INTRODUCTION

The treatment of distal radius fractures has evolved substantially over recent years. Most authors still agree that anatomic reconstruction of both the radiocarpal and radioulnar joints is required to restore normal wrist kinematics and achieve optimal outcomes in both the short and long term. More controversial is the question of how to achieve anatomic reconstruction of the distal radius. Stable extra-articular fractures may be treated with manipulation and casting. Intra-articular, unstable, and irreducible fractures, especially in the younger patient, require more invasive treatment.

The options for internal fixation have greatly increased over the past 10 years. Dorsal plating was popular for some time, but concerns lingered over the lack of recovery of wrist flexion, which is believed to result from a combination of an extensive dorsal exposure and capsulotomy, in addition to the space-occupying plate, which leads to thick scar formation and capsular contracture. Two prospective, randomized controlled trials, published in 2005, compared the results of predominantly dorsal internal fixation with percutaneous fixation and external fixation, including mini-open reduction if required. Kreder and colleagues found that when displaced intra-articular fractures can be treated by indirect reduction and percutaneous fixation, a more rapid return to function and a superior functional outcome will be obtained than by open reduction and internal fixation, provided that the intra-articular step and gap formation is minimized. Grewal and colleagues terminated enrollment half-way through their study, since the dorsal plating group showed significantly higher complication rates, as well as significantly higher pain levels, weaker grip, and longer surgical and tourniquet times. A meta-analysis of outcomes of external fixation versus plate osteosynthesis for unstable distal radius fractures was published later in the same year. The review included 917 patients in the external fixation group and 603 in the plating group, of which only 55 were treated with a volar fixed-angle device. The authors did not detect any significant differences in grip strength, range of motion, radiographic alignment, pain, or physician-rated outcomes. Patients had higher rates of infection, hardware failure, and neuritis with external fixation and higher rates of tendon complications and early hardware removal with internal fixation. The authors concluded that the literature offered no evidence to support the use of internal fixation over external fixation for these injuries.

The disappointing results of open reduction and internal fixation have to be revisited in light of the development of volar fixed-angle plate technology and fragment-specific low-profile fixation techniques. Robert Medoff and colleagues described a specific fragmentation pattern of the distal radius and derived his fragment-specific approach from this. They described five main articular fragments and developed the TriMed Wrist Fixation System (TriMed, Inc, Valencia, California), fragment-specific fixation implants for these fragments. This system enables the surgeon to reliably stabilize fracture fragments through limited volar and dorsal approaches and to institute immediate mobilization in the majority of cases.

The early experience in our department with this system showed a restoration of articular congruity to less than 2 mm in 20 of 21 patients with AO type C2 and C3 fractures, with no loss of reduction at a minimum 6-months’ follow-up. The mean range of motion was 50 degrees flexion, 63 degrees extension, and a pronation-supination arc of 149 degrees.

Before the advent of locking technology, volar plating was mainly indicated for volar rim shearing fractures. New angle stable plate designs have expanded the indications for volar plating to include dorsally displaced unstable fractures. A variety of designs (DVR, Hand Innovations; volar subchondral support systems, Avanta; and the LCP Distal Radius Plate, Synthes North America) were developed, and clinical results were presented. These confirmed the safety and efficacy of these devices. In a comparison with external fixation, the restoration of intra-articular congruity, radial length, and volar tilt was significantly improved with volar plating. Moreover, successful maintenance of reduction, with minor settling of the fracture in only 3 of 23 patients, was noted in an osteopenic patient population over 75 years.

The subsequent development of variable-angle volar locking plates offers the potential to combine the advantages of volar plating with the deliberate placement of fixation screws and pegs to achieve some degree of fragment-specific fixation.

EVOLUTION OF VOLAR ANGLE STABLE PLATE DESIGN

First-Generation Volar Plates

The first-generation volar angle stable plates were somewhat analogous to blade plate implants. They were a one-piece design with no capacity to adjust the angle or length of the blade components. An example of this design was the Tine plate (Avanta). These implants were at the forefront of the development of angle stable volar plating; however, they were technically challenging to use and limited in application to diverse fracture patterns.
Second-Generation Volar Plates

The second generation of volar plates may be divided into two categories. The first category had a distal screw angulation that was symmetrical from the radial to the ulnar side of the plate. The only variability was in terms of the length of the distal pegs or screws. One of the first plates of this design was the volar plate of the AO Pi Plate set; however, this was more frequently used in combination with a dorsal implant.

The second category of second-generation volar plates had fixed variation of screw angulation from the radial through to the ulnar side of the plate so that the natural anatomic slope of the radius could be more closely paralleled, resulting in more widespread subchondral support of the articular surface.

Third-Generation Volar Plates

The most recent development in volar implants for distal radius fracture fixation involves variable-angle screws, which maintain angular stability. The ability to vary the angle of screws imparts multiple benefits in dealing with radial fractures.

Goals in the deployment of a volar implant include the accurate and safe subchondral placement of screws or pegs, combined with the achievement of true radial column support. In using a fixed-angle plate, this may be difficult to achieve because of variations in the size of the radius as well as variations in the location of the fracture lines, particularly the volar fracture lines. In addition, variation in size and distribution of fracture fragments may present challenges in fixed-angle implants.

