratus for 5 to 8 cm to its insertion on the radial styloid. It is not necessary to completely transect the brachioradialis tendon in most acute cases. Elevation of the pronator in continuity with the volar half of the split brachioradialis tendon facilitates anatomic suture repair and ensures plate coverage at the conclusion of the procedure (Figures 17.41 and 17.43). The distal border of the pronator is sharply incised at the volar lip of the radius and the muscle sharply reflected ulnarly from the radius and volar fragments. The fracture is reduced with an initial hyperextension maneuver, followed by flexion of the wrist while the surgeon stabilizes and manually manipulates the apex of the deformity with a thumb. If anatomic reduction is confirmed with fluoroscopy, the fracture is temporarily fixed with an oblique 0.062-inch Kirschner wire inserted percutaneously through the radial styloid. A volar plate is chosen and contoured as necessary to fit the volar metaphyseal flare of the radius. Care is taken to avoid placement of the plate distal to the transverse radial ridge because implants on the volar lip of the radius are in direct continuity with the flexor tendons and risk tendon irritation and rupture (Figure 17.42).[26] If fixation of the plate distal to this ridge is deemed necessary to stabilize small marginal or volar ulnar fragments, the author recommends consideration of tension band fixation[19] or a low-profile miniplate or wireform as an alternative solution to avoid the serious complication of flexor tendon rupture (see later).

When optimal plate position is confirmed, the plate is provisionally fixed with Kirschner wires or with a single screw in the oval hole of the plate. Distal or proximal fine-tuning of plate position can be performed, as determined with fluoroscopy, to align the projected angles of the distal pegs immediately beneath the subchondral bone on the facet lateral fluoroscopic image. It is important that nearly anatomic restoration of volar tilt be restored before finalizing plate position to optimize peg placement beneath the subchondral bone and minimize articular penetration. This is particularly important when dealing with osteoporotic bone because subchondral buttressing will effectively control fracture settling or dorsal displacement, provided that the pegs are placed directly below the subchondral plate. It is also important to contour the plate to match the patient’s normal metaphyseal volar flare—undercontouring of the plate can translate the articular surface dorsally or rotate the articular fragment into an unacceptable position of dorsal tilt when associated with extensive dorsal comminution.

Distal fixation is achieved by inserting smooth pins or screws that lock into threaded holes in the distal plate. Dozens of different plates are available, and several feature “multi-axial” screw projection to enable alteration of screw or peg angle to suit a particular fracture anatomy. Precise drilling with special drill guides that are screwed or snapped into the distal holes is necessary when using fixed-angle devices to ensure engagement of the threaded heads on the plate. After placement of the subchondral pegs and screws, the plate is fixed proximally to the diaphysis with self-tapping screws. The implant is easily covered with the pronator quadratus by repairing the split portion of the brachioradialis to the remaining tendon on the radius (Figure 17.43). The wound is closed in layers, with suction drainage used at the discretion of the surgeon. Stability of the radioulnar joint is assessed and addressed as necessary. A plaster sugar tong splint is applied in full supination until suture removal 10 days postoperatively, followed by a removable wrist brace for comfort. Patients are encouraged to mobilize the digits immediately after surgery. Light functional use of the hand and wrist (eating, dressing, writing, typing) is permitted after suture removal (Figure 17.44). For elderly patients with osteoporotic bone, the postoperative regimen may be modified accordingly; if insufficient screw purchase was attained, a light forearm cast is applied after suture removal for a total of 5 weeks.

If anatomic reduction of the articular surface and dorsal marginal fragments cannot be achieved with manual reduction through the volar Henry incision, Orbay and Fernandez recommend an extended Henry approach to enable direct articular reduction.[91] To gain this degree of exposure, the entire proximal radius is pronated away from the fractured articular components by performing an extensive soft tissue release. It is thought that complete subperiosteal elevation from the metaphyseal-diaphyseal portion of the radius is tolerated because of a rich endosteal blood supply. The first step in the exposure is release of the radial septum (insertion of the brachioradialis and the palmar sheath of the first extensor compartment) to facilitate reduction of the radial styloid fragment. Next, the surgeon performs a subperiosteal exposure of the distal third of the radial diaphysis. Finally, to visualize the dorsal die punch and centrally impacted fragments through the fracture plane, the proximal shaft fragment is fully pronated with a bone clamp. Under direct vision, the fragments can be manipulated into a reduced position against the proximal carpal row (Figure 17.45). Thereafter, the proximal fragment is supinated back into place and a volar fixed-angle plate applied. An attempt is made to fix large dorsal ulnar fragments with locking screws through the plate. The authors cite preservation of the extensor tendon sleeve and a reduced incidence of extensor tendinopathy as advantages of this exposure.

Alternatively, displaced fragments of the dorsal rim or intermediate column can be reduced and fixated by direct exposure through a limited dorsal incision with the application of fragment-specific implants (see later). Similarly, if complete capture of a large or comminuted radial styloid fragment cannot be attained with one or two of the locked pegs, the surgeon should strongly consider the addition of a 2.0-mm radial column plate (see later) to complement volar fixation and prevent undesirable settling and consequent incongruity of the styloid and its scaphoid facet (Figure 17.46). Finally, volar fixed-angle plate fixation is not ideal for small volar ulnar corner or “teardrop” lunate facet fragments. Failure to adequately capture this fragment with plate coverage and one or two locked pegs may result in loss of fixation and palmar translation of the entire carpus in the postoperative period[51] (Figure 17.47). Additional fixation of this fragment may be achieved with Kirschner wires, a tension band, a 2.0-mm miniplate, or a volar buttress pin.

CRITICAL POINTS: VOLAR FIXED-ANGLE PLATE FIXATION

Indications

- Extra-articular fractures of the distal radius (including osteoporotic bone)
- Nascent and established distal radius malunion
- Articular fractures

Contraindications

- Marginal shear fractures, very distal fracture-dislocations
- Small volar ulnar corner fragment

Technical Points

- Make a longitudinal incision along the FCR tendon.
- Expose the pronator quadratus between the FCR and the radial artery.
- Detach the pronator quadratus with an “L”-shaped incision and leave a portion of the split brachioradialis attached to the pronator for subsequent closure.
- Reduce the fracture by restoring the volar cortex.
- Provide temporary fracture fixation with an oblique Kirschner wire through the radial styloid.
- Apply the plate volarly and fix it to the shaft through an oval hole.
- Determine the ideal plate position with fluoroscopy.
- Insert fixed-angle smooth pins in a subchondral position.
- Use a facet lateral fluoroscopic view to control drilling and pin insertion.
- Complete fixation of the plate to the shaft.
- Assess the adequacy of reduction and fixation of the dorsal ulnar fragment and augment as necessary with a 2.0-mm intermediate column plate.
- Consider additional radial column fixation for a large or comminuted radial styloid fragment.
- Consider alternative or additional fixation of the volar lunate facet fragment if not adequately captured by the volar plate.
- For irreducible intra-articular fractures, an extended FCR approach is an option:
  - Perform a tenotomy of the brachioradialis tendon.
  - Release the first dorsal compartment.
  - Pronate the proximal fragment to expose the articular surface.

Postoperative Care

- Apply a sugar tong splint in supination for 5 to 10 days until suture removal.
- Begin digital range of motion exercises immediately.
- Begin forearm rotation and gentle active wrist motion exercises at the postoperative visit.
- Evaluate with radiographs at the initial postoperative visit and at 6 weeks postoperatively.

Fragment-Specific Fixation

In an attempt to minimize the morbidity of extensive surgical dissections associated with conventional dorsal plate fixation of distal radius fractures, Robert Medoff devised a hybrid technique of percutaneous wire and plate fixation designed to fix individual fracture fragments through several small incisions.[7,74] His “fragment-specific” classification (see earlier) defines articular fractures of the radius by recognition of five elemental fracture fragments that are present alone or in combination in every fracture. The technique involves the use of ultrathin modular implants that can be shaped to customize fixation for different fragment configurations and builds on the work of Rikli and Regazzoni[99] by placing these implants strategically along the radial and intermediate columns to maximize construct rigidity.[56] The key component of the implant system is the so-called *pin plate* (TriMed, Inc., Valencia, CA), which combines the versatility of a Kirschner wire with the rigidity of plate and screw fixation. The bending stiffness of conventional Kirschner wire fixation is dramatically increased by passing the wire through the free end of a miniature 2.0-mm plate, secured proximally to the radial shaft, to create a pin plate hybrid with a three-point fixation. Mechanical studies using an unstable metaphyseal fracture model have demonstrated that dual 2.0-mm plates, when placed at 50- to 90-degree angles to each other in the axial plane, provide fixation that is statistically superior to that of either Kirschner wire–augmented external fixation or a traditional 3.5-mm dorsal "T"-plate.[28,94] Thus, the use of the term "fragment-specific fixation" in this text does not refer to a particular implant type, but to the concept of the use of two or more low-profile implants placed strategically along the columns of the distal radius to fix individual fracture fragments.

Three recent single-cohort clinical series totaling more than 180 patients and using bicolumnar low-profile miniplate or wireform fixation documented good to excellent results in 96% of patients with an average follow-up of 24 months.[10,56,66] The fractures were predominantly AO C-type fractures (75%), and supplemental bone graft was used in 42%. Grip strength was restored to 88% of the opposite side and flexion-extension to 85% (see Table 17.2). Disabilities of Arm, Shoulder, and Hand (DASH) scores on 85 of the patients measured 9 on a 100-point scale. Fragment-specific fixation is indicated for most unstable and high-energy articular fractures of the distal radius and is generally contraindicated for fractures with substantial metaphyseal-diaphyseal extension or severe osteoporosis.

The radial styloid fragment is regarded as the keystone of reduction and stability of articular fractures of the distal radius and is therefore addressed first in the sequence of multiple fragment reduction and fixation. The other key fragments to be considered include the volar lip fragment, the dorsal wall, the dorsal and volar components of the lunate facet, and the impacted articular fragments (see Figure 17.19). Five to 10 lb of traction, applied via finger traps on the index and long fingers or through the use of a formal traction table, is helpful to grossly align the fragments. Fluoroscopic images in traction are a valuable adjunct to assess the nature of the fracture and key components.

The radial styloid is approached through a 4- to 5-cm incision on the volar radial aspect of the metaphyseal flare, just radial to the radial artery and palmar to the tendons of the first dorsal compartment.[7] Superficial branches of the radial sensory and antebrachial cutaneous nerves are retracted in the skin flaps, and the first dorsal compartment is opened to expose and retract its tendons. The brachioradialis tendon is split longitudinally and the tendon and periosteum elevated in a dorsal and palmar plane to expose the radius (see Figure 17.43). Complete palmar exposure of the radius is accomplished by elevating the pronator quadratus in continuity with the palmar margin of the brachioradialis. If necessary, the entire radial styloid can be exposed by dorsal elevation beneath the second dorsal compartment. The styloid fragment is reduced anatomically and fixed provisionally with a 0.045-inch Kirschner wire. At this time, attention is directed to the intermediate column of the radius for reduction and fixation of the lunate facet and impacted articular fragments.

Dorsal intermediate column fragments are most commonly approached through a 4- to 5-cm universal dorsal incision over the third dorsal compartment, where the dorsal wall, articular fragments, and the dorsal ulnar corner can be simultaneously addressed. The EPL is isolated and primarily transposed out of its compartment, and the radial metaphysis can be widely exposed by elevating the second or fourth (or both) compartments in a subperiosteal fashion. The comminuted dorsal cortical wall can be lifted to expose the radial metaphysis and a Freer elevator used to disimpact the articular fragments and elevate the articular surface en bloc against the template of the proximal carpal row bones. It is not generally necessary to open the dorsal capsule to directly inspect the articular surface because fluoroscopy is used to document reduction of the fracture fragments and the articular surface. Autogenous bone graft or a suitable structural bone graft substitute (see Table 17.1) is recommended to augment and hold reduction of the impacted articular fragments. The dorsal intermediate column fragments are then directly reduced and fixed in position with any of a series of modular "wireform" implants that capture and hold the small periarticular fragments (Figure 17.48).

An isolated dorsal ulnar fragment may be accessed and reduced via a limited approach through the fifth dorsal compartment. It is important to note that this incison is not extensile and cannot be readily enlarged to gain access to larger metaphyseal and impacted articular fragments; thus, if multiple dorsal fragments require reduction and fixation, a standard dorsal approach is preferred. A 3- to 4-cm incision is made directly over the radioulnar joint. The extensor digiti minimi is identified and transposed out of its compartment after dividing the extensor retinaculum of the fifth dorsal compartment. Great care is taken to avoid iatrogenic disruption of the dorsal radioulnar ligament as the dorsal ulnar fragment is exposed and reduced. Reduction is facilitated with the use of a dental pick to anatomically align the proximal cortical margins of the fragment. A 0.045-inch Kirschner wire is placed obliquely from the dorsal and ulnar margin of the fragment into the stout volar metaphyseal bone. A three-hole ulnar pin plate is contoured to fit over the fragment and slid over the Kirschner wire, with care taken to not overlap the radioulnar joint. The plate is secured proximally with two bicortical screws. A second wire is driven through one of the distal holes and the two wires sequentially measured, cut, and bent 180 degrees at their tips before being impacted back into a free hole in the plate (Figure 17.49).

A frequently overlooked but critically destabilizing intermediate column fragment is the volar ulnar or "teardrop" fragment. This fragment constitutes the volar half of the lunate facet and is thus the primary restraint to volar subluxation of the carpus. It also represents the volar rim of the sigmoid notch and contains the origin of the volar radioulnar ligament, a prime stabilizer of the radioulnar joint. Failure to recognize or adequately stabilize this fragment can result in dramatic palmar subluxation of the carpus, articular incongruency, radioulnar instability, and ulnocarpal impaction. The fragment is often too small, too distal, and too ulnar to be adequately captured by the pegs of a fixed-angle palmar plate and, consequently, can complicate volar plate fixation by the delayed development of carpal subluxation (see Figure 17.47).[51]

Surgical Approach to the Volar Ulnar Fragment

Because only the volar aspect of the DRUJ and the ulnar corner of the radius need to be visualized, a limited incision that parallels the flexor carpi ulnaris tendon just proximal to the transverse wrist crease provides sufficient exposure. Surgical release of the transverse carpal ligament can be performed if needed by extending the incision in a zigzag fashion across the wrist crease and into the palm (extended carpal tunnel incision). The interval between the flexor tendons and the ulnar artery and nerve is easily developed by blunt dissection, through which the pronator quadratus and volar wrist capsule are exposed. Usually, the distal border of the pronator quadratus has been disrupted by the fracture; this allows ready visualization of the metaphyseal fracture line and displaced volar ulnar fragment with minimal soft tissue dissection. The pronator quadratus is partially released from its ulnar insertion and retracted radially and proximally to expose the fracture site. Extreme care must be taken to avoid injury to the volar arm of the radioulnar ligamentous complex. The volar ulnar fracture fragment is then carefully reduced to restore continuity of the palmar cortex at the metaphyseal area by applying a dorsally directed force with an awl or periosteal elevator. Though not rigid fixation, the fragment may be fixed with a Kirschner wire introduced obliquely in a volar to dorsal direction. The wire is retrieved through the dorsal skin while making sure that its palmar end lies flush with the cortical level of the fragment to avoid impingement of the flexor tendons. For more stable fixation, the wire should be augmented with a suture or figure-of-8 wire placed through the proximal metaphyseal cortex in a tension band configuration.[19] I find that a volar buttress pin (TriMed, Valencia, CA) provides the most stable fixation for this fracture fragment and prevents carpal subluxation (Figure 17.50). The two prongs of the implant serve as a fixed-angle support for the subchondral bone, and the proximal implant is rigidly secured to the intact diaphyseal bone with washers and 2.0-mm screws. This restores palmar stability of the fracture and provides a solid base on which the overlying dorsal ulnar or “die punch” fragment can be reduced. Alternative implants include a 2.0-mm plate or a Kirschner wire, with or without a tension band.[19] Additional volar rim fragments of the scaphoid facet can be stabilized with a 2.0-mm volar buttress plate or a fixed-angle volar plate, at the surgeon’s discretion.

The construct is completed by returning to the radial styloid to complete the fixation with a 2.0-mm radial columnar plate and screws (Figure 17.51). It is important to place the radial styloid implant in a plane 50 to 90 degrees counter to the plane of fixation of the intermediate column to maximize stability of the fixation construct. The ideal position for a radial column implant lies directly beneath and oblique to the first dorsal compartment tendons, such that the distal tip of the plate is dorsal to the tendons and the proximal end of the plate is palmar to the tendons. If the previously placed provisional styloid Kirschner wire is in optimal position, a three-, five-, or seven-hole radial column pin plate is slid over the wire and positioned beneath the first dorsal compartment tendons. The plate is fixed to the intact metaphyseal-diaphyseal flare with two or more 2.0-mm bicortical screws proximally. A second wire is passed through the plate distally and obliquely across the styloid to engage the apposing cortex. Each Kirschner wire is sequentially measured, cut, and bent 180 degrees before being impacted into a neighboring hole in the pin plate. Final reduction and position of the implants are checked with fluoroscopy, and the brachioradialis tendon is closed over the radial column plate with a single running suture to interpose soft tissue between the implant and the overlying first dorsal compartment tendons. By closing the brachioradialis tendon, the attached pronator quadratus simultaneously covers the volar implants. The dorsal wound is closed by transposing the EPL out of its compartment and closing the extensor retinaculum of the second and fourth extensor compartments beneath it. The DRUJ is then carefully assessed for stability, and appropriate treatment is rendered for residual instability. The wrist and forearm are temporarily immobilized with a sugar tong plaster splint in supination for 5 to 10 days to allow soft tissue healing.

