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Distal Radius Fractures: What Cannot Be Fixed With a Volar Plate?—The Role of Fragment-Specific Fixation in Modern Fracture Treatment

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The advent of volar fixed-angle plate osteosynthesis has greatly improved the technical ability of the surgeon to treat distal radius fractures and expanded the indications for operative treatment. Nevertheless, the volar plate is not a panacea for all distal radius fractures. Increasingly, it has been recognized that the loss of fixation, secondary displacement, and lack of stability can occur after volar fixed-angle plate osteosynthesis. This article addresses the treatment of distal radius fractures with complex disruption of the articular surface and the unique ability of fragment-specific fixation to achieve stable fixation of these injuries.

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Fractures of the distal radius have occupied a storied history in the field of orthopedic surgery. Sir Abraham Colles[1] (1773-1843) noted that although closed reduction of his eponymous fracture could be performed easily, "the distortion of the limb instantly returns" and "by such mistakes, the patient is doomed to endure for many months considerable lameness and stiffness of the limb, accompanied by severe pains on attempting to bend the hand and fingers." Since the time of Colles almost 200 years ago, the treatment of distal radius fractures has evolved on the shoulders of giants. Lorenz Böhler[2] introduced the concept of closed reduction by manual application of longitudinal traction on the limb and countertraction on the arm in 1929. As early as 1932, Ghormley and Mroz observed that "any injury to the articular surface of the radius is bound to set up active traumatic arthritis in the radiocarpal joint. Subsequently, Frykman[3] observed in 1967 the development of posttraumatic arthritis not only in the radiocarpal joint but also the distal radioulnar joint. Linking anatomy to outcomes, Gartland and Werley[4] proposed in 1951 that good clinical outcomes are correlated with the restoration of anatomy, a hypothesis confirmed to be true in subsequent outcome studies. Knirk and Jupiter[5] documented in 1986 that intra-articular distal radius fractures that heal with an articular depression of greater than 2 mm resulted in radiographic evidence of posttraumatic arthritis in more than 90% of patients. Trumble et al[6] found in 1994 that an articular step-off of greater than 1 mm in the healed distal radius fracture was correlated with marked pain and stiffness. Based on the large body of clinical and experimental evidence, operative indications and techniques have expanded with the goal of achieving an anatomic reduction of distal radius fractures.

Volar Fixed-Angle Plate Osteosynthesis

The advent of volar fixed-angle plate osteosynthesis has greatly improved the technical ability of the surgeon to treat distal radius fractures and expanded the indications for operative treatment. Before fixed-angle technology, conventional plate osteosynthesis exhibited limited utility in osteoporotic bone because of the inability of nonlocked screws to gain purchase within porous bone, leading to low pull-out strength and toggling between the plate and screws. The fixed-angle construct formed when screw heads lock firmly into the plate at varying angles eliminates the toggling phenomenon and the need for each screw to acquire bony purchase. The biomechanical strength of the construct increases with differential angles of multiple fixed-angle screws. The

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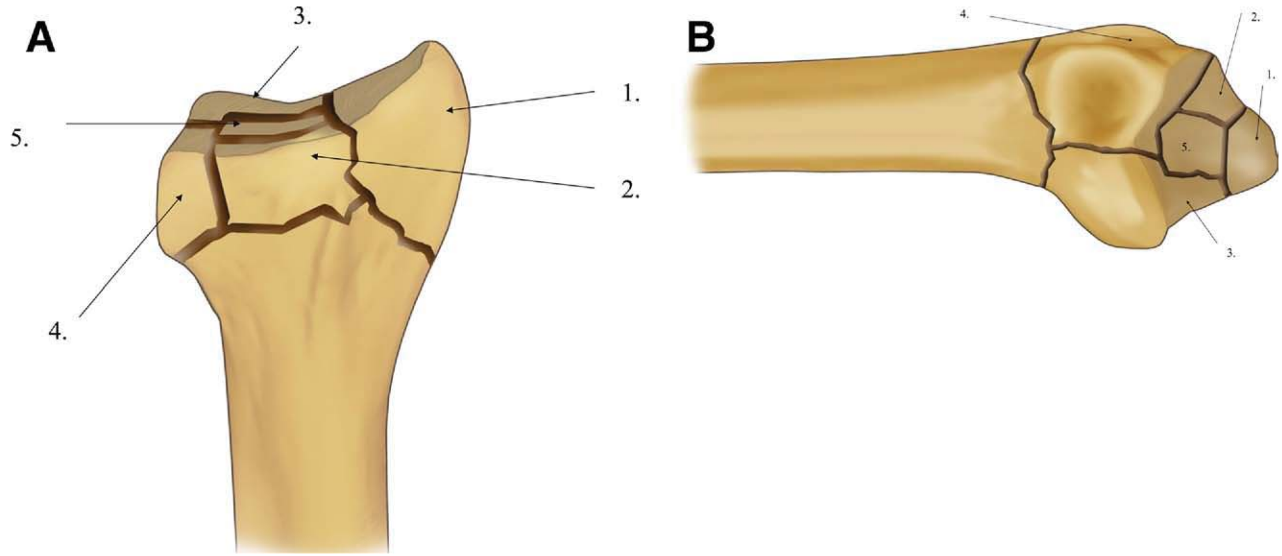

