External fixation has been used for the treatment of distal radius fractures for more than 50 years. Although the fixator configurations have undergone considerable modification over time, the type of fixator itself is not as important as the underlying principles that provide the foundation for external fixation. Although volar plate fixation is currently in vogue, the indications for external fixation remain largely unchanged. Newer fixator designs have also expanded the traditional usage to include nonbridging applications that allow early wrist motion. The following discussion focuses on the myriad uses for external fixation as well as the shortcomings and potential pitfalls. (J Hand Surg 2007;32A: 1624–1637. Copyright © 2007 by the American Society for Surgery of the Hand.)

Key words: External fixation, radial, distal.

There are some important anatomical points that one must bear in mind when considering external fixation of the distal radius. The articular surface of the radius is triangular, with the apex of the triangle at the radial styloid. It slopes in a volar and ulnar direction with a radial inclination of 23° (range 13–30°), a radial length of 12 mm (range 8–18 mm), and an average volar tilt of 12° (1–21°).1 The dorsal surface of the distal radius is convex and irregular, and it is covered by the 6 dorsal extensor compartments. The dorsal cortex is thin, which often results in comminution that can lead to an abnormal dorsal tilt. Lister’s tubercle acts as a fulcrum for the extensor pollicis longus tendon, which lies in a groove on the ulnar side of the tubercle. The volar side of the distal radius, which is covered by the pronator quadratus, is flat and makes a smooth curve that is concave from proximal to distal. When inserting the dorsal pins, it is important to engage the volar ulnar lip of the distal radius where the bone density is highest, especially in osteopenic bone.2

The dorsum of the radius is cloaked by the arborizations of the superficial radial nerve (SRN) and the dorsal cutaneous branch of the ulnar nerve. The SRN exits from under the brachioradialis, approximately 5 cm proximal to the radial styloid, and bifurcates into a major volar and a major dorsal branch at a mean distance of 4.2 cm proximal to the radial styloid. Either partial or complete overlap of the lateral antebrachial cutaneous nerve with the SRN occurs up to 75% of the time.3 The dorsal cutaneous branch of the ulnar nerve arises from the ulnar nerve, 6 cm proximal to the ulnar head, and becomes subcutaneous 5 cm proximal to the pisiform. It crosses the ulnar snuffbox and gives off 3 to 9 branches that supply the dorsoulnar aspect of the carpus, small finger, and ulnar ring finger. Open pin insertion allows identification and protection of these branches.

The proximal pins are placed at the junction of the proximal and middle thirds of the radius. At this level, the radius is covered by the tendons of extensor carpi radialis longus and extensor carpi radialis brevis as well as the extensor digitorum communis. The proximal pins can be inserted in the standard midlateral position by retracting the brachioradialis tendon and the SRN, in the dorsoradial position between the extensor carpi radialis longus and extensor carpi radialis brevis, or dorsally between the extensor carpi radialis brevis and extensor digitorum communis, which carries less risk of injury to the SRN.4

Ligamentotaxis

External fixation of distal radius fractures can be used in a bridging or nonbridging manner. Bridging external fixation of distal radius fractures typically relies on ligamentotaxis to both obtain and maintain a reduction of the fracture fragments. As longitudinal traction is applied to the carpus, the tension is transmitted mostly through the radioscaphocapitate and long radiolunate ligaments to restore the radial length. In a similar vein, pronation of the carpus can
indirectly correct the supination deformity of the distal fragment.

Limitations of Ligamentotaxis

Ligamentotaxis has a number of shortcomings when applied to the treatment of displaced intra-articular fractures of the distal radius. First, because ligaments exhibit viscoelastic behavior, there is a gradual loss of the initial distraction force applied to the fracture site through stress relaxation. The immediate improvement in radial height, inclination, and volar tilt are significantly decreased by the time of fixator removal.

Traction does not correct the dorsal tilt of the distal fracture fragment. This is because the stout volar radiocarpal ligaments are shorter, and they pull out to length before the thinner dorsal radiocarpal ligaments exert any traction. Excessive traction can actually increase the dorsal tilt. A dorsally directed vector is still necessary to restore the normal volar angulation. This is usually accomplished by applying manual thumb pressure over the dorsum of the distal fragment. With intra-articular fractures, ligamentotaxis reduces the radial styloid fragment, but for the above reasons, it does not reduce a depressed lunate fragment. When there is a sagittal split of the medial fragment, traction causes the volar medial fragment to rotate, which often necessitates an open reduction. External fixation cannot control radial translation; therefore, it cannot be used with an unstable distal radioulnar joint.