Rehabilitation is predicated on the strength of fracture fixation, but generally patients can be started on a program of active, unresisted motion exercises within a week of surgery. Strengthening exercises are begun after radiographic evidence of fracture consolidation, generally at 6 to 8 weeks postoperatively.

CRITICAL POINTS: FRAGMENT-SPECIFIC FIXATION

Indications
- Unstable extra-articular fractures of the distal radius (type I, AO type A)
- Articular fractures, simple to complex, multifragmentary fractures, shear fractures, fracture-dislocation (types II to IV; AO types B and C, all subtypes)
- Volar ulnar “teardrop” fracture with carpal subluxation
- In combination with percutaneous or fixed-angle plate fixation for unstable fragments
- Nascent and established distal radius malunion

Contraindications
- Severe osteoporosis
- Extensive diaphyseal comminution (type V)

Technical Points
- Place multiple incisions directly over unstable fragments.
- Make a volar radial incision to the radial column, and split the brachioradialis
- Elevate the pronator quadratus with a portion of the split brachioradialis as needed to expose the volar surface.
- Reduce the fracture with traction and direct manipulation of the fragment.

- Provide temporary fracture fixation with an oblique Kirschner wire through the radial styloid.
- Expose the intermediate column fracture via dorsal, volar, or both approaches and reduce it.
- Elevate impacted articular fragments through a dorsal 3- to 4-cm incision under fluoroscopic guidance.
- Support impacted articular fragments with a graft or substitute.
- Choose a dorsal wireform, 2.0-mm plate, or a pin plate to secure the intermediate column.
- Complete fixation of the volar rim or teardrop as needed with a 2.0-mm fixed-angle implant or a volar buttress pin.
- Apply a radial columnar plate or radial pin plate along the reduced styloid and fix proximally with a minimum of two to three screws.
- Assess distal radioulnar stability manually and repair or use internal fixation as needed.

Postoperative Care

- Apply a sugar tong splint in supination for 8 to 10 days until suture removal.
- Begin digital range of motion exercises immediately.
- Begin forearm rotation and gentle active wrist motion exercises at the initial postoperative visit.
- Evaluate with radiographs at the initial postoperative visit and 2 and 6 weeks postoperatively.

Other Fixation Methods

Virtually all fractures of the distal radius can be managed with the fixation strategies detailed previously, namely, percutaneous/external fixation, dorsal plate fixation, fixed-angle volar locked-plate fixation, and multiple low-profile implant fixation. A surgeon versed in each of these techniques can apply them in isolation or in combination to effectively reach each of the distal radius fracture treatment goals. Conversely, failure to understand the indications and contraindications or an inability to execute these techniques when necessary can corner the surgeon into inappropriate application of more familiar techniques to a particular fracture, with potential consequences of instability or loss of reduction.

On occasion, a highly comminuted distal radius fracture, if not amenable to complex periarticular reconstruction as detailed earlier or when associated with multiple extremity trauma, will need rapid, stable, and durable fixation to grossly restore radial alignment and length. In selected cases, the technique of distraction plating with an internal bridge plate, as initially described by Burke and Singer,[14] can provide highly satisfactory results. Ginn and colleagues recently published collaborative data on 22 patients who were treated with this technique and monitored for 25 months and demonstrated highly satisfactory results in a very difficult injury cohort.[42]

Technique of Distraction Plating

Incisions 4 cm long are centered over the long metacarpal and the dorsal radial aspect of the radial midshaft and a third 2-cm incision over the radiocarpal joint at Lister's tubercle.[42] A 3.5-mm low-contact compression plate that will span the fracture from the metacarpal shaft to a point at least three screw holes proximal to the most proximal fracture line is chosen. The plate is passed bluntly beneath the extensor tendons and across the fracture site to lie in the floor of the fourth dorsal compartment. To facilitate its passage, the EPL is freed from the retinaculum and an elevator used to develop a plane below the fourth dorsal compartment tendons, through which the plate is tunneled proximally into the most proximal wound (Figure 17.52). The plate is fixed to the third metacarpal with a single screw, ideally in the midshaft of the metacarpal to enable fine-tuning of fracture reduction. The hand and forearm are supinated approximately 60 degrees to avoid fixing the fracture in pronation, and a provisional fracture reduction clamp is applied to hold the plate to the radius proximally. The forearm is taken through a full range of rotation and gross alignment assessed with fluoroscopy. Care is taken to prevent excess radiocarpal or midcarpal distraction when setting the final position, and the author recommends a maximum radiocarpal gap of 5 mm. Proximal and distal fixation is finalized with a minimum of three bicortical screws. Attention is directed to the radiocarpal joint, where articular congruency is restored by subchondral elevation of the impacted fracture fragments, generous subchondral support with allograft, and percutaneous fixation of the periarticular fragments with Kirschner wires or screws (see mini-open fixation earlier). It is helpful to place one screw through the plate and immediately beneath the subchondral bone of the intermediate column. Contraindications to bone grafting include grade III open fractures, prior contamination, or insufficient soft tissue coverage. After assessing the radioulnar joint for stability and treating as necessary (see earlier), the wounds are closed and splint immobilization applied. Within 3 days of surgery, the splint is removed (except in cases of radioulnar instability), and patients may begin forearm supination-pronation and digital range of motion exercises. A 5-lb weightlifting limit is advised. The percutaneous wires are generally removed at 6 weeks and the plate at 4 to 6 months when healing is complete.

Hanel and colleagues recommend placement of a smaller, 2.4-mm locking plate on the index metacarpal, beneath the second dorsal compartment tendons at the radiocarpal level and fixed to the dorsal radial surface of the midshaft of the radius beneath the tendons of the two radial wrist extensors (see Figure 17.52C). This is a rapid and simple approach that minimizes interference with extensor tendon function postoperatively, and the internal position of the low-profile device allows it to be used for an extended period if necessary[49] (Figure 17.53).

Recently, novel methods have been developed to achieve rapid restoration of radial length, alignment, and tilt and are indicated as low-profile, minimal-incision alternatives to volar plate, fragment-specific, or bridging external fixation. These techniques are indicated primarily for unstable nonarticular or simple articular fractures and combine the stability and early mobility of internal fixation with the minimal additional surgical intervention of percutaneous fixation. The techniques lack long-term outcome or prospective comparative data and are offered as alternative fixation methods for predominantly lower-energy injuries (Figure 17.53).

The first is an intramedullary device that uses locked, diverging screws distally to support the articular surface and interlocking screws proximally to provide stability across the fracture. The implant is inserted percutaneously in a retrograde manner at the radial styloid "bare spot" between the first and second dorsal compartments. Care must be taken to prevent injury to branches of the radial sensory nerve during the procedure. In the setting of acute fractures, indications for this intramedullary implant include extra-articular fractures that are unstable and whose reduction cannot be maintained by closed treatment (AO types A2 and A3) and simple intra-articular fractures with large articular fragments that can be reduced percutaneously (AO types C1 and C2). Other relative indications include AO type B fracture patterns (provided that the distal fragment can be captured with at least two screws), potentially unstable fractures in active patients who desire wrist motion during the healing period, and individuals requiring early return to work for whom cast immobilization is impractical. Complex articular fractures with multiple small articular fragments (AO type C3) are relative contraindications to fixation with this device (Figure 17.54).

Another novel technique is a "crossed pin" nonbridging external fixation system that combines the rapid placement and simplicity of percutaneous Kirschner wires with the rigidity of external fixation while enabling immediate wrist range of motion. The device is applied on the radial border of the wrist and gains stability through the crossed nature of interlocked pins placed in two clusters at the radial styloid and in the proximal metaphyseal-diaphyseal junction. The pin clusters on the implant enable adjustable wire angulation, and the radiolucent implant can be placed slightly dorsal or volar to the mid-axial line to minimally interfere with visualization of the fracture (Figure 17.55).

The Ulnar Column

The most frequent complaints of residual disability and functional loss after fractures of the distal radius emanate from the ulnar column. Therefore, the ulnar column deserves as thorough an evaluation in the acute stage as the distal radial fracture itself to address these injuries and prevent long-term dysfunction.

Some element of DRUJ involvement is present in every displaced distal radius fracture. The acute pathoanatomy of the ulnar column can be reduced to several discrete entities: intra-articular incongruity (sigmoid notch, ulnar head), disruption of the TFCC, and avulsion of the ulnar styloid. Fernandez has classified these injuries into a simple and useful three-group system that is helpful in defining treatment (see Figure 17.21B).[32] The key to a successful result depends on precise restoration of the anatomic relationships of the radioulnar joint; identification of residual DRUJ instability through manual assessment, repair, or reconstruction; and maintenance of stability throughout the first 4 to 6 weeks after injury.

Anatomic reduction of the radius usually results in relocation of the ulnar head in the sigmoid notch, as occurs after reduction of Galeazzi-type fractures of the distal shaft. Any residual instability of the DRUJ requires disruption of at least one margin of the TFCC and its associated radioulnar ligament, the ulnar insertion being more commonly disrupted than the radial origin. A manual "shuck" test of the ulna is performed by grasping the ulnar head between the examiner's thumb and index finger and translating it dorsally and palmarly within the sigmoid notch to detect residual DRUJ stability. Gross instability is manifested by frank dislocation, but more subtle instability can be appreciated by the loss of a firm endpoint to translation and by increased subluxation relative to the uninjured wrist. I find it helpful to have assessed the contralateral wrist's DRUJ stability before preparing and draping the injured wrist. It is important that the shuck test be performed in all positions of rotation to specifically test both the palmar and the dorsal ligamentous constraints to ulnar translation (see Chapter 16).

Treatment Options for Distal Radioulnar Joint Lesions

As outlined in Figure 17.21B, three treatment options are possible: (1) early mobilization, (2) closed treatment and cast immobilization with or without radioulnar pinning, and (3) operative management, including open and arthroscopic techniques. *Functional aftercare* with early active forearm rotation exercises and no additional external support is recommended for type I stable injuries and also for fractures of the distal ulna or ulnar styloid in which radioulnar stability has been restored with rigid internal fixation. Early motion is likewise recommended for type III comminuted fractures of the ulnar head that are not amenable to internal fixation to allow fracture remodeling.

Type II subluxation can be treated successfully by 4 weeks of cast immobilization with the forearm in the most stable position of rotation; most often this is partial to complete supination.[114] Grossly unstable DRUJ dislocations may require percutaneous transfixion of the ulna to the radial shaft in the position of greatest stability with dual 0.062-inch Kirschner wires. The Kirschner wires are placed just proximal to the joint, and it is helpful to leave the tips of the wires protruding through both the radial and ulnar cortices in the unlikely event that wire breakage occurs in the interosseous space. The wires may be removed at 4 weeks postoperatively and rotation exercises begun (Figure 17.56).

For type II unstable DRUJ lesions with a large ulnar styloid fragment that has avulsed from its base (the so-called *basistyloid fracture*), fracture fixation should be considered if the DRUJ is unstable. The styloid is exposed with a 3- to 4-cm incision midway between the extensor carpi ulnaris and the flexor carpi ulnaris. Care is taken to identify and preserve the dorsal sensory branch of the ulnar nerve, which courses through the ulnar "*snuffbox*" just distal to the styloid tip. Tension band or interosseous wiring is the technique most frequently used because the ulnar styloid fragment may be too small for a compression screw. A 24-gauge wire or nonabsorbable suture can be passed either around or preferably through the styloid fragment and then through the ulna at the axilla of the shaft and the articular surface. The suture/wire is tensioned and tied with the forearm in neutral rotation. The forearm is immobilized in neutral rotation for 4 to 6 weeks, depending on the degree of stability attained. Alternatively, the fragment can be stabilized with two Kirschner wires and a tension band wire passed proximally through the ulnar shaft (Figure 17.57). With the advent of ultrathin "pin plates," basilar styloid fractures can be rigidly fixed with two Kirschner wires and an ulnar pin plate contoured to the ulnar shaft (Figure 17.58). Immediate stability of the DRUJ is restored, and gentle forearm rotation can be initiated within 7 to 10 days of surgery. Implants on the ulnar side of the wrist can, on occasion, cause irritation and discomfort when patients rest their hands on a tabletop—consequently, ulnar styloid hardware may require removal in 10% to 20% of patients.

Reattachment of peripheral TFCC tears by arthroscopic repair and placement of 2-0 resorbable sutures tied over the floor of the extensor carpi ulnaris sheath with the forearm in supination has been reported.[39] Arthroscopy can also provide information regarding indications for fixation of an ulnar styloid fragment. The articular disk is palpated and should be taut and have an intact "trampoline effect" when probed. When the articular disk is taut by palpation, the majority of the TFCC is still attached to the ulna and to the ulnar capsule. When the articular disk has lost its tension, a peripheral tear of the triangular cartilage is diagnosed. Arthroscopic repair of the peripheral tear can restore the tension of the articular disk in selected cases. If gross instability of the DRUJ is also present, it is likely that the entire TFCC has been avulsed from the fovea, with or without a basilar fracture of the ulnar styloid. Simple arthroscopic repair of the articular disk to the floor of the extensor carpi ulnaris subsheath is unlikely to adequately restore DRUJ stability in these cases. Repair of the ulnar styloid or immobilization in the position of maximum stability in an above-elbow cast or splint for 4 to 6 weeks is indicated to allow the TFCC to heal. When external fixation has been used as primary treatment of the associated distal radius fracture, Ruch and colleagues demonstrated that the addition of an "outrigger" pin and bar to temporarily fix the radioulnar joint in supination was as effective as internal fixation of the ulnar styloid, with fewer operative complications.[103] When DRUJ instability is associated with a dorsally displaced dorsal ulnar fragment of the distal radius as in type III lesions, exact anatomic reduction and fixation of the sigmoid notch are imperative to restore stability. Associated TFCC lesions should be addressed simultaneously as described previously.

AUTHOR'S PREFERRED TREATMENT: ULNAR COLUMN INSTABILITY

Anatomic restoration of length, alignment, and tilt of the fractured radius is performed with internal or percutaneous fixation at the surgeon's discretion. Unstable fractures of the dorsal and volar margins of the sigmoid notch are rigidly stabilized because unstable fragments have been demonstrated to mechanically lead to radioulnar subluxation.[21] Neck or head fractures of the ulna are anatomically reduced and fixed with 2.0- or 3.5-mm plates, interfragmentary screws, cerclage wiring, or tension bands, depending on the nature of the fracture and the degree of comminution. Residual instability of the DRUJ, as determined by a dorsal and volar "shuck" test in neutral, pronation, and supination, is treated aggressively. If a basilar styloid fracture is present, I prefer open reduction and fixation followed by early range of motion (see Figure 17.58). If no fracture is present and stability can be restored in full or partial supination, simple immobilization in a sugar tong splint is performed in the operating room and converted to a long arm cast at 10 days. The cast is removed 4 weeks postoperatively and supination- pronation exercises begun. If stability cannot be restored with positioning, augmentation with parallel 0.062-inch transfixion wires is performed and maintained for 4 weeks. I have not found arthroscopic repair of the TFCC to add appreciably to this algorithm.

EVIDENCE-BASED DECISION MAKING

Is there sufficient "evidence" in the literature in the form of randomized, prospective clinical trials to derive individual treatment decisions for distal radius fractures? Outcomes of treatment for distal radius fractures have been the subject of several large Cochrane meta-analyses performed by Handoll and colleagues over the last several years.[46-48] Not surprisingly, the heterogeneity of the injuries, variations in reporting outcomes, and differences in operative techniques and patient populations have made the extrapolation of any firm conclusions difficult. The authors made a plea for future investigators to use a common classification system and standardized validated outcome measurements so that data can be compared and contrasted.

That said, the Cochrane results demonstrate that both percutaneous pin fixation and external fixation provide improved anatomic restitution and diminished frequency of lost reduction when compared with cast treatment of *unstable* fractures. However, their exhaustive meta-analysis, which compared all operative treatments on 3371 patients in 48 randomized studies through 2002, concluded that there was insufficient data to provide "robust" credible support for any particular treatment method in terms of the long-term functional benefits of operative management versus closed treatment.

Since publication of the last Cochrane analysis and in part a reflection of the need for standardized outcome assessment, several well-executed randomized trials have added to our "evidence" for treatment decisions. Table 17.3 summarizes the available evidence of two dozen randomized trials over the last decade. Although individual fractures cannot be pigeon-holed into a convenient treatment niche, successful treatment strategies can be gleaned from the compiled data in large groups of patients.

For minimally displaced or nondisplaced fractures that do not require reduction, a simple dorsal splint is as effective as a cast and leads to improved motion and strength soon after fracture healing when compared with above- or below-elbow casting.[90] For extra-articular and simple articular fractures without incongruity that require closed reduction, two studies demonstrated that a well-applied sugar tong splint, short arm cast, or three-point custom fracture brace was essentially equally effective in maintaining the initial reduction.[13,115] The cumulative data suggest that loss of reduction with closed treatment is more dependent on the inherent stability of the fracture than on any particular cast technique. Though somewhat nihilistic, one may conclude from the available evidence that specific casting techniques, wrist position, and plaster molding may be less relevant to the treatment of these injuries than close observation, early identification of unstable fractures, and selective operative treatment. Importantly, re-reduction and casting of fractures that have lost their original reduction cannot be expected to improve outcomes.[86]

With minimally comminuted extra-articular or simple articular fractures without a step-off in healthy bone, casting, percutaneous pin fixation, and external fixation are virtually interchangeable.[67,81,127] In studies that combine patients with both stable and unstable fractures, the addition of percutaneous pin fixation to cast treatment leads to improved anatomic alignment and a reduced incidence of lost reduction but has not been demonstrated to provide improved *outcomes* over cast treatment alone.[6] Again, relative instability of the fracture (dorsal comminution, radial shortening) and patient age (bone quality) appear to be the prime determinants of *outcome* for the treatment of these fractures.

