Current Concepts in Volar Fixed-angle Fixation of Unstable Distal Radius Fractures

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We present new developments in the volar treatment of unstable distal radius fractures in adults. New perspectives on the anatomy of the wrist, the watershed line on the volar radius and the usefulness of the pronator fossa are presented and these help to avoid flexor and extensor tendon disturbance when using a volar approach. Other new insights on the bony anatomy of the distal end of the radius are discussed, which are important in improving the quality of fracture fixation, including the benefits of constructing a precise fixed-angle scaffold underneath the articular surface in order to stabilize it. A volar fixed-angle plate must support the dorsal, central and volar aspects of the subchondral bone in order to stabilize the most complex fractures. Awareness of the anatomy of blood supply to the distal radius: the dorsal retinaculum that feeds the distal fragments and the blood supply to the diaphysis through branches of the anterior interosseous artery is necessary to maximize healing potential and avoid complications. Volar fixed-angle plates need to withstand very high forces during rehabilitation, the magnitude of these forces are up to five times the loads applied on the hand.

Level of Evidence: Level V (expert opinion). See the Guidelines for Authors for a complete description of levels of evidence.

Modern fracture treatment aims to achieve bone union, rehabilitate soft tissues, and rehabilitate the adjacent joints. A thorough understanding of the anatomy of the wrist is a prerequisite for treating complex distal radius fractures.[44,55] The lack of adequate reduction in conservatively treated patients[41,83] led investigators to support open reduction and internal fixation (ORIF).[3,8,15,19,25,29,42,46,50,58,61,81] Open reduction and internal fixation allows accurate reconstruction of the joint surface, facilitates repair of associated intercarpal pathology, and allows for recog-

nizing any unstable fracture components.[8,18,29] Improvements in outcomes after ORIF of distal radius fractures have been reported during the past decade.[2–4,7,8,10–12,15,20,30,33,35,47,52,53,60,61,77,84] However, the complication rate is between 15% to 35%, mainly attributed to soft tissue disruption.[3,20,31,68,78] These problems reflect implant design issues and the underestimation of mechanics involved in wrist physiology.[22,32] The use of low profile internal fixation systems reduced many of these complications, but new problems still occurred.[11,40,61]

Since its introduction in 2000, volar fixed-angle fixation technique has provided an effective alternative for the management of dorsal and volar fractures.[50] This approach is used because fixed-angle plates obviate the need to place the implant on the unstable side of the fracture; therefore, the more physiologic volar approach can be used to treat the majority of fractures.[27,50,51] This approach is less disruptive to the tendons because there is more space available on the volar aspect of the radius. Flexor tendons are located away from the volar surface of the radius, while extensor tendons run directly on the dorsal surface. The volar approach allows the use of a thicker, stronger implant to better resist the loads applied during functional rehabilitation. Refinements of volar fixed-angle fixation were based on insights into the anatomy of the radius, biomechanics, and blood supply.[37,56,67,70,72,76]

For the purpose of this review, we did a cross referenced Medline search and review of anatomic, biomechanical, and surgical selected articles that we thought represented considerable breakthroughs that led to the current concepts in the fixation of unstable distal radius fractures.

We will provide new anatomic and biomechanical insights to assist hand surgeons in making accurate fractures reduction, and fixation therefore anticipating and alleviating the risks for subsequent complications.

Anatomic Considerations

Understanding the surgical anatomy distal radius fractures continues to evolve. Medoff and Kopylov[42,43] introduced

the fragment specific concept of surgical stabilization where a small implant is applied for each major articular fragment through a combination of volar, radial and dorsal (two or three) incisions, according to each patient's fracture pattern.