Biomechanical Considerations for External Fixation

Fracture Site Loads

External fixation is considered flexible fixation. The biomechanical requirements of external fixation for fractures of the distal radius have not been ascertained because, until recently, the magnitude and direction of the physiologic loads on the distal radius were dynamic and unknown. Recent work by Rikli et al, however, has shed new light on this point. Using a new capacitive pressure-sensory device, his group measured the in vivo dynamic intra-articular pressures under local anesthesia in the radioulnocarpal joint of a healthy volunteer. With the forearm in neutral rotation, the forces ranged from 107 N with wrist flexion to 197 N with wrist extension. The highest forces of up to 245 N were seen with the wrist in radial deviation and the forearm in supination. Presumably, any implant or external fixator would have to be strong enough to neutralize these loads in order to permit early active wrist motion. Rikli et al also identified 2 centers of force transmission. The first center was opposite the scaphoid pole, which would represent the radial column. The second center, which would represent the intermediate column of the wrist, took a considerable amount of the load and was opposite the lunate, extending ulnarly over the triangular fibrocartilaginous complex (TFCC).

Fixator Frame Rigidity

The strength of the fixator depends on the rigidity of the connecting rods and the clamps. Many external fixator rods are 0.5 to 1.0 cm in diameter, although radiolucent rods made from polyetheretherketones, Ultem resin, or carbon fiber might be larger. Increasing the diameter of the rods increases the rigidity by a factor of 4. Uniplanar fixators are common, but the rigidity of the construct can be increased by adding a second parallel rod. Placing the rod as close to the skin as possible also increases the stability against bending loads by reducing the lever arm from the neutral joint axis. Most distal radius external fixators use 3.0 or 4.0 mm threaded half pins. Modern threaded pins are hence designed with a larger core diameter and smaller core-thread diameter. If the pin threads are buried, the larger pin diameter at the near bone interface resists bending forces, whereas the small core thread resists pullout forces at the far cortex. A bicortically inserted pin with a short thread will provide the best pin–bone fixation. Theoretically, under-drilling the pin hole by 0.1 mm provides the best pin fixation with the least risk of bone resorption and pin loosening. It is also desirable to spread the force evenly across the entire shaft of the bone by creating a wide separation of the fixator pins. In order to achieve stable fixation and reduce the lever arm of displacing forces, the pins should be inserted close to the fracture site. One pin is hence inserted close to the fracture site, while the second is placed as far away as possible.

Construct Rigidity

Increasing the rigidity of the fixator does not appreciably increase the rigidity of fixation of the individual fracture fragments. There are a number of ways, however, in which to augment the stability of the construct. After restoration of radial length and alignment by the external fixator, percutaneous pin fixation can lock in the radial styloid buttress and support the lunate fossa fragment. A fifth radial styloid pin attached to the frame of a spanning AO (Synthes, Paoli, PA) external fixator prevents a loss
of radial length through settling and leads to improved wrist range of motion as compared to a 4-pin external fixator. The addition of a dorsal pin attached to a sidebar easily corrects the dorsal tilt found in many distal radius fractures. K-wire fixation enhances the stability of external fixation. The combination of an external fixator augmented with 1.6-mm (0.62 in) K-wires approaches the strength of a 3.5 mm dorsal AO plate (Synthes, Paoli, PA). Supplemental K-wire fixation is more critical to the fracture fixation than is the mechanical rigidity of the external fixator itself. Stabilizing a fracture fragment with a nontransfixing K-wire that is attached to an outrigger is just as effective as a K-wire that transfixes the fracture fragments.

Bridging External Fixation
Temporary External Fixation: Indications
As compared to conventional plate fixation, bridging external fixation can be used in a temporary manner or it can be used for definitive management of the distal radius fracture. Bindra has listed the following indications for this technique:

1. Initial management of severe grade open fractures with extensive soft tissue loss
2. Temporizing measure to resuscitate a polytraumatized patient
3. Pending transfer to a tertiary referral facility for definitive fracture management

Rikli et al use temporary bridging external fixation for complex fractures to both aid in the provisional fracture reduction and to allow a better computed tomography (CT) evaluation of the fracture characteristics prior to double plate fixation.