Figure 1 (A) Posteroanterior and (B) medial view of the "critical" fragments: (1) radial column, (2) dorsal wall, (3) volar rim, (4) ulnar corner, and (5) impacted articular. (Copyright TriMed, Inc. Used with permission.)

additional utility of fixed-angle devices arises from their precontoured shape, which enables the use of the plate as an in situ template for reduction of the fracture in the acute setting or for the restoration of volar tilt during an osteotomy for malunion. Furthermore, the greater cross-sectional thickness of soft tissue between the volar cortex of the distal radius and the adjacent flexor tendons compared with the dorsal cortex and the overlying extensor tendons minimizes the incidence of soft-tissue complications, including tendinopathy and tendon rupture. Accordingly, volar fixed-angle plate osteosynthesis has quickly become one of the most useful tools in the surgical armamentarium for the treatment of distal radius fractures. Nevertheless, the volar plate is not a panacea for all distal radius fractures.

Increasingly, it has been recognized that extensor and flexor tendon injury, loss of fixation, and secondary displacement can occur after volar fixed-angle plate osteosynthesis.[7] These complications show the inability of the volar fixed-angle plate to address certain fracture patterns and clinical scenarios. The shortcomings of volar fixed-angle plate osteosynthesis can be categorized into the following situations in which the isolated use of a volar plate may fail: (1) complex multifragmentary disruption of the articular surface caused by shear or compressive forces; (2) fracture-dislocations (shear fractures) of the wrist; (3) carpal, radiocarpal, or radioulnar instability; and (4) complex fractures with substantial metaphyseal-diaphyseal extension. The key to avoidance of such pitfalls is recognition of the therapeutic challenges associated with each scenario.

Fragment-Specific Fixation

This article focuses on the treatment of distal radius fractures with complex disruption of the articular surface and the unique ability of fragment-specific fixation to achieve stable fixation of these injuries. Complex articular surface fractures of the distal radius typically involve 5 critical fracture fragments[8] (Fig. 1): (1) the radial column (styloid), (2) the dorsal wall, (3) the volar rim, (4) the dorsal and volar ulnar corner fragments (sigmoid notch), and (5) the impacted articular surface.

It is essential to acquire a thorough understanding of the anatomy of a complex articular surface fracture to enable the creation of a surgical treatment plan. Beyond standard radiographs of the wrist, it is often helpful to obtain computed tomographic coronal; sagittal; and, as needed, 3-dimensional reconstruction views to enable adequate visualization of complex articular fracture fragments. Harness et al[9] showed that a computed tomography scan with 3-dimensional reconstruction views results in (1) an increase in the number of fracture fragments visualized, (2) improved intraobserver and interobserver reliability in fracture classification, (3) increased sensitivity and accuracy in identifying specific fracture characteristics such as articular depression, (4) a significantly greater number of decisions for an open approach with combined dorsal and volar exposure, and (5) increased operative indications.[9] With adequate imaging of the complex articular surface fracture in hand, a customized plan can be made to address each fracture fragment.

The concept of fragment-specific fixation of distal radius fractures was advanced by Medoff and Kopylov[10] to enable osteosynthesis of individual fracture fragments with a hybrid technique of wire and plate fixation. In its original inception, implants consisted of pin plates that combine the rigidity of plate osteosynthesis with the versatility of Kirschner wire fixation. These pin plates allow for the stable fixation of the radial column, the dorsal ulnar fragment, and the ulnar styloid. Additional wireform implants consist of pin and precontoured wire constructs that enable the buttressing of small articular rim fragments. The wireform implants are fixated to the metaphysis proximally, creating a hybrid wire-plate construct with fixed-angle 3-point fixation (Fig. 2). Subsequent iterations of fragment-specific fixation systems