For *unstable* extra-articular and articular fractures, external fixation provides improved anatomic and clinical outcome over cast treatment alone,[61,67] and augmented external fixation provides improved articular reduction over percutaneous pin and cast treatment.[50] Use of the Kapandji pin technique for unstable fractures did not demonstrate improved results over cast treatment alone or augmented external fixation and was associated with higher rates of complications.[48,111] Taken together, the data suggest that unstable fractures or displaced articular fractures in active individuals require more effective fixation than can be provided with casting or percutaneous pins and that augmented external fixation or internal fixation is warranted. The role of nonbridging external fixation requires further definition, but in selected fractures (large fragments, good bone stock), nonbridging external fixation provides improved radiographic parameters when compared with spanning external fixation.[4,84]

For displaced, comminuted, and unstable articular fractures, several operative options exist. Cast treatment is not appropriate in physiologically young or active patients. Augmented external fixation has been demonstrated to result in fewer complications than has low-profile fixed-angle dorsal plates.[45] However, with the advent and relative ease of application of volar fixed-angle plates, the use of dorsal fixed-angle plating has diminished. At the time of this writing, there were no published randomized trials that compared volar fixed-angle devices with low-profile multiple implant fixation or augmented external fixation; thus, treatment comparisons have been simplified into percutaneous/indirect/mini-open fixation versus ORIF. For comminuted articular fractures with primary dorsal angulation, two series comparing modern fixation techniques and using validated outcome scoring demonstrated improved results with indirect reduction and percutaneous fixation.[45,68] Similarly, range of motion, anatomic restoration, articular congruity, and the incidence of degenerative disease are improved with arthroscopic reduction and percutaneous fixation when compared with ORIF.[29] The data suggest that if indirect or arthroscopic reduction and percutaneous fixation can restore articular alignment, 1- to 3-year outcomes will be *superior* to those of arthrotomy and ORIF. For comminuted articular fractures with primary volar displacement and volar rim or volar ulnar corner fragments, percutaneous and augmented external fixation is not generally appropriate and internal fixation is the preferred option. Whether fixed-angle volar plating or multiple implant fixation will lead to improved functional or radiographic results (or both) over indirect reduction and percutaneous fixation cannot be stated based on the evidence available. Limited retrospective[79] and unpublished prospective data suggest that the techniques of modern volar fixed-angle plating and percutaneous/external fixation yield comparable functional and radiographic results. Interestingly, nonbridging external fixation resulted in improved radiographic volar tilt, diminished perioperative pain, and statistically fewer reoperations for hardware-related complications than did fixed-angle volar plate fixation (Jesse Jupiter et al., 2008, personal communication). Patient preference for an internal implant rather than an external device because of the perceived benefit of early wrist motion, as well as avoidance of pin cleaning and pin track infections, may sway individual surgical decisions in favor of open reduction. However, bridging and nonbridging external fixation techniques continue to demonstrate excellent outcomes in properly selected cases and should not be abandoned.

AUTHOR'S PREFERRED TREATMENT: A CASE-BASED APPROACH TO OPERATIVE MANAGEMENT

… it is neither the fixation nor the implant which dictates the outcome but the ability of the surgeon to meet the goal of satisfactory reduction and vascular preservation with the least invasive procedure possible.

—KREDER, H.J., ET AL., 2006

It is no surprise that randomized trials fail to show convincing evidence of the superiority of one technique of treatment over another for the entire spectrum of "distal radius fractures." The variety and complexity of fracture patterns, associated injuries to the distal radioulnar and intercarpal ligaments, and widely divergent patient factors (osteoporosis, activity level, systemic illness) mitigate against a single treatment modality for all types of injuries. Instead, a treatment strategy must be developed to customize the treatment to the injury, with the overarching principle that the least additional surgical disruption of the soft tissue sleeve that is necessary to gain fracture stability and articular congruency will generally impart the best functional outcome.

To paraphrase Lee Trevino, "It's the archer, not the arrow." Although the literature is replete with a bewildering array of techniques and implants, it is important to understand that it is the judgment and skill of the surgeon in reaching the operative goals that will be the most important determinant of success. As stated earlier, the goals of operative treatment (ARMS) are

1. *A*rticular congruity (to prevent shear on articular cartilage and degenerative changes)
2. *R*adial alignment and length (to enable normal kinetics and kinematics of the carpus and radioulnar joint)
3. *M*otion (digits, wrist, and forearm to optimize return to functional activities)
4. *S*tability (to preserve length, alignment, and congruency until healing of the fracture)

My approach is built around three fundamentally different categories of fixation that when matched to the particular fracture pattern, enable the surgeon to plan and execute successful wrist fracture surgery for nearly all of its variations:

- Percutaneous/indirect fixation
- Fragment-specific fixation
- Volar fixed-angle plating

For treatment purposes, I present an algorithm based on the Fernandez mechanism-based classification of distal radius fractures. Treatment recommendations are based on fractures in a physiologically young and active patient cohort; treatment may be tempered according to the patient's age, activity level, functional impairments, and general medical condition.

Treatment of Nonarticular Fractures of the Distal Radius

For all injuries, the patient's history and physical examination should include age, handedness, occupation, aerobic activity level, sports and leisure activities, an extensive medical history, and list of medications. Particular attention must be paid to conditions that might affect bone mass or bone quality, including endocrine disorders, inflammatory diseases, renal disease, steroid use, and other factors. The wrist should be inspected for wounds and tendon and nerve function and special attention paid to function of the median nerve. Nondisplaced distal radius fractures in the physiologically young and active cohort can be treated with either a splint or short arm cast at the surgeon's discretion while leaving the elbow, fingers, and thumb free to avoid stiffness. Patients should be advised of the possibility of EPL rupture, which although rare, can complicate treatment of nondisplaced fractures. Follow-up radiographs should be obtained at 2, 4, and 6 weeks, with closer scrutiny given to elderly or osteoporotic patients.

Bending Fractures—Type I

The prime determinant in dorsally displaced, nonarticular bending (Colles') fractures is the predicted stability of the fracture (see earlier). In younger patients with minimal comminution of the dorsal cortex and less than 3-mm loss of radial length, an adequate closed reduction will be predictably quite stable. For active patients with a stable fracture type and excellent reduction, I prefer a sugar tong splint, which permits acute swelling for the first 2 to 3 weeks and then conversion to a short-arm cast for 3 weeks, until the fracture is healed both clinically and radiographically. Radiographs are taken at 1, 2, or 3, and 6 weeks to ensure maintenance of reduction. A simple removable splint may be needed for comfort and support for an additional 2 weeks after cast removal. By providing patients with a removable splint that they can wean themselves from as they regain wrist motion and upper extremity confidence, much of their anxiety of reinjury is relieved and their rehabilitation process is shortened.

Minimizing Hand and Shoulder Stiffness

During the period of immobilization and weaning from the splint, all patients are instructed to keep their fingers, elbow, forearm, and shoulder mobile. The "six-pack" of hand exercises was popularized by Dobyns and is illustrated in Figure 17.27. Passive and active shoulder, elbow, and forearm motion should also be targeted as priorities as soon as the injury pain subsides and specific immobilization requirements permit. In general, motion should be encouraged at least three times a day. Some patients benefit from supervised hand therapy, as well as a home program under the guidance of a hand therapist.

Unstable dorsal bending fractures are suspected in patients with comminution of greater than 50% of the lateral width of the radial diaphysis at the fracture site and initial radial shortening of greater than 3 mm. As MacKenney, Lafontaine, and others have demonstrated, advancing age is the most important predictor of instability, and the presence of these two factors in a patient older than 60 years should be considered unstable.[72,82] Volar extra-articular bending fractures are decidedly less common than their dorsal counterparts and usually involve comminution of the important stout metaphyseal flare; consequently, these fractures are implicitly unstable and generally require operative stabilization. Patient education is extremely important in this group of injuries because the patient is likely to wish to take an active role in the decision for treatment. In healthy and active individuals, regardless of age, I counsel the patient concerning the nature of the injury, its inherent instability, and the additional treatment time that would be required should the fracture demonstrate late instability and collapse in a cast. If the patient elects nonoperative treatment, close observation of unstable fractures with weekly visits is necessary for the first 3 to 4 weeks, along with several cast changes as necessary to maintain optimal three-point fixation. The surgeon should be vigilant for early signs of collapse and avoid the "slippery slope" of accepting a few degrees of additional dorsal tilt or loss of radial length on successive radiographs (Online Case 17.1). The patient should be attuned to the potential need for relatively urgent operative intervention if the fracture collapses because a second attempt at closed reduction and casting is ineffective.[86] I am not as aggressive in the treatment of unstable extra-articular fractures in elderly and sedentary patients because of the mitigating effect of advanced age (>80 years old) on perceived hand dysfunction caused by malunited fractures.[36]

Because the articular surface is intact, this group of injuries enjoys a high rate of functional return and patient satisfaction after several different types of treatment, provided that anatomic indices of reduction are reasonably restored. Treatment possibilities include, but are not limited to closed reduction and pinning, augmented bridging external fixation, nonbridging external fixation, low-profile columnar fixation, intermedullary fixation, and volar locked plating (Online Case 17.2). I discuss the limitations and advantages of different techniques with the patient and tailor my treatment to a patient's preferences and individual needs, with each of these fixation techniques being used with some frequency. If I anticipate a sizable metaphyseal bone void because of the extremes of dorsal displacement or osteoporosis, the balance is tipped in favor of volar locked plating (Online Case 17.3) augmented by bone graft or substitute as needed. Similarly, if the fracture is several weeks old and I anticipate takedown of a "nascent" malunion, volar locked plating is my preferred treatment (Online Case 17.4). More and more frequently, active patients express the desire to avoid a 6-week period of casting when presented with a viable alternative; similarly, when given an option, many patients in the urban setting in which I practice choose internal fixation over external fixation devices because of the associated pin cleaning and the risk for pin track infection. For elderly and active patients who need or request operative fixation, especially those with decreased bone mass, I prefer the increased rigidity of volar locked-plate fixation. After surgery, I immobilize the patients in a sugar tong splint for 7 to 10 days postoperatively and begin range of motion of the digits and shoulder immediately. Wrist and forearm motion is begun in a removable splint at the time of dressing change, and return to activity is initiated at 6 to 8 weeks as permitted by radiographic evidence of healing.

Algorithm for Management of Articular Fractures of the Distal Radius

Type II—Shear Fractures

The basic feature common to *shearing marginal fractures of the joint surface* is that a portion of the metaphysis of the distal radius is intact and in continuity with the unaffected area of the joint surface. These fractures are inherently unstable because of the high deforming forces and fare poorly with nonoperative treatment. The ultimate prognosis of these fractures is generally good because the displaced articular fragment or fragments can be precisely reduced and solidly fixed to the intact radius. Furthermore, fractures with a distinct shearing component usually occur in young adults, whose firm cancellous bone offers ideal holding power for internal fixation.

Volarly displaced shear fractures are not generally amenable to percutaneous fixation because of the gross instability, the strong deforming forces of the flexor tendons, and the vulnerability of major nerves and vessels to percutaneous implant insertion. The obliquity of the fracture line and loss of palmar support of the carpus make these fractures inherently unstable. Shortening and palmar displacement of the fragment are always associated with volar subluxation of the carpus. This fracture may affect only the most radial aspect of the palmar articular surface, or it may extend ulnarly into the sigmoid notch. Depending on the quality of bone and the severity of the impact, a variable amount of comminution of the volar fragment may be present. Particular attention must be given to rule out the presence of a separate volar ulnar or "teardrop" fragment (see earlier); its presence demands that the implant or implants rigidly capture and maintain reduction of this fragment to prevent postoperative carpal subluxation[52] (see Figure 17.50) (Online Case 17.5). An increase in the AP distance on the lateral film (see earlier) suggests that a sagittal split in the articular surface is present and is concerning for a lunate facet or teardrop fragment. If there is any question about whether a separate lunate facet fragment is present, a CT scan is indicated.

For volarly displaced shear fractures with a single fragment, I prefer a volar fixed-angle plate, although a traditional 3.5-mm volar buttress plate or low-profile plate fixation is also applicable (Online Case 17.6). The standard FCR approach is performed, and provisional fixation of the fragment with one or more 0.062-inch Kirschner wires is helpful to maintain reduction before the application of permanent fixation (see earlier). For injuries with a separate "teardrop" fragment, I prefer to fix this lunate facet fragment with a volar buttress pin placed through a volar flexor carpi ulnaris approach (see earlier), followed by support of the radial column fragment with a 2.0-mm radial column plate. I am not impressed by the ability of most volar plates to adequately capture a small lunate facet teardrop fragment (see Figure 17.47), and advancement of the plate distally to cover the volar rim is not recommended because of concern for flexor tendon rupture (Figure 17.59; also see Figure 17.42).[26] In the event of primary median nerve symptoms associated with a volar shear fracture, I prefer to release the carpal tunnel through a separate 3-cm incision in the palm because extension of the volar radial approach into the palm risks injury to the palmar cutaneous branch of the median nerve.

A volar plaster splint with the wrist in neutral position is worn for 7 to 10 days, followed by a removable wrist splint for 4 to 5 weeks until healing. The patient is encouraged to use the hand for activities of daily living, but heavy manual work or sports are forbidden for 5 to 6 weeks after surgery, at which time fracture healing is complete.

Isolated dorsal shearing fractures (*dorsal Barton's fractures*) are rare. As a group, dorsal marginal shear fractures represent less than 2% of all distal radius fractures and share the defining characteristic of (1) a fracture of the dorsal articular rim and (2) dorsal radiocarpal subluxation. This is a high-energy injury that occurs in a predominantly young male cohort. The injury is characterized by an intact volar metaphyseal rim in most cases. Lozano-Calderón and colleagues have identified four discrete subtypes based on the degree of articular surface involvement (Figure 17.60).[78] The least common subtype is characterized by extension of the fracture line across the volar cortex with a relatively large and dorsally rotated volar lip component and no appreciable articular impaction. Fractures of this subtype can often be indirectly reduced and stabilized via a volar approach and fixed-angle plate. For the remainder of these fractures, however, adequate articular disimpaction and support cannot be achieved without direct visualization, carpal reduction, and stabilization through a dorsal or combined approach.

I prefer to approach these fractures through dual incisions: a volar radial columnar approach (see earlier) and a universal dorsal approach through the third extensor compartment (see earlier). First, the radial styloid fragment is carefully reduced through the radial column incision, checked for proper realignment at the metaphyseal level, and pinned provisionally to the proximal radial shaft with an oblique 0.45-inch Kirschner wire. Then the dorsal rim fragment is reduced against the scaphoid and lunate, and dorsal subluxation of the carpus is corrected. The fragments are provisionally pinned and intra-articular congruity is confirmed with fluoroscopy. Depending on the extent of metaphyseal comminution, autogenous bone graft or structural bone graft substitute (see earlier) may be required to support the reduced articular surface. The dorsal rim fragment can then be secured to the intact volar radius with a dorsal wireform (typically a dorsal buttress pin or small-fragment/buttress pin combination) (see earlier) (Figure 17.61). As an alternative, use of the recently introduced 2.0-mm fixed-angle dorsal plates may provide sufficient stability to obviate the need for structural bone graft.[78] A three- or five-hole radial column pin plate or 2.0-mm fixed-angle radial column plate is then applied directly on the radial column to maintain reduction of the styloid fragment and provide the increased mechanical stability of orthogonal fixation, with the implants placed in two planes at least 50 to 70 degrees apart (see Figure 17.61).[7,56] Fixation should be sufficiently stable to begin wrist and forearm range of motion on removal of the sutures and the postoperative splint at 7 to 10 days.

Shear fractures of the radial styloid (*chauffeur's fracture*) are not uncommon and can be associated with intercarpal bony and soft tissue injuries. Scaphoid fractures and perilunate injuries, ranging from partial or complete scapholunate ligament disruption to lunate dislocation, may on occasion be associated with this injury (Figure 17.62A). If the radial styloid fragment shows substantial proximal and radial displacement and the fracture line enters the joint at the level of the interfacet ridge between the scaphoid and lunate fossae, there is a distinct possibility of disruption of the scapholunate ligament. The scaphoid displaces proximally with the radial fragment, whereas the lunate remains in its anatomic position. Treatment should be directed at (1) diagnosis and management of associated soft tissue injuries and (2) rigid fixation of the styloid fragment.

I recommend a low index of suspicion for concomitant scapholunate ligament disruption, and a large radial styloid fracture is my prime indication for arthroscopically assisted percutaneous reduction and fixation (see earlier).[37,123] In this procedure, irrigation of the articular hematoma, direct inspection of the scapholunate ligament from both the radiocarpal and midcarpal portals, and arthroscopic/fluoroscopic reduction of the articular surface is performed (see Figure 17.38). For incomplete disruptions of the scapholunate ligament, fluoroscopic and arthroscopic stress testing of the ligament is performed with a scaphoid shift maneuver to determine the degree of instability (see Chapter 15). After assessment of the ligament, the cartilage-bearing fragment is manipulated with an awl or a periosteal elevator through a small skin incision under fluoroscopic and arthroscopic guidance, with a minimum of soft tissue dissection. Most of these cases may be stabilized with percutaneously inserted implants, such as cannulated screws, Kirschner wires, external fixation, or any combination (bridging or nonbridging), provided that there is good bone quality (Figure 17.63). Care must be taken to protect the superficial radial nerve, the radial artery, and the extensor tendons at the anatomic snuffbox level. For larger or more unstable fragments, I prefer the rigidity of a radial column plate applied through a 3- to 4-cm volar radial approach (see earlier text and Figure 17.51). Bone graft or bone graft substitute may be required if there is a subchondral metaphyseal void after fragment reduction. I repair *complete* ruptures of the dorsal component of the scapholunate ligament through a limited dorsal approach that involves the use of a bone anchor in the scaphoid. Although there are limited data available, I immobilize the reduced scapholunate joint with a temporary cannulated screw inserted just distal to the radial styloid. The advantage of a temporary screw over wires is that it may be left in place while radiocarpal wrist motion is initiated. For incomplete tears (e.g., Geissler grade 2) with fluoroscopic or arthroscopic evidence of scapholunate instability during a scaphoid shift examination, I perform percutaneous temporary pin or screw fixation without open ligament repair. If radial styloid fixation alone is performed, wrist and forearm range of motion is begun at the first postoperative dressing change. If the scapholunate ligament was repaired and fixed with pins or a temporary screw, gentle wrist range of motion is begun 6 to 8 weeks postoperatively, and the screw is removed 4 months after surgery.

