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Malunions of the Distal Radius

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Fractures of the distal radius are common injuries, comprising approximately 8% to 17% of fractures seen in the emergency department.[1–3] These injuries largely occur in 2 distinct populations: a smaller subset composed of high-energy fractures, which are often seen in young adults, and a larger group of low-energy fragility fractures, which are more frequently noted in older adults. The overall incidence of the injury is expected to increase over the next 20 years, paralleling the aging of the US population as a whole.[4–6,7]

Treatment paradigms for distal radius fractures have evolved significantly as the biomechanics of the wrist have been elucidated. Although initial descriptions classified distal radius fractures as a largely homogenous group of injuries that healed well with minimal treatment, it is now recognized that these injuries display significant variation in fracture pattern and stability, with certain fracture deformities leading to poor prognosis if left uncorrected.[4,8] Considerable effort has been expended in investigating and determining appropriate treatments for different fracture types, taking into account patient-specific factors including functional demands and overall health. In spite of significant advances in developing treatment strategies, complication rates from improper or failed treatment regimens remain high, ranging from 23% to 31%.[9,10]

Malunion is the most common complication following distal radius fractures. This occurs in approximately 23% of nonsurgically treated injuries and approximately 11% of operatively treated fractures.[2,11,12] Malunions may be extra-articular (involving the metaphyseal region) or intra-articular (manifesting with residual joint incongruity) and can present along a spectrum of severity, ranging from asymptomatic radiographic abnormalities to disabling deformities associated with significant pain and functional impairment. The incidence of clinically apparent malunions will likely increase in the future, reflecting both the overall increase in distal radius fractures and the increased functional demands of a longer-living adult population.[13–15]

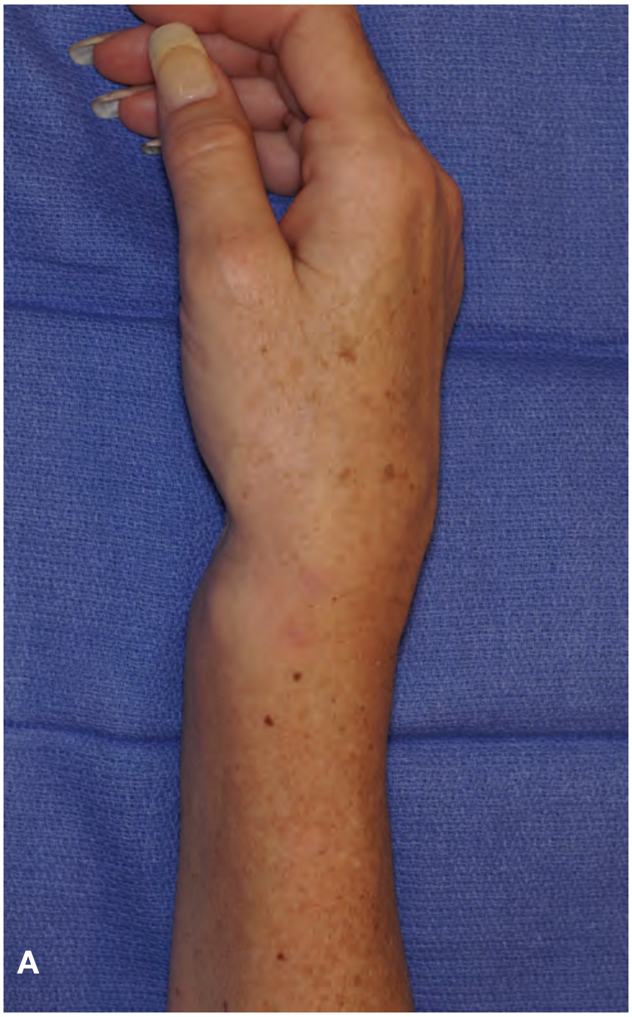
Historically, treatment for clinically significant malunion has been operative, consisting primarily of corrective osteotomies with adjunct bone grafting and fixation. Recent research to define optimal treatment protocols for malunions has focused on: (1) determining the appropriate indications for intervention; (2) developing appropriate surgical techniques incorporating new insights into the biomechanics of wrist function; and (3) developing new technologies to improve the accuracy and efficacy of operative intervention. In this chapter we will attempt to provide a summary of the current literature regarding distal radius malunions while detailing some of the work that has gone into addressing the questions listed above.