Variable-angle screws allow adaptation of the plate position to volar fracture lines in both a proximal-to-distal plane and a radial-to-ulnar plane. This adaptation in position may be achieved while still minimizing the risk of screw perforation of either the distal radioulnar joint or the radiocarpal joint by directing screws away from the joint. In addition, the screw direction can be adapted to specific fracture fragments. Furthermore, there is an enormous variability in the arc of screw coverage that can be achieved (Fig. 10-1).

**Material Hardness Mismatch**

The most common design in this group uses higher grade 5 titanium screws or pegs, which achieve purchase by tapping into a softer grade 2 titanium within the plate. An example of this type of plate is the VariAx Distal Radius Locking Plate System (Stryker, Kalamazoo, MI). These screws may be inserted or re-inserted at an angle of plus or minus 15 degrees up to three times.

Other material mismatch plates have included titanium plates with zones of polyetheretherketone (PEEK) in the distal portion of the plate through which titanium screws may be inserted.

**Mobile Expansion Bearings**

This design is a variation on the expansion bolt concept frequently used in construction. In this setting, a mobile spherical expandable bearing rests within the plate; when the conical screw head engages the bearing, it expands the bearing such that the bearing achieves an interference fit within its corresponding spherical portion of the plate and thus achieves angular stability. The bearing mechanism may be disengaged and then re-engaged with alteration in the angulation of the screw on several occasions. An example of this style of implant is the Bearing Plate (TriMed, Inc).

**Interference Fit**

The third group of plates uses an interference fit between the screw head and the plate. An example of this type of plate is the Aptus Distal Radius Plate (Medartis, Switzerland).

**INDICATIONS FOR VOlar PLATING**

Volar plating is currently our preferred choice of fixation when a decision has been made to perform internal fixation of distal radius fractures and it is technically feasible to employ this type of implant (see Contraindications, following).

A detailed discussion of the indications for fixation is beyond the scope of this chapter; however, it is important to recognize certain principles. Although discussion of the unstable fracture is common, a radiographic or morphologic definition of what constitutes an unstable fracture requiring fixation has not been possible. In addition, simple numeric indices may give some guidance but need to be adjusted for factors such as physiologic age and functional demands. Shortening that is not acceptable in a 20-year-old patient may often be acceptable in a functionally less demanding, 70-year-old patient. Furthermore, the improved efficacy and potentially decreased complication profile of internal fixation with these implants mean that there is also an expansion of relative indications including ease and speed of rehabilitation. Within these qualifications there are still parameters that require careful consideration before fixation:

- Articular stepoff or gap of 1 to 2 mm
- Dorsal tilt greater than 5 degrees (young patient) to 20 degrees (elderly patient)
- Radial shortening of more than 2 to 5 mm
- Radial translation of distal fragment with visible widening of distal radioulnar joint (DRUJ)
- Worsening position on serial radiographs, particularly after initial closed reduction
- Patient with poor supination in cast at 1- to 2-week clinical follow-up
It is important to appreciate that with extremely careful attention to cast changes, it might be possible to control recurrence of angulation with cast treatment, but shortening is almost certain to recur or worsen by the time of union.

**CONTRAINDICATIONS TO VOLAR PLATING**

Although variable-angle stable implants have broadened the indications for volar plating, there remain certain circumstances in which it is inadvisable to use volar plates. These include:

**Very small radial column fragments.** In addition to indicating a highly comminuted fracture, very small radial column fragments pose a considerable challenge because even with appropriately directed screws, adequate support of the radial column is difficult to achieve.

**Very distal volar fracture line or absent volar fracture line.** If the volar fracture line is too distal, it is difficult and potentially hazardous to position the plate far enough distally to stabilize the fracture. When there is no volar fracture line present at all, there are significant biomechanical concerns in using a volar implant to stabilize a dorsal shear fracture.

**Highly comminuted articular surface.** There remain articular fractures in which the number and distribution of articular fragments are such that even with modern implants, volar plating is inadvisable. Frequently, these types of fractures present a challenge in achieving, as well as maintaining, adequate articular reduction.

**Fracture dislocations.** Clearly these are more in the realm of radiocarpal dislocations. Although fracture dislocations may often have a reasonably significant radial column fragment, the volar fragments are usually just small ligamentous avulsions and there is significant dorsal instability associated with the shearing nature of the injury. Volar plating is not appropriate for these injuries, and excellent reconstructions may be achieved with fragment-specific fixation.

**SURGICAL TECHNIQUE**

The surgical approach is through the bed of the flexor carpi radialis (FCR) tendon. This approach is actually ulnar to the classic Henry's approach, which uses the interval between the superficial branch of the radial nerve and the radial artery. After opening the sheath of the FCR tendon, the tendon should be retracted in an ulnar direction. This reduces the possibility of injury to the palmar cutaneous branch of the median nerve that lies between the FCR tendon and the palmaris longus tendon. The deep portion of the FCR sheath is incised to enter a plane that is defined by the distal aspect of the flexor digitorum sublimis (FDS) muscle and the flexor pollicis longus (FPL) muscle and tendon on the ulnar aspect and by the radial artery on the radial aspect. The plane between the flexor tendons and the pronator quadratus tendon is easily developed.