The similar columnar fixation theory[60] is based on three principal zones of support: the medial, central, and lateral columns. Rikli and Regazzoni[60] stated these zones should be addressed separately with two or more small orthogonal implants applied mainly through a dorsal approach. However, dorsal fixation of fractures is still correlated with a high rate of complications and revisions.[11,30,61] Until recently, volar reduction and fixation of dorsally displaced distal radius fractures was avoided as it was not believed possible. Initial attempts to achieve volar fixation of dorsal fractures were successful,[21,34] leading to the extended flexor carpi radialis (FCR) volar approach that allows volar management of complex dorsally displaced distal radius fractures or their malunions.[27,51]

The most attractive anatomic feature of the volar aspect of the distal radius is the absence of flexor tendon-bone intimacy. Implant fixation on the volar aspect of the distal radius is also advantageous because its surface, except at the very distal margin, is relatively flat in the transverse plane. This feature facilitates the accurate restoration of rotational alignment. The volar radius also presents a concave profile in the sagittal plane (the pronator fossa). This feature is limited distally by a ridge called the watershed line[6,9,16,23,37] and allows the application of implants of substantial profile. The gliding surface of the flexor tendons should not come in contact with the plate as long as the implant is nested in the pronator fossa, does not cross its distal boundary, or project above it (Fig 1). The watershed line used as a surgical landmark because it is easily palpable as a bony prominence through the fibrous tissue that covers it, especially over the most ulnar aspect (volar rim of lunate fossa) where it is very close (2 mm) to the joint line. The radial aspect of the watershed line is proximal (10–15 mm) to the joint line as it courses along the base of the styloid process. The volar wrist capsule and ligaments insert distal to the watershed line, and the most distal edge of the pronator quadratus muscle is located several millimeters proximal. The intermediate fibrous zone is located here between capsule and muscle. Fracture fixation frequently requires a thorough exposure of the volar surface of the radius, including the volar rim of the lunate fossa where rare volar marginal fragments originate. This exposure is best obtained by elevating all soft tissue proximal to the watershed line including the intermediate fibrous zone and pronator quadratus muscle. Dorsally displaced fractures frequently present with a rupture of the pronator quadratus muscle located through its most distal fibers proximal to the intermediate fibrous zone.
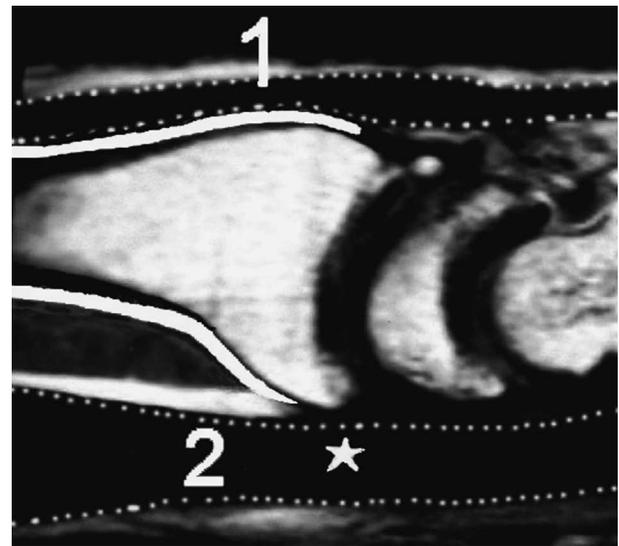
Fig 1A–B. (A) The extensor tendons run in intimate contact with dorsal plates. The flexor tendons only approach the volar radius at the watershed line (*). (B) Magnetic resonance imaging shows the flexor tendons are well separated from volar plates. The best location for the application of fracture implants is the volar aspect of the distal radius. Reprinted from Orbay J. Volar plate fixation of distal radius fractures. *Hand Clin.* 2005; 21:347–354 with permission from Elsevier.
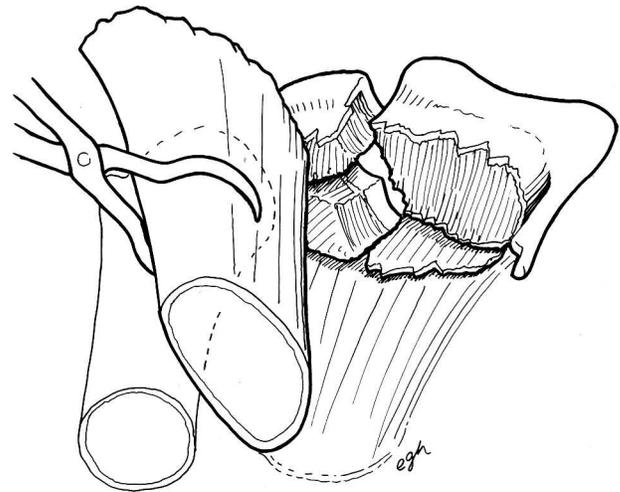
Proper volar exposure frequently results in the formation of one narrow distal fibrous tissue flap consisting of the intermediate fibrous zone and a second more proximal muscle flap that includes the bulk of the pronator quadratus muscle (Fig 2). Volar exposure of dorsal fractures is enhanced by releasing the radial septum (distal FCR tendon sheath, intermuscular septum, first extensor compartment, and brachioradialis). Distal release of the dorsal and volar aspects of the FCR sheath, usually distal to the superficial radial artery and scaphoid tuberosity, locates the fracture site in a more central position on the surgical approach and greatly facilitates reduction. The sheath of the first dorsal compartment must be opened on its proximal aspect to retract the abductor pollicis longus (APL) and identify the insertion of the brachioradialis into the radial styloid. Releasing this tendon eliminates the major deforming force on the radial column. A step cut tenotomy facilitates the tendon's subsequent repair and create an anchoring point for suturing the pronator quadratus muscle over the plate. Mobilizing the proximal radial fragment into pronation provides the exposure necessary to access the dorsal and articular aspects of the fracture. Exposure through the fracture plane (intrafocal exposure) allows easy debridement of fracture hematoma or interposed callus, and allows reduction of complex dorsally displaced distal radius fractures (Fig 3). Direct observation of the

