Intra-articular fractures of the distal radius are more challenging to treat than extra-articular fractures. Optimal treatment is achieved when the pattern of injury is recognized and its component parts are adequately addressed. The importance of the final articular surface alignment has received substantial emphasis, but extra-articular alignment, the overall complexity of the injury, associated injuries, and complications are also very important determinants of the final functional result. No single implant or technique is appropriate for all fractures and surgeons should be familiar with a variety of options.

Displaced fractures of the articular surface of the distal radius have a worse prognosis than extra-articular fractures because of the potential for incongruity and arthrosis of the radiocarpal and distal radioulnar joints, carpal subluxation, and associated intercarpal ligament injuries. Surgical stabilization of distal radial articular fragments is hindered by close association of the fragments with surrounding ligaments and tendons, metaphyseal comminution and poor bone quality, the potential for digit swelling and nerve dysfunction, and complications associated with implants. Articular fractures of the distal radius occur in basic patterns, each of which has specific pitfalls. Although treatment of these injuries has improved over the past few decades, the continued expansion in the variety of implants and techniques for treating fractures of the distal radius reflects not only technical advances, but also the drawbacks of existing techniques and lack of consensus.

ANATOMY

The articular surface facing the carpus is split into distinct facets that articulate with the scaphoid and lunate. The basic compressive articular fracture line usually occurs between these facets. Additional compressive force will split the fragments in the coronal plane or cause central fragmentation and impaction.

The alignment of unstable displaced fragments is affected by soft-tissue attachments. The triangular fibrocartilage complex (TFCC) attaches to the ulnar margin of the lunate facet. The volar and dorsal margins of the complex (radioulnar ligaments) can contribute to malrotation of lunate facet fragments. Stout radiocarpal ligaments attach to the volar margin of the distal radial articular surface and tend to pull it dis-
tally and rotate it into extension. The dorsal radiocarpal ligaments are thinner and less important. The brachioradialis is the only tendon that inserts onto the distal radius. It can contribute to malalignment of the radial styloid fragment.

The sigmoid notch on the ulnar surface of the radius articulates with the ulnar head. The sigmoid notch has a greater radius of curvature than the ulnar head and motion at the distal radioulnar joint is a combination of rotation and translation. The TFCC and the interosseous ligament stabilize the distal radioulnar joint. The TFCC originates from the base of the ulnar styloid. A large fracture of the ulnar styloid or peripheral tear of the TFCC can destabilize the distal radioulnar joint.

The carpal bones function as sophisticated ball bearings between the hand and wrist. They have been characterized as an intercalated segment because no tendons directly affect their function. Instead, the behavior of the carpal bones is determined by their shape and ligament attachments. When an axial force injures the articular surface, the injury force may propagate through the carpus leading to carpal fractures (most commonly the scaphoid) or intercarpal ligament injuries (most commonly the scapholunate interosseous ligament). There is a strong association of associated carpal ligament injury with radial styloid fractures.2

**ARTICULAR INCONGRUITY: ITS MEASUREMENT AND CONSEQUENCES**

Although the worse prognosis of articular fractures has long been recognized,3 the past 2 decades of the 20th century witnessed a greater dissatisfaction with these results and an interest in improving treatment.

Arthrosis of the radiocarpal or distal radioulnar joints was second only to compressive neuropathy in the description by Cooney et al4 published in 1980 of the problems arising from fracture of the distal radius. Arthrosis was nearly always associated with an articular fracture.

In 1986, Knirk and Jupiter5 reviewed 43 articular fractures of the distal radius in 40 patients younger than 40 years of age at an average of 6.7 years after injury. Twenty-one were treated in a cast, 17 in pins and plaster, and 2 in an external fixator. They found that the development of arthrosis was strongly related to articular incongruity; that the magnitude of the incongruity correlated with the development and severity of arthrosis; and that articular incongruity was the factor most strongly related to an unsatisfactory functional result. Because all of the patients with greater than 2 mm of articular incongruity had arthrosis and a poor functional result, 2 mm has become the oft-referenced upper limit for acceptable articular alignment; however, the relationship between articular incongruity and arthrosis was essentially linear as has been confirmed by several subsequent investigators, some of whom have suggested the goal of no more than 1 mm of articular incongruity.6-8

The value of such precise parameters depends on valid and reliable measurement techniques. Standard measurement techniques have been described: articular step has been distinguished from articular gap,9 and a computed tomography–specific arc method of measurement has been advocated.10 Nonetheless, Kreder et al9 found that measurements of articular step and gap made by experienced surgeons on standard radiographs varied substantially. Other investigators have found that the use of tomography11 or computed tomography10,11 can improve the reliability of the measurements, but that there is still only moderate agreement between observers and with repeated measurements. Others claim that the only reliable method to assess articular congruity is direct evaluation by using arthroscopy.12-14

Catalano et al15 reviewed 21 patients less than 45 years old at an average of 7.1 years after an articular fractures of the distal radius treated surgically. They confirmed that the development of arthrosis is strongly associated with residual articular incongruity. In contrast to Knirk and Jupiter,5 however, they found that arthrosis did not correlate with the functional result. The patients in the series of Catalano et al15 had surgical treatment using more advanced techniques compared with those in the Knirk and Jupiter5 series. Consequently, the extra-articular alignment of the radius and the radiocarpal alignment were more predictably restored. The results of this investigation suggest that restoration of this extra-articular alignment was more important than residual articular incongruities and ar-
arthrosis in determining the functional result and the need for reconstructive surgeries.