In our experience, it is almost never necessary to develop the volar plate significantly more far proximally than the radial column. This reduces the possibility of injury to the palmar cutaneous branch of the median nerve and to the palmaris longus tendon. In most surgical cases, significant benefit lies in releasing the brachioradialis distal to the fracture line. The brachioradialis is usually a deforming force, and in all but the most acute fractures that are operated on within the first 72 hours, it tends to resist correction of radial height and inclination. The brachioradialis may be safely released from its bony insertion onto the radius without risk of significant proximal retraction due to its extensive fascial insertions in the region. We have not found it necessary to perform a complex Z-type release of the brachioradialis because we do not specifically reattach the brachioradialis tendon at the end of surgery.

Careful attention should be given to the elevation of the pronator quadratus muscle. The pronator quadratus is usually elevated in an L-shaped fashion with the longitudinal limb elevating the muscular part of the pronator off the radial border of the radius. The transverse incision in the pronator should be through the well-defined tendinous portion, leaving good-quality tendinous tissue on both sides of the incision to facilitate subsequent repair.

Our motivation for repairing the pronator quadratus is solely for the purpose of soft tissue coverage of the distal aspect of the plate. Early in our experience with volar plating when we were using fixed-angle implants, the nature of the fixed-angle implants meant that the plate was never positioned in a particularly distal fashion. As such, the risk of flexor tendon irritation or attrition was very low. In these cases, we did not repair the pronator quadratus and we observed no significant functional limitations. Variable-angle plates can be placed more distally to deal with more complex and more distal fracture patterns, which brings the plate into the zone of the distal radius, where there is close contact between the flexor tendons and the volar ridge of the distal radius. As a consequence, the more distally the plate is positioned, the more important it is to achieve some degree of soft tissue coverage over the plate to afford some protection to the flexor tendons.

Although other authors have suggested suturing the pronator quadratus in a radial fashion to the brachioradialis tendon, we have found that this is not reliable in achieving coverage of the most distal aspect of a distally placed implant. As a consequence, our priority is achieving distal reattachment of the pronator tendon to its original anatomic tendinous insertion (Fig. 10-2A and B). We do not restrict postoperative motion to protect this repair.

It is worth noting that in the small percentage of cases in which we have removed implants after fracture union, the pronator repair has appeared intact with good soft tissue coverage of the plate. With a careful anatomic distal reattachment of the pronator quadratus muscle, we have observed almost no instances of flexor tendon erosion on the distal aspect of the plate.

**FRACTURE REDUCTION**

Fracture reduction is generally undertaken through a combination of strategies including indirect fracture reduction through the classic techniques of traction and manipulation. This may be combined with direct fragment manipulation, which can be achieved to a large extent through the volar incision. In addition, fracture fragments may be manipulated through the fracture lines. This is undertaken most commonly through the volar approach. After elevation of the brachioradialis tendon, there is very frequently a soft area of the fracture line on the radial border immediately deep to the brachioradialis insertion through which access to the fracture line can be achieved, even if volar cortical apposition has not been disrupted. Through this fracture line,
intra-articular fragments often can be elevated using a fine bone punch or other device. This so-called soft spot is also useful for the insertion of bone graft or bone graft substitute without the necessity for resorting to a separate dorsal incision.

We have found that it is uncommon to have to use the more extensive approach described by Orbay and Fernandez\(^\text{13}\) involving release of the radial septum and pronation of the proximal diaphyseal portion of the radius to achieve access to the fracture line, including dorsal fragments. The most problematic dorsal fragments are the dorsoulnar fragments, which may be associated with a coronal plane split in the distal radioulnar joint. These fragments are extremely important because their stabilization is essential for the achievement of an early pain-free restoration of supination and pronation. We have actually found it to be more beneficial to undertake a small strategically placed incision over the dorsoulnar aspect of the radius to facilitate reduction of these fragments after the remainder of the fracture complex has been reduced. Temporary fixation with a Kirschner (K) wire may be used with direct visualization even of quite small fragments.

With variable-angle stable implants, a useful technique is to pass a fine K wire centrally through the ulnar-most hole of the plate within the fracture fragment under direct vision through the small dorsal incision. When the optimal K wire direction has been ascertained, the drill guide can be locked into position on the volar aspect of the plate. The K wire is then withdrawn, and the drill is passed down the drill guide ensuring that the drill will go in the exact location required to stabilize the critical dorsoulnar fragment. In addition, direct inspection over the fragment allows an optimal estimation of screw length with satisfactory engagement and stabilization of the fragment without the risk of excessive dorsal penetration and consequent extensor tendon irritation or damage. A small incision of this nature used primarily for temporary fixation followed by optimal positioning of volar angle stable screws does not seem to be associated with a compromise of flexion range, as is seen when positioning dorsal implants through dorsal incisions.

Although we have utilized the above-mentioned technique described by Orbay and Fernandez\(^\text{13}\) with pronation of the proximal ray or fragment to access and reduce dorsal and intra-articular fragments, we have certainly been satisfied with the safety and efficacy afforded by the use of a small supplementary dorsal incision. Access to the dorsoulnar fragment can usually be achieved through the interval between the fourth and fifth extensor compartments with the majority of the exposure occurring proximal to the main part of the extensor retinaculum.