Fig 2A–B. An intraoperative photograph shows the (A) intermediate fibrous zone. It is a strip of fibrous tissue and periosteum located between the wrist capsule and the (B) pronator quadratus. In dorsal fractures, the pronator quadratus is frequently ruptured at its junction with the intermediate fibrous zone. The IFZ is therefore raised as a narrow ulnar based flap during exposure. Reprinted from Orbay J. Volar plate fixation of distal radius fractures. *Hand Clin.* 2005;21:347–354 with permission from Elsevier.

Fig 3. An illustration shows the extended FCR approach used for volar management of complex fractures. Rotating the proximal fragment into pronation provides the access needed for fracture debridement and articular reduction. Reprinted from Orbay J. Volar plate fixation of distal radius fractures. *Hand Clin.* 2005;21:347–354 with permission from Elsevier.

reduced surface is not possible through a volar approach. Assessment of fracture reduction must be achieved with fluoroscopy. Perfusion of the distal fragment occurs mainly through a dorsal vascular retinaculum that remains undisturbed during a volar approach. Perfusion to the proximal fragment occurs through branches of the anterior interosseous artery that lay on the interosseous membrane and must be protected.[69,71] After osteosynthesis, the intermediate fibrous zone flap and the pronator quadratus muscle are repositioned over the plate. This adds a soft tissue layer between the flexor tendons and the plate while tightening the distal radioulnar joint, a structure disturbed in the majority of these injuries. We think carpal tunnel release is best performed through a separate incision as a radial side release can cause flexor pollicis longus (FPL) dysfunction and distal surgical wound extension for standard release can produce trauma to the palmar cutaneous nerve.

Anatomic details of distal radius fractures and numerous classification schemes have been proposed.[17,45,48] The more common articular fracture patterns are now well recognized as recent progress has focused on the intra-articular injuries. All classifications depend on the authors' perspectives, and their usefulness depends on the chosen treatment method. In treating extra-articular fractures, the application of an anatomically contoured volar plate to the proximal fragment assists in fracture reduction

by functioning as a template for restoration of volar tilt. When performing volar fixed-angle fixation of intra-articular fractures it is important to understand the pattern of articular comminution and the size and shape of fragments. The most useful information is the direction of the fracture planes. Articular fragment displacement in the sagittal or coronal planes requires different reduction techniques. Articular fragments displaced through a coronal fracture plane will reduce, after fracture debridement, by longitudinal traction and direct pressure on the dorsal skin. This maneuver reduces dorsal against volar fragments and the plate acts as a template to restore volar tilt. Articular fragments displaced through a sagittal fracture plane are reduced by stabilizing the ulnar side fragments with fixed-angle pegs and reducing the radial fragments against this construct. This is done by direct pressure on the skin over the radial styloid, or by radial deviation of the wrist. All main articular fracture fragments are stabilized by volar fixed-angle fixation. Posteromedial (dorsoulnar) fragments are fixed by the most ulnar pegs on the plate's proximal row, anteromedial fragments by the volar buttressing surface and the ulnar pegs on the distal row, and radial styloid fragments by the most radial pegs on both rows (Fig 4).