In other words, an emphasis on the articular alignment may be somewhat misdirected. The quality of the articular reduction may actually be less important than factors such as the severity of the injury, associated injuries, the quality of the extra-articular reduction (the alignment of the carpus and hand with the forearm), and associated complications. Although it is clear that the best possible articular reduction is desirable, this must be balanced with the drawbacks and risks of the various surgical techniques and the specific goals of treatment for each patient. In addition, precise restoration of articular congruity may not be possible for some complex articular fractures, but this does not necessarily preclude restoration of wrist function.

**GOALS OF TREATMENT**

The treatment method selected should emphasize restoration of full range of motion of the digits, which usually requires limitation of edema and early exercises and functional use of the hand; full, stable, pain-free forearm rotation, which usually requires healing of the fracture with good extra-articular as well as intra-articular alignment; and a strong grip and limited pain, which usually return in the absence of arthrosis, nerve compression, mal- or nonunion. Restoration of wrist flexion and extension is less predictable and has a more variable influence on upper-extremity function. Perhaps one of the most important goals of treatment is to limit complications—the surgeon should always ensure that the potential risks of surgical intervention are always balanced by the potential benefits.

**Classification**

**Patient-Related Factors**

The functional demands and expectations of individual patients may be a more important determinant of successful treatment of an intra-articular fracture of the distal radius than radiographic or clinical parameters. A distinction has long been made on the basis of age. The majority of distal radius fractures occur in older patients. The prevalence of limited functional demands and acceptance of deformity in this group of patients contributes to a high degree of satisfaction even in the presence of poor alignment. It is a common clinical observation that older patients more readily regain motion, particularly forearm rotation, and that residual deformity is less problematic than in younger patients. This may be because, in part, these are usually relatively low-energy injuries.

On the other hand, it may be unwise to allow these age-related factors alone to guide treatment. The segment of our society that is over age 60 is growing rapidly and becoming healthier and more active. The alignment and functional result that is good for a relatively infirm and home-bound patient may not be well accepted by a patient that plays golf or tennis daily. The goals of treatment are different for an infirm or inactive patient than they are for a healthy, active patient who wants to remain active, regardless of chronologic age.

**Fracture Characteristics**

**Classification Systems.** Attempts to classify distal radius fractures have emphasized important management issues. Frykman distinguished articular involvement of both the radiocarpal and distal radioulnar joints as well as fracture of the distal ulna, but not the complexity or pattern of articular involvement, the degree of displacement of the fragments, or the size of the ulnar styloid fracture. The importance of this classification lies in its emphasis on the distal radioulnar joint.

Melone described the most common major articular fragments: the radial styloid (or scaphoid facet), the dorsal lunate facet, and the volar lunate facet. He emphasized the importance of the lunate facet. In particular, the entire carpus can displace volarly with a displaced volar lunate facet. In addition, radiocarpal ligament attachments tend to pull this fragment into malrotation that is difficult to correct and stabilize with closed reduction and percutaneous Kirschner wires—a separate volar exposure of the fragment and internal fixation is often required. Malalignment of lunate facet fragments also affects the distal radioulnar joint.

The term *die-punch* has been used variably to refer to either an impacted dorsal medial lunate facet fragment, impaction of the entire lunate facet, or impaction of central articular fragments with no lig-
Impact central articular fragments will not reduce with ligamentotaxis or manipulation of the major fragments—they require direct visualization and manipulation.

The Comprehensive Classification of Fractures distinguishes 3 types of fractures: extra-articular (Type A), partial articular (Type B), and complete articular fractures (Type C). Each type is subdivided into 3 groups and 9 subgroups based on the extent of articular and metaphyseal fragmentation and the orientation of the articular fracture lines. Although the use of this system for research purposes is limited by the unreliability of group and subgroup distinctions, the concept of stratifying articular and metaphyseal fragmentation is useful. In particular, the degree of metaphyseal comminution may be as important as the complexity of the articular injury because stable realignment of articular fragments is more challenging in the absence of a stable metaphyseal base. In a study of extra-articular fractures treated with intrafocal pinning, Trumble et al conceived of the metaphysis of the distal radius as a box with 4 sides. They specifically looked for comminution of each of the dorsal, volar, ulnar, and radial cortices of the metaphysis. They found that involvement of 2 or more cortices was associated with loss of alignment, less so when external fixation was used.

The system of Fernandez and Jupiter is also comprehensive, but is limited to simpler, higher-level distinctions: extra-articular fractures (Type 1); shearing, or partial-articular fractures (Type 2); compression articular fractures (Type 3); radiocarpal fracture-dislocations (Type 4, featuring avulsion fractures); and complex, high-energy fractures (Type 5).

Current trends have emphasized and expanded on the idea that articular fractures of the distal radius create predictable fragments to suggest that each column or fragment merits specific fixation. Rikli and Regazzoni conceived of the wrist as a 3-column structure with the radial and ulnar aspects of the distal radius representing 2 columns and the distal ulna the third column. Similar to Trumble et al, Medoff divides the radius into 4 columns: ulnar, radial, dorsal, and volar, and has developed a variety of implants to reconstruct each column.