In most cases, we have been able to achieve satisfactory reduction utilizing these techniques. We have tried to avoid arthrotomy when performing dorsal incisions. Our belief is that dorsal arthrotomy increases the risk of stiffness, particularly with regard to loss of flexion. Improvements in image intensification technology have led to the availability of high-quality intraoperative images. In addition, an understanding of appropriate positioning of the arm for intraoperative imaging has allowed a very satisfactory assessment of articular reduction without the need for arthroscopy in the majority of cases. Certainly, the use of the 15-degree inclined lateral to bring the articular surface of the lunate fossa into relief has been extremely valuable in indirect assessment of reduction.

The major area with a risk of malreduction through indirect assessment relates to malrotation of the radial column and scaphoid facet in the sagittal plane. This is considerably more difficult to assess using image intensification. Although it is rare to see rotational malalignment of a portion of the scaphoid facet, an index of suspicion needs to be maintained. This frequently occurs when a fracture line that involves the radial column passes between the radial origins of the radioscapohamate ligament and the long and short radiolunate ligaments within the region of the ligament of Testut. In this circumstance, care should be given to intraoperative screening to assess the reduction of the radial column in both the posteroanterior (pronated) view as well as the anteroposterior (supinated) view. The reduction may appear satisfactory in one of these views, but a clue to unsatisfactory reduction due to malrotation may be obtained in the alternate view. In addition, we have found that frequently this fracture pattern, which occurs between the above-mentioned ligamentous attachments, is often associated with a volar capsular rent within the same interligamentous plane. This is a rare circumstance in which we may choose to minimally extend this capsular rent with elevation of a small portion of capsule between the two major ligamentous structures, thereby affording a direct intra-articular view through a small arthrotomy. We have not seen any significant adverse sequelae in terms of stability,
extension range, or pathologic ulnar translation of the carpus when we have used this minor arthrotomy, although we have been careful to respect the integrity of the radioscaphocapitate and radiolunate ligaments.

**INTRAOPERATIVE TECHNIQUES WITH VARIABLE-ANGLE PLATES**

These techniques and benefits may be achieved with all three classes of variable-angle stable plates previously described.

**Accommodating Volar Fracture Line Variation**

**Distal Volar Fracture Line**

When the volar fracture line is quite distal, the risk of joint perforation by screws exists if the plate is positioned in the optimal location covering the distal fragment. If the plate is positioned more proximally to ensure an appropriate relation between the distal screws and the distal articular surface, there is a risk that the volar fracture line may not be covered by the plate. This can lead to a biomechanically inferior construct.

With a variable-angle plate, the plate may be positioned more distally to cover the volar fracture line. The more ulnar screws may be directed perpendicular or even angled slightly proximal relative to the plate to ensure that articular perforation does not occur, but at the same time the angulation of the more radial screws may be adjusted so that radial column support is still achieved.

**Volar Ulnar Fracture Line**

When a sagittal plane fracture line exists on the more ulnar aspect of the distal radius, there is a similar risk of perforation of the distal radioulnar joint by fixed-angle screws when the plate is positioned to cover the volar fracture line and fragment (Fig. 10-3). The sequelae of failing to stabilize the volar ulnar corner fragment with the risk of secondary loss of position and possible carpal subluxation is well described.

With the variable-angle implant, the plate may be positioned in a more ulnar location to cover the fracture line. The ulnar screw may then be directed back toward the radial aspect to avoid the risk of distal radioulnar joint perforation (Fig. 10-4).

**Achieving True Radial Column Support**

Identification of fracture fragmentation patterns and fragment-specific fixation has clearly demonstrated the benefit of radial column fragment fixation in terms of establishing fracture stability. One of our desires when making a transition toward treating more distal radius fractures—and in particular more intra-articular distal radius fractures—with volar fixation was that we could achieve stabilization of the radial column fragment similar to that which we had achieved with fragment-specific radial column fixation. The value of the radial column is its tricortical nature; even when the fragment is relatively small, it usually remains strong and carries a significant portion of the scaphoid facet and the origins of the important volar radial ligaments.

The benefit of variable-angle screws is that if sufficient angulation of the screws relative to the longitudinal axis of the plate can be achieved, then one or two screws may be directed from the volar radial aspect of the plate in a dorsal and radial direction such that the screw or screws can be inserted almost to the tip of the radial column. This stabilizes the column from the inside in a form somewhat analogous to the central pole of a marquee tent (Fig. 10-5).
UNIQUE INTRAOPERATIVE TECHNIQUES WITH MOBILE BEARING PLATES

In mobile bearing plates, the distal locking screws may be inserted into the bearing such that the thread engages the bearing without expanding the bearing sufficiently to lock it against the plate. The net effect is that the screw and bearing move as one and are able to move independently of the plate. This introduces a number of unique intraoperative techniques for optimizing and adjusting fracture reduction and implant position.