Type III—Compression Fractures of the Joint Surface

Compression fractures have a variety of fracture configurations, but all variants share comminution of the articular surface of the intermediate column,[56,99] the so-called die punch fracture.[89] These fractures occur most commonly in young and active individuals, so accurate reduction and maintenance of reduction are essential for an optimal outcome. Critical to their treatment is a thorough understanding of the fracture anatomy, and I recommend the “fragment-specific” classification (see earlier) to identify critical fracture components and guide treatment options. The surgeon should have a low threshold for advanced imaging studies (CT with or without three-dimensional reconstruction) of these challenging injuries to better understand the fracture anatomy and plan the operative approaches.

Single-Fragment Fractures of the Intermediate Column

If the intermediate column fracture is characterized by a simple nondisplaced or minimally displaced articular fragment (and is without significant metaphyseal comminution), closed reduction and cast application may be all that is necessary. In many cases, however, the higher energy of this fracture group displaces the intermediate column fragment, and operative reduction and stabilization are required. Joint distraction with horizontal finger trap traction is not generally capable of disimpaction and realignment of small cartilage-bearing fragments, nor can it accomplish reduction of rotated volar lip and dorsal ulnar corner fragments.

Isolated and displaced fractures of the dorsal or volar ulnar corner are rare, but potentially serious injuries (Online Case 17.7). It is important to recognize these fractures and treat them aggressively to avoid late subluxation of the carpus. More commonly, the combination of a *radial column or dorsal bending fracture and a dorsal or volar intermediate column fragment* is seen. These fractures may be misdiagnosed as Colles’ fractures because the small (but critically important) ulnar corner fragment may be overlooked. An unreduced intermediate column fragment can lead to carpal subluxation, distal radioulnar incongruency, or both. If closed manipulation fails to provide anatomic congruity and stability of the joint surface, open reduction with direct fragment fixation is my preference (Online Case 17.7), although mini-open reduction with percutaneous/external fixation is a suitable alternative for many fractures with a dorsal ulnar corner component and good bone quality.

I begin with closed reduction under fluoroscopy and use finger trap traction as necessary to maintain the reduction during the surgical exposure. The radial column is approached first through the volar radial column approach (Online Case 17.7; see earlier) and, after reflection of the first dorsal compartment tendons, fixed provisionally with an oblique 0.045-inch Kirschner wire to the proximal radial shaft. I expose dorsal ulnar corner fractures that are not associated with an impacted articular or dorsal wall component with a limited, nonextensile incision over the fifth dorsal compartment (see earlier). A provisional 0.045-inch Kirschner wire is directed across the fragment at a 45-degree angle to both the coronal and sagittal planes and secured to the proximal radial shaft. A three-hole ulnar pin plate or a 2.0-mm fixed-angle plate is affixed to the proximal metaphysis to stabilize the fragment (see Figure 17.49). A radial pin plate or 2.0-mm radial column plate is used to stabilize the radial styloid fragment. The wrist is taken through a full range of motion under fluoroscopy to confirm a stable reduction. Stable fractures are mobilized with early hand therapy beginning 7 to 10 days postoperatively.

Volar intermediate column fractures (volar ulnar corner, teardrop) are exposed through a limited volar ulnar approach (see p. 603), as well as the radial column approach, and radial columnar fixation is performed as described previously. Fixation of the volar teardrop fragment is performed as described earlier, with volar buttress pin or tension band fixation, followed by fixation of the radial column plate. Patients with stable fracture reductions are begun on an early mobilization protocol (Online Case 17.8).

Three- and Four-Part Injuries

Further fragmentation of the intermediate column produces more complex diagnostic and treatment challenges. Delineation of the location, relative stability, and number of fragments is essential in planning the operative approach and fixation strategy. CT in these cases is paramount and has been demonstrated to alter not only the decision to operate but also the surgical approach in nearly 50% of cases.[53]

In general, these fracture types will require a combination of (1) longitudinal traction or reduction of the metaphyseal fracture, (2) open reduction for restoration of joint congruity, (3) bone grafting of the defect, and (4) some form of percutaneous or internal fixation. Many of these fractures can be treated with augmented external fixation consisting of bone graft and Kirschner wire fixation as described earlier. New implant technology, including the fixed-angle devices and miniplate and wireform techniques described earlier, have enabled stable internal fixation of these complex injuries and have reduced the need for combined internal and external fixation. Subchondral placement of smooth pegs that buttress the small articular fragments and simultaneously control shortening and angular displacement are particularly helpful in osteoporotic bone.[92] Although fixed-angle volar plating is straightforward and provides outstanding fixation strength for the less comminuted fracture variants, it is difficult to adequately reduce and stabilize small or unstable dorsal rim, central articular, and dorsal ulnar corner fragments with a volar fixed-angle device unless an “extended Henry approach” is used (see Figure 17.45). I avoid this particular approach for the more comminuted fractures because of the extensive subperiosteal exposure required and the potential for fragment devascularization.

Management of these complex articular fractures through a traditional dorsal approach and dorsal single- or double-plate fixation enables reduction of the dorsal carpal subluxation, the radial styloid, central articular impaction fragment, dorsal rim, and the dorsal ulnar fragment (see Figure 17.40). Although it may be used with a nondisplaced volar ulnar fragment, the risk for iatrogenic displacement of this fragment is relatively high. The major disadvantage of the dorsal exposure is its inability to permit direct control and manipulation of the volar ulnar “teardrop” fragment, which is the *keystone* of the distal radial articular surface. Failure to restore the anatomy of the volar ulnar corner, the concavity of the lunate fossa, and the corresponding area of the sigmoid notch gravely compromises both the radiocarpal joint and the DRUJ. Furthermore, traditional dorsal plates placed directly under the extensor tendons have a higher incidence of irritation, attrition tendinitis, and late tendon rupture.

For these reasons, I prefer fragment-specific fixation for the more highly comminuted fracture patterns because it allows me the greatest latitude for multifragmentary fixation. A combination of radial, dorsal, and volar incisions is used, depending on the number and displacement of the fracture fragments, as determined by preoperative radiographs and CT. Through a volar radial approach (see earlier), the radial column can be reduced anatomically and provisionally pinned in position. Elevation of the pronator gives access to the volar rim through the same incision (see Figure 17.41), and manual reduction is readily performed. Large scaphoid facet or volar rim fragments can be stabilized with a buttress plate or volar fixed-angle device as needed. If there is a separate volar ulnar fragment, it is next reduced and stabilized with a volar buttress pin through a volar ulnar incision parallel to the flexor carpi ulnaris (see earlier). The forearm is pronated and a universal dorsal approach (see earlier) is used to gain access to the dorsal rim, dorsal ulnar corner, and impacted articular fragments. I often find it helpful to make all incisions before final fixation of any particular fracture fragment to ensure simultaneous and optimal reduction in all planes. Lifting of one of the larger metaphyseal fragments enables access to the subchondral impaction zone, where the articular fragments are elevated en bloc against the template of the scaphoid and lunate. Bone graft or structural graft substitute is packed into the resultant defect, and the dorsal rim and dorsal ulnar corner fragments are reassembled. Dorsal fixed-angle wireforms and pin plates are contoured to support the elevated articular surface and simultaneously secure the articular and metaphyseal cortical fragments to intact volar bone. The articular surface reduction and fixation are checked with fluoroscopy. The radial styloid fragment is fixed with a three-, five- or seven-hole radial pin plate along the radial column. Stability of the ulnar column is checked manually before closure and treated as necessary. The wrist is immobilized in neutral and the forearm in supination for 10 days in a sugar tong splint. Digital and shoulder motion exercises are initiated immediately, and the operative splint and sutures are removed when the edema and swelling have subsided, at which point wrist and forearm range of motion exercises are begun.

Type IV—Radiocarpal Fracture-Dislocation

These are high-energy injuries in a young patient cohort that combine bony and soft tissue components and have the potential for marked wrist dysfunction. Dumontier and colleagues describe two distinct variants of radiocarpal fracture-dislocation, with important treatment implications.[30] Though distinctly uncommon, a radiocarpal dislocation with only a small fleck of attached bone has by necessity disrupted each of the volar and dorsal extrinsic ligamentous stabilizers of the carpus and will predictably progress to an ulnar translational deformity unless meticulous repair of the volar ligaments is performed through an extended volar carpal tunnel incision (Figure 17.64). Multiple Kirschner wire or temporary dorsal distraction plating (see earlier) should be performed to stabilize this injury during ligament healing.

More commonly, a large fragment of the radial styloid, with or without a portion of the articular surface and its attached dorsal radial rim, is avulsed at the time of injury. Treatment consists of anatomic reduction and rigid fixation of the styloid and dorsal rim fragments. Fragments that comprise at least a third of the scaphoid facet of the radius preserve the radioscaphocapitate and long radiolunate ligaments in continuity with the carpus such that anatomic reduction and healing restore stability to the carpus.[30] I prefer rigid columnar fixation of the styloid piece with a radial pin plate or a 2.0-mm radial column plate through a volar radial incision (see earlier), combined with dorsal rim fixation using a dorsal wireform (Online Case 17.10) or 2.0-mm dorsal plate. Fixation stability is tested in the operating room under fluoroscopy and postoperative immobilization customized. Cannulated screw fixation, isolated Kirschner wires, or a tension band can also be used, depending on the size of the styloid fragment and surgeon preference.

Type V—Combined/Complex Injury

Finally, for more *complex fracture patterns*, such as type V or C3-3 high-energy fractures (combined articular, metaphyseal, and diaphyseal injuries), no single implant or treatment paradigm is appropriate to solve all the components of the fracture and the soft tissue injuries. If the fracture has a relatively simple intra-articular component and extensive metaphyseal-diaphyseal comminution with large butterfly fragments, internal fixation with interfragmentary screws and a fixed-angle device is the method of choice to simultaneously restore radial alignment and radial length and bridge the metaphyseal-diaphyseal comminution. Initial application of a bridging external fixator to gain length and alignment may be helpful, and it may be left in place at the surgeon's discretion for additional stability (Online Case 17.11). For more comminuted articular fractures, a combined dorsal and volar exposure with compartment and median nerve release, autologous cancellous bone grafting of the metaphyseal defect, and a combination of external and internal or fragment-specific fixation may be required (Figure 17.65).

For cases with extensive articular and metaphyseal- diaphyseal disruption, particularly in multitrauma patients or those who require load bearing on their injured wrist in the immediate postoperative period, bridge (distraction) plating is a comparably rapid and effective solution that preserves radial length during the healing process. I prefer the use of a smaller 2.4-mm bridge plate spanning the second extensor compartment and affixed to the index metacarpal distally (see earlier and Figure 17.52C).

ASSOCIATED INJURIES

Distal radius fractures may be the result of significant trauma to the entire upper extremity. Whether evaluating a patient with an acute or chronic distal radius fracture, a complete examination of the entire upper extremity should always be undertaken to identify and treat associated musculoskeletal and neurovascular injuries. Conversely, on occasion, serious associated injuries such as shoulder dislocation or scapulothoracic dissociation, elbow fracture/dislocation, plexus injury, or vascular injury can overshadow a concomitant distal radius fracture. The associated injuries, particularly injuries to a peripheral nerve, often lead to more problems than the distal radius fracture itself.

Open Fractures

Most fractures of the distal radius are closed injuries, but I consider any fracture that communicates with the external environment to be an open fracture. The associated skin injury may be massive, or it may be a pinpoint, with the only real indication that the wound communicates with the fracture being a small amount of fatty fluid exuding from the wound. All open fractures should be treated as surgical emergencies. My treatment plan for open distal radius fractures calls for clinical and radiologic evaluation in the emergency department followed by local cleansing, wound irrigation, and temporary stabilization in plaster. Specimens should be obtained from the wound for culture after initial cleansing, and intravenous broad-spectrum cephalosporin antibiotics are initiated before transport to the operating room. Farm injuries or grossly contaminated wounds should receive additional anaerobic and aminoglycoside coverage. The patient is transported to the operating room expeditiously, where the wound is enlarged, the skin and fracture margins débrided, and the wound irrigated with abundant quantities of saline. Restoration of stability is paramount to control of infection; thus, if the fracture is unstable, there is adequate soft tissue coverage, and the wound has been suitably cleaned, I prefer to stabilize the fracture with internal or percutaneous fixation, depending on the particular fracture characteristics. If the fracture is stable, the wound extensions can be closed primarily (while leaving the traumatic wound open) and the fracture immobilized in a cast. If the wound cannot be suitably cleaned or if the wound has been open for more than 12 hours, the fracture is stabilized with an external fixator, the wound left open, and the patient returned to the operating room at 48 hours for definitive treatment and wound closure as possible.

Associated Median Nerve Injury

Varying levels of median nerve compromise, usually caused by blunt contusion or stretch of the nerve over the angulated distal radius, commonly accompany acute distal radius fractures. Fracture hematoma can also compromise the nerve within the carpal tunnel, particularly in patients who may have mild or nocturnal symptoms preceding the injury. It is essential to record the degree of nerve involvement with careful measurements of two-point discrimination and, if possible, thenar motor function before treatment. Closed reduction is performed under adequate local or regional anesthesia, and if satisfactory reduction is obtained, observation plus careful follow-up is all that is necessary in most instances. If the reduction can be maintained, the nerve compression syndrome will generally improve substantially over the subsequent 24 to 48 hours. If neurologic symptoms worsen or show no improvement over the first 24 to 48 hours or if the reduction cannot be obtained or maintained in the presence of median nerve compression, I favor early closed reduction under anesthesia, carpal tunnel release, and operative stabilization of the fracture. There are no data to support routine release of the carpal tunnel at the time of operative fixation in patients without preoperative evidence of median nerve compromise.

Associated Carpal Ligament Injuries

Carpal ligament disruption can occur with both intra- articular and extra-articular fractures of the distal radius. Certain fracture patterns, such as radiocarpal fracture- dislocations and severely displaced radial styloid fractures entering the ridge between the scaphoid and lunate fossae, are particularly at risk for associated carpal ligament injury (see earlier). The incidence of associated carpal ligament disruption with fractures of the distal radius has been documented with arthroscopy by several authors, and an approximate incidence of 30% for partial or complete scapholunate tears and 15% for lunotriquetral tears has been demonstrated.[41] There is no clear association between fracture type and location or the extent of interosseous ligament injury.

Arthroscopic assessment is recommended when injury to the interosseous scapholunate or lunotriquetral ligament is suspected. Complete interosseous ligament injuries in young and active individuals require aggressive operative treatment. Open repair of scapholunate disruptions is recommended after reduction and fixation of the distal radial fracture. Arthroscopic pinning or cannulated screw fixation is appropriate for partial scapholunate lesions with instability and for unstable or complete lunotriquetral injuries.

OUTCOME AND PATIENT EXPECTATIONS

Table 17.2 (see earlier) summarizes a compilation of data from single-cohort studies published since 2000, broken down into broad fixation categories. One can generalize from these data that the use of modern fixation techniques generates highly successful *physician-reported* outcomes in the vast majority of patients, with restoration of grip strength to 80% to 90% of preinjury values, restoration of range of wrist flexion-extension to 80% to 85%, and nonvalidated outcome measures indicating 85% to 95% good to excellent results. The patient cohorts are largely comparable, with a trend toward less comminuted fractures in the fixed-angle volar plate group and higher use of bone graft in the fragment-specific and dorsal plate cohorts. It should be noted that the outcome data for volar plating and external fixation are nearly identical, which runs contrary to the conventional wisdom that rigid internal fixation with early motion necessarily leads to improved outcomes. This finding, however, is substantiated by a recent meta-analysis involving more than 1500 patients in 46 studies over the past 3 decades.[83] The data for dorsal plate fixation, though including slightly more highly comminuted C3-type fractures, demonstrate overall lower satisfaction scores, higher rates of soft tissue complications, and a higher percentage of lost reductions and may correlate with the recent apparent diminution in enthusiasm for dorsal plate fixation.

Factors that lead to a patient's perception of a successful outcome after any surgical intervention are poorly understood and abundantly illustrated by the lack of consensus on primary outcome measures for management of distal radius fractures. After an exhaustive review of 3371 treatment comparisons in 48 randomized trials of treatment of distal radius fractures, Handoll and colleagues were unable to definitively identify particular surgical interventions that produced consistently improved long-term patient outcomes when compared with nonsurgical treatment. Their 2003 review was hampered by inconsistency in reporting and the paucity of validated outcome tools in most publications. The authors made a plea for a validated "standard core data set" for classification and uniform reporting of *objective* and *patient-derived* outcomes.[47] Clearly, data in both domains must be collected and reported to provide a comprehensive assessment of outcome and to make comparisons between different clinical trials at different centers.

