Reliable internal fixation for the comminuted or osteoporotic distal radius fracture finally became available with the introduction of fixed angle fixation implants [1,2]. These implants function as neutralization devices; they provide distal stability by direct support of the subchondral bone and do not depend on distal screw purchase to maintain reduction. Most distal radius fractures are dorsally displaced [3] and surgeons have long been familiar with the concept of buttress plating. Also, the dorsum of the radius is subcutaneous and of easy access. For these reasons, the initial experience with fixed angle internal fixation of dorsally displaced distal radius fracture was through the dorsal approach [1,4–13]. Because there is little space available on the dorsal aspect of the distal radius, implant related extensor tendon problems were reported and these tempered the enthusiasm for the new technique [1,8–10,12,14–21]. Volar fixed angle fixation of dorsally displaced distal radius fractures was introduced to circumvent the problems related to the dorsal approach [22]. This new method presented many advantages and new challenges, all of which are the subject of this article.

Anatomic considerations

There are several reasons why the dorsal aspect of the radius is a poor site for the placement of internal fixation hardware: little space is available between the skin and the bone surface and it is occupied fully by extensor tendon sheaths; the dorsal surface of the radius is convex, inducing extensor tendons to rub forcefully against dorsal implants, therefore increasing their likelihood of injury; blood vessels to the distal fragments are mainly on the dorsal aspect, exposing them to harm during dissection; the dorsal cortex usually is comminuted, increasing the difficulty of the procedure; and finally, dorsal scars are less well tolerated [20,23]. The volar aspect is a better choice for implant application for the following reasons: more space is available, because flexor tendons are located far from the volar radial surface and the pronator quadratus is conveniently interposed; the concave surface of the distal radius protects flexor tendons from hardware irritation; blood supply is less likely to be disturbed by a volar approach; the volar cortex usually is less comminuted, facilitating volar osteosynthesis; and finally, volar scars are better tolerated [20,23] (Fig. 1).

Careful examination of the volar aspect of the distal radius reveals anatomic features that must be considered to optimize the technique of volar fixed angle fixation. The concave surface of the volar radius is limited distally by a transverse ridge or watershed line. Distal to the watershed line, the radius slopes in a dorso-distal direction and receives the proximal attachments of the volar wrist capsule and the volar capsular ligaments. This ridge lies close (2 mm) to the joint line on its ulnar aspect and well proximal (10–15 mm) from the joint line on its radial aspect. Although not a straight line, its overall trajectory is roughly normal to the axis of the radius, not following the radial inclination of the joint surface. Fixation implants must be placed proximal to and their profile must not project above the watershed line for them not to come in contact with flexor tendons. Implants placed over or projecting above the watershed line can impinge on flexor tendons and can cause injury. The fractured volar rim of the lunate fossa or volar marginal fragment is found on the ulnar aspect of the distal radius [12]. It is critical for stability of the radio-carpal joint.
Distal radius fractures are easy to reduce closed when the fractures are recent and the hematoma has not yet organized. A few days after the fracture, as the healing process begins, they become much more difficult to reduce. It then becomes necessary to debride the organizing fracture hematoma to obtain an acceptable reduction; this is particularly true of intra-articular fractures. The traditional volar approach provides access only to the volar surface of the radius. Although sufficing for volar fractures, this exposure is insufficient to manage complex dorsally displaced fractures, because the dorsal hematoma is not accessible. The extended flexor carpi radialis (FCR) approach was introduced to manage complex dorsal fractures through a volar incision. Exposure is provided by releasing the radial septum and pronating the proximal radius out of the way to access the dorsal aspect of the fracture (Figs. 3 and 4). This maneuver allows debridement of the fracture hematoma or callus and therefore reduction of complex articular injuries. To pronate the radius and to facilitate reduction, the brachioradialis tendon, which inserts on the floor of the first extensor compartment, must be released. This is accomplished best by opening the proximal aspect of the first extensor compartment, finding the insertion of the brachioradialis, and releasing it with a step-cut tenotomy; this facilitates its subsequent repair. This tendon has substantial proximal insertions and therefore does not retract; its repair, on the other hand, allows the proper anchoring of sutures for reattaching the pronator quadratus.

Fig. 1. The volar aspect is a better environment for the application of fracture implants. Although extensor tendons are in intimate contact with dorsal plates (1), flexor tendons are well separated from volar plates (2) and only approach at the watershed line (1).

Fig. 2. A properly designed volar plate must provide sufficient distal buttressing surface to control the volar marginal fragment (2) but must not project beyond or above the watershed line (1) to prevent contact with flexor tendons.