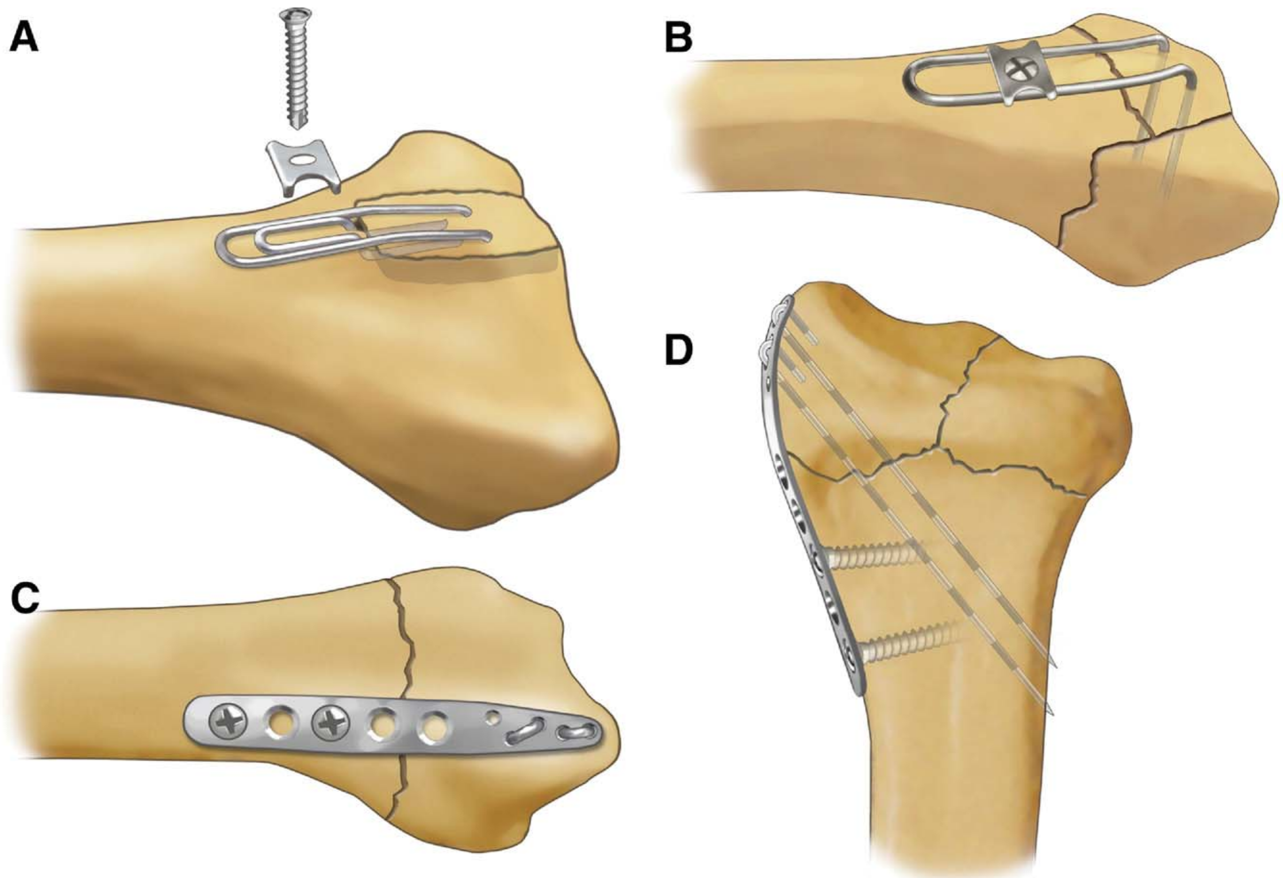

Figure 2 Pin plates and wire form constructs: (A) wireform implants consist of pin and precontoured wire constructs that are fixated to the metaphysis proximally, creating a hybrid wire-plate construct with fixed angle three-point fixation. (B) The wire form dorsal buttress pin enables the buttressing of small articular rim fragments. (C and D) Radial pin plate combining the rigidity of plate osteosynthesis with the versatility of Kirschner wire fixation, allowing for the stable fixation of the radial column. (Copyright TriMed, Inc. Used with permission.)

by different manufacturers include precontoured plates incorporating the option of fixed-angle screws designed for positioning on the volar, dorsal, radial, or juxta-articular surfaces of the distal radius.

From a mechanical perspective, the rigidity of fixation is increased by applying more than 1 implant in different planes, addressing each "column" of the radius.[11] Biomechanical studies confirm that the placement of two 2.0-mm implants with a 50° to 90° offset angle to each other in the axial plane provides stronger mechanical fixation than either a single 3.5-mm plate or Kirschner wire–augmented external fixation.[12] The versatility and clinical utility of fragment-specific fixation arises from its ability to rigidly and anatomically fixate fractures that cannot be adequately addressed with a single implant or external fixation.

We examine 6 typical fracture patterns that present unique challenges when fixation is attempted with a fixed-angle volar plate: (1) unstable radial styloid; (2) dorsal ulnar corner; (3) volar ulnar corner; (4) central articular impaction; (5) complex articular shear fracture; and (6) instability of the distal radioulnar, radiocarpal, or carpal joints.

Unstable Radial Styloid Fragment

The radial styloid, or radial column fragment, is typically reduced first in the process of fragment-specific fixation because it serves as a keystone onto which the reduction of additional fracture fragments can be accomplished. The adequacy of the reduction of the radial styloid fragment can be judged by the alignment of the radial cortex along the metaphysis of the distal radius and visual or fluoroscopic inspection of the radiocarpal articular surface. Tenotomy or Z-lengthening of the brachioradialis tendon can be performed to alleviate the deforming force on the radial styloid fragment to facilitate reduction. Provisional fixation of the reduced radial styloid fragment is usually achieved with Kirschner wires. Typically, the surgeon then proceeds with reduction and fixation of the articular fragments and intermediate column fixation before returning for the final fixation of the radial column. Small styloid fragments or those with a coronal split may be inadequately secured with a single peg of a fixed-angle volar device; consequently, the surgeon