Anatomy

The normal functional anatomy of the distal radius is well-described. The articular surface is divided by a longitudinal, sagittal ridge into 2 facets for the scaphoid and lunate respectively. A third key articulation, the distal radioulnar joint (DRUJ), is composed of the distal ulna and the sigmoid notch on the ulnar surface of the distal radius. This is the anatomic location of forearm rotation, allowing the radius and the carpus to rotate around the ulna. Four radiographic measures with well-established normal values are commonly used to describe the anatomy of the distal radius and are essential for accurately evaluating malunions. The distal radius typically demonstrates a palmar inclination of approximately 11º to 12º, a radial inclination of 22º to 23º, a radial length of 11 to 12 mm, and an ulnar variance of ±1 mm on a neutral rotation posterior-anterior (PA) radiograph. Ulnar variance differs greatly among individuals and should be evaluated by comparison to the contralateral, uninjured extremity. The magnitude of acceptable postinjury deviation from these normal parameters has also been established. Most authors agree that palmar inclination between 15º dorsal to 20º volar, radial tilt >15º, radial length between 7 to 15 mm, and ulnar variance <3 mm from the contralateral side are compatible with acceptable alignment.[1,15,16]

Deformity beyond the limits defined above correlates with significant alterations in the normal biomechanics of the wrist, with associated clinical manifestations. In the normal wrist, approximately 82% of the axial load is distributed onto the radius with the remaining 18% borne by the distal ulna through the triangular fibrocartilage complex. With 2.5-mm radial shortening, this relationship changes so that the ulna bears 42% of the axial load. Continued shortening further increases ulnar load bearing and can result in symptoms of ulnocarpal abutment. Radial shortening has further deleterious effects in that it alters the congruency of the DRUJ and increases tension on the triangular fibrocartilage complex; these changes can result in increased pain and decreased rotation at the DRUJ, with nearly 50% loss in pronation and approximately 30% loss in supination with 10-mm shortening.[17–21]

Dorsal angulation has similar effects on force distribution by shifting the locus of axial load bearing from volar-radial to dorsal-ulnar. At 20° dorsal angulation, the load seen by the ulna increases to 50% of the total; at 45° angulation this increases to 67% of the total load. Dorsal angulation also affects DRUJ mechanics by altering the congruity of this joint, increasing the likelihood of range of motion deficits in forearm rotation and symptomatic instability. Carpal biomechanics are affected as well, with patients developing 1 of 2 patterns of instability. One subset develops dorsal radiocarpal subluxation while maintaining midcarpal anatomy; a separate subset tends to progress to an adaptive dorsal intercalated segment instability (DISI) deformity, with a flexion deformity developing at the midcarpal joint in an effort to compensate. Evidence suggests that the latter subset is more frequently symptomatic.[22] Both deformity types tend to lead to deficits in wrist flexion and forearm supination. Dorsal angulation malunion can also cause an unsightly deformity (Fig. 1A). Volar angulation deformities, commonly seen as a product of Smith's fractures, will often result in deficits in extension and forearm rotation.[23–25]