Definitive External Fixation: Indications
1. Unstable extra-articular distal radius fractures
2. Two-part and selected 3-part intra-articular fractures without displacement
3. Combined internal and external fixation

Contraindications
Bridging external fixation should not be used as the sole method of stabilization in the following situations:

1. Ulnar translocation due to an unstable distal radioulnar joint
2. Intra-articular volar shear fractures (Bartons, reverse Bartons)
3. Disrupted volar carpal ligaments/radiocarpal dislocations
4. Marked metaphyseal comminution

Combined index and middle finger metacarpal fractures preclude the use of this technique due to the interference with distal pin site placement.

Complications
Fixator loosening with loss of fracture position can be avoided by periodically checking and tightening the fixator connections. Fixator failure by itself is uncommon, but many commercially available fixators are approved for single use only due to the risk of unrecognized material fatigue or failure of any locking ball joints. Pin site complications include infection, loosening, and interference with extensor tendon gliding. The risk of injury to branches of the superficial radial nerve mandate open pin-site insertion. Bad outcomes associated with external fixation are often related to over-distraction. One biomechanical study documented the effect of distraction of the wrist on metacarpophalangeal (MCP) joint motion. More than 5 mm of wrist distraction increases the load required for the flexor digitorum superficialis to generate MCP joint flexion for the middle, ring, and small fingers. For the index finger, however, as much as 2 mm of wrist distraction significantly increases the load required for flexion at the MCP joint. Many cases of intrinsic tightness and finger stiffness that are attributed to reflex sympathetic dystrophy are a consequence of prolonged and excessive traction, which can be prevented by limiting the duration and amount of traction and instituting early dynamic MCP flexion splinting even while in the fixator.

The degree and duration of distraction correlates with the amount of subsequent wrist stiffness. Distraction, flexion, and locked ulnar deviation of the external fixator encourage pronation contractures. Distraction also increases the carpal canal pressure, which may predispose to acute carpal tunnel syndrome. Metaphyseal defects should be grafted to diminish bending loads and to allow fixator removal after 6 to 7 weeks, which minimizes the fixator related complications.

Results
Margaliot et al performed a meta-analysis of 46 articles with 28 external fixation studies (917 patients) and 18 internal fixation studies (603 patients). They did not detect a clinically or statistically significant difference in pooled grip strength, wrist range of motion, radiographic alignment, pain, and
physician-rated outcomes between the 2 treatment arms. There were higher rates of infection, hardware failure, and neuritis with external fixation and higher rates of tendon complications and early hardware removal with internal fixation. Considerable heterogeneity was present in all of the studies, which adversely affected the precision of the meta-analysis.26

Westphal and colleagues performed a retrospective comparative study of 166 of 237 patients who had surgery for AO/ASIF A3 or C2 distal radius fractures. The fractures were treated with either external fixation or open reduction and internal fixation using palmar or dorsal plates. Open reduction and internal fixation, in particular palmar plate fixation, demonstrated the best radiological and functional results.27

External fixation falls short when used as the sole treatment for displaced intra-articular fractures. In a study of 27 patients with comminuted, displaced intra-articular fractures of distal radius that were treated exclusively by external fixation, Arora and co-authors concluded that although the external fixation is reliable in maintaining the reduction in displaced comminuted intra-articular fractures, it is inadequate in restoring articular congruity in many cases.28

Augmented External Fixation

The use of supplemental K-wire fixation can expand the indications for external fixation. As noted earlier, K-wire fixation not only enhances the reduction of the fracture fragments but also increases the rigidity of the entire construct. Many authors have stressed the importance of using the external fixator as a neutralization device rather than as a traction device. Ligamentotaxis is used to obtain a reduction of the fracture fragments, which is then captured with percutaneous K-wire fixation. The traction on the fixator can then be reduced, which allows positioning of the wrist in neutral or slight extension.9 This serves to reduce extensor tendon tightness and facilitates finger motion. In a study of intrafocal pinning, Trumble and colleagues noted that in patients over 55 years of age and in younger patients with comminution involving 2 or more surfaces of the radial metaphysis (or >50% of the metaphyseal diameter) bridging fixation was necessary in addition to percutaneous pin fixation to prevent late fracture collapse.29 In 4-part fractures where there is a sagittal split of the medial fragment, longitudinal traction accentuates the palmar translation and rotation of the volar medial fragment. Dorsal to volar K-wire placement carries the risk of injury to the volar neurovascular bundles, especially with K-wire migration. For these reasons, any sagittal split of the articular surface typically requires open treatment.40