Although we have made excellent progress over the past decade with the increased use of validated outcome instruments such as the DASH, PRWE, and Michigan Hand Outcome questionnaires, the publication of several well-executed prospective randomized trials, and improved reporting of objective radiographic and clinical data, there is little evidence to identify with certainty factors that are the best determinants of *patient-derived* outcomes of distal radius fracture treatment. The degree to which objective determinants of physical impairment (such as range of motion and radiographic alignment) or the largely subjective measures of disability (such as functional assessment, grip and pinch strength, and pain) influence patients' perception of outcome is poorly understood.

Karnezis and Fragkiadakis performed a multivariate analysis of objective outcomes after the percutaneous treatment of 31 unstable distal radius fractures to identify which factors correlated best with patient functional outcome as determined by the PRWE.[62] Surprisingly, only grip strength at each follow-up interval up to 24 months postoperatively correlated with patient function as assessed by the PRWE; neither forearm rotation nor wrist flexion-extension correlated with outcome. In a later study by the same authors, the radiographic parameters of dorsal malunion and radial shortening were found to correlate significantly with worsening outcomes in the pain domain of the PRWE. Similarly, articular incongruency of 1 mm or greater correlated with increasing wrist dysfunction on the PRWE.[63] Ring and colleagues studied a larger group of patients treated surgically with locked volar plate fixation and found at an average of 22 months postoperatively that pain was more strongly correlated with the DASH score and the Gartland-Werley demerit score system; grip strength explained a high degree of the variability when using the Mayo wrist scoring system. The authors pointed out that these scoring systems are somewhat arbitrary in their allocation of points; the former is heavily weighted toward pain and the latter toward grip strength, and this helps explain the correlations in part. Among the objective parameters measured, only forearm range of motion correlated with the DASH score. The authors concede that volar plate fixation resulted in nearly anatomic reduction in almost all of their patients, and this may have limited the outcome variability and any potential correlations. Authors in all three series commented on the relative weakness of the traditional Gartland and Werley, Green and O'Brien, and Mayo scoring systems, which in addition to arbitrary allocation of points for pain, motion, and radiographic alignment, have not been validated for responsiveness to change and repeatability. Furthermore, Ring and associates believe that the dominance of subjective measures, including pain and grip strength, as predictors of outcome may increase the vulnerability of these scoring systems to psychosocial confounding variables.[110]

In a study of 78 patients treated by either closed reduction or external fixation, Wilcke and coauthors found that dorsally malunited fractures or fractures with greater than 2-mm radial shortening correlated with decreased DASH outcome and visual analog scale (VAS) satisfaction scores at 22 months postoperatively.[121] Similarly, grip weakness and loss of extension, ulnar deviation, or pronation were all statistically associated with lower satisfaction scores, and all but loss of pronation correlated with lower DASH scores as well. One can summarize from the available data that there is a correlation between restoration of radiographic indices of bony alignment and patient-perceived outcome. Moreover, it seems apparent that patient satisfaction early in the recovery process is largely dominated by pain, that grip strength and especially forearm rotation continue to improve over the first 12 months after surgery, and that in the long-term, dorsally malunited or shortened fractures may result in pain, loss of grip strength, and diminished extension or rotation and will adversely affect active patients' perception of outcome.

Going forward, it will be increasingly important for wrist investigators to use common classification and outcome parameters if we are to successfully collect data with which to compare and contrast treatment interventions for wrist injuries. At a minimum, it would seem prudent to collect a "standard core data set" that includes the following:

- AO classification of the wrist fracture type
- One or more validated, preferably "disease-specific" patient outcome instruments such as the PRWE, Michigan Hand Outcome questionnaire, or the DASH
- Range of motion of the digits, wrist, and forearm (bilateral)
- Grip strength (bilateral)
- Pain and satisfaction assessment (VAS score)
- Radiographic parameters (inclination, volar tilt, ulnar variance, articular congruency)

COMPLICATIONS

Although it was once believed by many that all patients with distal radius fractures did relatively well regardless of treatment, it is now well recognized that treatment of distal radius fractures is associated with a high complication rate. As can be seen in Table 17.2, surgical complications with modern fixation techniques, particularly after articular or high-energy injuries (or both), are still reported in upward of 50% of patients.

The complications that continue to plague treatment of distal radius fractures include persistent neuropathy, radiocarpal or radioulnar arthrosis, malunion, nonunion, tendon rupture, chronic regional pain syndrome (CRPS), ulnar impaction, loss of rotation, finger stiffness, and rarely, compartment syndrome. An understanding of these complications should lead us to be more aggressive in the original care of such fractures.

Chronic Regional Pain Syndrome

Although full-blown reflex sympathetic dystrophy is a relatively infrequent problem, milder variants are surprisingly common in conjunction with distal radius fractures. Early recognition and attention to patients with an inordinate amount of pain, finger stiffness, swelling, allodynia, or paresthesias may prevent many of the problems of this serious complication. Removal or splitting of a dressing or cast to relieve pressure, elevation of an edematous hand, and intensive hand therapy are frequently very helpful in preventing the development of full-blown CRPS. More often than not, an irritated or entrapped peripheral nerve underlies most cases of early dystrophy, and the surgeon should have a low threshold for performing electrodiagnostic studies or surgical decompression (or both) for suspected nerve entrapment. For patients who do not respond to early local measures, sympathetic blocks, even with a cast in place, should be considered (see Chapter 59). In patients who have a previous history of CRPS, there may be value in preemptive treatment with a long-acting sympathetic block or indwelling catheter for regional nerve blockade for any proposed surgical procedure.

Nonunion

Nonunion of distal radius fractures is rare but presents unique treatment challenges because of the associated pain, joint contractures, tendon imbalance or rupture, and occasional severe bony deformity.[96] In contrast, nonunion of ulnar styloid process fractures in conjunction with distal radius fractures is quite common and yet is rarely symptomatic. Treatment of distal radius nonunion must be individualized and based on the patient's symptoms, functional deficit, and bony substance. Basically, however, one should strive to achieve union with rigid internal fixation and autogenous bone grafting. Symptomatic nonunion of the ulnar styloid is best treated by excision of the styloid unless the ulnar styloid fragment is quite large, in which case the fragment should be treated by ORIF. It is essential, however, for the examiner to discriminate between radioulnar instability secondary to TFCC detachment and ulnar styloid nonunion or impingement. If DRUJ instability is suspected clinically, magnetic resonance imaging (MRI) of the radioulnar ligaments or CT of both wrists in full supination and pronation (or both) can help discriminate between the different conditions (see Chapter 16). If a styloid nonunion is accompanied by distal ulnar instability, the TFCC should be reattached to the fovea at the time of fragment excision or fixation.

Malunion

Malunion of distal radius fractures may result in wrist pain (radiocarpal, radioulnar, ulnocarpal), decreased range of motion, midcarpal instability, or any combination of these complications. In general, ulnar-sided wrist pain is the factor that leads most patients with malunited distal radius fractures to seek treatment. Recognition of associated carpal malalignment and DRUJ derangement is mandatory to decide whether additional procedures together with radial osteotomy are necessary to help ensure a good result. Assessment of carpal malalignment with malunited Colles' fractures includes determination of the presence of (1) dorsal subluxation of the carpus, (2) a type I (*adaptive*) dorsal intercalated segment instability (DISI) that is *reducible* by radial osteotomy, or (3) a type II or *fixed* DISI pattern that does not improve after radial osteotomy. A reducible deformity is usually characterized by a mobile lunate on flexion and extension lateral radiographs. A fixed DISI is generally associated with a more chronic deformity and may be associated with an unrecognized disruption of the scapholunate ligament. Correction of post-traumatic wrist deformity must be tailored to the specific site of deformity and depends on whether the malunion is extra-articular, involves the radiocarpal or radioulnar joints (or both), or is complex (metaphyseal and articular deformity). The decision to perform a simultaneous procedure at the DRUJ depends on the amount of radial shortening and the presence of osteoarthritic changes or instability of the joint. Instability or ulnocarpal impingement that results from radial shortening, angulation, or malrotation without associated degenerative changes can generally be corrected by restoration of radial anatomy alone. My indications for corrective osteotomy in a young, symptomatic, and active individual include 15 degrees or more of dorsal tilt, 5 mm of radial shortening, or marked radial angulation. Less commonly, increased volar tilt will result in carpal subluxation and be manifested as painful deformity and loss of extension, rotation, or both. If an impending malunion is recognized in the subacute stage, before complete bony healing, and the patient is medically stable, early intervention provides easier radial and DRUJ realignment because of the absence of soft tissue and capsular contractures. Early intervention results in a considerable decrease in total disability and earlier return to work.[57] In fully healed deformities, however, it may be prudent to wait until the soft tissues have stabilized and the patient has regained maximal wrist, digital, and forearm motion before osteotomy and fixation.

Technique of Extra-articular Radial Osteotomy

The aims of radial osteotomy are to restore function and improve the appearance of the wrist by correcting the deformity at the level of the fracture site. The osteotomy should reorient the joint surface to restore normal load distribution, re-establish the mechanical balance of the midcarpal joint, and improve the anatomic relationships of the DRUJ. Because radial shortening is a constant component of the deformity in both volar and dorsal malunions, an opening wedge osteotomy that is transverse in the frontal plane and oblique (parallel to the joint surface) in the sagittal plane is used to permit radial lengthening. Such an osteotomy allows

- Radial lengthening of up to 10 to 12 mm
- Correction of volar tilt in the sagittal plane
- Correction of radial inclination in the frontal plane
- Correction of rotational deformity in the axial plane

It is important that the osteotomy be parallel to the articular surface. If it is parallel to the long axis of the radius, a secondary deformity will be created when the osteotomy is opened (Figure 17.66).

With large defects, a corticocancellous bone graft from the iliac crest may be used to fit the bone defect created by the osteotomy. If partial or complete resection of the distal end of the ulna is performed simultaneously, the resected ulnar head can be sculpted and used to fill the radial defect. Preoperative planning and the use of Kirschner wires to mark the angle of deformity are mandatory to guarantee accurate angular correction, simplify the procedure, and reduce the degree of exposure to fluoroscopy.[31] Radiographs of the uninjured wrist are mandatory to determine the physiologic ulnar variance and calculate restoration of radial length (Figure 17.67).

Corticocancellous grafts shaped and interposed in the defect restore cortical continuity and increase intrinsic stability, provided that bone quality is adequate. Nonstructural cancellous grafts can also be used, but only in combination with an implant that maintains stable correction of the distal fragment throughout the time required for bony healing.[101] *Fixed-angle plates* are ideal for corrective osteotomies in osteopenic bone and nascent malunions and when using nonstructural bone grafts.

Technique: Dorsal Approach for Osteotomy of Malunited Distal Radius Fractures

Dorsal malunions may be exposed through a universal dorsal incision between the third and fourth extensor compartments (see earlier). For severe deformities, this has the benefit of a single approach through which soft tissue release, bone grafting, and internal fixation can be performed. The healed fracture site is identified with fluoroscopy. If dorsal plate fixation of the osteotomy is planned, Lister's tubercle should be removed with a rongeur to provide a flat surface on which to apply the plate. If Kirschner wire or low-profile columnar fixation of the osteotomy is planned, Lister's tubercle may be left undisturbed. To be sure that the osteotomy, as seen in the sagittal plane, is parallel to the joint surface, a 25-gauge needle is introduced through the dorsal part of the capsule into the radiocarpal joint and along the articular surface of the radius. In accordance with the preoperative plan,[31] two 2.5-mm Kirschner wires with threaded tips are inserted so that the angle of correction in the sagittal plane is subtended on both sides of the future osteotomy (see Figure 17.67). These wires not only control intraoperative angular correction but also help manipulate and maintain the distal fragment in the corrected position with a small external fixator bar until the graft is inserted in the defect. The osteotomy is performed with an oscillating saw, with care taken to not osteotomize the volar cortex completely. It is then opened dorsally and radially by manipulating the wrist into flexion, by applying a laminar spreader dorsally, or by using 2.5-mm Schanz screws as joysticks. The osteotomy is opened until both wires are parallel in the sagittal plane.

A small external fixator bar with two clamps is attached between both Schanz screws to maintain reduction of the distal fragment. Opening up the osteotomy on the radial side can be difficult, and complete tenotomy of the brachioradialis tendon is recommended to facilitate realignment.

The iliac bone graft is shaped to conform to the dorsal radial bone defect and is inserted while making sure that the fit is snug. At this point, a 1.6- or 2.0-mm Kirschner wire is driven obliquely from the radial styloid across the graft and into the proximal fragment, after which the threaded screws and the external fixator bar may be removed. Then, with the elbow in 90 degrees of flexion, intraoperative forearm rotation and wrist motion are checked. Radiographic control with the image intensifier may be advisable at this point to assess the quality of correction and radial lengthening before definitive internal fixation of the osteotomy is undertaken.

The osteotomy can be stabilized by a variety of methods. In young adults with good bone quality and especially when the volar cortex is not disrupted, simple Kirschner wire fixation (one through the radial styloid and one through Lister's tubercle in an oblique dorsal palmar direction) offers adequate stability. However, this method requires more prolonged immobilization.

Rigid fixation with plates may be used alternatively; they offer the advantage of early wrist rehabilitation after suture removal, usually 2 weeks after surgery. The use of lower-profile implants has helped diminish extensor tendon irritation. Low-profile 2.7-mm condylar plates or any of a number of dorsal fixed-angle devices can be placed beneath the fourth dorsal compartment. For dorsal fixation, I prefer the use of a radial pin plate and a fixed-angle "buttress pin" wireform implant that spans the opening wedge osteotomy and provides rigid fixation when combined with corticocancellous graft (Figure 17.68).

CRITICAL POINTS: RADIAL OSTEOTOMY FOR MALUNITED COLLES' FRACTURE

Indications
- Symptomatic malunion (pain, weakness, cosmetic disturbance)
- Limited palmar flexion
- DRUJ incongruency, limited forearm rotation
- Adaptive carpal instability

Technical Points
- Use a 6- to 7-cm dorsal approach with the incision centered on Lister's tubercle
- Expose the distal radius between the third and fourth compartment.
- Mobilize the EPL tendon.
- Mark the osteotomy at the previous fracture line.
- Use 2.5-mm Kirschner wires to determine the angle of correction (they may also be used as joysticks).
- Perform an osteotomy parallel to the joint surface in the sagittal plane and transverse in the frontal plane.
- Open the osteotomy dorsally until the Kirschner wires are parallel (use a laminar spreader or temporary external fixator).
- Fill the defect with preshaped corticocancellous bone graft.
- Use temporary Kirschner wire fixation and fluoroscopic control (for position of the distal fragment and DRUJ congruency).
- Perform internal fixation of the osteotomy (2.7-mm dorsal fixed-angle device with a radial pin plate and a fixed-angle buttress pin).
- Morcellized cancellous grafts or bone substitutes can alternatively be used in combination with fixed-angle dorsal plate.

Postoperative Care
- Apply a dorsal and palmar splint for 14 days, until suture removal. Use a sugar tong cast in supination when concomitant distal ulna excision is performed.
- Apply a short arm cast for 4 to 6 weeks until radiographic healing when using pin fixation.
- Apply a palmar splint and initiate gentle range of motion exercises if fixed-angle fixation is used.
- Large dorsal implants may produce tendon irritation and require removal at a later date.

Technique: Volar Approach for Osteotomy of a Malunited Distal Radius Fracture

Alternatively, malunited dorsally angulated fractures can be corrected through a volar approach to avoid the extensor tendon irritation that may be associated with dorsal plate fixation. A fixed-angle volar device anatomically designed to match the normal anatomic contours of the palmar radial surface may be used as a guide for precision restoration of palmar tilt (Figure 17.69). I prefer to calculate the degree of correction in the sagittal and coronal planes, apply the volar plate to the distal fragment with parallel smooth pegs before osteotomy, and then remove the plate to cut the osteotomy (Online Case 17.12). The plate is then reapplied distally by inserting the parallel smooth pegs into the predrilled holes and rotated into position on the proximal radial shaft to simultaneously realign the articular surface in both planes. Fixation is completed both proximally and distally with additional screws and pegs. Large deformities may require a concomitant dorsal incision, periosteal division, and the use of a laminar spreader to gain length. The resultant defect should be filled with cancellous bone graft, corticocancellous bone graft, or demineralized bone matrix, provided that fixation is secure. The presence of severe degenerative changes in the DRUJ mandates resection of the distal ulna or prosthetic replacement of the joint.

If the length discrepancy between the ulna and the radius is more than 10 mm, a combined radial osteotomy and simultaneous ulnar shortening can be performed. Rigid fixation of both the radius and the ulna, combined with autogenous graft, is recommended. If the radial shortening is greater than 2 to 3 cm, progressive lengthening with distraction osteogenesis techniques may be necessary to prevent nerve or tendon dysfunction, or both.

Watson's Trapezoidal Osteotomy

In 1988, Watson and Castle described the technique of biplanar osteotomy plus a trapezoidal distal radial local autogenous bone graft for the treatment of malunion of the distal radius (Figure 17.70).[118] These authors recommend exposure of the distal radius through a transverse dorsal incision, although a universal dorsal approach may also be used. The articular surface of the radius is visualized, and the osteotomy is made parallel with the articular surface and approximately 1 cm proximal to it. In a biplanar mode, to correct the loss of radial tilt and volar inclination, the osteotomy is opened and held in position with a laminar spreader while a radiograph is obtained. If the correct amount of tilt has been produced to restore normal radial inclination and volar tilt, a trapezoidal corticocancellous graft is obtained from the radius just proximal to the osteotomy site dorsally. The bone graft is removed from the radius, rotated 90 degrees, and then reinserted into the osteotomy site. If correction of the volar tilt is insufficient, it is increased by flexing the wrist while the graft is wedged deeper into the osteotomy space. The osteotomy and graft are secured with two crossed 0.0625-inch Kirschner wires to "cage" the corticocancellous graft, and the wrist is protected in a cast for 4 to 6 weeks. This technique has the advantage of using a local graft, so it can be performed with the use of regional anesthesia. I would, however, not recommend it for severe radial malunion or when substantial length discrepancy is present.