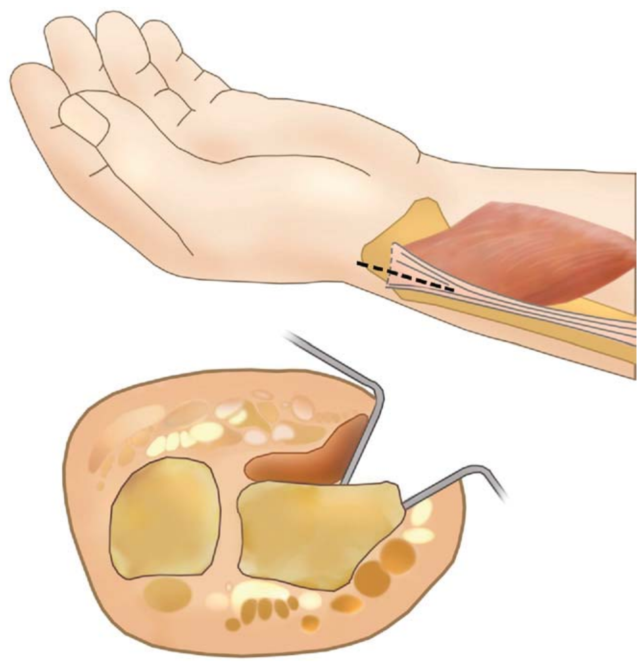

Figure 3 Volar radial approach: the volar radial approach uses the interval between the radial artery and the first dorsal compartment extensor tendons.

should be facile with techniques of radial columnar fixation to augment volar plating in these situations.

Definitive fixation of the radial styloid fragment is performed with a radial pin plate or a precontoured radial column plate designed to buttress the styloid with the options of Kirschner wire or fixed-angle screw fixation. These implants are typically positioned on the radial aspect of the distal radius between the first or second dorsal extensor compartment tendons, with 50° to 90° degrees of offset in the axial plane to implants positioned dorsally or volarly. Commonly used surgical approaches to this location include the volar radial interval between the radial artery (Fig. 3) and the first dorsal compartment tendons and the dorsoradial approach between the first and second dorsal extensor compartments (Fig. 4). If the volar flexor carpi radialis approach is used for volar implant positioning, the dorsoradial approach can be performed concomitantly without the risk of vascular compromise to the intervening skin bridge because the radial artery lies within the interval.

Dorsal and Volar Ulnar Corner Fragments

Dorsal and volar ulnar corner fracture fragments constitute the bony rim of the sigmoid notch and serve as the origin of the dorsal and volar radioulnar ligaments. Accurate reduction and stable fixation of the volar ulnar fracture fragments are critically important to maintaining the stability of the radiocarpal joint in the sagittal plane. Incongruous reduction of the dorsal or volar ulnar corner fragments can lead to posttraumatic arthritis of the distal radioulnar joint and laxity of the dorsal and volar radioulnar ligaments, with resulting fixed subluxation or instability of the distal radioulnar joint. Because of deforming forces applied to these fracture fragments by the dorsal and volar radioulnar and extrinsic carpal ligaments, these fragments cannot be easily reduced indirectly by ligamentotaxis.[13] Percutaneous fixation of small volar ulnar fragments is not possible without jeopardizing nearby critical anatomic structures. Because there is usually minimal subchondral bone for traditional implant fixation, dorsal and volar ulnar corner fracture fragments can be stably fix-

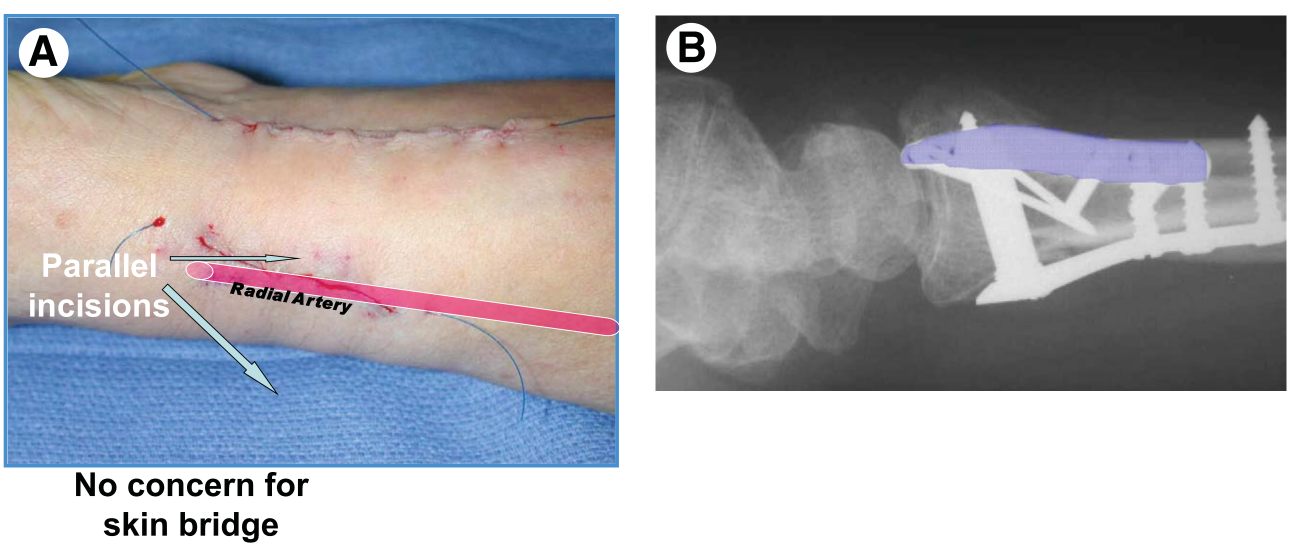

Figure 4 Dorsoradial approach: (A) the dorsoradial approach between the first and second dorsal extensor compartments can be performed concomitantly with the volar flexor carpi radialis approach without risk of vascular compromise to the intervening skin bridge because the radial artery lies within the interval. (B) A combination of radial columnar fixation of the styloid and a locked volar plate fixation of the metaphyseal fragment. (Copyright, Scott W. Wolfe, MD.)