Another indication for volar fixed-angle plating is the correction of established deformity. Changes in the osseous architecture of dorsal malunited fractures affect the mechanics of the radiocarpal joint, the distal radioulnar joint (DRUJ), and the forearm axis. Several investigators
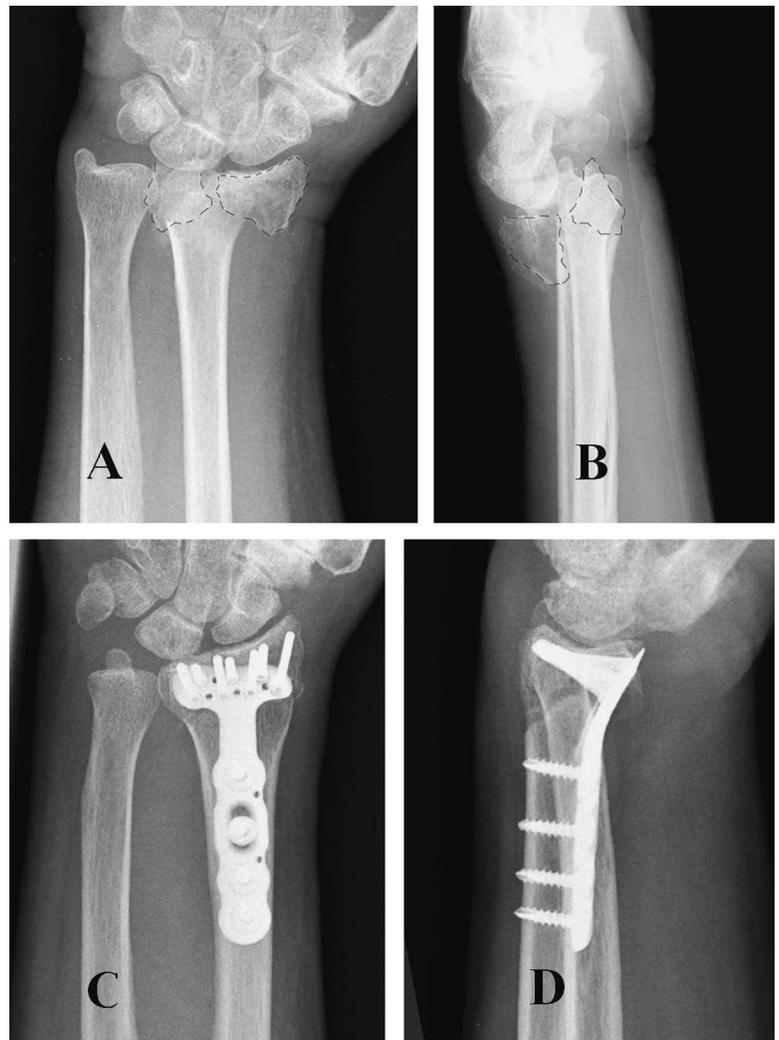
Fig 4A–D. A four part articular fracture fixed by a volar fixed-angle plate is shown. (A) A preoperative PA radiograph shows a four-part articular fracture. (B) A preoperative lateral radiograph better shows the displacement of the fracture. (C) A postoperative PA radiograph shows all the major articular fragments fixed by a volar fixed-angle plate including the radial styloid. (D) A postoperative lateral radiograph shows the pegs position at the subchondral bone level.

have advocated early surgical management of this problem to prevent degenerative changes and reduce rehabilitation time.[1,57,72] Opening wedge osteotomy or closed wedge osteotomy combined with ulnar shortening can be used. The extended FCR approach provides the exposure and fixed-angle volar plates the fixation necessary for volar opening wedge correction of dorsal deformity. It is imperative to perform an adequate soft tissue release to obtain correct length and volar tilt. This includes releasing the brachioradialis and the dorsal periosteum. If needed, packed autogenous bone graft can be inserted[62] from the volar approach.