Malunited Smith's Fractures

The classic symptoms of volar malunion include decreased wrist extension and supination because of the tendency for Smith's fractures to heal with a pronation deformity. These malunions are exposed through a standard FCR incision, with radial detachment of the pronator quadratus muscle and partial disinsertion of the FPL from the radial shaft. Two Kirschner wires or a two-pin external fixator are inserted on the volar aspect to mark the angle of correction, as shown in Figure 17.71. The palmar opening wedge osteotomy, grafting, and plating are then carried out as for a Colles' deformity, but in a reversed manner from the volar side. Care must be taken to not overcorrect the physiologic palmar tilt of 10 degrees when manipulating the distal fragment into dorsiflexion. Another common pitfall is to translate the entire distal radius fragment dorsally and, in so doing, fail to gain adequate correction. Temporary Kirschner wire fixation through the radial styloid and a second wire placed volar to dorsal from the radial rim help stabilize the correction, which is verified with fluoroscopy. Application of a fixed-angle volar plate automatically derotates the pronation deformity of the distal fragment by virtue of the contoured surface of the plate. Dorsiflexion of the distal fragment and derotation, as well as lengthening, reorient the sigmoid notch of the radius with respect to the ulnar head (see Figure 17.71). Degenerative arthritis of the DRUJ may necessitate simultaneous distal ulnar excision or replacement in chronic cases.

Intra-articular Osteotomies

The role of osteotomy in correcting an intra-articular malunion of the radiocarpal joint after a distal radius fracture is limited by both chronology and the type of injury. The osteotomy should be done as early as possible after fracture, and the fracture plane can readily be identified upward of 8 to 12 weeks after injury.[100] High-resolution CT with multiplanar reformatting is particularly helpful in identifying the fracture plane and planning the osteotomy. MRI with cartilage- sensitive sequences or concomitant wrist arthroscopy may play a useful role in evaluating the amount of cartilage damage and intra-articular incongruence. The presence of areas bare of subchondral bone represents a formal contraindication to osteotomy. I prefer to reserve such a procedure for malunited fractures that have a relatively simple intra-articular component (Figure 17.72). Such fractures include malunited radial styloid fractures, volar or dorsal shearing (Barton's) fractures, and dorsal die punch fractures. The choice of surgical approach is as indicated for the fracture scenario in the acute stage. Rigid fixation of the osteotomized fragment enables early rehabilitation of the radiocarpal and radioulnar joints.

Distal Radioulnar Joint Procedures

The most common cause of residual wrist disability after fracture of the distal radius involves the ulnar side of the wrist. The three basic conditions responsible for pain associated with limitation of forearm rotation are incongruency, impaction, and instability of the joint. Less frequent (or concomitant) findings are painful nonunion of the ulnar styloid, capsular contracture of the joint, and radioulnar impingement (after distal ulnar resections or Sauve-Kapandji procedures). Incongruency of the DRUJ may be due to (1) extra-articular deformity of the radius or ulna, which leads to an abnormal orientation of the joint surfaces (sigmoid notch and ulnar head) in space; (2) disruption of the intra-articular joint surface by a fracture line affecting the sigmoid notch or the ulnar head, or both; and (3) extra- and intra-articular factors combined. Impaction, defined as abnormal contact of two bony surfaces, occurs at the ulnocarpal joint as a result of post-traumatic radial shortening and is synonymous with ulnocarpal abutment. With continuing impaction of the ulnar head against the carpus, progressive traumatic changes follow in a predictable sequence, including attenuation and tears of the TFCC; chondromalacia of the ulnar head, lunate, and triquetrum; attenuation and tears of the triquetrolunate ligament; and finally, ulnocarpal degenerative change, heralded by cyst formation in the apposing bones. Instability is the result of loss of ligament support because of avulsion of the palmar and dorsal radioulnar ligaments from their foveal insertion. Additional lesions of secondary joint stabilizers (capsular ligaments, sheath of the extensor carpi ulnaris, interosseous membrane, pronator quadratus) or intra-articular bony disruption of the joint surface may aggravate the degree of laxity.

If the patient's main complaints are localized to the DRUJ (pain associated with limitation of forearm rotation) and the angulation of the radial articular surface in the sagittal and frontal planes is less than 10 degrees, a reconstructive procedure at the distal radioulnar level is indicated, without a corrective radial osteotomy. However, if significant radial deformity is clearly associated with identifiable DRUJ problems, radial osteotomy and the appropriate DRUJ procedure are performed simultaneously.

For radial shortening and ulnocarpal impaction with acceptable congruency of the sigmoid notch and ulna, as demonstrated by CT, a shortening osteotomy of the ulna is the procedure of choice. Ulnar shortening decompresses the ulnar compartment of the wrist, re-establishes DRUJ congruity, and tightens the TFCC, which exerts a stabilizing effect on the distal ulna. An oblique osteotomy with resection of a bony segment and rigid fixation with a compression plate is recommended (see Chapter 16).[18]

If associated instability of the DRUJ is present, transosseous reattachment of the TFCC is performed simultaneously with the radial osteotomy.[54] If the dorsal and palmar radioulnar ligaments are in continuity with an ulnar styloid fragment, bony reattachment with a screw, ulnar pin plate, or tension band is preferred.

If plain radiographs or CT demonstrate post-traumatic incongruity or degenerative changes of the radioulnar joint, either a resection arthroplasty, an ulnar head prosthetic replacement (Figure 17.73), or a Sauve-Kapandji arthrodesis is required to alleviate pain. A partial ulnar head or "matched ulna" resection[119] with periosteal and capsular imbrication preserves the ulnocarpal ligaments and the TFCC in continuity with the distal ulnar stump. Partial ulnar resection does not alter the ulnar variance, and therefore additional ulnar shortening, either at the styloid level or at the ulnar shaft, may be required to prevent stylocarpal impingement. The disadvantages of the Darrach procedure, such as loss of grip strength, loss of ulnar support of the carpus, and instability of the distal ulnar stump, are well described, but the two most common causes of failure are due to excessive resection of the distal ulna and failure to correct a concomitant distal radius malunion.

Radioulnar impingement, or convergence and scalloping of the resected ulna on the radial metaphysis, can be treated with an ulnar head prosthesis, and acceptable midterm results have been reported with this procedure.[116] Table 17.4 is an algorithm for ulnar-sided disorders that may accompany fractures and malunions of the distal radius. The Darrach procedure still has a place in the treatment of distal ulnar derangement or osteoarthritis after a Colles' fracture in elderly patients, or it can be used as a salvage procedure for failed reconstructive procedures of the radioulnar joint (see Chapter 16).

DRUJ arthrodesis with the creation of a proximal pseudarthrosis preserves both the ulnocarpal ligaments and the bony support of the carpus. This operation is extremely useful in younger, active patients to improve forearm rotation in those with fixed DRUJ subluxation after articular fractures of the distal radius and severe destruction of the joint (Figure 17.74). I recommend primary stabilization of the remaining distal ulna with distally based tendon weaves using slips of both the flexor carpi ulnaris and the extensor carpi ulnaris, as described by Lamey and Fernandez.[73]

Distal Radioulnar Joint Contracture

Capsular contraction of the DRUJ may be responsible for limitation of forearm rotation after distal radius fractures. Having ruled out joint incongruity, subluxation, radioulnar synchondrosis, interosseous membrane contracture, or derangement of the proximal radioulnar joint as other possible causes of limitation of forearm rotation, surgical release is helpful if the condition does not improve after a trial of physiotherapy.

The volar aspect of the joint is exposed through a longitudinal incision just ulnar to the flexor carpi ulnaris tendon. Having exposed and protected the dorsal cutaneous branch of the ulnar nerve, the flexor carpi ulnaris tendon and the ulnar neurovascular bundle are retracted radially. Next, the pronator quadratus is sectioned longitudinally 5 mm radial to its ulnar insertion. The contracted palmar capsule is exposed to retract the pronator quadratus radially. It is useful to place a 25-gauge needle between the TFCC and the ulnar head and confirm placement under fluoroscopy before resection of the palmar capsule. A longitudinal capsulotomy just proximal to the volar radioulnar ligament close to the sigmoid notch is performed and then continued proximally to the neck of the ulna. The entire palmar capsule is excised to expose the articular surface of the ulnar head. A "silhouette" capsulotomy[64] of the dorsal capsule is then performed through a counterincision on the dorsal side to displace the extensor digiti minimi and gain access to the DRUJ. Postoperatively, I begin immediate mobilization of the forearm and use dynamic supination bracing if necessary.

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Figure 17.1 The scaphoid and lunate articulate with the distal articular surface of the radius, and the ulnar head articulates with the sigmoid notch. The triangular fibrocartilage complex (TFCC) is interposed between the ulnar carpus and the ulnar head. L, lunate; S, scaphoid; T, triquetrum.

Figure 17.2 Arthroscopic anatomy of the radiocarpal joint. Pictured are the articular surfaces of the scaphoid, lunate, triquetrum, radius, and triangular fibrocartilage complex. The major extrinsic—radioscaphocapitate, long radiolunate, radioscapholunate, ulnolunate, and lunotriquetral—ligaments of the wrist are shown. The very important intrinsic ligaments of the wrist—the scapholunate ligament and lunotriquetral ligaments—are also shown. *(Copyright Elizabeth Martin.)*

Figure 17.3 Dissection and illustration composite showing the dorsal ligaments of the wrist. DIC, dorsal intercarpal ligament; RS, radioscaphoid; RT, radiotriquetral; TFCC, triangular fibrocartilage complex. *(Copyright Elizabeth Martin.)*

Figure 17.4 The ulnar head articulates with the sigmoid notch of the radius at the "seat" of the distal radioulnar joint (DRUJ). The triangular fibrocartilage complex (TFCC), the distal restraint of the DRUJ, arises from the most ulnar border of the radius and inserts into the base of the ulnar styloid process.

Figure 17.5 Artist's drawing of the distal radius. **A,** Dorsal view illustrating Lister's tubercle. **B,** Palmar view showing the scaphoid and lunate fossae distally, as well as the sigmoid notch ulnarly. Vascular foramina can be noted on the palmar and dorsal aspects of the distal radius. **C,** End-on view of the distal radius and radioulnar joint showing the scaphoid fossa, lunate fossa, and ulnar head resting in the sigmoid notch. **D,** View of the sigmoid notch from the ulnar aspect. *(Copyright Elizabeth Martin.)*

Figure 17.6 The sigmoid notch showing distinct dorsal, palmar, and distal borders and an indistinct proximal border. D, distal; P, proximal.

Figure 17.7 A, Posteroanterior radiograph of a wrist demonstrating radial inclination (23 degrees) and neutral ulnar variance. **B,** The "facet lateral" x-ray is performed by aligning the x-ray beam in a plane parallel to the lunate facet of the radius, approximately 15 degrees distal to proximal. *(Drawing copyright Elizabeth Martin.)*

Figure 17.8 "Teardrop angle." **A,** The angle is measured as a tangent to the articular surface of the volar teardrop with respect to the longitudinal axis of the radius and is normally 70 degrees. **B,** Increased teardrop angle with a displaced volar marginal fracture. **C,** Decreased teardrop angle with a dorsally angulated extra-articular fracture. **D,** Restoration of a normal teardrop angle after internal fixation of the teardrop.

Figure 17.9 AP distance and AP/lunate diameter ratio. **A,** In an uninjured wrist, the AP distance (20.3 mm) is nearly equal to the diameter of a best-fit circle of the lunate contour (19.8 mm). **B,** In an injured wrist, the AP diameter is grossly widened (26 mm), and the AP/lunate diameter ratio is 1.3.

Figure 17.10 The dorsal rim of the radius normally projects 3 to 5 mm distal to the dense subchondral bone of the articular surface, and this relationship may be altered by post-traumatic changes in volar tilt or die punch injuries.

Figure 17.11 Use of computed tomography. **A** and **B,** Posteroanterior and lateral radiographs of a comminuted articular fracture after reduction demonstrating what appears to be satisfactory reduction of the articular surface. **C** and **D,** Coronal and axial scans of the articular surface demonstrating multiple fragmentation, articular impaction, and incongruency. Note the separate volar lunate "teardrop" fragment that may not have been appreciated on the lateral radiograph.

Figure 17.12 Diagrammatic representation of the typical deformity seen in a Colles' fracture. Dorsal comminution and displacement with shortening of the radius relative to the ulna are present. *(Copyright Elizabeth Martin.)*

Figure 17.13 Thomas' classification of Smith's fractures. A type I Smith fracture is an extra-articular fracture with palmar angulation and displacement of the distal fragment. A type II Smith fracture is an intra-articular fracture with volar and proximal displacement of the distal fragment along with the carpus. A Smith type II fracture is essentially a volar Barton's fracture. A dorsal Barton's fracture, illustrated for comparison, shows the dorsal and proximal displacement of the carpus and distal fragment on the radial shaft. A type III Smith fracture is an extra-articular fracture with volar displacement of the distal fragment and carpus. (In type III the fracture line is more oblique than in a type I fracture.) *(Copyright Elizabeth Martin.)*

Figure 17.14 A chauffeur's fracture is illustrated with the carpus displaced ulnarly by the radial styloid fracture. A lunate die punch fracture is shown with a depression of the lunate fossa of the radius that allows proximal migration of the lunate or proximal carpal row (or both). *(Copyright Elizabeth Martin.)*

Figure 17.15 Frykman's classification of distal radius fractures. Types I, III, V, and VII do not have an associated fracture of the distal ulna. Fractures III through VIII are articular fractures. Higher-classification fractures have worse prognoses. *(Copyright Elizabeth Martin.)*

Figure 17.16 Melone's classification of distal radial fractures. The four major fragments are (1) the radial shaft, (2) the radial styloid region, (3) the dorsal medial facet, and (4) the volar medial facet. The major fragment of this four-part fracture is the medial facet (i.e., fragments 3 and 4). *(Copyright Elizabeth Martin.)*

Figure 17.17 The comprehensive classification of fractures (AO). **A,** Extra-articular. This fracture affects neither the articular surface of the radiocarpal nor the radioulnar joints. **A1,** Extra-articular fracture of the ulna with the radius intact. **A2,** Extra-articular fracture of the radius, simple and impacted. **A3,** Extra-articular fracture of the radius, multifragmentary. **B,** Partial articular. This fracture affects a portion of the articular surface, but continuity of the metaphysis and epiphysis is intact. **B1,** Partial articular fracture of the radius, sagittal. **B2,** Partial articular fracture of the radius, dorsal rim (Barton's). **B3,** Partial articular fracture of the radius, volar rim (reverse Barton's, Goyrand-Smith II). **C,** Complete articular. This fracture affects the joint surfaces (radioulnar, radiocarpal, or both) and the metaphyseal area. **C1,** Complete articular fracture of the radius, articular simple and metaphyseal simple. **C2,** Complete articular fracture of the radius, articular simple and metaphyseal multifragmentary. **C3,** Complete articular fracture of the radius, multifragmentary.

Figure 17.18 Mayo Clinic classification of distal radial fractures. Type 1 is an extra-articular fracture, and types 2 to 4 are intra-articular fractures. Emphasis is given to whether the fracture is displaced or nondisplaced and reducible or irreducible. *(Copyright Elizabeth Martin.)*

Figure 17.19 Fragment-specific classification.

Figure 17.20 The columnar concept of the wrist. *(Copyright Elizabeth Martin.)*

Figure 17.21 **A** and **B,** The Fernandez classification of distal radius fractures and associated distal radioulnar joint (DRUJ) lesions. **B,** DRUJ injury classification. *(Copyright Elizabeth Martin.)*

Figure 17.22 According to McQueen and colleagues,[86] carpal malalignment is defined when the longitudinal axis of the capitate and the radius intersect outside the boundaries of the carpus (*arrow*).

Figure 17.23 Alternative and rapid assessment of carpal malalignment using the "radial box." The center of the capitate proximal pole should fall within a box generated along the dorsal and palmar cortical outlines of the radius on a true lateral x-ray.

Figure 17.24 **A** and **B,** Distal radius (Colles') fracture. **C** and **D,** My recommended reduction of this fracture. After suspending the arm from finger traps and allowing disimpaction of the fracture, pressure is applied with the thumb over the distal fragment. *(Copyright Elizabeth Martin.)*

Figure 17.25 Sugar tong splint for a distal radius fracture. This splint controls forearm rotation while allowing some elbow flexion. The palmar crease should be free to allow full metacarpophalangeal flexion and the dorsal plaster should extend to the metacarpal heads.

Figure 17.26 **A,** Typical radiographic appearance of a Colles' fracture in a young adult. **B,** The fracture was manually reduced and held in slight flexion, ulnar deviation, and slight pronation in a sugar tong splint for 3 weeks, followed by a short arm cast for another 3 weeks. **C,** Follow-up radiographs at 1 year reveal loss of 2 mm of length but maintenance of normal volar and ulnar tilt. Notice the asymptomatic nonunion of the tip of the ulnar styloid.