Fernandez and Jupiter have classified distal radioulnar joint injuries associated with distal radius fractures as stable, unstable, or potentially unstable. When there is wide displacement of the distal radius (greater than 20° of dorsal angulation or greater than 5 mm of shortening by ulnar variance), the triangular fibrocartilage complex is probably also injured. This can occur through a peripheral tear, a tear from the margin of the distal radius, or fracture of the ulnar styloid at its base. Alternatively, there may be a more proximal fracture of the distal ulna—these have been classified under the Comprehensive Classification of Fractures by using a Q modifier as follows: (1) ulnar styloid fracture, (2) simple fracture of the ulnar neck, (3) comminuted fracture of the ulnar neck, (4) ulnar head fracture, (5) ulnar head and neck fracture, and (6) fracture of the ulna proximal to the neck.

Management issues. None of the current classification systems captures all of the important management issues, and in some cases important issues may seemed underemphasized because of the complexity of the system.

One important issue is stability. Widely displaced fractures are very likely to settle and redisplace after closed reduction, particularly when bone quality is poor. Fractures with very little displacement on the initial radiographs (shortening by ulnar variance and articular incongruity less than 2 mm; dorsal tilt less than 5°) are inherently stable, will rarely displace with cast immobilization, and may not need to be reduced.

Another issue is the energy involved in the injury and the quality of the bone. A young, healthy person with a displaced fracture of the distal radius has sustained a high-energy injury. Such patients are at risk for acute carpal tunnel syndrome and forearm compartment syndrome and are much more likely to struggle regaining digit, wrist, and forearm range of motion because of the greater soft-tissue injury and swelling. In contrast, older patients with osteoporotic bone may have complex fractures involving the radius and the ulna after simple falls and may do well despite persistent radiographic deformity because they have little trouble regaining mobility.

A major distinction to make among relatively simple fractures is that between a shearing-type fracture (usually volar—also known as Barton’s fracture) and a compression-type fracture. Shearing-type fractures are inherently unstable, and by consensus are best treated with buttress plating.
Compression-type fractures vary substantially in complexity. The extent of both articular and extra-articular comminution will affect the technical difficulty and predictability of surgical intervention.

The simplest type of articular injury is a split between the scaphoid and lunate facets of the radiocarpal articular surface. The next degree of complexity usually occurs at the lunate facet where a coronal fracture line can create dorsal and volar lunate fragments. This is important because the volar lunate facet fragment may be difficult to realign and secure by using closed techniques. Also, when not recognized or secured adequately, the carpus can subluxate with this fragment. A displaced volar lunate facet fragment also affects the distal radioulnar joint.

Greater degrees of fragmentation can involve central impaction and very small articular fragments. These are particularly challenging fractures.

Given that stable fixation requires realignment of articular fragments with one another and with a metaphyseal base, it is not surprising that comminution, either between articular fragments or in the metaphysis, will make it substantially more difficult to restore and maintain alignment.

**Evaluation and Initial Treatment**

Large wounds are uncommon in association with fracture of the distal radius, but small wounds created by fracture fragments or tearing of the skin with marked deformity occur occasionally. These are most commonly volar-ulnar in location because the fragments displace dorsal-radial. Even the most innocuous wound merits immediate treatment with extension of the wound, debridement of devitalized tissue, and irrigation of the wound; however, definitive treatment may be delayed, particularly if the fracture is so complex that referral to a colleague with more experience treating these fractures is merited.

The median nerve should be carefully evaluated, particularly in high-energy injuries. Older patients injured in simple falls may have median nerve symptoms or dysfunction related to deformity. This usually resolves with reduction of the fracture, but should be carefully evaluated and observed. In contrast, the median neuropathy associated with high-energy injuries may develop over 48 to 72 hours. When patients with high-energy injuries are discharged home after surgical treatment or for planned treatment in a few days, they should be taught how to recognize progressive median neuropathy and given clear instructions for contacting their surgeon. Very high energy injuries can also be associated with forearm compartment syndrome. Acute carpal tunnel syndrome or forearm compartment syndrome merit prompt surgical treatment.

Acute tendon injuries are uncommon, but the tendons should be evaluated, particularly the extensor pollicis longus and flexor pollicis longus.

Some fractures for which surgical treatment is planned will not benefit from attempts at reduction in the emergency room if the overall alignment is reasonable (eg, most volar shearing or Barton’s fractures). A supportive volar splint should be used for comfort. It is important to leave the digits free, particularly the metacarpophalangeal joints, and encourage motion and elevation of the hand to prevent stiffness and edema.

Swelling in the fingers can contribute to digit stiffness and intrinsic contracture, adding a hand problem to the original wrist problem. When forced to choose the surgeon should always choose to protect the hand, even if it means that the distal radius will require surgical treatment. Because the alignment of unstable articular fractures cannot be maintained in a cast no matter how good the mold, there is no role for tight splints or casts. When patients present to the office with swollen digits, tight casts or splints should be removed and replaced with noncircumferential support. If surgical treatment is planned, the involvement of an occupational or hand therapist before the surgery to help diminish edema and restore digit range of motion is worthwhile.

**Imaging and Preoperative Planning**

Radiographs taken before reduction of the fracture show the initial displacement of the fragments, which is one of the best predictors of stability after manipulative reduction (Figs 1A and 1B). Fracture lines and specific fragments are often more easily identified on radiographs made after manipulative reduction (Figs 1C and 1D). Both are important.