Biomechanical Aspects

Increased knowledge of the biomechanics of the hand, wrist, and forearm contribute to improvements in the treatment of unstable distal radius fractures. Forces occurring across a distal radius fracture are substantial, resulting from externally applied loads and internal muscle forces. The muscle forces vary considerably from a physiologic resting muscle tone of approximately 8 lb[64,75] to 19 to 30 lb[24,72,73] during active unconstrained wrist motion. It has been reported that 5 to 11 lb of force is produced for each 2 lb of hand grip.[59] Assuming the coefficient of friction of between the skin and an object being grasped is 1, it will be necessary to produce a grip force of the same magnitude as the weight of the object in order to lift it. This implies that the distal radius fracture fixation implant will face an axial load of up to five times the weight of the object being lifted. The ulna will decrease the magnitude of the forces applied to the distal radius by virtue of load sharing.

This information has practical applications. For example, we commonly allow patients to lift weights up to 5

lb in the early stages of rehabilitation, a practice based on the reasoning that 25 lb of force will be induced across the implant and this force magnitude will be well below the 200 lb rating of the implant we use. The clinical importance of an adequate reduction has been stressed,[52] and laboratory studies have shown that optimal restoration of normal volar tilt of the distal radius is crucial to prevent increased contact forces in the radiocarpal and radioulnar joints.[72,82] Biomechanical studies comparing volar fixed-angle fixation plates with conventional dorsal implants report volar fixed-angle fixation plates are stronger.[36,39,54,80] Fixed-angle volar plates prove stronger under cyclical loading tests than dorsal implants as the implant-bone interface is the limiting factor.[52,54]

The need for fixed-angle plates arose from the failure of conventional buttress plates to achieve stable fixation. Conventional screws toggle as purchase on the weak bone of the distal fragment is usually poor. Fixed-angle implants do not depend on screw purchase, they depend on direct bone support through an interference effect. Volar and dorsal fracture fixation constructs require different implant architecture. Dorsal fracture fixation is usually performed with at least two orthogonal implants. Based on our experience, volar plating, by virtue of precise peg distribution, allows a single fixed-angle plate to provide the same dorsal stability as with multiple dorsal implants. Most distal radius fractures are dorsally displaced. Support of the dorsal aspect of the articular surface is of primary importance, hence the distal tilt of the pegs. Fixed-angle volar fixation of dorsally unstable distal radius fractures results from the capture of distal fragment(s) between distally inclined pegs and the surface of the plate. The distal inclination of the pegs in the lateral plane will neutralize dorsal displacing forces while inducing a volar force, which must be opposed by a properly configured volar buttressing surface. Also, divergence of the pegs in space to closely follow the complex three-dimensional shape of the articular surface improves fixation. Pegs support load in a cantilever manner, therefore the greatest resist physiologic loads. Pegs can be smooth or threaded. Smooth pegs are easier to insert and provide the necessary subchondral support. Threaded pegs are useful for stabilizing a coronal fracture plane and preventing diastases of the articular fragment. Fixed-angle volar plates transfer loads directly from the articular surface to the proximal radial shaft, circumventing any metaphyseal comminution. The implant acts as an internal fixator in which stability across the fracture becomes a function of the properties of the plate. A volar fixed-angle plate supporting a fracture unstable in dorsal and volar directions can bear loads better than a dorsal fixed-angle plate. It is able to do this because of shape of the distal radius. Its articular surface is offset with respect to the diaphysis by a few millimeters in a volar direction, placing the joint reaction force closer to the volar plate and decreasing its bending moment. With severe comminution, volar instability, and/or osteoporosis the Distal Volar Plate (DVR™) (Hand Innovations, LLC, Miami, FL) can be used. It has a second more distal row of pegs that provide additional support to the central and volar aspect of the subchondral bone. The second row of pegs prevents dorsal rotation of an anteromedial fragment and volar rotation of a severely osteoporotic or unstable single distal fragment. These two rows create a three-dimensional scaffold that cradles the articular surface (Fig 5).