Figure 17.27 "Six-pack" exercises. Drawings 1 through 6 illustrate the position that the patient's hand should assume when performing these exercises. It is helpful to illustrate to the patient that full metacarpophalangeal (MP) extension makes the hand look like an arrow, full MP flexion makes the hand look like a tabletop, full MP extension combined with proximal and distal interphalangeal flexion creates a claw, complete finger flexion creates a fist, and abduction and adduction of the fingers create an in-and-out motion; finally, to complete the exereises, the individual touches the tip of the thumb to the tip of each finger. *(Copyright Elizabeth Martin.)*

Figure 17.28 Several different techniques of percutaneous pinning of unstable bending fractures have been described. **A,** Pins placed primarily through the radial styloid. **B,** Crossing pins from the radial and ulnar sides of the distal fragment into the distal shaft. **C,** The intrafocal technique advocated by Kapandji. **D,** Ulnar-to-radius pinning without transfixation of the distal radioulnar joint (DRUJ). **E,** A radial styloid pin and one across the DRUJ. **F,** Multiple pins from the ulna to the radius, including transfixation of the DRUJ.

Figure 17.29 **A-H,** An unstable fracture in healthy but comminuted bone can be stabilized adequately with percutaneous pins and a cast for 6 weeks with the expectation of restoration of alignment and function.

Figure 17.30 Kapandji technique of "double intrafocal wire fixation" to reduce and maintain distal radial fractures. A 0.045- or 0.0625-inch Kirschner wire is introduced into the fracture in a radial to ulnar direction. When the wire reaches the ulnar cortex of the radius, it is used to elevate the radial fragment and recreate the radial inclination. This wire is then introduced into the proximal ulnar cortex of the radius for stability. A second wire is introduced at 90 degrees to the first in a similar manner to restore and maintain volar tilt. *(Copyright Elizabeth Martin.)*

Figure 17.31 Augmented external fixation. **A** and **B,** Posteroanterior and lateral radiographs of an unstable extra-articular fracture. **C** and **D,** Crossed pin augmentation of external fixation yields optimal construct strength. **E** and **F,** The fixator is in a neutral position to allow full flexion and extension of the digits postoperatively. **G** and **H,** Healed fracture in satisfactory alignment. **I** and **J,** Symmetric range of motion postoperatively.

Figure 17.32 An external fixation device being applied after two 3-mm half-pins have already been introduced into the base of the second metacarpal. Two 3-mm half-pins are then introduced into the distal radius via direct exposure of the radius. The radial nerve is protected by directly identifying the nerve and then inserting the half-pin through a tissue protector that is placed directly on the radius. BR, brachioradialis; ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus. *(Copyright Elizabeth Martin.)*

Figure 17.33 Augmented external fixation of an unstable intra-articular fracture with a bone graft substitute. **A** and **B,** Comminuted unstable fracture in an elderly woman. **C,** Packing of the metaphyseal void with coralline hydroxyapatite through a limited dorsal approach. **D** and **E,** Radiographs 3 weeks postoperatively demonstrating the crossed pin configuration and incorporation of the graft. **F,** Importance of neutral position and full digital motion. **G** and **H,** Three-year postoperative radiographs.

Figure 17.34 **A,** Radiographs of an unstable dorsally displaced extra-articular fracture of the distal radius. **B,** Fluoroscopic control of the nonbridging fixator. Notice the converging position of the distal pins in the frontal plane and parallel to the joint surface in the sagittal plane. **C,** Control radiographs 10 days after injury with well-maintained reduction. **D,** Early motion of the wrist is allowed as soon as the swelling has subsided. **E,** Radiographs at 3 months. The fracture has healed without displacement and correlates with free wrist motion and restoration of complete forearm rotation.

Figure 17.35 Hybrid internal and external fixation in an elderly patient. **A** and **B,** Comminuted fracture with dorsal and volar marginal fractures of the lunate fossa. **C** and **D,** Augmented external fixation combined with a volar implant through a limited-incision approach to fix the volar ulnar corner fragment. **E,** Full motion of the digits encouraged postoperatively. **F** and **G,** Radiographs 4 years postoperatively. **H** and **I,** Nearly symmetric range of motion.

Figure 17.36 Limited open reduction. **A,** Limited exposure of the radial metaphyseal void between the third and fourth dorsal compartments enables percutaneous elevation of the articular surface and bone graft augmentation. EDC, extensor digitorum communis; EPL, extensor pollicis longus; PIN, posterior interosseous nerve. **B,** Healed 3-cm dorsal incision *(arrow)* for articular reduction and placement of bone graft (see Figure 17.35). ***(A,** Copyright Elizabeth Martin.)*

Figure 17.37 **A,** Severely displaced four-part intra-articular fracture with 60 degrees of dorsal displacement and 5 degrees of ulnar tilt. After manual reduction and pinning of the radial styloid, intraoperative fluoroscopy shows insufficient reduction of the ulnar fragment and the large size of the metaphyseal bone defect. **B,** After the application of an external fixator, anatomic reduction of the joint surface is achieved through a dorsal approach (see Fig. 17.32); while the sagittal fracture gap is maintained with a pointed clamp, a third Kirschner wire is driven across both articular fragments and the defect grafted. **C,** The pins and fixator were removed at 5 weeks. A follow-up radiograph at 9 months shows a well-preserved joint space and overall adequate fracture alignment.

Figure 17.38 Operative technique: arthroscopic reduction and pinning of distal radial fractures. **A,** The arm is suspended from finger traps on the index and long fingers. The following anatomic landmarks are identified: arthroscopic portals 1-2, 3-4, 4-5, 6R (radial), 6U (ulnar), MCR (midcarpal radial), and MCU (midcarpal ulnar). The dorsal sensory branch of the ulnar nerve is noted. **B,** The arthroscope is introduced through the 3-4 or 4-5 portal, and with a probe through the 6R portal, the comminuted distal radial fracture is visualized. Clot and hemorrhage extrude from the fracture fragments. **C,** Joysticks (0.0625-inch Kirschner wires) are introduced into the major fragments percutaneously to elevate the fracture fragments into an anatomic position. **D,** Additional Kirschner wires are then introduced percutaneously into the fracture. **E,** The joysticks are then removed, the fixation pins are cut off outside the skin, and caps are applied. *(Copyright Elizabeth Martin.)*

Figure 17.39 Ideal positioning of a volar fixed-angle plate. Notice the subchondral positioning of the distal fixed-angle pegs, by virtue of which axial loading is transmitted to the pegs and the volar plate and to the radial shaft. The dorsal comminuted area has not been grafted in this case.

Figure 17.40 Comminuted articular fracture treated by dorsal plate fixation. **A** and **B,** Posteroanterior and lateral films demonstrate marked dorsal comminution. **C,** Subperiosteal exposure through a universal dorsal approach demonstrates dorsal fragmentation. **D,** A low-profile fixed-angle dorsal plate is applied after removal of Lister's tubercle. **E,** Retinacular closure. **F** and **G,** Healed postoperative radiographs demonstrate restoration of length and alignment. *(Courtesy of Andrew J. Weiland, M.D., with permission.)*

Figure 17.41 Volar approach to the distal radius. The brachioradialis tendon may be split and elevated subperiosteally to expose the radial and intermediate columns and the volar aspect of the distal radius. APL, abductor pollicis longus; EPB, extensor pollicis brevis. *(Copyright © 2001, Virginia Ferrante.)*

Figure 17.42 **A,** Incorrect placement of a volar fixed-angle device. The plate is placed too far distally, on the transverse ridge of the volar marginal lip of the radius; without coverage by the pronator, the flexor tendons are in direct contact with the plate and may rupture. **B,** Correct placement of the implant, recessed proximally and with sufficient soft tissue coverage to prevent flexor irritation and rupture. *(Copyright Elizabeth Martin.)*

Figure 17.43 Splitting the brachioradialis distally and leaving its volar tendinous portion attached to the pronator quadratus allow a stout repair over the volar plate on closure.

Figure 17.44 Coronal split Smith type II fracture fixed with a volar locked plate and immediate motion. **A** and **B,** Coronal split through the articular surface (*arrow*). **C** and **D,** Volar locked-plate fixation. **E** and **F,** Range of flexion and extension 12 weeks postoperatively.

Figure 17.45 The extended volar approach enables direct disimpaction of articular fragments by subperiosteal exposure of the distal third of the radius and pronation of the proximal fragment. APL, abductor pollicis longus; BR, brachioradialis; EPB, extensor pollicis brevis. *(Adapted from Orbay JL, Fernandez DL: Volar fixation for dorsally displaced fractures of the distal radius: a preliminary report,* J Hand Surg [Am] *27:205-215, 2002. Redrawn by Elizabeth Martin.)*

Figure 17.46 Hybrid fixation of the radial styloid. **A** and **B,** Posteroanterior (PA) and lateral radiographs demonstrating a comminuted articular fracture with palmar displacement and a large radial styloid fragment. **C,** PA radiograph 3 weeks postoperatively demonstrating incomplete fixation of the radial styloid. **D** and **E,** Computed tomography confirms insufficient styloid fixation with articular incongruency. **F,** Revision stabilization of the radial column with a radial column plate and bone graft. **G** and **H,** PA and lateral radiographs of the healed construct.

Figure 17.47 **A** and **B,** Palmar subluxation of the carpus after volar plate fixation. Note the palmar and proximal translation of the carpus as a result of loss of fixation of the volar ulnar fragment on the lateral radiograph.

Figure 17.48 **A,** Intraoperative fluoroscopy demonstrating subchondral support for the articular surface and fixation of the comminuted dorsal cortex with a dorsal wireform implant. **B,** Posteroanterior view of a wireform implant used to secure a shear-type fracture of the articular surface.

Figure 17.49 An ulnar "pin plate" or 2.0-mm miniplate can be used to fix unstable dorsal intermediate column fragments. **B,** The ulnar pin plate uses 0.045-inch Kirschner wires and 2.0-mm screws and can be placed through a limited fifth dorsal compartment incision. It is important for most fractures that fixation of the intermediate column be supplemented with orthogonal (90-90) fixation of the radial column. *(**A,** Copyright Elizabeth Martin.)*

Figure 17.50 Fixation of the volar ulnar corner. **A,** Palmar subluxation of the carpus secondary to a volar ulnar "teardrop" fracture. **B** and **C,** A volar buttress pin is contoured to support the articular surface and can be placed immediately atop the palmar ridge of the radius and secured proximally beneath the pronator quadratus. **D** and **E,** Posteroanterior and lateral radiographs of the healed fracture at 1 year. *(**B** and **C,** Copyright Elizabeth Martin.)*

Figure 17.51 A 2.0-mm radial pin plate incorporates 0.045-inch Kirschner wires and two bicortical screws in a tension band configuration to capture unstable radial styloid fracture fragments.

Figure 17.52 **A,** Distraction plating is performed through a limited dorsal incision with tunneling of the plate beneath the fourth dorsal compartment. Screws are placed proximally and distally to span the fracture site, and (**B**) additional screw or wire fixation of the articular fragments may be performed through or outside the plate. **C,** Alternative positioning of a low-profile 2.4-mm plate below the second dorsal compartment and affixed to the index metacarpal. *(Copyright Elizabeth Martin.)*

Figure 17.53 Bridge plate fixation. A 20-year-old man sustained life-threatening polytrauma in a fall from a height, including bilateral distal radius fractures (**A**) and a Monteggia fracture-dislocation on the left (**B**). **C,** The ulnar fracture was stabilized with a plate, the volar rim of the left radius was reconstructed with volar 2.5-mm implants, the impacted subchondral bone was elevated and supported with allograft cancellous bone, and the severely comminuted dorsal metaphyseal bone was stabilized with a spanning plate in the second dorsal compartment. **D,** Healed fracture at the time of removal of the spanning plate 4 months postoperatively. **E,** The volar plates were removed at 1 year. **F,** Radiographs at 1 year demonstrating active range of motion. *(Courtesy of Douglas P. Hanel, M.D., University of Washington, Seattle.)*

Figure 17.54 **A** and **B,** Posteroanterior and lateral radiograph of an intra-articular distal radius and ulnar styloid base fracture. **C** and **D,** A locked intramedullary nail (Micronail, Wright Medical, Arlington, TN) was used to stabilize the distal radius fracture, and suture fixation of the ulnar styloid was performed. **E** and **F,** Range of motion 2 months postoperatively; no immobilization was used postoperatively. *(Courtesy of Virak Tan, M.D., with permission.)*

Figure 17.55 **A-E,** Cross-pinned nonbridging external fixation of the distal radius (CPX, AM Surgical, Smithtown, NY). For selected unstable fractures with large articular fragments and healthy bone, nonbridging fixation enables early wrist motion and compares favorably with bridging external fixation.

Figure 17.56 **A-F,** Gross instability of the radioulnar joint after anatomic realignment of a distal radius fracture can be treated satisfactorily with 4 weeks of cross-pinning of the ulnar and the radius. Dual 0.062-inch Kirschner wires are recommended, and perforation of all four cortices is important.

Figure 17.57 **A,** Severely displaced radiocarpal fracture-dislocation. After open reduction and Kirschner wire fixation of the radial styloid, the distal radioulnar joint (DRUJ) was grossly unstable. Bony avulsion of the triangular fibrocartilage complex was treated by tension band wiring. **B,** Follow-up radiographs at 2 years show a congruent DRUJ.

Figure 17.58 A 2.0-mm ulnar pin plate can be applied over a percutaneous Kirschner wire to rigidly fix unstable basilar ulnar styloid fractures with two proximal screws.

Figure 17.59 Advancement of a palmar plate onto the palmar rim of the radius should be avoided because there is no soft tissue buffer between the plate and the overlying flexor tendons.

Figure 17.60 Four discrete types of dorsal shear fractures have been described by Lozano-Calderón and colleagues.[78] **A,** A relatively common variant has a large rotated volar fracture fragment that constitutes the majority of the articular surface. **B,** The most common subtype demonstrates a small volar lip (teardrop) fragment, from which the important short and long radiolunate ligaments originate. **C,** The central impaction pattern, associated with the shear fracture of the dorsal margin, is relatively uncommon, as is the true radiocarpal fracture-dislocation (**D**), which constitutes a serious combined ligamentous and bony injury. *(Copyright Elizabeth Martin.)*

Figure 17.61 Type A dorsal shear fracture. **A** and **B,** Posteroanterior and lateral radiographs demonstrating shear of the entire articular surface with little attached subchondral bone. **C,** Dorsal view of the highly comminuted dorsal surface after closed reduction. **D,** Fixation of the thin dorsal rim and articular surface fragment with a dorsal wireform implant. **E** and **F,** Postoperative radiographs demonstrating restitution of articular alignment and length.

Figure 17.62 Mechanism of injury of intercarpal ligament disruption. **A,** Extension and radial deviation produce a proximally displaced shearing fracture of the radial styloid, scapholunate dissociation, and an avulsion fracture of the ulnar styloid. **B,** Axial compression with severe impaction of the lunate fossa accounts for shearing loading of the scapholunate junction and tearing of the ligaments at this level. **C,** Axial compression and ulnar deviation with severe radial shortening produce acute ulnocarpal abutment and disruption of the lunotriquetral and triangular ligaments.

Figure 17.63 Combined radial styloid and dorsal shearing fracture (dorsal Barton's) in a 23-year-old woman. Notice the intact volar ulnar portion of the joint surface in the lateral view. Both fragments were securely stabilized with lag screws, which permitted early wrist motion after suture removal.

Figure 17.64 Radiocarpal fracture-dislocation with minimal bony avulsion. Treatment must be directed at the necessary subtotal ligamentous disruption with the use of multiple Kirschner wires. Alternatively, a temporary bridge plate could be considered. *(Reprinted with permission from Dumontier C, Meyer zu Reckendorf G, Sautet A, et al: Radiocarpal dislocations: classification and proposal for treatment. A review of twenty-seven cases,* J Bone Joint Surg Am *83:212-218, 2001.)*

Figure 17.65 **A,** Radiographs of a severely displaced type V complex distal radial fracture with intra-articular and metaphyseal comminution. **B,** Partial insufficient reduction obtained with the application of an external fixator. **C,** Intraoperative fluoroscopic views showing reconstruction of the metaphyseal fracture with two transverse lag screws, provisional fixation of the radial and ulnar fragments with Kirschner wires, and application of a volar fixed-angle device. An oblique Kirschner wire inserted palmarly to dorsally has been applied to the volar ulnar fragment. **D,** Postoperative radiographs showing acceptable reduction and restoration of radial length. The fixator was maintained for 3 weeks. **E,** Fracture healed at 6 weeks after surgery. Notice healing of the dorsal and ulnar comminuted area. At this time the additional Kirschner wire was removed. **F,** Radiographs at 1 year show good restoration of the joint surface and a well-remodeled distal radius. **G,** Adequate arc of flexion and extension and free forearm rotation restored.

Figure 17.66 It is imperative that the osteotomy be parallel to the articular surface to avoid creating a secondary deformity. *(Copyright Elizabeth Martin.)*

Figure 17.67 **A,** Radiographs of a malunited Colles' fracture with 30 degrees of dorsal tilt, 15 degrees of ulnar inclination, and an ulnar-plus variance of 3 mm. **B,** Comparative radiographs for preoperative planning. **C,** Preoperative planning for the opening wedge dorsal osteotomy and fixation with the minicondylar plate. **D,** Immediate postoperative radiographs. **E,** Radiographs 1.5 years after osteotomy with anatomic restoration of wrist anatomy and carpal alignment.

Figure 17.68 **A,** A dorsally malunited distal radius fracture is corrected with a dorsal opening wedge osteotomy and the use of a laminar spreader to correct volar tilt. A pre-bent dorsal wireform implant is in place, but final screw tightening has not yet been performed. **B,** Radiograph 2 weeks postoperatively demonstrating correction of volar tilt and biplane fixation. **C,** Posteroanterior radiograph at 2 weeks demonstrating an iliac crest graft and reduction of the radial inclination and length.