For very complex fractures—or even simple articular fractures when there is uncertainty about the status of the lunate facet—computed tomography provides additional information. With standard 2-dimensional computed tomography scans it can be
difficult to follow specific fragments between images (Figs 1E and 1F). Three-dimensional reconstructions have made interpretations very easy—particularly when the carpus is subtracted from the scan.\textsuperscript{14} Three-dimensional reconstructions accurately depict the size of the volar fragment, the extent of comminution of both the dorsal and volar lips, and central impaction of articular fragments (Figs 1G and 1H). This can help
determine the surgical exposures, the use of arthroscopy, the need for capsulotomy, and whether there are a few specific fragments that can be supported against one another or there is extensive fragmentation so that the goal should be containment and support of the fragments.

When there is concern about the integrity of the scapholunate interosseous ligament and arthroscopy or capsulotomy are not otherwise necessary, the image intensifier can be used to view the wrist under traction once the patient is anesthetized. A break in the proximal carpal arc with traction suggests a complete tear (Fig 2).

**Specific Treatment**

Shearing Fractures

There is general agreement that shearing fractures of the dorsal or volar articular margin are best treated with plate and screw fixation. The oblique fracture lines and radiocarpal subluxation are not well controlled by external fixation or Kirschner wires. For this reason, shearing and compression articular fractures are usually considered separately. Volar marginal fractures (volar Barton’s fractures) are common, whereas dorsal marginal fractures (dorsal or reverse Barton’s fractures) are unusual.

**Volar shearing fractures.** One of the pitfalls of treatment of a volar shearing fracture is an unrecognized dorsal cortical fracture line. Standard surgical technique for volar shearing fractures involves leaving the plate relatively straight so that as screws are inserted from distal to proximal, the plate compresses the volar marginal articular fragments against the intact dorsal metaphysis. If the dorsal metaphyseal cortex is fractured, this technique will displace the articular fragments dorsally, leading to dorsal translation and, in some cases, dorsal angulation of the articular surface.

In a more complex fracture the dorsal fracture line may be displaced and the injury may not be recognized as a shearing-type fracture. The argument can be made that, when the dorsal cortex is fractured, the fracture should not be classified as a partial articular fracture (AO Type B) because the entire articular surface is separated from the metaphysis (AO Type C). On the other hand, because the major fragment—the volar articular margin—has an unstable oblique shearing pattern, attempts to treat this fracture with external fixation and Kirschner wires may not be able to prevent displacement and radiocarpal subluxation. Because fragments with oblique, shearing-type fracture lines are best treated with plate and screw fixation, these fractures are best distinguished from compression articular fractures—the treatment of which is more variable.

Another pitfall in the treatment of volar shearing fractures is failure to account for fragmentation of the volar articular margin. Through the standard volar-radial (Henry) approach, it may be more difficult to visualize and manipulate more ulnar (lunate facet) fragments. If the plate does not adequately capture this fragment, particularly if the fragment is very small, it may slip around the plate and the entire carpus may subluxate with it. Small fragments may benefit from a wire or suture loop engaging the radiocarpal ligament attachments to the fragment. In addition, a direct volar or volar ulnar exposure may afford better access to the ulnar aspect of the distal radius.

Jupiter et al reviewed 49 patients with volar shearing fractures of the distal radius treated with...
plate and screw fixation. Forty-four fractures (90%) were comminuted. The results were good or excellent in 84% of patients.

Keating et al noted reversal of the normal palmar tilt of the articular surface of the distal radius reflecting an unrecognized or unaccounted for dorsal cortical fracture in 22 of 79 patients (28%).

Dorsal shearing fractures. Dorsal shearing fractures are much less common and are usually associated with some central impaction of the articular surface (Fig 3). These can be treated with an open reduction and dorsal capsulotomy with realignment of the articular surface and buttress plating of the dorsal articular margin with or without bone grafting. The prognosis is not as good as with volar shearing fractures.

Compression Fractures

Nonsurgical treatment. The inherent instability of displaced articular fractures is well documented. Knirk and Jupiter noted in their series that all of the displaced articular fractures that were immobilized in plaster alone lost some reduction. In some cases this was extra-articular and the settling of the fracture actually improved the articular reduction. They also observed loss of reduction despite traction treatment (pins in plaster or external fixation). Perhaps most interesting was their observation of late settling of the fracture fragments in a few patients when immobilization was discontinued 6 to 11 weeks after injury. The risk for late settling may be greater when there is a substantial metaphyseal defect across which healing can be delayed.

Leung et al reviewed the treatment of 80 displaced articular fractures. Displacement was defined as greater than 10° of dorsal angulation or 2 mm or greater of articular incongruity or radial shortening compared with the opposite side. Thirty-one fractures redisplaced in a cast. Twenty of those displaced after a second reduction and were treated surgically. For the remaining 11 fractures treated in a cast, the average
final dorsal angulation was 16°, reflecting the inherent stability of these fractures. Residual articular incongruity was not addressed.

Rodriguez-Merchan treated 20 patients with displaced articular fractures of the distal radius (>10° dorsal angulation, >3 mm articular step-off) in a cast as part of a prospective trial. Fifteen of 20 redisplaced in the cast and were remanipulated.

**Minimally displaced fractures.** Fractures with less than 5° of dorsal angulation of the distal radius articular surface and less than 2 mm of articular incongruity or shortening (by ulnar variance) on the initial injury radiographs are very unlikely to displace in a cast. Treatment of these minimally displaced fractures should provide comfort and protection. There is no need for reduction or tightly molded casts. In a reliable patient, a removable splint will facilitate bathing. The splint or cast should not restrict motion of the digits or forearm. Functional use of the hand for light tasks should be encouraged.