Providing stable fixation in the presence of substantial osteopenia has been challenging because the holding power of a conventional screw is directly proportional to the density of the bone. About 100,000 distal radius fractures in osteoporotic bone have been reported annually in the United States, most from low energy falls.[49] Knowledge remains incomplete about the causes of osteoporosis and its effect on the fracture repair process in humans.[38] Fixed-angle support has successfully overcome the limitations of the more traditional forms of internal fixation.[76,81] The subchondral plate is usually the strongest bone on the distal fragment, and fixed-angle pegs provide reliable fixation if applied immediately underneath it.

DISCUSSION

Difficulties with dorsal fixed-angle plates prompted the use of volar fixed-angle plates for dorsal fractures. The

Fig 5. The Distal Volar Plate™ (Hand Innovations) is shown. Two rows of pegs create a three-dimensional scaffold to support the articular surface. Threaded pegs help stabilize displacement through a coronal fracture plane. Reprinted from Orbay J. Volar plate fixation of distal radius fractures. *Hand Clin.* 2005;21:347–354 with permission from Elsevier.

Fig 6. A fixed-angle volar plate must (1) avoid contact with flexor tendons by not projecting beyond or above the watershed line and must (2) provide sufficient distal buttressing surface to control a volar marginal fragment. Reprinted from Orbay J. Volar plate fixation of distal radius fractures. *Hand Clin.* 2005;21:347–354 with permission from Elsevier.

first available volar implants designed for volar fractures were used as an alternate indication.[22,26,65] The benefits of this new approach include early return of function, improved final motion, the virtual elimination of extensor tendon problems, and the lack of need for routine plate removal.[27,50,51] However, new problems occurred because the early implants were weak and lacked adequate peg configuration. The first volar plates designed for dorsal fractures were made stronger by improved peg distribution. Pegs were directed in distinct nonparallel axis into the region underneath the dorsal subchondral bone.

Threaded pegs were also introduced to aid fixation of dorsal fragments in the event of a coronal fracture plane. These changes and refinements in the surgical approach enabled the routine volar management of many dorsally unstable fractures. Past reports represent the best available information regarding trends in distal radius fracture fixation, however, and after the thorough analysis of our initial results, constant refinements of the technique as well as of the implant design had to be implemented to address our new vision of the anatomic and biomechanical concepts.

Subsequent experience with intra-articular distal radius fractures contributed to the improvements. Volar marginal fragments that originate from the volar rim of the lunate fossa must be properly buttressed as they are essential for wrist joint stability. The plate's buttressing function was improved by carefully contouring its shape and designed to cover the entire surface of the pronator fossa without extending across or above the watershed line (Fig 6). Another more distal row of pegs was placed on the expanded plate to support the more central and volar sections of the subchondral bone and neutralize volar displacing forces. Volar implants took advantage of provisional fixed-angle K-wires to facilitate the surgical procedure. The K-wires fit snuggly through the plate without toggling and maintain reduction during the process of peg insertion. They also assist the surgeon in deciding where to place the plate by anticipating the final position of its proximal peg row. The surgeon can optimize the plate's position by finding where balance occurs between support of the dorsal subchondral bone, buttressing of the volar cortex, and respect for the watershed line (Fig 7). Surgeons familiar with treating high end fractures contributed to the improvements in plate design. The proximal row pegs were angled more accurately to improve support for the radial styloid and the dorsoulnar fragments. The distal row was moved further
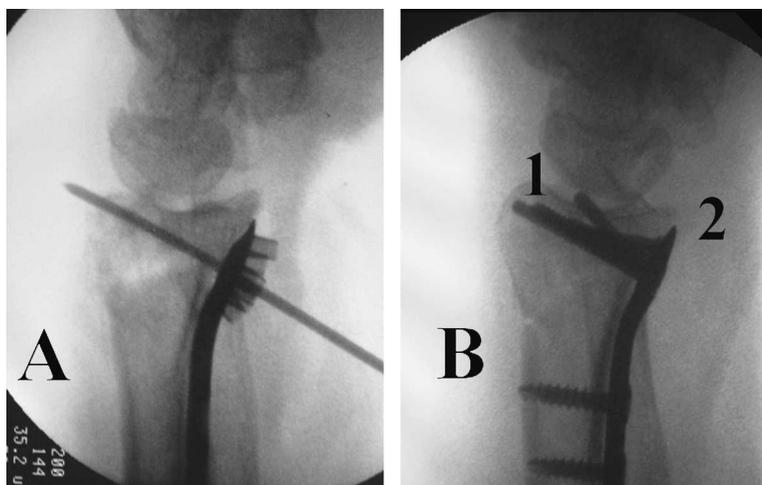
Fig 7. Fixed-angle K-wires provide temporary fracture stability and anticipate future peg position. (A) The K-wires assist in placing the plate in the optimal position, (B) where balance occurs between (1) support of the dorsal subchondral bone and (2) buttressing of the volar cortex.