Indications
1. Intra-articular radial styloid fractures
2. Three-part intra-articular fractures
3. Following percutaneous reduction of a depressed lunate fragment
4. Arthroscopic aided reduction of distal radius fractures

Contraindications
1. Marked metaphyseal comminution
2. Volar/dorsal intra-articular shear fractures

Results

Kreder et al compared the results of open reduction and internal fixation (ORIF) versus external fixation and pinning.31 A total of 179 adult patients with displaced intra-articular fractures of the distal radius were randomized to receive indirect percutaneous reduction and external fixation (n = 88) or ORIF (n = 91). There was no statistically significant difference in the radiological restoration of anatomical features or the range of movement between the groups at 2 years. The patients who had indirect reduction and percutaneous fixation, however, had a more rapid return of function and a better functional outcome than those who had ORIF, provided that the intra-articular step and gap deformity were minimized.

Grewal and co-authors noted the superiority of external fixation and K-wire fixation over internal fixation with a dorsally placed Pi plate for displaced intra-articular fractures of the distal radius. The plate group also had higher levels of pain at 1 year when compared with the external fixator group; however, this equalized after hardware removal. The external fixator group showed an average grip strength of 97% when compared with the normal side versus 86% in the dorsal plate group.32

Complications

In one study of 70 cases of external fixation and percutaneous pinning, 34 cases lost more than 5° of volar tilt following reduction at the 6-month follow-up examination despite the use of pinning. Initial deformity, patient age, use of bone graft, and duration of external fixation were not predictors of loss of reduction. No specific predictor of loss of reduction...
was noted, although there was a trend toward a loss of reduction in younger patients.33

Nonbridging External Fixation

Bridging fixation does not lend itself to early wrist motion. Efforts to dynamically mobilize the wrist with joint-spanning fixators have been largely unsuccessful. This is related to the difficulty in reproducing the complex kinematics of the carpus, as well as the inability of the fixator to maintain ligamentotaxis throughout the entire arc of motion.34,35 Good results have been achieved with nonbridging fixation of extra-articular distal radius fractures, which does allow early wrist motion. The final wrist range of motion and grip strengths are superior to those attained with bridging external fixators.36,37

Extra-Articular Fractures

Indications

Nonbridging external fixation is indicated in any extra-articular fracture where there is a high risk of late collapse. Lafontaine et al identified a number of risk factors that were associated with secondary fracture displacement despite a satisfactory initial reduction. These included the presence of dorsal tilt >20°, comminution, intra-articular involvement, an associated fracture of the ulna, and age greater than 60 years. If 3 or more of these factors were present, there was a high likelihood of fracture collapse.38 When there is significant displacement on the injury films, there is a high likelihood of collapse even if the initial reduction is satisfactory. Trumble recommends supplemental internal and/or external fixation in younger patients for fractures with >2 mm of radial shortening and >15° of dorsal tilt following a closed reduction, especially if there is comminution of 2 or more cortices.39 Although this is easier if done early on, the fracture site can be still be freed up with a percutaneous elevator as late as 3 weeks, which then allows a reduction of the distal fragment using the dorsal fixator pins.

Contraindications

Nonbridging external fixation is contraindicated when the distal fragment is too small for pin placement. At least 1 cm of intact volar cortex is required for pin purchase. Dorsal comminution does not preclude a successful result. This technique is not applicable to volar displaced or volar shear fractures and in children with open epiphyses.40

Figure 1. Biomechanical studies using the Fragment Specific Fixator (South Bay Hand Surgery LLC, Torrance, CA).

Figure 2. Cutaway view of sawbones demonstrating the 3-dimensional pin fixation.