Leung et al treated 11 minimally displaced fractures in a short arm cast without reduction and noted no loss of reduction and good or excellent results in all patients.

**Displaced fractures in inactive or infirm patients.** When the goal of treatment is healing of the fracture and early return to function, and the patient and surgeon have decided to accept deformity because of limited functional demands or infirmity, there is no need for a tight circumferential cast. A simple volar splint usually provides adequate support for comfort and healing and, because it is nonconstricting, may help limit swelling and improve hand function (Fig 4). A removable plastic splint facilitates hygiene and is usually lighter and less cumbersome. Functional use of the limb should be encouraged.

**Surgical Techniques**

**Intraoperative assessment and restoration of articular alignment.** The alignment of articular fractures can be monitored with image intensification, arthroscopy, dorsal capsulotomy, or indirectly by exposing and realigning metaphyseal fracture lines. The advocates of arthroscopic-assisted treatment of articular fractures of the distal radius claim that image intensification does not depict articular alignment accurately; however, the clinical significance of small residual incongruities that are not well depicted by image intensification is uncertain. Arthroscopy and dorsal capsulotomy allow inspection of the intercarpal ligaments and the triangular fibrocartilage complex, but it is unclear how identification and treatment of these injuries affects the functional results. For instance, it is not clear that partial tears of the scapholunate interosseous ligament benefit from specific treatment.

**External fixation.** External fixation was introduced as an alternative to pins and plaster as a method of sustained portable traction. Unfortunately, traction alone cannot always restore articular alignment. Traction may worsen the alignment of some fragments (eg, the volar aspect of the lunate facet) and will not affect others (eg, impacted central articular fragments). Attempts to improve the radiographic appearance of a fracture may result in a distracted wrist positioned in flexion. Substantial distraction across the wrist may contribute to wrist stiffness and digit stiffness, the
latter by tightening the extrinsic flexor and extensor tendons.\textsuperscript{41–43} Wrist flexion will contribute to digit stiffness by diminishing the effectiveness of the extrinsic tendons (tight extensors, lax flexors) as one can easily show by attempting to make a tight fist with the wrist flexed. A flexed position can also increase pressure in the carpal tunnel and contribute to a median neuropathy.

The complications associated with the external fixation device and its placement include injury to the superficial radial nerve, tethering and scarring of muscles or tendons, pin track infections including pin track osteomyelitis, fracture through a pin site, pin loosening, and tender or unsightly scars.\textsuperscript{41,44} Pin track infections are common, but are usually easily managed with oral antibiotics. Severe or recalcitrant infections will require pin removal.

Given the complications of external fixation, there has been some interest in using a plate applied across the wrist for sustained traction. The plate can be placed by using 2 small incisions and is removed under local anesthesia 8 weeks after the injury.\textsuperscript{35}

External fixation that does not cross the wrist (so-called nonbridging fixation) has been suggested for extra-articular and simple articular fractures.\textsuperscript{46–49} A fracture that creates a simple split between the scaphoid and lunate facets can be controlled with a Schantz screw (Synthes, Ltd, Paoli, PA) placed in each major articular fragments stabilized to Schantz screws anchored in the diaphysis. The screws placed into the articular fragments can be used to directly manipulate the fragments. The technique is only suitable when there is limited metaphtyseal comminution and the bone quality is adequate for the Schantz screws to hold in the small metaphtyseal fragments. Superficial infections around the distal Schantz screws are common because early wrist motion creates substantial motion between the skin and the screws.\textsuperscript{39} Oral antibiotics will usually control the infection and allow retention of the frame for the duration of treatment.

\textit{Percutaneous Kirschner wire fixation.} Direct or intrafocal Kirschner wire fixation of articular fractures with cast or splint immobilization instead of external fixation is only suitable for very simple articular fractures. Although the intrafocal technique was originally described without ancillary cast immobilization, a cast or external fixator is usually used.\textsuperscript{30} A cast is most appropriate when soft-tissue swelling and metaphyseal comminution are limited. Kirschner wires provide very limited fixation and are best neutralized or protected with more rigid external fixation.\textsuperscript{30} In addition, it is desirable to avoid potentially constrictive circumferential immobilization when there is substantial digital swelling. The prospective trial of Rodriguez-Merchan clearly showed the advantages of percutaneous pinning and cast immobilization over cast immobilization alone.\textsuperscript{40}

\textit{Combined external fixation and Kirschner wires.} The combination of external fixation and Kirschner wires can help overcome the drawbacks of each individual technique.\textsuperscript{23} With Kirschner wires helping to secure the fragments, the external fixator can be placed in a relatively neutral position and with limited distraction. External fixation provides more rigid neutralization of Kirschner wire fixation than can be achieved with a cast. However, even with external fixation, Kirschner wires may not provide adequate fixation of small articular fragments, particularly disimpacted central fragments and volar lunate facet fragments.

\textit{Bone grafts and bone substitutes.} Autogenous cancellous bone grafts can accelerate healing across metaphyseal defects created by realignment of fracture fragments.\textsuperscript{50} They are also used to support disimpacted articular fragments.\textsuperscript{6,7,26} Other materials (so-called bone graft substitutes) have been used for this purpose in an attempt to avoid the morbidity and inconvenience associated with obtaining an autogenous graft. These include coral, solid and injectable hydroxyapatites, allograft bone, and bone derivatives.\textsuperscript{31} Recent basic science advances hold promise for tissue engineering and the use of growth factors. Currently, at least when healing across a metaphyseal defect is the concern; autogenous bone grafts remain the most reliable choice.