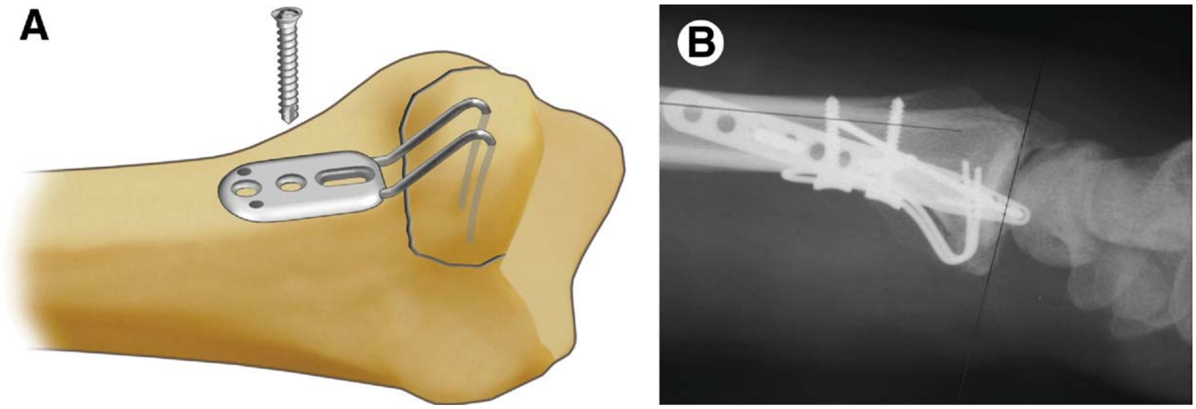

Figure 5 Volar ulnar corner construct: (A) a wire form buttress pin construct stably fixates the volar ulnar corner fracture fragment. (Copyright TriMed, Inc. Used with permission.) (B) A lateral radiograph of the wrist showing stable wire form buttress pin fixation of the volar ulnar corner fracture fragment, and radial pin-plate fixation of the radial styloid fragment. (Copyright, Scott W. Wolfe, MD.)

ated with a combination of wire and tension band[14] or, alternatively, a low-profile fixed-angle device. A custom wireform buttress pin construct readily addresses the volar ulnar corner with a minimum of soft tissue disruption (Fig. 5). The inappropriate use of a volar fixed-angle plate in this circumstance has been complicated by subluxation of the fragment, volar translation of the entire carpus, and articular uncongruency.[7] An attempt to advance a fixed-angle plate more distally to engage small volar rim fragments can lead to attritional damage or rupture of flexor tendons by the prominent implant.[15]

Volar ulnar corner fragments can be exposed by the standard volar approach through the flexor carpi radialis tendon sheath; however, the retraction of the median nerve and flexor tendons necessary to reduce and fix small medial fragments may place the nerve in jeopardy. The authors prefer to use the proximal portion of the "extended carpal tunnel approach" that uses the plane between the flexor carpi ulnaris and the ulnar neurovascular bundle ulnarly and the flexor tendons and median nerve radially. With elevation of the pronator quadratus radial wards, the volar ulnar fragment is readily exposed and fixated.

Unstable and displaced dorsal ulnar corner fragments are ideally suited to dorsal pin-plate fixation (Fig. 6). This technique can be performed as an adjunct to fixed-angle volar plating when insufficient reduction or fixation of this fragment is achieved by volar pegs or screws or as part of a fragment-specific approach if the radioulnar joint is deemed unstable or incongruous. The dorsal surgical approach to the distal radius between the third and fourth dorsal extensor compartments can be used to expose a dorsal ulnar corner fragment. Alternatively, isolated dorsal ulnar fragments can be exposed by a limited approach through the fifth dorsal compartment. It is cautioned that this approach cannot be readily extended to gain access to larger metaphyseal and impacted articular fragments. The dorsal pin-plate is sufficiently low profile in that it produces no appreciable irritation of the overlying tendons.