Figure 3. (A) Displaced 3-part distal radius fracture. (B) Dorsal tilt of the joint surface. (C) Anteroposterior CT scan highlighting the size of the medial fragment. (D) Lateral CT demonstrating the sagittal split of the medial fragment. (E) AP x-ray after percutaneous reduction and application of nonbridging fixator. (F) AP CT view demonstrating closure of the coronal gap. (G) Coronal CT showing a congruent sigmoid notch. (H) Clinical appearance of fixator after reduction. (I) Active wrist flexion in fixator. (J) Anteroposterior view after fixator removal at 6 weeks. (K) Lateral view.
Complications
Pin pullout due to fracture of the distal fragment can occur if the distal fragment is too small or osteopenic or if the reduction is too vigorous. If this occurs, the fixator can be converted to a bridging construct. An incomplete reduction is also possible, especially with nascent malunions. Over-reduction of the fracture can also occur, especially when there is volar comminution.

Results
McQueen et al performed a prospective study of 641 patients with unstable fractures of the distal radius treated with external fixation. Of these cases, 378 were treated with nonbridging external fixation, mostly in AO type A3.2 and C2.1 fractures. Patients treated with nonbridging external fixation had statistically significant better radiological results throughout the period of review (p < 0.001). In particular, this technique consistently restored the volar tilt and carpal alignment. Radiological improvement was mirrored by functional improvement. Most functional indices were statistically better at an early stage (p < 0.040), whereas wrist flexion and grip strength remained significantly better at the final review (p < 0.012). Complication rates were similar between the 2 groups.

Intra-Articular Fractures
Early wrist motion following intra-articular fractures provides a number of possible benefits, including diminished stiffness, stimulation of cartilage repair, and decreased osteopenia of the distal fragments. In order to accomplish this with nonbridging external fixation, the construct must be able to withstand the forces generated during active and passive wrist motion.

Biomechanical Considerations
The author undertook a biomechanical study to examine the feasibility of nonbridging external fixation of simulated 3- and 4-part intra-articular fractures (DJ Slutsky, QG Dai, personal communication, September 2003). The study was performed in 3 phases. In the first phase, this method was tested in a 3-part intra-articular fracture model using either 1 or 2 external fixators applied in a nonbridging fashion. Five fresh-frozen cadaver arms had biomechanical testing using single and double nonbridging fixator configurations. During the second phase, the maximum static force that could be withstood during simulated passive-assisted wrist extension and simulated gripping without causing articular displacement in a 4-part fracture model was examined in 8 cadaver arms. All of the fractures were stabilized using a single, custom, nonbridging external fixator, which has an integrated dorsal sidearm (the Fragment Specific Fixator, South Bay Hand Surgery LLC, Torrance, CA) (Fig. 1). In the third phase, the author examined the effects of cyclical loading on a 3-part intra-articular fracture model with dorsal comminution as described by Dodds et al. All of the fractures were stabilized with the Fragment Specific Fixator.

The specimens were mounted vertically with an 89-N (20-lb) preload applied via gravity traction by hanging 5-lb metal plates from the wrist tendons. Active wrist motion was simulated by manually ranging the wrist through a complete flexion and extension arc. Passive-assisted wrist motion was simulated by applying an additional load to the carpus with a servohydraulic materials testing machine (Instron 1321 Biaxial Hydraulic System, Instron Corporation, Canton, MA). Gripping was simulated by direct axial loading of the lunate fossa. There was a wide variation in the stiffness of the constructs during phases 1, 2, and 3. Despite this, fragment-specific external fixation was able to maintain articular congruity with forces that exceed physiologic loading. The stiffness of the construct stabilized with the fragment-specific fixator averaged 149 N in axial loading with an intact TFC and 117 N with a cut TFC. These values compared favorably with the stiffness data of 5 commercially available distal radius plates, which ranged from 95.5 N to 136 N. In the third phase of the study, there was no observable articular displacement in any of the wrists after 200 cycles of wrist flexion and extension with loads of up to 145 N. The study conclusion was that nonbridging external fixation with new fixator designs could be applied to the treatment of intra-articular fractures.
Putnam et al have shown that for every 10 N of grip force, 26 N is transmitted through the distal radius metaphysis. They have recommended that the rehabilitation grip forces should be kept under 140 N with external fixation in order to prevent or minimize fixation failure. This also appears to be a safe limit as it pertains to nonbridging external fixation.