\textit{Internal fixation.} Internal fixation of fractures of the distal radius has increased in popularity recently, partly as a result of the introduction of several new implants.

\textit{Inherent Drawbacks of Internal Fixation} Implants placed on the distal radius are directly under or adjacent to tendons. Even very smooth implants can cause extensor tendon irritation and rupture.\textsuperscript{6,7,22,55} Trimming a plate will create sharp surfaces that can be particularly problematic—\textsuperscript{39} if a plate used on the distal radius is trimmed, the edges should
be filed smooth. In many cases, the plates must be placed in a very distal position adjacent to the joint. This represents a relatively prominent site over which tendons pass and can also contribute to problems. It appears that, no matter how carefully designed, implants placed directly adjacent to the tendons pose some risk for painful irritation or rupture. Patients need to understand that these tendon ruptures can occur and that a second surgery to remove the implant may be necessary. In practice, dorsal plates are usually removed and volar plates are removed only when they irritate the flexor pollicis longus.

Considering these drawbacks, it may be best to reserve plate and screw fixation for shearing fractures and complex articular fractures. Although some surgeons have suggested that even simple articular fractures of the distal radius merit internal fixation, there is insufficient evidence of benefit over simpler techniques such as the combined use of external fixation and Kirschner wires to merit the additional dissection, cost, and surgical time, not to mention the risks to tendons and the possibility of a second surgery to remove the implant.

**Implants**

Several new implants have recently been introduced. The features of these new plates include recessed screw heads or pins; smaller, better positioned screws; and fixed-angled tines or buttress pins. Recessed screws and other design features have not eliminated the risk for tendon problems.

The standard 3.5-mm oblique T-plate (Synthes, Paoli, PA) and the Forte plate (Zimmer, Warsaw, IN) use 3.5-mm screws that are often too large and risk fragmenting small articular fragments. In addition, standard screws may not gain adequate fixation of bone that is fragmented or osteopenic. Volar displacement of the fragments was a common problem in a series of patients treated with the Forte plate.

Another approach has been to use a combination of wire forms and narrow plates that provide internal support for standard Kirschner wires (Trimed, Valencia, CA). Wire forms are wires bent into shapes intended to provide a fixed buttress for articular fragments. The wire forms are secured to the radius with a screw. It is becoming clear that these implants are less predictable in poor quality bone.

The notorious disadvantages of small screws and wires in poor quality bone have increased the appeal of fixed-angled devices that do not depend on implant-bone engagement, and several implants now incorporate this concept. This technique has been applied with success for metaphyseal fixation at other sites; however, there are no comparative studies documenting improved outcomes for fractures of the distal radius.

**Fragment-Specific Fixation**

The Trimed implants were developed for fragment-specific fixation of the distal radius. In other words, each of the specific components of the injury is addressed individually with a specific fixation device. The appeal of this approach relates to the relatively predictable pattern of articular injuries. The recommended management of articular fractures has essentially been fragment-specific for some time: Fernandez and Geissler recommended that the radial styloid and dorsal lunate fragments be reduced and secured with Kirschner wires, whereas a volar lunate facet fragment often requires direct open manipulation and internal fixation. The difference with the current version of fragment-specific fixation is that each fragment is secured internally through a separate incision.

One relatively unusual aspect of the Trimed system is the use of an implant applied to the direct radial surface of the radial styloid. Even with the newer plates that have longer radial extensions for capturing the radial styloid, fixation of the radial styloid has proved unpredictable, particularly when the fragment or its metaphyseal fracture line are comminuted. A direct radial plate provides a direct buttress for this fragment.

Smaller 2.0- and 2.4-mm plates have been used for fragment specific fixation (Figs 1I and 1J). Implants incorporating fixed-angle blades or buttress pins have proved useful (Fig 1J) and new plates for fragment-specific fixation will incorporate these features.

**Surgical Exposures**

Safe surgical exposure of the distal radius can be achieved in a variety of ways. The skin incision must account for and protect the branches of the superficial radial nerve, the dorsal cutaneous branch of the ulnar nerve, and the palmar cutaneous branch of the median nerve. Volar incisions should cross the transverse wrist crease obliquely to limit scar contracture. Oblique, curved, or Y-shaped incisions are not necessary on the dorsum of the wrist where the skin is more mobile and
elastic and is not prone to form scar contracture. Deep exposure must protect the median nerve and the ulnar nerve and artery.

Volar exposure is usually achieved through Henry’s interval (between the radial artery and the flexor carpi ulnaris) or a volar ulnar exposure (between the flexor tendons and the ulnar nerve and artery). A more radial incision and interval has been used to facilitate additional access to the direct radial aspect of the radial styloid. In addition, many favor a direct volar exposure identifying and protecting the median nerve and creating an interval between the flexor tendons. The pronator quadratus must be incised and mobilized and cannot always be strongly repaired. Nonetheless, functional problems are rarely encountered.

Exposure of the dorsal surface of the distal radius requires mobilization of the tendons of the second, third, and four extensor compartments. Traditionally, this was performed directly through the fourth extensor compartment. In an attempt to protect the extensor tendons from implants placed on the dorsal surface of the distal radius, dorsal exposure has been modified to attempt to elevate the fourth extensor compartment subperiosteally. The extensor retinaculum is incised over the extensor pollicis longus tendon (third compartment) and the fourth compartment is elevated subperiosteally. The extensor pollicis longus is mobilized radialward and left in the subcutaneous tissues at the time of closure.