Central Articular Impaction Fragments

Central articular impaction or "die punch" fracture fragments require elevation to eliminate articular depression or step-off and buttress fixation to prevent settling until osseous consol-

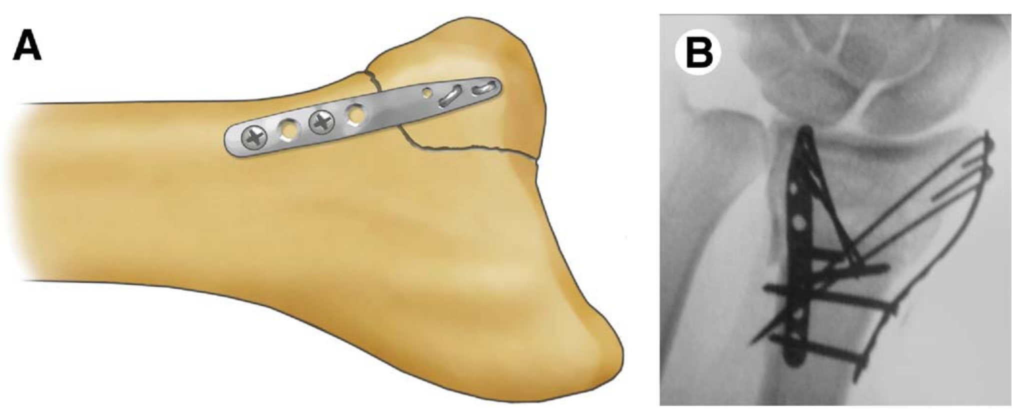

Figure 6 Dorsal ulnar corner construct: (A) the dorsal ulnar corner fragment is ideally suited to dorsal pin-plate fixation. (Copyright TriMed, Inc. Used with permission.) (B) A posteroanterior radiograph of the wrist showing stable dorsal pin-plate fixation of the dorsal ulnar corner and radial pin-plate fixation of the radial styloid fragment.

idation of the injury occurs. Complex articular fractures often have 4 or more articular fragments. An approach has been described to reduce dorsally comminuted and impacted articular fragments through an extended volar approach whereby the proximal radius is exposed subperiosteally and everted to gain dorsal exposure.[16] Not all surgeons are comfortable with the extent of radial diaphyseal and metaphyseal periosteal stripping that is required of such an approach; consequently, a limited and direct dorsal approach to the fractured fragments may be more expedient.

The judicious use of fluoroscopy can document the adequacy of the reduction of impacted articular fragments and avoid a dorsal capsulotomy and/or iatrogenic compromise of the dorsal extrinsic ligaments. Juxta-articular dorsal wall fracture fragments can be fixated with wire form buttress pin-plate constructs that simultaneously support the reduced impacted articular fragments and apply rigid 3-point fixation at the metaphyseal level (Fig. 7). Alternatively, 2.0-mm fixed-angle dorsal plates can also be used for subchondral buttressing of these articular fragments. An autogenous osseous graft, allogenic graft, or synthetic bone void filler can be used to augment the reduction of impacted articular fragments as needed. The use of a fixed-angle device in this context reduces the need for structural osseous graft because the likelihood of secondary displacement of articular fragments is lessened by the rigidity of the fixed-angle construct.

Articular Shear Fractures

Complex articular shear fractures combine elements of unstable radial styloid, dorsal and volar ulnar corner, and articular impaction fractures in the setting of minimal thickness of underlying subchondral bone or a high degree of subchondral comminution (Fig. 8). The successful treatment of complex articular shear fractures requires recognition of the severity of injury, adequate imaging to enable a thorough grasp of the 3-dimensional anatomy of the fracture fragments, and appropriate application of fixation strategies to address the multiple elements of the fracture. The defining characteristic of these fractures is the minimal thickness of the articular fragment, which is essentially a shell of articular cartilage and subchondral bone. This makes adequacy of fixation with an isolated volar fixed-angle device tentative at best. The versatility of fragment-specific fixation enables the reduction and rigid fixation of thin subchondral fracture components to the intact metaphysis. In complex injuries with multiple thin articular fragments, the radial styloid fragment is often addressed first to create a foundation onto which the remaining fracture fragments are assembled. Key fragments to be addressed include the volar rim fragment, dorsal and volar elements of the lunate facet and the sigmoid notch, and impacted articular fragments. The final construct draws enhanced biomechanical strength from rigidly fixated fracture fragments with implants positioned in 50° to 90° of angular offset between the dorsoradial styloid implant and the dorsal and volar implants.

Instability of the Distal Radioulnar, Radiocarpal, or Carpal Joints

The severity of complex distal radius fractures can be augmented by concomitant instability of the distal radioulnar, radiocarpal, or carpal joints. The assessment of distal radioulnar, radiocarpal, and carpal joint stability must be per-