Fig. 3. At the level of the distal radial metaphysis, the radial septum is a complex fascial structure that includes the insertion of the brachioradialis (1) and the first extensor compartment (2) (Courtesy of Dr. Eduardo Gonzales, MD).
It is important to maintain blood supply to the proximal radial fragment by preserving branches of the anterior interosseous artery. These supply the radial shaft along its ulnar border and are located on the surface of the interosseous membrane. Most severe dorsally displaced distal radius fractures present with a rupture of the pronator quadratus that occurs commonly at its distal edge, where separation of the muscle fibers from the distal fibrous tissue occurs. This rupture is located several millimeters proximal to the rim of the radial concavity or watershed line. To achieve the exposure of the volar radial surface required for fracture reduction and plate application, it is usually necessary to dissect off the fibrous tissue found distal to the zone of rupture but proximal to the origin of the volar wrist capsule. This zone of thick fibrous tissue and periosteum is called the intermediate fibrous zone (IFZ) (Please provide year of communication for Nelson and Bindra reference. D. Nelson and R. Bindra, personal communication). It is best raised as a narrow ulnar-based soft tissue flap by incising along the watershed line and lifting it up by means of sharp dissection (Fig. 5).

After completion of osteosynthesis, replacing the pronator quadratus back into place improves stability of the distal radioulnar joint and restores the soft tissue layer underneath the flexor tendons. The IFZ flap is repositioned first, covering the distal edge of the plate. Subsequently the muscular part of the pronator quadratus is sutured to it and to the previously repaired brachioradialis. The median nerve and radial artery must be protected at all times. It is not necessary to dissect out these neurovascular structures; they should be kept safe in an intact soft tissue envelope.

**Biomechanical aspects**

Many severe distal radius fractures present instability in a dorsal and a volar direction. Under these circumstances loads transferred through bone contact across the fracture are minimal; therefore a fixed angle implant that restores the radius to its original length faces the full magnitude of the joint reaction force. Putnam reported that the joint reaction force on the distal radius is three to five times the measured grip strength [28]. Light activities of daily living can require 5–10 lb of grip strength; this induces up to 50 lb across the implant. Heavier use of the hand generates proportionally higher forces. Clearly the design of fixed angle plates for distal radius fractures must account for loads much higher than those faced by conventional buttress plates. Surprisingly a volar fixed angle plate supporting a fracture unstable in a dorsal and a volar direction is in a more favorable biomechanical situation than a corresponding dorsal fixed angle plate. This is because of the particular geometry of the distal radius, whose articular surface is offset a few millimeters in a volar direction with respect to the diaphysis. This places the joint reaction force closer to the...
volar plate and decreases the induced bending moment.

Fixed angle distal radius implants provide distal fixation by means of pegs that can be smooth or threaded. The latter are known also as locking screws or angle stable screws. These fixed angle elements rigidly attach onto the plate and provide fixation to the distal fragment primarily by buttressing or interference (Fig. 6). In the presence of osteoporosis, the strongest remaining bone on the distal fragment is the subchondral plate, and smooth pegs and threaded pegs provide reliable fixation only if applied immediately below this structure. Because most distal radius fractures are dorsally displaced, it is of primary importance to support the dorsal aspect of the subchondral plate to prevent fracture redislocation. Dorsal support is provided best by placing the pegs inclined in a proximal-volar to distal-dorsal direction in the lateral plane and by diverging or fanning them out in space to closely follow the complex 3-dimensional shape of the articular surface. The inclination of the pegs in the lateral plane neutralizes dorsal displacing forces while inducing a volar force. This force vector tends to displace the distal fragments in a volar direction, an effect that must be opposed by a properly configured volar buttressing surface. In essence, fixed angle volar fixation of dorsally unstable distal radius fractures entails capturing the distal fragments between distally inclined subchondral support pegs and a volar buttressing plate. Threaded pegs find application in the event of a coronal fracture plane. Here the force applied by the lunate tends to spread apart the fragments of the lunate fossa; this effect is opposed by the presence of threads (Fig. 7). In the case of severe comminution, volar instability, or osteoporosis, this basic configuration might not be enough to assure proper fixation and a third fixation element must be introduced. This is the secondary or distal peg row, which consists of an additional row of pegs originating from a more distal position on the plate and having an opposite inclination. This distal row therefore crosses the proximal row approximately at its midline and is intended to support the more central and volar aspect of the subchondral bone. It controls dorsal rotation of a volar marginal fragment and volar rotation of severely osteoporotic or unstable distal fragments. Together both rows form a 3-dimensional scaffold that cradles the articular surface, maintaining reduction despite extreme instability (Fig. 8). Because pegs are loaded in a cantilever manner, the greatest stresses are placed close to the plate–peg interface. Pegs must be of sufficient strength and the link between pegs and plate must be strong enough to resist the high bending loads that are generated during rehabilitation.

Review of clinical experience

Volar fixed angle fixation of distal radius fractures was introduced as a solution for the dorsal fracture shortly after the initial disappointment with dorsal fixed angle plates. Volar fixed angle plates designed for the management of volar fractures were commercially available at that time and were simply used for the new indication. The

Fig. 6. Fixed angle elements can be smooth or threaded. They are attached rigidly onto the plate and provide fixation to the distal fragment primarily by buttressing or interference.