The second compartment cannot be elevated subperiosteally. The creation of an ulnar-based flap of extensor retinaculum to place between the radial wrist extensor tendons and dorsal implants has been suggested, but may not be able to prevent tendon problems any better than recessed screws.

The dorsal skin is elastic and easily mobilized and retracted. As a result, a straight longitudinal skin incision will provide access to nearly the entire dorsum of the radius. Branches of the superficial radial nerve and the dorsal cutaneous branch of the ulnar nerve are elevated with the skin flap. The skin incision is usually centered over Lister’s tubercle.

Exposure and fixation of the direct radial aspect of the radius is becoming more popular. The radial styloid points volarily as it extends radialward. Placement of an implant on the direct radial aspect of the radius can be achieved through a volar radial or direct radial skin incision. The first dorsal compartment must be opened and the implant is often placed directly below these tendons.

Alternatively, implants can be placed on the dorsal aspect of the radial styloid between the first and second dorsal compartments. Incision of these compartments and mobilization of the tendons is often required, but the implant is less likely to be directly under the tendons, at least distally. The dorsal aspect of the radial styloid can be accessed through a dorsal skin incision. Usually a single limited incision centered over Lister’s tubercle allows access to the dorsal radial and dorsal ulnar aspects of the distal radius.

Dorsal capsulotomy can be performed either longitudinally or transversely and should not be repaired at closure. In some cases with extensive comminution it may be preferable to mobilize small fracture fragments with the capsule rather than cutting the capsule and creating small free fragments (Fig 3B). Incision of the volar capsule should be avoided if possible.

Arthroscopy can be performed with traction or with external fixation used to distract the wrist. An infusion pump is not necessary and may increase the risk for forearm compartment syndrome or other problems related to fluid extravasation. In addition to standard dorsal portals, a volar portal has been suggested.

**Treatment Options for Specific Types of Displaced Compression Fractures**

Simple split between scaphoid and lunate facet. One of the most common types of compression articular fractures is a simple split between the scaphoid and lunate facets. Often this split is minimally displaced and treatment can focus on the displaced metaphyseal component of the injury.

A displaced fracture between the scaphoid and lunate articular facets of the distal radius can usually be manipulated and monitored by using closed means and image intensification. The static injury radiographs combined with a traction image of the wrist under fluoroscopy will usually identify a complete tear of the scapholunate interosseous ligament. Arthroscopy would provide direct visualization of the carpal ligaments and the triangular fibrocartilage complex, but is probably not necessary for monitoring the articular reduction.

Fixation with Kirschner wires and either a cast or external fixator is usually adequate. A nonbridging
fixator with pins stabilizing each of the major articular fragments could be considered.

Some of these simple articular fractures have substantial metaphyseal comminution (Subgroup C2 of the Comprehensive Classification of Fractures). When realignment of the articular fragments creates a metaphyseal defect, there may be a tendency for settling of the fragments or delayed healing. If stable fixation can be achieved with Kirschner wires and/or external fixation, then considerations include either leaving the fixator in place for longer than usual (8-10 wks rather than 6 wks), or packing the defects with autogenous cancellous bone grafts to help support the fragments and speed healing. If the metaphyseal comminution prevents stable realignment of the articular fragments by using closed or percutaneous techniques, then open reduction and internal fixation with or without bone grafting may need to be considered.

**Coronal split of the lunate facet.** The next level of complexity involves a coronal split in the lunate facet. This fragment is often depicted in schematic drawings as being small and confined to the lunate facet. In many cases, however, the volar lunate facet fragment extends quite radial with the radial styloid fragment being smaller and more dorsally based. Although some investigators emphasize the added challenges of the coronal split, indicating that open exposure and internal fixation of the volar lunate fragment is usually required, others describe reduction by using an arthroscope or dorsal capsulotomy to assist reduction and fixation without the use of a separate volar incision.

The potential problems associated with the volar lunate fragment should not be underestimated. The volar radiocarpal ligaments tend to rotate this fragment into a relatively extended position. This rotational malalignment can block wrist flexion and forearm rotation and may not be apparent on image intensification or arthroscopy. The volar lunate fragment is also an important support of the carpus. Treatment with a dorsal plate alone can push this fragment and the carpus into a volarly subluxated position (Fig 5). Inadequate control of this fragment with Kirschner wires may have the same result.

A volar exposure allows direct visualization of the metaphyseal fracture line, reduction of which usually realigns the fragment. Large fragments can be fixed with a plate and screws. Small fragments can be secured with a suture or wire loop.

**Central impaction.** Central impaction usually occurs in the scaphoid or lunate facet of the articular surface, occasionally both. For relatively simple fractures (such as radial styloid fractures with impaction of the scaphoid facet articular surface), arthroscopic-assisted reduction can be performed. Associated scapholunate interosseus ligament injury is common and can be addressed simultaneously (Fig 6). On the other hand, an open exposure for application of supportive bone grafts and for direct repair of the scapholunate ligament may be desirable.