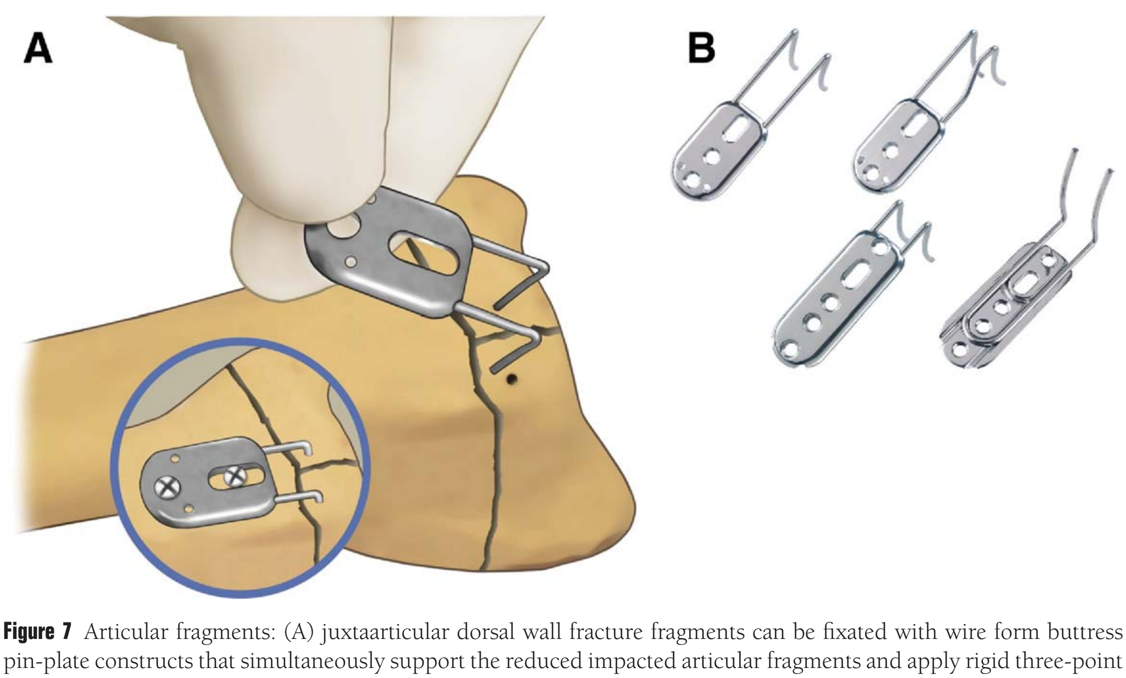

Figure 7 Articular fragments: (A) juxtaarticular dorsal wall fracture fragments can be fixated with wire form buttress pin-plate constructs that simultaneously support the reduced impacted articular fragments and apply rigid three-point fixation at the metaphyseal level. (B) A variety of "wireform" implants can be adapted to different fracture patterns and sizes for both volar and dorsal application. (Copyright TriMed, Inc. Used with permission.)

formed systematically after the fixation of every distal radius fracture to avoid the sequelae of late clinical presentation because of missed diagnosis. Once the osseous fracture fragments have been stabilized, any remnant instability suggests injury to the ligamentous structures that confer stability to these joints, which lack a high degree of inherent bony constraint. Treatment should be rendered appropriately to address injury to the distal radioulnar ligaments, the extrinsic radiocarpal ligaments, or the interosseous carpal ligaments.

Options for restoring distal radioulnar stability include immobilization with the forearm in supination, cross-fixation of the radius to the ulna, repair of ulnar styloid base fractures (Fig. 9), and repair versus reconstruction of distal radioulnar ligament injuries at the ulnar fovea. Radiocarpal and interosseous ligamentous injury can be repaired primarily with the assistance of suture anchors or soft-tissue augmentation or treatment staged for definitive reconstruction after fracture healing.

Conclusions

Volar fixed-angle plate osteosynthesis constitutes one of the most versatile and useful tools in the surgical armamentarium for the treatment of distal radius fractures. Nevertheless, distal radius fractures with complex disruption of the articular surface can require additional techniques and implants to achieve stable internal fixation. The versatility and clinical utility of fragment-specific fixation arises from its ability to rigidly and anatomically fixate fractures that cannot be adequately addressed with a single implant or external fixation.

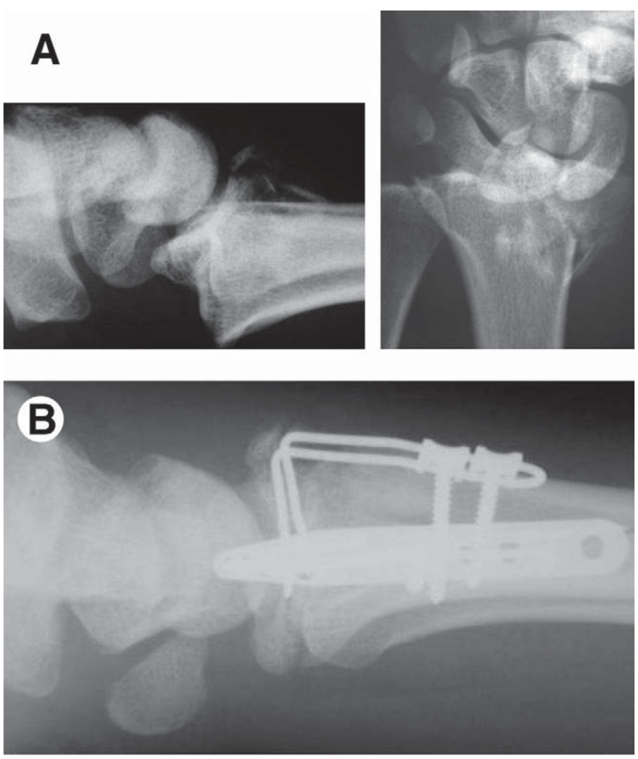

Figure 8 Articular shear fracture: (A) posteroanterior and lateral radiographs of an articular shear fracture of the distal radius. (B) A lateral radiograph of the wrist showing stable wire form dorsal buttress pin-plate fixation of juxta-articular dorsal wall fracture fragments and support for reduced impacted articular fragments. (Copyright, Scott W. Wolfe, MD.)