In Situ Gross Deformity Correction

Partial fracture reduction may have been achieved through indirect reduction techniques, including manipulation and traction. At this point, the plate may be applied to the volar aspect of the radius in the desired position and temporarily fixed to the proximal radial shaft with K wires. At least one screw is then positioned in the optimal location, achieving tangential subchondral support of the dorsal half of the articular surface. The screw may be advanced such that it engages the bearing but does not lock the bearing. A drill can then be passed through an adjacent screw hole with the drill again being positioned in an optimal subchondral location (Fig. 10-6). At this point, additional improvement in reduction can be achieved through a combination of further traction and flexion as well as by using the drill bit as a lever to correct dorsal tilt. During this adjustment of the distal fragment, the screw that has been previously positioned will move with the bearing relative to the plate (Fig. 10-7).

Pressure on the drill bit can then be used to maintain the improved reduction while the adjacent screw is tightened in its new position to lock the bearing. This results in maintenance of the correction. The drill bit may then be removed and substituted by a further locking screw (Fig. 10-8).

Reduction Fine-Tuning

When a more satisfactory reduction has been achieved either through the initial indirect reduction techniques or through the tactic previously described, it may still be possible to further fine-tune correction of sagittal plane deformity with both the plate and distal locking screws remaining in situ. The key to this technique is the fact that the plate has not been definitively fixed with proximal screws but rather is held with temporary K wires. This technique is somewhat analogous to the so-called distal fragment first strategy used with fixed-angle plates.

If residual dorsal tilt is believed to be present after positioning of the distal screws, further adjustment is possible. The distal locking screws may be loosened such that the bearing is no longer engaged with the plate. However, the screw thread remains engaged within the bearing. This usually requires backing out of approximately 50% of the screw thread of the conical locking head. Once this has been achieved, the bearing is now free to rotate relative to the plate. The amount of additional correction required can be assessed, and the proximal end of the plate can be elevated off the shaft of the distal radius. The amount of elevation should roughly parallel the required angular correction (Fig. 10-9). This maneuver can be achieved simply by passing a periosteal elevator under the most proximal aspect of the plate and then rotating it. The amount of rotation can then be used to dial up the required amount of angular correction. Once the desired angulation between the plate and the shaft is achieved, the distal screws may be retightened, thus locking the bearings to the plate and re-creating a rigid implant (Fig. 10-10). When the proximal end of the plate is reduced back onto the radial shaft, correction of the residual tilt is achieved (Fig. 10-11).
Distal Locking Screw Preloading

In certain circumstances—particularly those involving more osteoporotic fractures—the previously mentioned tactic of loosening off the screws, elevating the plate (Fig. 10-12A), and retightening the screws before reducing the plate back to the radius may be used to improve the position of the distal screws or pegs relative to the dorsal subchondral plate (Fig. 10-12B). The desirability of positioning the distal screws tangentially to the dorsal half of the articular surface has been well described. In addition, in more osteoporotic fractures Orbay and Fernandez have described the possibility of settling of the articular surface onto the distal screws when a gap exists between the screw and the subchondral plate dorsally.

By using this tactic, a suboptimal positioning of the distal screws or pegs may be improved without removing the implants. In many of these fractures, there is nothing other than fracture hematoma and very loose trabecular bone proximal to the subchondral plate. As such, it is relatively easy to advance the screws toward the subchondral plate with this technique. We have termed this technique “screw preload.” Some concerns have been raised with regard to the risk of actually penetrating the joint owing to an extremely osteoporotic subchondral plate being perforated by the screws during this tactic. In spite of the use of this tactic in numerous cases, we have not observed this complication, although we remain vigilant to ensure that it does not occur. Our belief is that this may well be a safer way to achieve optimal subchondral placement of the distal screws than trying to drill directly into the subchondral regions. If there is concern that translation of these pegs distally toward the subchondral plate may lead to articular perforation, then we believe that the risk of
The two fragments together (Fig. 10-13B), and the drill guides (Fig. 10-13A). The drill bits can then be used as joysticks to bring drill guides that have been left mobile relative to the plate the center of each of these fragments having been passed through facet in the coronal plane, then drill bits may be positioned in is residual separation between the scaphoid facet and the lunate guide may be locked, and this results in fixation of position of both the drill guide and the drill itself. As an example, if there is residual separation between the scaphoid facet and the lunate facet in the coronal plane, then drill bits may be positioned in the center of each of these fragments having been passed through drill guides that have been left mobile relative to the plate (Fig. 10-13A). The drill bits can then be used as joysticks to bring the two fragments together (Fig. 10-13B), and the drill guides may then be locked, thereby holding the reduction. If the reduction is satisfactory, it may be held with the temporary passage of K wires across the fracture line or by the definitive positioning of screws into the relevant fragments through adjacent screw holes within the plate. Once the fixation is secured, the drill bits and drill guides may be removed and substituted with definitive fixation screws.

This tactic may be used to adjust the position of either one or two fragments and also to adjust the orientation of fragments in both the coronal and sagittal planes.

OVERVIEW OF SURGICAL STRATEGY

The surgical strategy obviously varies, depending on whether the fracture is extra-articular or intra-articular and, if intra-articular, depending on how many fragments are involved. Nevertheless the general order of the approach remains the same. It should also be noted that the general conceptual approach to fixation applies to both variable-angle and fixed-angle implants.