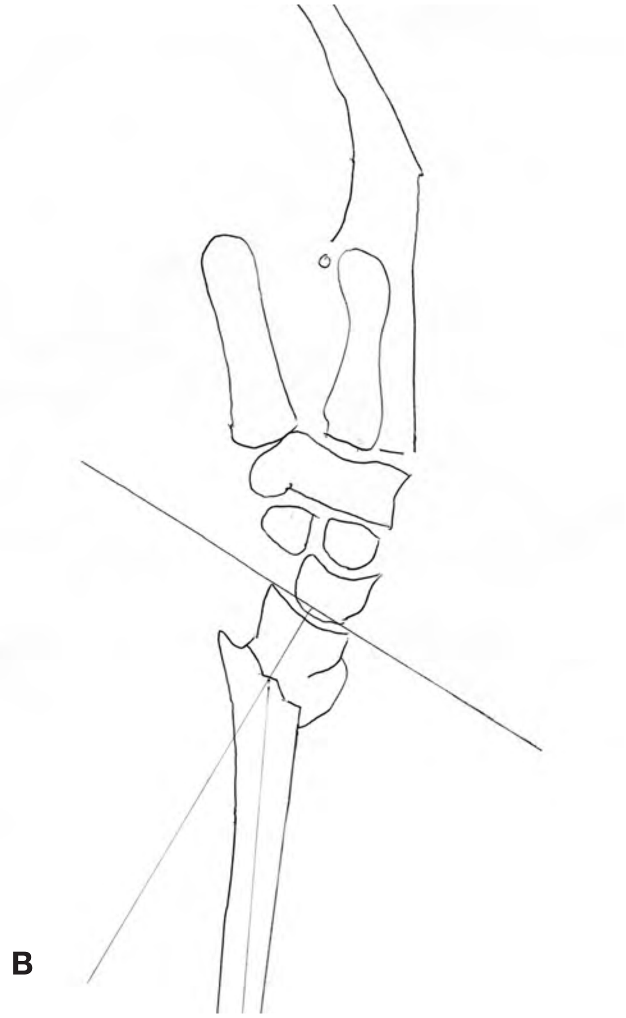


Figure 1: **A)** Clinical photograph of dorsally-angulated malunion following distal radius fracture. **B)** Preoperative template for design of osteotomy. **C)** Template illustrating magnitude and direction of correction of the distal fragment following osteotomy. **D)** Posteroanterior and **E)** lateral radiographs showing significant dorsal angulation, radial shortening, and DRUJ incongruity. Dorsal translation of the carpus is also noted.

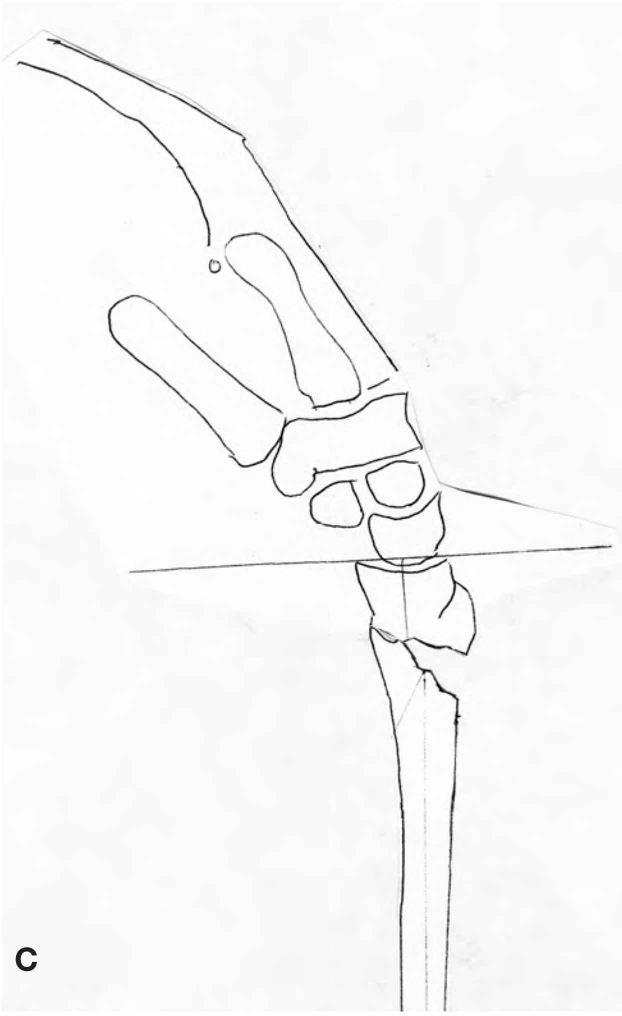


Figure 1: (*Continued*)

Decreases in radial inclination are another common feature of extra-articular malunions that can interfere with normal wrist biomechanics. The changed position of the carpal tunnel is hypothesized to decrease the mechanical advantage of the finger flexors, reducing grip strength. Decreases in radioulnar deviation are also commonly noted. Finally, decreases in radial inclination are thought to be associated with changes in load-bearing across the wrist, with increased force transmitted across the lunate facet of the distal radius.[26]