When using the Fragment Specific Fixator (South Bay Hand Surgery LLC, Torrance, CA), the 3.0-mm fixator pins are used in place of K-wires and have
dual roles. They provide interfragmentary fixation, but when attached to the fixator, they also act like blade plates to resist bending moments and buttress the fracture fragments (Fig. 2). The immediate subchondral position of the pins supports the joint surface and is critical in maintaining articulur congruity during fracture healing. Ligamentotaxis through joint bridging can be avoided in order to allow early wrist motion. Similar to a fixed-angle plate, the biomechanical rationale for the Fragment Specific Fixator is to transfer load from the fixed support of the articular surface to the intact radial shaft, bypassing any metaphyseal comminution. Unlike a fixed-angle blade plate, the fixator pin angle is freely adjustable so that it can be adapted to the fracture site plane, which may diminish fracture malalignment.

Indications
Nonbridging external fixation is ideally suited for the treatment of 2- and 3-part intra-articular fractures of the distal radius provided there is good bone density and a stable distal radioulnar joint (DRUJ). Its use following an arthroscopic-aided reduction and K-wire fixation of an intra-articular fracture permits early, protected wrist motion, although bridging fixation is warranted in the presence of marked articular comminution (Figs. 3A–3K).

Contraindications
Volar and dorsal marginal fractures (Bartons and reverse Bartons) are excluded and should be treated with internal fixation. Fractures with extensive metaphyseal/diaphyseal comminution require supplemental internal fixation.

Caveats
Nonbridging external fixation of intra-articular distal radius fractures should be reserved for manually active patients with good bone quality and without evidence of prior wrist arthritis. The lunate fragment must be sufficiently large to support two 3.0-mm pins. A CT scan with anteroposterior, lateral, and coronal views is helpful to assess the fracture line patterns in order to aid pin insertion.

Complications
The immediate complications consist of injury to branches of the superficial radial nerve or dorsal cutaneous branches of the ulnar nerve. Loss of fixation due to poor pin placement or interference with extensor tendon gliding can be minimized by careful technique and open rather than percutaneous pin insertion. The use of many standard external fixator frames applied in a nonbridging manner can result in articular incongruity. Late collapse after fixator removal can occur in osteopenic bone, which often requires subchondral support beyond the 6 weeks of fixator application. Due to the risk of late collapse, adjuvant internal fixation with locking plates is advised in elderly and osteopenic patients because fracture site settling may occur for up to 6 months.33

Results
Reports of nonbridging external fixation (or radio-radial external fixation) for the treatment of intra-articular fractures are sparse and mostly restricted to the European literature. Krishnan et al reported a clinical trial of 30 patients with Frykman type 7 and 8 fractures who were treated with the nonbridging Delta Frame External Fixator (Mathys Medical Ltd., Bettlach, Switzerland).47 Although favorable wrist motion was reported, the median intra-articular step was 2.8 mm (range 0–9.1 mm) with a median intra-articular gap of 1.8 mm (range 0–13.4 mm).42

Gradl et al examined 25 consecutive patients with fractures of the distal radius who were treated with nonbridging external fixation for 6 weeks.48 The stepwise surgical technique comprised a preliminary joint-bridging construction for reduction purposes, the subsequent insertion of 3 to 4 K-wires in the distal fragment, the assembling of the K-wires to a dorsal outrigger bar that was nearly parallel to the fracture line, and finally the removal of the joint-bridging part. Clinical and radiologic evaluation was performed on the first and seventh days, at 6 weeks, and 2 years after surgery. All fractures united with a palmar tilt of ≥0° and articular step-off of <2 mm. A loss of radial length occurred in 4 patients in which only 3 K-wires were inserted in the distal fragment. No radial shortening was seen in fractures with 4–K-wires inserted in the distal fragment. The functional results at 2 years after surgery showed an average extension of 55° and flexion of 64° without notable differences between extra-articular and intra-articular fractures. There were no instances of extensor tendinitis or pin loosening in the distal fragment; however, there were 3 cases of proximal pin track infections.48

Arthroscopic Assisted Reduction and Nonbridging External Fixation
Indications
More than 2 mm of articular displacement or gap are typical indications for surgical treatment. Isolated radial styloid fractures and simple 3-part fractures are
most suited to this technique. Four-part fractures should be tackled only after one has gained experience with simpler fracture patterns. After reduction and percutaneous pin fixation, many authors use a bridging external fixator as a neutralization device or apply a volar locking plate. In many instances, it has been my preference to use the Fragment Specific Fixator (South Bay Hand Surgery LLC, Torrance, CA) in a nonbridging application to allow early wrist motion (Figs. 4A–4I).