1. Gross Reduction Through Indirect Manipulation

Restoration of overall alignment and length should be optimized wherever possible through indirect manipulation. If a position can be achieved that is close to satisfactory, it may be temporarily pinned before a final adjustment of fracture position is performed using the plate and screws as reduction devices.

2. Articular Surface Reduction

The distal articular surface and the articular surface of the sigmoid notch should next be reduced. As previously noted, this may include a combination of direct and indirect reduction techniques. It is very often the case that the reduction of the articular surface itself may be held with multiple temporary K wires positioned in such a fashion that they do not inhibit subsequent positioning of the volar implant. It is entirely satisfactory during this stage to position these temporary K wires in percutaneous fashion. We have found it particularly useful to position them through the radial styloid in the interval between the first and second extensor compartments as well as through the dorsal aspect in the region of the fourth and fifth extensor compartments. It is important at this stage to optimize the reassembly of the articular surface before attending to the relationship between the articular/metaphyseal region and the diaphysis.

3. Distal Plate Fixation

If there is a reasonable relation between the distal portion of the radius and the shaft at this stage, the plate may be provisionally fixed to the shaft with K wires. If residual malalignment exists between the articular surface and the shaft, then this should be taken into consideration when determining the angulation of the plate in both the coronal and sagittal planes such that when the plate is ultimately reduced onto the shaft it will correct the relation between the articular surface and the shaft. As an example, when there is residual loss of radial angulation, then the plate may be applied with the proximal end directed ulnarward so that when the plate is finally brought back onto the radial shaft after definitive placement of distal locking screws into the distal fragments, the radial angulation will be corrected.

4. Distal Locking Screw Placement

At this point, one or more of the reduction strategies unique to mobile bearings as already described may be used. The locking screws are distributed to achieve maximal subcondral support as well as fixation of specific fragments. Screws may be directed to avoid articular fracture lines. With variable-angle screws, safe positioning of the screws with respect to articular surfaces of both the radiocarpal and distal radioulnar joints may be achieved regardless of the plate position that is optimized for the location of the volar fracture lines.
5. Definitive Plate Fixation

Once the distal screw positioning is completed, then satisfactory control of the distal articular surface will have been achieved. In the case of intra-articular fractures, the net result is that the distal articular surface can then be manipulated as one fragment utilizing the plate as a reduction device for final fine-tuning of the relation between the articular surface and the diaphysis.

**Sagittal Plane Deformity**

Correction of residual dorsal tilt of the articular surface may be undertaken. This may involve loosening the distal screws and lifting the plate to increase the angulation between the distal screws and the plate. This is more appropriate in extra-articular fractures and simple intra-articular fractures. There may be some risk of loss of position if this technique is used on complex articular fractures that have been reduced and held using multiple distal locking screws.

**Coronal Plane Deformity**

If the plate has been applied appropriately to the distal fragment and there is residual loss of radial angulation, then reduction of the plate onto the shaft at this stage can achieve correction of coronal plane deformity.

**Radial Length**

When the proximal aspect of the plate is first fixed to the shaft, the fixation should be performed using a single screw positioned in the distal aspect of the “sliding” hole of the plate. This allows a further adjustment of radial height by loosening this screw slightly and either putting pressure on the proximal end of the plate to translate the plate distally or combining this with traction. When the satisfactory radial length has been restored, the screw may be tightened again.

**Residual Radial Translation of Distal Fragment**

Radial translation of the distal fragment is an underestimated cause of potential distal radioulnar joint instability. We believe that this malpositioning of the distal fragment results in a detensioning of the distal portion of the interosseous membrane and/or the pronator quadratus muscle (Fig. 10-14). As a consequence, even if the sigmoid notch is well positioned in all other respects (length and coronal and sagittal planes), the ulnar head may not be held firmly into the concavity of the sigmoid notch. We have not seen persisting distal radioulnar joint instability when the sigmoid notch is properly positioned, including the correction of any residual radial translation. This has been the case even involving type 3 ulnar styloid fractures that have not been fixed.

At this point in the fixation, residual radial translation of the distal fragment, where present, can easily be corrected. The single screw that is present in the sliding hole is loosened slightly but maintained in place and forms a pivot point for the correction. A claw-type bone holder can then be positioned with one limb over the ulnar border of the radius just proximal to the fracture line and one limb over the radial side of the plate or through one of the holes on the plate. When the clamp is tightened, progressive ulnar translation of the distal fragment occurs using the proximal screw as a pivot point (Fig. 10-15). When satisfactory translation has been achieved, the single screw is tightened, and as long as length has also been restored, the remaining shaft screws can be inserted.

Correction of radial translation of the distal fragment restores distal interosseous membrane and pronator quadratus muscle tension, which subsequently holds the ulnar head firmly into the concavity of the sigmoid notch (Fig. 10-16). We have not had to fix any type 3 ulnar styloid fractures since paying attention to this aspect of the reduction.