Intra-articular involvement is frequently noted in distal radius fractures. While mild incongruence, as seen following low-energy fractures in older patients, is often well-tolerated, this is generally not the case in younger, more active individuals. Numerous studies have found that greater than 1 to 2 mm of residual radiographic intra-articular stepoff after healing of distal radius fractures is associated with radiographic radiocarpal arthritis and a poor clinical outcome, especially in young patients.[27–30]

Evaluation

Initial evaluation of the patient with a malunion consists of a detailed history and physical examination, with specific emphasis placed on eliciting the common findings of a history of pain, weakness, decreased range of motion, instability, or neurologic symptoms. The patient's handedness, overall health, functional demands, and expectations should be documented as these can strongly affect the choice of treatment. Attempts should be made to localize any pain to a specific anatomic locus, especially distinguishing between radiocarpal versus ulnar-sided wrist pain.

Physical examination, with comparison to the contralateral uninjured side, should test grip strength, range of motion in flexion/extension, pronation/supination, and radial/ulnar deviation, as well as stability at the DRUJ, radiocarpal, and midcarpal joints. Specific tender points should be identified. Particular attention should be directed to the ulnar side of the wrist, eliciting tenderness and/or signs of ulnocarpal abutment. A neurologic examination can help identify features of complex regional pain syndrome (CRPS), carpal tunnel syndrome, or other neurologic deficits. Information should also be obtained regarding the initial injury, including the mechanism and treatment. As part of this evaluation, previous radiographs, including those of the initial injury, should be obtained and reviewed if possible.

Further radiographic evaluation will be essential. This begins with a minimum of a neutral rotation PA and lateral view of each wrist. It is essential to image the contralateral wrist in order to obtain a baseline for comparison. These radiographs will allow determination of the anatomic parameters defined earlier and quantification of the magnitude and direction of the malunion. Additional radiographs can be very useful if further evaluation is deemed necessary. Directing the beam for the lateral view 20º to 25º distal to proximal will permit visualization of the distal radius articular surface; further information regarding the articular surface can be gleaned from oblique views, with the partially supinated oblique PA view to evaluate the dorsal facet of the lunate fossa and the partially pronated view to improve visualization of the radial styloid.[31]

In cases of significant articular surface disruption, or considerable rotational deformity, plain radiographs may not provide sufficient information. Several studies have established that plain films consistently underestimate the magnitude of intra-articular disruption in distal radius fractures. In these cases, computed tomography (CT) scans, with sagittal, coronal and 3-dimensional reconstructions can improve quantification of the deformity and understanding of fracture fragment morphology compared with plain films.[12]

Treatment

The goal of treatment of a distal radius malunion is to provide a pain-free wrist that meets the functional demands of the patient. The corollary to this is that patients with significant anatomic abnormalities, clinically or on radiographic examination, may not require intervention if they are pain-free and able to function adequately given their current and anticipated functional requirements. Other relative contraindications to operative intervention include poor overall health, advanced posttraumatic arthritis, severe osteoporosis, complex intra-articular deformity, and existing features of CRPS. In these cases, physical therapy may help achieve soft tissue adaptation. If operative treatment is warranted, a salvage procedure such as a partial or total wrist fusion may be preferred.

On the other hand, activity-limiting symptoms or severe deformity with an increased risk for degenerative arthritis or ulnocarpal abutment in a patient with expected high functional demands is an indication for operative treatment. In these situations, the goal is to restore the normal anatomy of the wrist, or at the very least, restore wrist anatomy to within the acceptable parameters described earlier. In this way near-normal biomechanics can be reestablished, thereby reducing pain, improving function, and diminishing areas of abnormal articular stress concentration.

Proper preoperative planning is essential in this process. Planning begins by comparing the injured and uninjured wrists, including templating (Fig. 1B, C). This will allow precise quantification of the magnitude and direction of the deformity to help define the following features of the appropriate treatment strategy: (1) the nature and direction of the proposed osteotomy (opening vs. closing, volar vs. dorsal); (2) the need for and type of bone graft to be used; and (3) the requirement for any additional ulnar-sided procedures. Determination of the timing of any proposed intervention is also an important part of the planning process. Although some studies have determined that equivalent clinical results are obtained from early intervention (<8 weeks) and late intervention (>40 weeks), others have shown that earlier surgery is technically easier and reduces the overall period of disability. However, delay may be an appropriate strategy in select cases of significant comminution or established malunion. In the former, delaying surgery until some measure of consolidation has occurred may facilitate the ultimate procedure. In the latter, physical therapy in the interval prior to definitive treatment may improve mobility and soft tissue balance.[32–34]