Contraindications
Large capsular tears, which carry the risk of marked fluid extravasation, active infection, neurovascular compromise, and distorted anatomy are some typical contraindications. Marked metaphyseal comminution, shear fractures, and volar rim fractures require open treatment, although the arthroscope can be inserted to check the adequacy of the joint reduction.

Ulnar Styloid Fractures and DRUJ Instability
Ulnar styloid fractures may or may not be associated with disruption of the deep foveal insertion of the TFCC and secondary DRUJ instability. Many authors recommend initial fixation of the distal radius fracture and then assessment of the DRUJ for instability because fracture reduction often restores DRUJ instability. If there is more than 5 mm of anteroposterior displacement of the distal ulna during stress testing, wrist arthroscopy is beneficial. Basi-styloid fractures carry the risk of TFCC detachment, but in an arthroscopic study of the soft tissue lesions associated with distal radius fractures, Lindau noted that the TFCC is more commonly avulsed off its radial insertion. Any peripheral TFCC tear is repaired arthroscopically, using an outside-in technique. If the articular disc has normal tension to palpation, the styloid fracture is ignored or excised if there is the worry of late carpal impingement. The deep fibers of the DRUJ can be directly assessed through a volar DRUJ portal. If there is a disruption of the deep fibers of the TFCC, an open foveal repair can be performed. If the TFCC remains well attached to the ulnar styloid fragment, ORIF of the styloid using K-wires and tension band fixation, cannulated screws, or bone anchors is performed.

Ruch et al described the use of a dorsal outrigger attached to a bridging external fixator in cases of associated DRUJ instability. They found that patients in whom the ulnar styloid can be reduced and maintained in supination can be treated effectively with fixed supination using an outrigger attached to the external fixator. This method resulted in a statistically significant improvement in supination (p <0.05) as well as a lower rate of distal radioulnar joint complications, and it required fewer secondary procedures.

Combined Fixation
Combined fixation can be performed with the fixator applied in either a bridging or a nonbridging mode. In many instances, the Fragment Specific Fixator (South Bay Hand Surgery LLC, Torrance, CA) is applied in a nonbridging radial uniplanar configuration in conjunction with a combination of a volar and/or dorsal plate (Figs. 5A–5G). In these instances, the fixator acts as a “third plate,” which replaces the radial styloid plate. Alternatively, this can be combined with a bridging uniplanar configuration when there is marked periarticular dorsal comminution (Figs. 6A–6I).

Indications
Despite the plethora of volar plate designs, fixation of a small radial styloid fragment is often tenuous. The Fragment Specific Fixator can be applied in a uniplanar radial application when there is a small radial styloid fragment that cannot be adequately captured with a plate. Any sagittal split of the medial fragment that cannot be successfully reduced with percutaneous or arthroscopic methods is treated with fragment-specific implants. Joint bridging fixation is indicated when there is central comminution to help unload the articular fragments.

Contraindications
Inadequate or unstable soft tissue coverage or marked swelling would preclude the use of multiple skin incisions and implants.

Complications
The complications are similar to those described earlier. There is a greater risk of hardware interference with tendon gliding and cutaneous nerve branches as the number of plates increase. The volar and dorsal exposure can also devascularize small fragments that can lead to delayed healing or late collapse, which is the rationale for the use of locking plates rather than conventional mini-plates. In elderly populations with osteopenic bone, some fracture site settling cannot be avoided, even following bone grafting, external fixation, and locking plates.

Although it is currently not in vogue, ligamentotaxis still has its uses, especially in situations that
would preclude internal plate fixation. Novel fixator designs are opening new horizons, but multicenter clinical trials are necessary in order to determine whether the superior results obtained with nonbridging fixation of extra-articular fractures can be duplicated with intra-articular fractures. The combination of external fixation with limited internal fixation is a useful adjunctive technique with multifragmented fractures. Gaining an understanding of the principles and limitations of external fixation allows one to be flexible and adapt the fixation to the specific fracture pattern in order to maximize the chances for an acceptable outcome.

References

30. Fernandez DL, Geissler WB. Treatment of displaced artic-