**COMPLICATIONS**

Although the soft tissue benefits of volar over dorsal plating have been well described, less attention has been paid to the undoubted potential for soft tissue problems with volar plating, particularly if care is not taken with surgical technique. The biggest risk is inadvertent perforation of the dorsal cortex by the distal locking screws. The length of the locking screws may be difficult to judge using depth gauges because of osteoporosis and dorsal comminution. In addition, fluoroscopy is particularly hazardous owing to the trapezoidal cross-section of the distal radius, which means that
screws may appear to be in bone but are too long. Of particular concern is the third extensor compartment containing the extensor pollicis longus. If even a small amount of cortical perforation is in this region, the risk of tendon damage is substantial. The screw that is most at risk of causing this problem is usually the second screw from the radial side of the plate.

It is worth noting that engagement of the dorsal cortex is necessary only occasionally in more complex intra-articular fractures. Screw length can be optimized by direct visualization through a small incision if there are concerns. In this setting, any concern regarding screw length and fracture stabilization is a strong justification for considering a small open incision to confirm screw positioning and screw length. We have not observed any compromise of flexion range when this additional minimal incision is used.

There is also a small potential for extensor tendon irritation by the shaft screws. This problem is most likely to be seen in the two most distal shaft screws if they are directed toward the second dorsal extensor compartments. Again, the difficulty is that the floor of the second compartment in the distal part of the radius is the periosteum of the radius itself, and there is much less leeway for screw perforation.

On the volar aspect, we have already discussed the importance of using the pronator quadratus to provide soft tissue cover for the plate. As more variable-angle implants are utilized, this will become more important because of the additional potential for distal positioning of the implant. We have seen one case of flexor pollicis longus tendon rupture referred from another institution. Factors involved in this case may have included incomplete seating of the distal screw into the plate, and we are aware from operative notes that the pronator quadratus was not repaired over the plate.

One of the most devastating yet insidious complications of internal fixation of distal radius fractures relates to the so-called volar ulnar corner fragment. The difficulty with this fragment is that even when all other aspects of the fracture are adequately internally fixed, if this fragment is not stabilized, then it may translate in a volar and ulnar fashion in association with volar and ulnar subluxation of the carpus (Fig. 10-17). Unfortunately, even volar plating is not immune to this complication, and care must be taken when dealing with intra-articular fractures that involve the volar cortex to ensure that the plate covers and stabilizes all the relevant fragments across to the ulnar aspect.

The other concerning complication of volar angle stable plating relates to the risk of articular perforation. This exists for both the distal radioulnar joint and the radiocarpal joint. This risk would seem to be greater when trying to apply a fixed-angle plate to more complex fracture patterns in which the screw directions are predetermined. In addition, we have described surgical strategies for advancing the screws toward the subchondral surface after insertion.

**OPTIMAL DESIGN FEATURES FOR VARIABLE-ANGLE VOLAR PLATES**

The following design features are beneficial for optimizing the utility of a variable-angle plate.

1. Small holes in the proximal portion of the plate facilitate temporary fixation of the plate to the shaft with K wires.
2. The distal aspect of the plate should have an anatomic contouring to fit with the distal portion of the radius, and the very distal aspect of the plate should be polished smooth and tapered to minimize the risk of soft tissue irritation when positioned distally.
3. The resistance to deflection of the screw at the locking mechanism should be sufficient to resist loss of angular stability when four screws are used in an unsupported construct, such as a complete radial osteotomy filled with nonstructural bone graft.
4. Regardless of the means by which variable-angular stability is achieved, the arc from the perpendicular to the maximum screw angulation should be a minimum of 15 degrees and preferably 20 degrees in each direction. Furthermore, the plate should be designed so that the most radial screw achieves its maximum angulation relative to the plate in a proximal and radial direction and so that radial column support can be optimized. Conversely, the ulnar screw should achieve maximum angulation in a more directly ulnar rather than distal direction (Fig. 10-18A and B).

**OUTCOMES**

We performed a prospective analysis of a consecutive series of fractures internally fixed using a variable-angle stable volar implant (Volar bearing plate, TriMed, Inc). Patients were recruited between May 2004 and January 2005. All patients treated with the volar variable-angle implant were included in the study. It is
worth noting that this study period was very early in our experience with this implant.

Materials and Methods

A prospective analysis of 27 consecutive distal radius fractures was undertaken. Preoperative fracture pattern was classified according to the AO classification. Range of motion and grip strength were recorded at 1 month after surgery and at final follow-up. Subjective analysis was undertaken at final follow-up using the patient-rated wrist evaluation (PRWE). Intraoperative radiographs and radiographs at final follow-up were also assessed for standard radiographic parameters.

Demographics

There were 10 women and 17 men with a mean age of 42 years with 5 unstable extra-articular fractures (A3), 2 simple articular fractures (C1), 12 articular fractures with metaphyseal comminution (C2), and 8 fractures with articular and metaphyseal comminution (C3).

Postoperative Management

Patients left the operating theater with a bulky wool and crepe bandage, that supported the wrist; a plaster cast or slab was not used. Patients were referred immediately for hand therapy, which was commenced an average of 1.5 days postoperatively. At the first hand therapy visit, the bulky dressing was removed and replaced with a compliant compressive sleeve and removable thermoplastic splint. Patients were educated on early forearm rotation and digital flexion. They were permitted to remove the splint for performance of nonloaded activities of daily living after the first therapy visit, including eating, personal care, and computer use. Early wrist motion was therefore achieved actively in the course of activities of daily living with therapy focused primarily on forearm rotation and digital flexion.