Fig 8A–D. A 58-year-old man with a right intra-articular distal radius fracture presenting with proximal extension and a concomitant scaphoid fracture. Preoperative (A) PA and (B) lateral radiographs are shown. Postoperative (C) PA and (D) lateral radiographs taken at 4 months after fracture fixation show the fracture has been fixed with a long plate.

distally to improve support for the volar aspect of the articular surface. Plates of different widths and lengths have been developed, including plates specifically for patients with proximal fracture extensions from high speed trauma (Fig 8).

Distal radius fractures in the elderly or infirmed populations are common and continue to occur more frequently. These patients have specific needs: stable fixation for poor quality bone, simple anesthesia because of poor general health, and the need for quick rehabilitation. Volar fixed-angle fixation offers an adequate treatment method for this patient population, as the technique relies on the only substantial bone remaining in advanced osteoporosis—the subchondral plate.[13,53] The volar approach is well tolerated and can be performed under regional anesthesia (Fig 9).

There are few complications with using volar fixed-angle fixation, and these are frequently related to the surgical technique[5,14,15,49,52] because of the learning curve. This is in contrast to complications reported with other methods, where problems are related to the surgical approach itself.[28,31,40,63,66] Failure to achieve anatomic reduction is usually because of inadequate surgical exposure. Most frequently, failure to utilize the extended FCR approach to remove the offending dorsal hematoma or callus and to perform the necessary soft tissue releases prevents the surgeon from achieving an anatomic reduction. This problem is aggravated when the fracture is older than 2 weeks, or when there is severe articular fragmentation because reduction by indirect means becomes impossible. It is important that adequate reduction be achieved prior to plate application, otherwise pegs will not correspond to their intended position on the distal fragments. Pegs of excessive length can injure extensor tendons if they protrude through the dorsal cortex. Loss of fixation can occur if improperly sized implants fail to span the breadth of the articular surface (and therefore fail to support all the fragments) or if pegs are placed too proximal and fail to support the subchondral bone. Flexor tendon injury can occur if the fracture collapses back into a

Fig 9A–D. For the same patient shown in Figure 8, final wrist motion for (A) extension, (B) flexion, (C) supination, and (D) pronation are shown.

dorsal deformity and the plate lifts off from the volar surface into the flexor tendons. If this occurs it must be reoperated on immediately. Implant breakage can occur if fracture healing is delayed and the race against fatigue failure is lost. This problem is prevented by the proper use of bone graft and by preserving bone perfusion. Delayed healing is rare after fracture fixation but more frequent after deformity correction, especially when using nonautologous bone graft. Stiffness and complex radius pain syndrome are uncommon but must be treated aggressively and at its early stages. These last two problems are usually prevented by early functional use of the hand.

Contraindications include those patients with skeletally immature bone and open epiphysis, patients with simple fracture patterns and or severe medical illness that do not justify this procedure. This technique is capable of addressing most of the complex fractures patterns.

The overall experience with volar fixed-angle fixation for the general treatment of unstable distal radius fractures has been favorable, and the technique has gained widespread acceptance. The surgeon must be familiar with the appropriate indications and with the surgical technique, especially if managing complex fractures. It is a simple and reproducible procedure that improves recovery from this common injury.

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