Dorsally angulated malunions (Fig. 1D, E) are typically treated with a dorsal opening wedge osteotomy. The advantage of the opening wedge osteotomy over the closing wedge variant is that it effectively lengthens the radius, thereby ameliorating any radial shortening deformity. A closing wedge osteotomy, on the other hand, will likely accentuate axial shortening. By creating a free distal fragment, opening wedge osteotomies also permit multiplanar deformity correction, restoring more normal radial and volar inclination in the distal radius. There are 2 salient disadvantages associated with the opening wedge technique. First, an opening wedge osteotomy creates a void, which must be filled with graft. Typically, this graft has been supplied by autogenous corticocancellous or cancellous bone graft, with the attendant morbidity associated with graft harvest. Secondly, these osteotomies rely on healing of the graft construct for stability. In the presence of significant osteoporosis or an otherwise poor healing milieu, there is an increased risk of nonunion or construct failure compared with closing wedge procedures. However, the improved deformity correction afforded by opening wedge osteotomies has made them the preferred surgical technique for malunion correction.[35]

In the case of dorsally angulated extra-articular malunions, osteotomy with plate fixation was historically performed through a dorsal approach, accessing the distal radius between the second and fourth dorsal compartments. However, with the advent of precontoured, volar locking plate technology, surgeons now have the ability to perform the osteotomy and fixation via a volar approach. This approach provides more space to accommodate the plate on the volar side, and the overlying pronator quadratus forms a barrier between the plate and the flexor tendons.[36–40]

In this technique, the Henry approach may be used to expose the volar distal radius (Fig. 2A). A common strategy is to fix the plate distally first, allowing the surgeon to identify the optimal osteotomy location and direction (Fig. 2B). Ideally, the cut should be parallel to the articular surface and at the apex of the deformity. The osteotomy is started with an oscillating saw and completed with an osteotome. The plate-distal fragment construct is then reduced to the radial shaft, in the process correcting the deformity in the form of a dorsal opening wedge (Fig. 2C–E). Angulatory deformities without bone loss or axial shortening can often be corrected solely by hinging open dorsally and radially on the apposed volar cortices; adequate restoration of anatomy in more complex malunions may result in a gap between the anterior cortices, especially when significant lengthening is required. Optimal