**Complex articular fractures.** It is common for published studies of articular fractures of the distal radius to identify most fractures as complex Subgroup C2 and C3 fractures, but show relatively simple and straightforward fractures in the illustrations. High-energy injuries in young patients and moderate-energy injuries in osteoporotic individuals can create very complex articular and metaphyseal fractures that are uniquely difficult to treat and need to be considered separately. It is not uncommon to find articular fragments in the soft tissues of the forearm and cortical bone fragments in the joint after reduction of the fracture. External fixation will not support the fragments adequately and there is no place to anchor Kirschner wires except, perhaps, the ulna. If there is extensive articular fragmentation it will prove difficult to anchor the small fragments reliably with wires. If a plate is applied to the volar or dorsal surface the fragments will collapse opposite the plate.

The complexity of these fractures and the difficulties in treatment are apparent in the fact that some surgeons have considered primary wrist arthrodesis. This seems extreme given that, despite the difficulties managing complex articular fractures of the distal radius, subsequent wrist arthrodesis is unusual, at least within the first decade after injury.

Other surgeons have used combined internal and external fixation or combined dorsal and volar plate fixation. Combined dorsal and volar plate fixation cradles the complex articular comminution and supports both volar and dorsal metaphyseal comminution (Fig 7). This type of double plating raises concerns regarding...
avascular necrosis, infection, and nonunion, but these have not been observed at the distal radius.\textsuperscript{16,17}

\section*{RESULTS}

Surgical fixation of fractures of the distal radius leads to good or excellent results according to the rating system of Gartland and Werley\textsuperscript{3} in 52\% to 86\% of patients in various series.\textsuperscript{5,14,16,53} When the system of Cooney et al\textsuperscript{62} is used, the results are usually much worse because the system is far more stringent. Residual articular incongruity correlates with arthrosis, but not always with function.\textsuperscript{15}

Inconsistencies in classification are commonplace. For instance, Melone Type 4 fractures represent complex articular comminution and should be classified as Group C3 in the Comprehensive Classification of Fractures, but are often classified as Group C2.\textsuperscript{9} Another study lists volar shearing fractures as an exclusion criteria and then includes several Group B3 fractures.\textsuperscript{14} Although most series include mostly Group C2 and C3 fractures, the severity of comminution and displacement vary substantially and are not well accounted for. These inconsistencies hinder reliable interpretation and comparison of studies.

Even with the direct visualization and manipulation possible with open reduction and internal fixation, residual articular malalignment is not uncommon.\textsuperscript{16,17} When Schneeberger et al\textsuperscript{17} reviewed their results in 18 patients, 7 had a residual step or gap of 2 mm or more on the immediate postoperative radiograph. Three patients had subsequent loss of reduction so that only 8 patients (44\%) had less than 2 mm step or gap at final follow-up. These findings reflect the inherent limitations in our ability to achieve stable anatomic alignment of complex articular fractures. These relate to fragmentation of the articular surface and the metaphysis, diminished bone quality, and imperfect fixation devices.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{A 30-year-old woman was in a motor vehicle collision and sustained a fracture of the femur and the contralateral distal radius. (A) Careful review of a lateral radiograph after closed reduction and casting suggests a displaced, rotated volar lunate facet fragment. (B) Treatment with a dorsal plate contributed to volar displacement of the carpus with this fragment. (C) A second plate applied volarly helped restore radiocarpal alignment. Copyright © held by David Ring, MD.}
\end{figure}
The variety of treatment methods and the number of management issues that are controversial are a reflection of continued dissatisfaction with the treatment of intra-articular fractures of the distal radius. Areas of dispute include indications for surgical treatment, particularly in older-aged patients; the relative merits of internal and external fixation; whether osteopenic bone limits the use of internal fixation; the need for direct

**FIGURE 6.** A 28-year-old man injured his wrist in a motorcycle accident. (A) The injury radiograph shows central impaction of the scaphoid into the scaphoid facet of the distal radius. (B) Arthroscopic-assisted reduction and fixation showed a complete tear of the scapholunate interosseous ligament. Reduction and fixation with 3.0-mm cannulated screws were accomplished percutaneously. (C) A posteroanterior radiograph after hardware removal shows slight settling of the articular fragments. An open exposure for the application of a bone graft or bone graft substituted to the defect created by the reduction might have prevented this. (D) The final lateral radiograph shows good scapholunate alignment. Copyright © held by David Ring, MD.
A 33-year-old man fell from a tree onto his outstretched hand. (A) The lateral radiograph taken before manipulative reduction shows a complex articular fracture with complex comminution and impaction of the articular surface and both dorsal and volar metaphyseal comminution. (B) Treatment with combined dorsal and volar exposure and plate fixation helped cradle the fragments and support the elevated articular fragments. (C) The complexity of the injury is emphasized by the fact that, on exposure, a metaphyseal cortical bone fragment was found in the joint and an articular fragment was found proximally in the dorsal soft tissues. (D and E) Lateral and posteroanterior radiographs taken after hardware removal show a reasonable radiographic result. Full forearm and digit range of motion were regained and the arc of wrist motion was 90°. Copyright © held by David Ring, MD.
exposure and fixation of a volar lunate facet fragment; the role of bone graft and bone graft substitutes; and the role of wrist arthroscopy. Even when the alignment of the distal radius is restored, digit stiffness, peripheral neuropathy and nerve injury, unsightly scars, and implant-related complications often affect the result. Study of these issues is hindered by variability in classification and radiographic measurement of fractures.

REFERENCES

31. Ritik D, Regazzoni P. Fractures of the distal radius treated by