Results

All 27 patients were followed up with a minimum follow-up of 9 months and an average follow-up of 14 months. Active range of motion at final review is presented in Table 10-1.

The average score on the patient-rated wrist evaluation was 13, with a range of 1 to 23. 0 is considered normal, and 100 is the worst possible score. It is worth noting that in our previously published series utilizing fragment-specific fixation in a similar cohort of patients, the average score was 21, with a range of 1 to 68. This cohort of patients treated with fragment-specific fixation scored very well when their outcome data including range of motion and grip strength were compared with previously published data on internal fixation of distal radial fracture. We assessed the flexion/extension arc as a percentage of the uninjured side in this cohort of patients. The outcome was 83% of the normal side. This was superior to our fragment-specific cohort, who achieved 76% of the normal side.

With regard to radiographic analysis, there was no loss of reduction from intraoperative films to final radiographs. In terms of key variables, average restoration of palmar tilt was plus 5 degrees, average restoration of radial angulation was plus 21 degrees, and average ulnar variance was negative 1 mm. We also assessed grip strength as a percentage of the normal side and achieved an average 86% return of grip strength, which was comparable to the outcome from our fragment-specific study with 84%.

Complications

No infections were seen. There was one tender/hypertrophic scar that responded to massage and Silastic gel pads over a 6-month period. There were no instances of median nerve compression.
FIGURE 10-19 Case 1: Eighteen-year-old male with distal volar fracture line.

FIGURE 10-20 Case 1: Distal plate placement with subchondral ulnar side screws and radial column support.

FIGURE 10-21 Case 2: High-speed motorbike accident (MBA): C3 fracture distal radius on left.

24-year-old male
High-speed MBA
Bilateral fractures
FIGURE 10-22 Case 2: Distal radius and distal ulnar fractures on right.

FIGURE 10-23 Case 2: Postoperative radiographs.

FIGURE 10-24 Case 2: Clinical result at 8 weeks postinjury.
CASE EXAMPLES

CASE 1

An 18-year-old male sustained a very distal, essentially extra-articular fracture of the radius in a high-energy fall while snowboarding (Fig. 10-19). In spite of the fairly distal location of the volar fracture line, particularly on the ulnar aspect, it was felt that there was sufficient distal volar cortical basis for securing a volar plate. With the variable-angle implant, the plate was able to be positioned in the optimal location with regard to the volar fracture line and the screws directed to achieve optimal subchondral placement on the ulnar side while still being able to direct the radial screw to achieve radial column support (Fig. 10-20).

The left radius was fixed with a double-row variable-angle implant with screws being directed specifically into the respective implants and avoidance of positioning of screws in the region of the fracture lines. The ulnar styloid fracture was not internally fixed. On the right side, a relatively simple volar plate construct was applied, and the ulnar neck fracture was fixed with a 2-mm titanium locking plate (Fig. 10-23). Immediate mobilization was commenced, and satisfactory movement and function with return to work at 8 weeks were achieved (Fig. 10-24).

CASE 2

A 24-year-old man sustained bilateral distal radial fractures in a high-speed motorbike accident. The left wrist was an AO type C3 fracture with significant metaphyseal extension and at least four articular fragments associated with a type 2/3 ulnar styloid fracture (Fig. 10-21). The right wrist was a more straightforward extra-articular fracture of the radius. However, it was associated with a fracture through the neck of the distal ulna (Fig. 10-22).

The general benefits of variable-angle stable plates include:

- Flexible deployment with respect to variations in radial size
- Accommodation of proximal/distal variation in volar fracture lines
- Accommodation of medial and lateral variation in fracture lines
- Adaptation of screw direction to specific fracture fragments

The specific benefits of a mobile bearing plate include:

- In situ gross adjustment of reduction
- In situ fine-tuning of reduction
- In situ adjustment of articular fragment reduction
- Screw preloading

REFERENCES


SUMMARY

The usage of volar angle stable implants has certainly extended the indications for fixation of distal radius fractures. The addition of the variable-angle option has further extended the utility of the volar plating approach.

In a recent audit of our practices in terms of distal radius fracture fixation over the course of a year, we were able to subdivide all the wrist fixation cases into four main groups. The largest group involved a single volar approach and application of a single volar angle stable plate. This accounted for 85% of all distal radius internal fixation cases.

The second group involved a volar approach and a volar angle stable plate; however, this was combined with a small directed dorsal incision, which was utilized for reduction of dorsal fragments and confirmation of adequate positioning of angle stable screws. This accounted for 5% of the cases.

The third group involved the volar approach with a volar angle stable plate combined with a small dorsal approach and utilization of some supplementary fragment-specific or mini-plate fixation for control of dorsal fragments that could not be adequately controlled using the volar screws. This accounted for another 5% of cases.

The fourth group represented the most complex fracture pattern. In this group, internal fixation was performed using two or three dorsal, radial, or volar incisions with implantation of multiple fragment-specific implants. This was also 5%.