Fig. 7. Threaded pegs are most useful in the event of a coronal fracture plane where the force applied by the lunate tends to spread apart the fragments. Fixed angle K-wires provide temporary stability and anticipate peg location.
new approach quickly revealed its benefits: early return of function, improved final motion, the virtual elimination of extensor tendon problems, and the abolition of routine plate removal. Because these primitive implants were not designed for this purpose, problems were soon apparent; plate breakage and failure of distal fixation was common. These early plates proved too weak for this application and their inadequate peg configuration allowed dorsal rotation of the distal fragment and provided poor support to comminuted dorsal lunate and radial styloid fossa fragments. To improve results, the first plates designed specifically for volar fixation of dorsal fractures were made stronger and peg distribution was improved. Plates were designed to project their pegs underneath the entire span of the dorsal subchondral plate, requiring the placement of each individual peg on a unique nonparallel axis. Threaded pegs also were introduced to aid fixation of dorsal fragments in the event of comminution through a coronal fracture plane. These improvements together with refinements of the surgical approach enabled the routine volar management of most dorsally unstable fractures.

Naturally these first volar fixed angle plates designed for dorsal fractures also were used to stabilize volarly displaced fractures, and experience with these prompted new improvements. Small volar marginal fragments that originate from the volar rim of the lunate fossa occur occasionally as secondary fracture lines and mostly in volar directed injuries. These fragments must be buttressed properly, because they are crucial for stability of the radiocarpal joint. Improvement of the volar buttressing function of the volar fixed angle plate was accomplished by extending the supporting surface distally to just short of the watershed line while maintaining the pegs in the already optimized dorsal subchondral position. This resulted in a longer buttressing surface, particularly on the ulnar aspect where it addresses the volar marginal fragment and a plate profile presenting a reversed silhouette. In addition, the enlarged buttressing area allowed the incorporation of a second and more distal row of pegs designed to support the volar section of the articular surface. These distal pegs are inclined in an opposite direction to the proximal ones to better neutralize volar displacing forces.

A large number of distal radius fractures occur in elderly and infirm patients and these have special requirements: their limited coping abilities compel that function be restored promptly to maintain their independence, their poor bone quality requires particularly capable fixation, and the risk for anesthesia and surgical morbidity must be minimized. Volar fixed angle fixation has proven an adequate treatment method for this patient population [29], because the technique relies on the only substantial bone remaining in advanced osteoporosis, the subchondral plate. Also, the volar approach is well tolerated and the procedure can be performed under regional anesthesia (Fig. 9).

Complications encountered with volar fixed angle fixation are few and frequently are related to surgical technique. Failure to achieve anatomic reduction is usually caused by inadequate surgical exposure, ie, failure to use the extended FCR approach for the purpose of fracture debridement. This usually occurs when the injury is more than 2 weeks old or when there is severe articular fragmentation and displacement. Extensor tendon injury still can occur if pegs of excessive length, which protrude through the dorsal cortex and into the extensor tendon sheaths, are implanted. Loss of fixation is uncommon but can occur, especially in the more complex fractures, if improperly sized plates are used or if pegs are placed too proximal to the subchondral bone. To facilitate proper plate placement, the newer plates permit the temporary application of specialized fixed angle K-wires that maintain reduction and anticipate the final position of the pegs. This allows the surgeon to optimize the plate’s position by finding the point at which balance occurs between support of the dorsal subchondral bone and buttressing of the volar radial surface. Flexor tendon impingement can occur if the fracture rediscovers...
Fig. 9. (A,B) PA and lateral preoperative films of a 78-year-old woman with a left osteoporotic intra-articular distal radius fracture. (C,D) PA and lateral 3-month follow-up views showing the healed fracture with anatomic restitution. (E) Final wrist extension, flexion pronation, and supination.
into a dorsal deformity and the plate therefore is lifted off from the volar surface and into the path of the flexor tendons. Redisplacement into dorsal deformity must be reoperated early to prevent flexor tendon injury. Implant breakage is rare, but, as for any implant, it can occur if fracture healing is delayed and the race against fatigue failure is lost. This can be prevented by the proper use of bone graft and careful technique to preserve vascularity of the diaphyseal fragment. Delayed healing is rare in fresh fractures but more likely after performing an osteotomy and using non-autologous bone graft or a synthetic substitute. Stiffness and reflex sympathetic dystrophy (RSD) are uncommon with this technique but must be watched for and treated aggressively in their early stages. Allowing the patient to perform early functional use of the hand is preventive. In general, vigilance and attention to detail avoid most complications.

The overall experience with volar fixed angle fixation for the general treatment of unstable distal radius fractures has been favorable, and for this reason the technique has gained widespread acceptance recently. It is an easy to learn, simple, and reproducible procedure that has improved the outcome of this common injury.

References