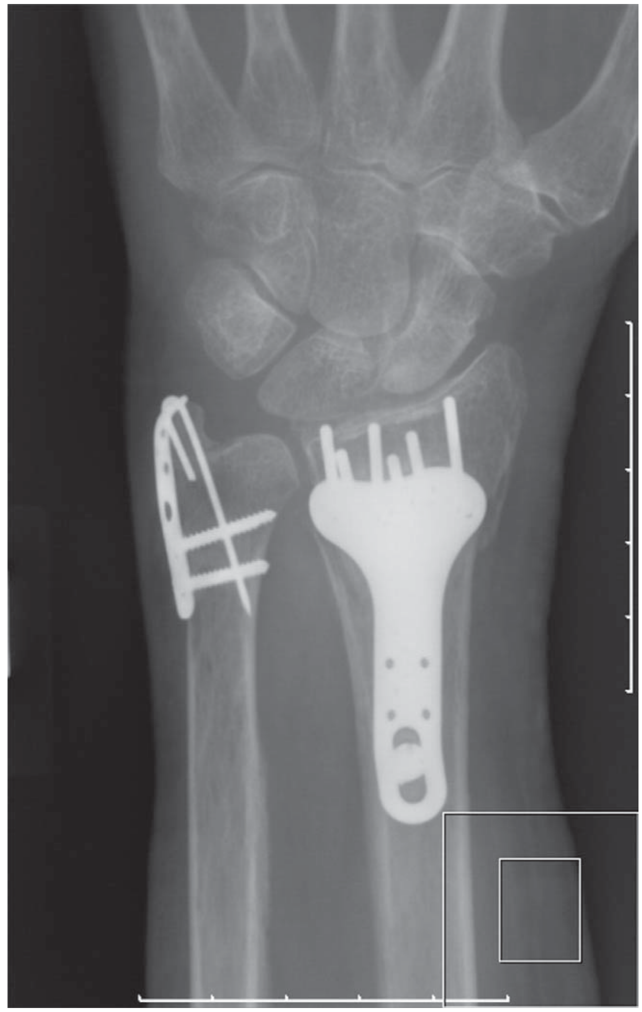

Figure 9 Ulnar Styloid Base Fracture: Posteroanterior radiographs of an ulnar styloid base fracture stably fixated with an ulnar pin plate construct, and a distal radius fracture stably fixated with a volar fixed-angle plate. (Copyright, Scott W. Wolfe, MD.)

References

1. Colles A: On the fracture of the carpal extremity of the radius: Edinb Med Surg J 10:181-186, 1814
2. Böhler L: Treatment of Fractures. Vienna, Wilhelm Maudrich, 1929
3. Frykman G: Fracture of the distal radius including sequelae: Shoulder-hand-finger syndrome, disturbance in the distal radioulnar joint and impairment of nerve function. Acta Orthop Scand Suppl 108:1-153, 1967
4. Gartland JJ, Werley CW: Evaluation of healed colles' fractures. J Bone Joint Surg Am 33:895-907, 1951
5. Knirk J, Jupiter JB: Late results of intra-articular distal radius fractures in young adults. Orthop Trans 9:456-457, 1985
6. Trumble TE, Schmitt SR, Vedder NB: Factors affecting functional outcome of displaced intra-articular distal radius fractures. J Hand Surg Am 19:325-340, 1994

7. Harness NG, Jupiter JB, Orbay JL, et al: Loss of fixation of the volar lunate facet fragment in fractures of the distal part of the radius. J Bone Joint Surg Am 86A:1900-1908, 2004
8. Leslie BM, Medoff RJ: Fracture specific fixation of distal radius fractures. Tech Orthop 15:336-352, 2000
9. Harness NG, Ring D, Zurakowski D, et al: The influence of three-dimensional computed tomography reconstructions on the characterization and treatment of distal radial fractures. J Bone Joint Surg Am 88:1315-1323, 2006
10. Medoff RJ, Kopylov P: Immediate internal fixation and motion of comminuted distal radius fractures using a new fragment-specific system. Orthop Trans 22:165, 1998
11. Peine R, Rikli DA, Hoffmann R, et al: Comparison of three different plating techniques for the dorsum of the distal radius: A biomechanical study. J Hand Surg Am 25:29-33, 2000
12. Dodds SD, Cornelissen S, Jossan S, et al: A biomechanical comparison of fragment-specific fixation and augmented external fixation for intra-articular distal radius fractures. J Hand Surg Am 27: 953-964, 2002
13. Bartosh RA, Saldana MJ: Intraarticular fractures of the distal radius: A cadaveric study to determine if ligamentotaxis restores radiopalmar tilt. J Hand Surg Am 15:18-21, 1990
14. Chin KR, Jupiter JB: Wireloop fixation of volar displaced osteochondral fractures of the distal radius. J Hand Surg Am 24:523-533, 1999
15. Cross AW, Schmidt CC: Flexor tendon injuries following locked volar plating of distal radius fractures. J Hand Surg Am 33:164-167, 2008
16. Orbay JL, Badia A, Indriago IR, et al: The extended flexor carpi radialis approach: A new perspective for the distal radius fracture. Tech Hand Up Extrem Surg 5:204-211, 2001