Figure 17.69 **A,** Dynamic midcarpal instability in a malunited Colles' fracture with 10 degrees of dorsal tilt. The patient has painful clicking on ulnar deviation. **B,** Comparative radiographs of the left wrist showing normal carpal alignment. **C** and **D,** Preoperative radiographs and planning. The opening wedge osteotomy was performed through a volar approach and fixed with a fixed-angle plate and morcellized cancellous bone. Preapplication of the fixed-angle plate to the distal fragment at the anticipated angle of correction with two parallel pegs allows the surgeon to subsequently remove the plate, make the osteotomy, and then reattach the plate to precisely rotate the distal fragment into position. **E,** Realignment of the distal radius with restoration of a 10-degree volar tilt, improved carpal alignment, and controlled instability. Notice the subchondral positioning of the central fixed-angle pegs. *(**D,** Copyright Elizabeth Martin.)*

Figure 17.70 The operative technique of trapezoidal osteotomy for the treatment of malunion of the distal radius, as described by Watson and Castle,[118] uses distal radial bone. **A** and **B,** The osteotomy is made 1 cm proximal to the articular surface and parallel with the articular surface, **C,** With a lamina spreader, the distal fragment is elevated and displaced to produce a biplanar osteotomy. An appropriate section of distal radial bone is then outlined on the dorsal aspect of the distal radius. **D** and **E,** The bone graft is harvested, rotated 90 degrees, packed into the biplanar osteotomy site, and fixed with two Kirschner wires. *(Copyright Elizabeth Martin.)*

Figure 17.71 **A** and **B,** Malunited Smith's fracture with palmar translation and a pronation deformity of the distal fragment resulting in marked loss of supination (**C** and **D**). **E** and **F,** Intraoperative photograph and fluoroscopy demonstrating the use of a two-pin external fixator to simultaneously gain length, rotation, and sagittal alignment of the distal fragment with an opening wedge osteotomy. Preoperative degenerative disease of the distal radioulnar joint in this 70-year-old necessitated matched excision of the distal ulna. **G** to **J,** Radiographic and clinical results at 3 months postoperatively demonstrating marked improvement in rotation and wrist alignment.

Figure 17.72 Relatively simple articular malunion involving articular depression of the scaphoid facet.

Figure 17.73 Forty-two-year-old with a chronically painful and unstable ulna after multiple procedures for distal radial malunion. **A,** Radically shortened ulna. **B,** Stability of the distal radioulnar joint was restored with a custom ulnar head replacement. **C** and **D,** Functional and pain-free supination and pronation 2 years postoperatively.

Figure 17.74 Suave-Kapandji procedure. **A,** Twenty-eight-year-old emergency medical technician with a chronically unstable and degenerative distal radioulnar joint after multiple procedures for a malunited distal both-bones fracture. **B,** Intraoperative photograph of the flexor carpi ulnaris tendon woven through the proximal stump of the Sauve-Kapandji reconstruction. **C** and **D,** Radiographs 4 years postoperatively. **E** and **F,** Pain-free functional rotation enabled return to all activities.

Table 17.1 Alternatives to Autogenous Bone Graft for Management of Distal Radius Fractures

Type	Formulation	Application	Indications	Advantages	Disadvantages
Allograft					
Demineralized bone matrix	Amorphous, powder, gel, strips, putty, combinations	Manual insertion	Compromised host, impaired healing, nonunion	Osteoinductive and limited osteogenic potential	Variable osteogenic capability depending on composition and formulation; marginal to no structural support
Cancellous chips	5- to 7-mm freeze-dried cancellous chips	Manual packing	Metaphyseal void, elevated articular surface	Some structural support; osteoconductive and limited osteoinductive potential	Variable osteoinductive capability; limited structural support
Fresh frozen	Corticocancellous bone segments	Cut to shape, internal fixation	Segmental defect	Customized to defect, high structural support, osteoinductive	Rarely indicated for distal radius fractures, disease potential, immunogenicity, slow incorporation
Cancellous Substitutes					
Tricalcium phosphate combinations	Mixed with hydroxyapatite, collagen, marrow aspirate; available in strips, granules	Manual insertion	Metaphyseal void, elevated articular surface	Osteogenic and inductive when mixed with marrow aspirate	Minimal to no structural support, variable resorption rates
Calcium sulfate	Pellets, paste, putty	Manual or injectable; may harden to block form	Metaphyseal void, elevated articular surface	Resorbable defect filler, replaced by bone; injectable through minimal incision; may be combined with antibiotics	Minimal to no structural support, water soluble, rapidly resorbed
Nanoparticulate β-tricalcium phosphate (beta)	Blocks or granular, mixed with marrow	Manual or injectable	Metaphyseal void, elevated articular surface	Resorbable, injectable, porous; moderate compressive strength	Osteogenic and osteoinductive only if mixed with marrow
Coralline hydroxyapatite	Blocks, granules	Trimmed to shape defect	Metaphyseal void, elevated articular surface	Osteoconductive and porous; compressive strength equal to or exceeding that of cancellous bone; can shape to fit defect	Slow resorption; radiopacity may obscure healing
Bovine cancellous bone	Manual, trim to defect	Metaphyseal void, elevated articular surface	Osteoconductive, moderate structural support	Immunogenicity, variable osteoinductivity; not approved for use in United States	
Cements					
Calcium phosphate	Mixed components, hardens with time	Injectable, putty or block	Metaphyseal void, elevated articular surface	Can be injected percutaneously; animal models demonstrate	Not osteoconductive or inductive; slow to remodel and reabsorb; lacks

Type	Formulation	Application	Indications	Advantages	Disadvantages
				resorption/remodeling; high compressive strength	shear or tensile strength
PMMA	Mixed components, hardens in minutes	Injectable	Bone defect, metaphyseal void; augment ORIF in osteopenic bone	Can be injected percutaneously; high compressive strength	Not osteoconductive or inductive; exothermic; may cause thermal necrosis; brittle, poor shear or tensile strength; limited indications for distal radius
Biologics					
Recombinant BMP	Powder, strips, putty	Manual, injectable	Compromised host or tissue bed, nonunion or delayed union	Osteoinductive; may accelerate healing	Limited indications for distal radius application; dosage and timing not well studied

BMP, bone morphogenetic protein; ORIF, open reduction and internal fixation; PMMA, polymethyl methacrylate.

Table 17.2 Outcomes of Percutaneous, Single Plate, and Multiple Plate Fixation of Distal Radius Fractures

Year	Author	No. Patients	Age	Female	C Type	C3 Type	Follow-up (mo)	Grafted	Compl	Loss of Reduction	GE	F/E	Grip
Volar Plate Fixation													
2002	Orbay	31	54	55%	45%	10%	12	10%	3%	0%	100%	82%	77%
2004	Orbay	24	79	71%	10%	4%	12	38%	17%	13%		82%	79%
2005	Musgrave	32	57	91%	66%	0%	13	0%	34%	0%		80%	
2005	Kamano	40	57	70%	15%	3%	12	10%	5%	0%	100%	85%	78%
2006	Ruch	14	46	50%	100%	71%	22	14%	29%	0%	86%	85%	78%
2006	Rozental	41	53	63%	46%	12%	17	7%	22%	10%	100%	70%	94%
2007	Rein	15	54	47%	100%	100%	48	0%	13%	7%	47%	80%	90%
Average		197	57	64%	55%	29%	19	11%	18%	4%	87%	81%	83%
Dorsal Plate Fixation													
2005	Grewel	29	46	62%	100%	100%	18	86%	72%	0%		60%	86%
2006	Kamath	30	59	53%	70%	13%	18	33%	13%	3%	93%	85%	78%
2006	Ruch	20	49	55%	100%	75%	21	45%	20%	25%	75%	75%	74%
2006	Simic	51	55	59%	16%	0%	24	0%	12%	0%	78%	81%	92%
2007	Rein	14	45	71%	100%	100%	48	0%	50%	14%	36%	70%	85%
Average		144	50	60%	77%	58%	25.8	33%	33%	8%	71%	74%	83%
Multiple Plate Fixation													
2000	Jakob	74	60	70%	66%	41%	12	51%	22%	6%	97%	84%	90%

Year	Author	No. Patients	Age	Femal e	C Type	C3 Type	Follow-up (mo)	Grafted	Compl	Loss of Reduction	GE	F/E	Grip
2002	Konrath	25	53	44%	70%	33%	29	0%	28%	4%	92%	82%	83%
2006	Benson	85	50	68%	89%	21%	32	76%	20%	0%	100%	88%	92%
Average		184	54	61%	75%	32%	24	42%	23%	3%	96%	85%	88%
External Fixation													
2001	Sakano	25	49	40%	76%	8%	30	100%	0%	0%	100%	88%	89%
2003	Werber	50	58	70%	60%	0%	6	0%	14%	0%	90%	65%	60%
2004	Harley	25	43	52%	80%	44%	12	12%	56%	0%	48%	81%	79%
2005	Grewal	33	45	36%	100%	85%	18	45%	24%			65%	97%
2005	Kreder	88	40	43%	83%		24	13%	11%	0%		94%	90%
2005	Gradl	25	60	12%	44%	20%	24	0%	16%	4%	96%	92%	
2008	Leung	74		38%	100%	39%	24	22%	13%	0%	94%		
Average		320	49	42%	78%	33%	20	27%	19%	1%	86%	81%	83%

Compl., Complications; F/E, flexion/extension; GE, good to excellent.

Table 17.3 Evidence for Treatment Decisions

First Author/Country	Date	*N*	Demographic/Excl usion Criteria	Validated Outcome Measurement?	Results	Comments
Casting vs Splinting						
O'Connor,[90] Ireland	2003	66	Minimally displaced, no reduction	No. Gartland-Werley	Increased motion in splint at 6 wk. No difference in radiologic, functional, objective results at 12 wk	1 loss of reduction in each group
Tumia,[115] Scotland	2003	329	Displaced and nondisplaced. SAC vs 3-point brace	No. Gartland-Werley	Increased grip in brace group early. No difference in radiologic findings, pain, or function at 24 wk	Age and initial displacement correlated with loss of reduction
Bong[13]	2006	85	Displaced, stable and unstable	DASH	No difference. 40% lost reduction at 1 wk. DASH favored splint group	30% of stable group and 50% of unstable group lost reduction
Casting vs Calcium Phosphate Cement						
Sanchez-Sotelo,[104] Spain	2000	110	AO types A3 or C2. 50-85 yr old. Cement casted 2 wk. Unstable fractures	No. Green & O'Brien, VAS	Statistical improvements in motion and grip early for cement, not sustained. 42% malunion rate in control group	Cement extrusion in 69%, 1 intra-articular. 18% malunion rate with cement
Casting or External Fixation vs Calcium Phosphate Cement With or Without Kirschner Wires						
Cassidy,[16] USA	2003	323	Displaced, unstable	SF-36, Jebsen dexterity, Green & O'Brien	Early improvement in pain, motion, strength but unsustained in cement group. Greater loss of radial length	Cement extrusion in 70%, 4 intra-articular. 55% fair to poor results. 29% lost reduction with cement
Casting vs Pin Fixation						

First Author/Country	Date	*N*	Demographic/Exclusion Criteria	Validated Outcome Measurement?	Results	Comments
Azzopardi,[6] Scotland	2005	57	Unstable extra-articular, age >60. SAC vs percutaneous pins/cast	Nonblinded. SF-36 and VAS	Nonsignificant improvements in function, pain but improved radial tilt and inclination in pin group	No functional benefits in elderly population
Stoffelen,[111] Belgium	1999	98	Extra-articular fractures. Average age 60 yr	No	Increased radial shortening in Kapandji pin group (1 mm). No other differences	Unstable fractures had significantly worse outcomes in both groups. No excellent results in pin group
Casting vs External Fixation						
McQueen,[86] Scotland	1996	90	Redisplaced fractures, extra-articular	No. Nonblinded	Improved correction of dorsal tilt in EF group	Carpal alignment best predictor of function
Young,[127] UK	2003	85	Displaced, mostly extra-articular fractures, all ages	No. Gartland-Werley. Nonblinded	No differences in objective, dorsal tilt, or Gartland-Werley scores. Fewer malunions in EF group	51% rate of malunion. No augmented EF performed. Improved radial length and inclination in EF group
Kapoor,[61] India	2000	60	Displaced, articular fractures	No. Sarmiento	57% fair-poor with cast vs 20% fair-poor with EF	Augmented EF not used
Kreder,[67] USA	2006	113	Displaced, extra-articular. Unstable fractures excluded	MFA, SF-36, Jebsen. Nonblinded	Trend for improved functional, radiographic, and clinical outcomes with EF	40% augmented. 9% of cast group required conversion. All excellent radiographic outcomes
Pins/Cast vs External Fixation						
Harley,[50] USA	2004	50	Unstable, age <65	DASH, SF-36, Gartland-Werley. Blinded	Significant improvement in articular surface with EF. No difference in tilt, function	Percutaneous treatment: excellent results with difficult fractures
Ludvigsen,[81] Norway	1997	60	Unstable, articular	No. Gartland-Werley. Nonblinded.	No difference in grip, motion, radiologic results	Ulnar variance increased in both groups after removal of fixation
Static vs Dynamic External Fixation						
Sommerkamp,[109] USA	1994	50	Unstable fractures	No. Gartland-Werley	Greater loss of radial length, motion, and Gartland-Werley scores in dynamic group	More complications in dynamic group
McQueen,[86] Scotland	1996	60	Redisplaced fractures, extra-articular	No. Nonblinded	No difference in grip, motion, radiologic results	Carpal alignment best predictor of function
Bridging vs Nonbridging External Fixation						
McQueen,[84] Scotland	1998	60	Displaced intra-articular excluded	No	Significant improvement in grip, motion, and carpal alignment in nonbridging group. NS increase in ulnar variance	No augmented external fixation. 42% complication rate
Krishnan,[70] Australia	2003	60	Intra-articular fractures only	No. Nonblinded	No functional, radiologic, or objective differences	70% complication rate; 3 EPL ruptures in nonbridging group

First Author/Country	Date	*N*	Demographic/Exclusion Criteria	Validated Outcome Measurement?	Results	Comments
Atroshi,[4] Sweden	2006	38	Age >60. Displaced articular excluded	DASH, SF-12. Blinded	No functional, or objective differences. Significant improvement in variance in nonbridging group	No augmented external fixation. Motion improved 10-26 wk postoperatively
ORIF vs Arthroscopic Reduction and Percutaneous Fixation						
Doi,[29] Japan	1999	88	Articular fractures	No. Gartland-Werley, Green & O'Brien	Improved radiographic, functional, anatomic scores in arthroscopic group, reduced DJD	Strong correlation between step-off and DJD in both groups
ORIF vs External Fixation						
McQueen,[86] Scotland	1996	90	Redisplaced fractures, extra-articular	No. Nonblinded	Improved correction of dorsal tilt in ORIF group	Carpal alignment best predictor of function
Kapoor,[61] India	2000	60	Displaced, articular fractures	No. Sarmiento	Equivalent functional outcomes. ORIF improved articular alignment and tilt	Augmented EF not used
Kreder,[68] USA	2005	179	Displaced, articular	MFA, SF-36, Jebsen	More rapid and improved functional results in indirect group	Arthrotomy used in all ORIF. 2-mm articular step associated with DJD
Grewal,[45] Canada	2005	62	Unstable, displaced articular, age <70	DASH, SF-36, VAS	Significant increase in complications, pain, operative time with ORIF	Similar functional results favor EF over dorsal ORIF
Leung,[75] Hong Kong	2008	144	Displaced, articular, age <60	No. Gartland-Werley, Green & O'Brien	97% ORIF vs 94% external fixation good-excellent results, favored ORIF group using Gartland-Werley criteria	No subjective or functional differences between groups. >50% DJD in both groups. Hardware removal in 50%

DASH, Disabilities of Arm, Shoulder, and Hand; DJD, degenerative joint disease; EF, external fixation; EPL, extensor pollicis longus; MFA, multiple factor analysis; NS, nonsignificant; ORIF, open reduction with internal fixation; SAC, short arm cast; SF-36, short form health survey (36 items); VAS, visual analog scale.

Table 17.4 Management Algorithm for Distal Radioulnar Joint Disorders After Distal Radius Fracture

Disorder	Management
DRUJ incongruity	
Extra-articular	Reorient the sigmoid notch with a radial osteotomy
Intra-articular (post-traumatic arthrosis)	Depending on the severity of degenerative changes, age, dominance, and occupation, resection arthroplasty, Sauve-Kapandji procedure, or prosthetic replacement
Combined	Radial osteotomy and DRUJ procedure as for an intra-articular disorder
DRUJ instability	Reattachment of the triangular fibrocartilage complex (open/arthroscopic)
	Proximal reinsertion of the ulnar styloid nonunion
	Capsulodesis (ulnar sling procedure—Herbert)
	Shortening osteotomy of the ulna
	Other ligament reconstructions

Disorder	Management
Ulnocarpal abutment (impaction)	Restore the radioulnar index or ulnar variance to normal
	Ulna-shortening osteotomy
	Wafer procedure (Feldon)
	Radius-lengthening osteotomy
	Combined radius-ulna osteotomies
Symptomatic (painful) nonunion of the ulnar styloid	Simple excision
Capsular retraction	Capsulotomy
Pronatory contracture of the DRUJ	Pronator quadratus release and palmar capsulotomy
Radioulnar impingement	Ulnar head prosthesis

Note: If these conditions occur in association, two or more procedures may need to be combined. A classic example is a malunited Colles fracture and degenerative changes in the DRUJ.

DRUJ, distal radioulnar joint.