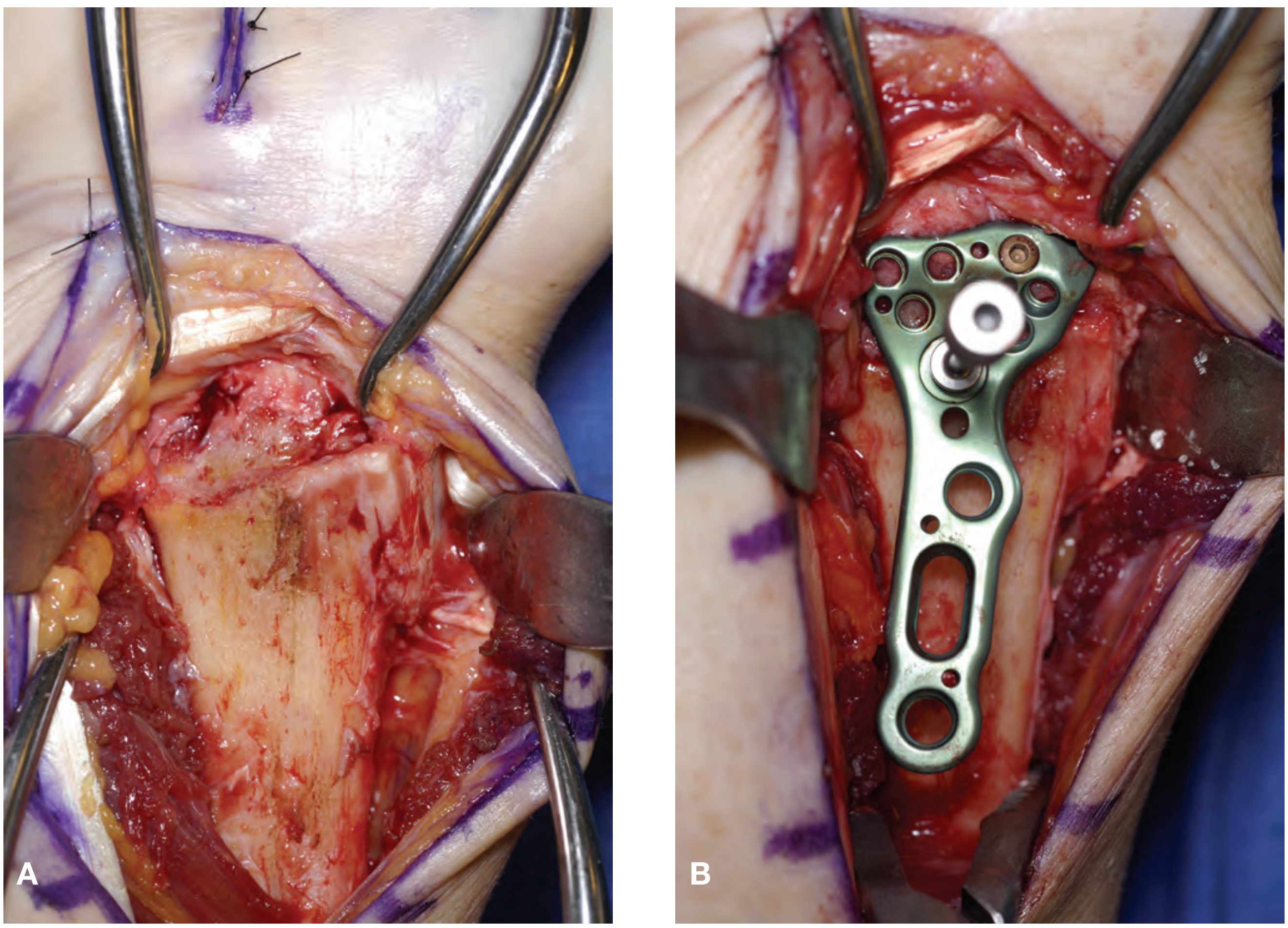


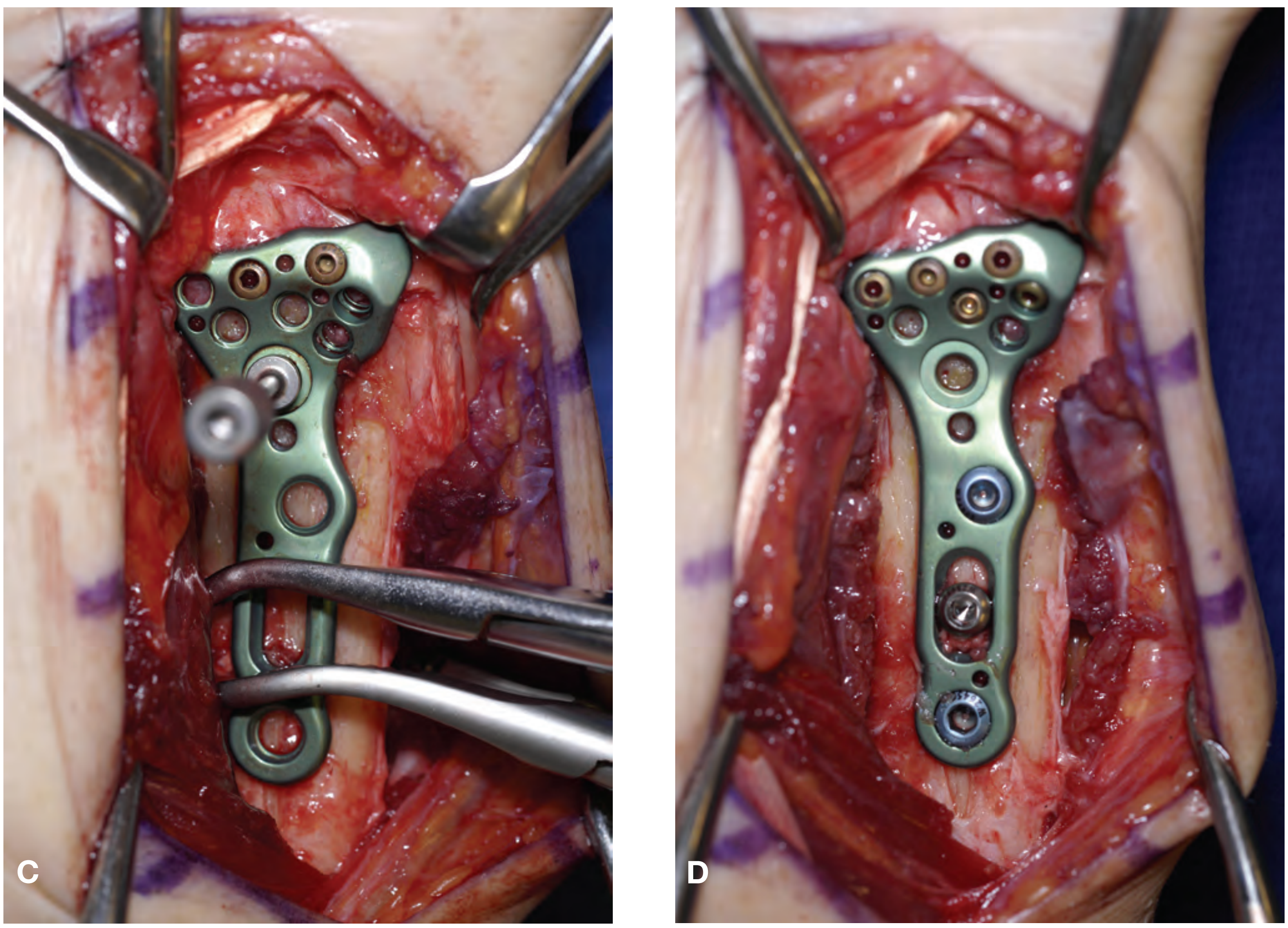
Figure 2: A) Intraoperative picture showing volar exposure of the distal radius. The healed fracture line is clearly visible. **B)** The volar locking plate is provisionally applied to the distal fragment. **C)** Following the osteotomy, the plate was reapplied to the distal fragment, and the plate-fragment construct reduced to the proximal shaft. **D)** Volar locking plate following final fixation. **E)** Lateral fluoroscopic image following plate application. The newly created dorsal defect is clearly visible.

positioning of the distal fragment may also be facilitated by releasing the brachioradialis tendon, which acts as a shortening, radially-deviating deforming force. Abundant dorsal callous and thickening/scarring of the dorsal periosteum may require a dorsal approach to gain adequate mobility of the distal fragment. The dorsal defect that is created is then filled with appropriate bone graft. The graft may be packed in via the volar exposure; however, a limited dorsal approach improves visualization (Fig. 3). Postoperative radiographs should demonstrate a good fill of the defect (Fig. 4).[41–43]

Closing wedge osteotomies, discussed briefly above, present a tenable alternative surgical technique in specific situations. Older adults with osteopenia have a significant risk of construct failure and loss of fixation with opening wedge osteotomies, and may be indicated for a closing wedge procedure, which does not generally require graft use. This technique allows appropriate restoration of radiocarpal and midcarpal alignment. However, as mentioned, this technique also results in net shortening of the radius, which may produce or worsen existing DRUJ incongruity. These procedures are therefore often coupled with an ulnar-sided intervention, in the form of an ulnar head resection or an ulnar shortening osteotomy. Performing the ulnar procedure prior to fixation of the radial fragments may increase the mobility of the distal radial fragment and improve the final reduction.[44–46]

Palmarly angulated malunions are far less commonly encountered but may result from failed treatment of Smith's fractures. In these malunions, the distal fragment is often flexed, pronated, and shortened. The operative technique is similar to that detailed above for dorsally angulated malunions. A volar approach is used, and an opening wedge osteotomy performed. The distal fragment is typically then extended and supinated to correct the deformity. Bone graft is placed in the palmar gap, and a volar plate is applied for fixation. Correcting the deformity in this fashion significantly improves grip strength and forearm range of motion.

The surgical treatment of intra-articular malunion is fraught with challenges, including difficulty in visualizing the articular surface, finding and developing the fracture lines, and impairing the vascular supply to fracture fragments. Relatively narrow indications for this procedure exist; it should not be attempted in the presence of significant intra-articular



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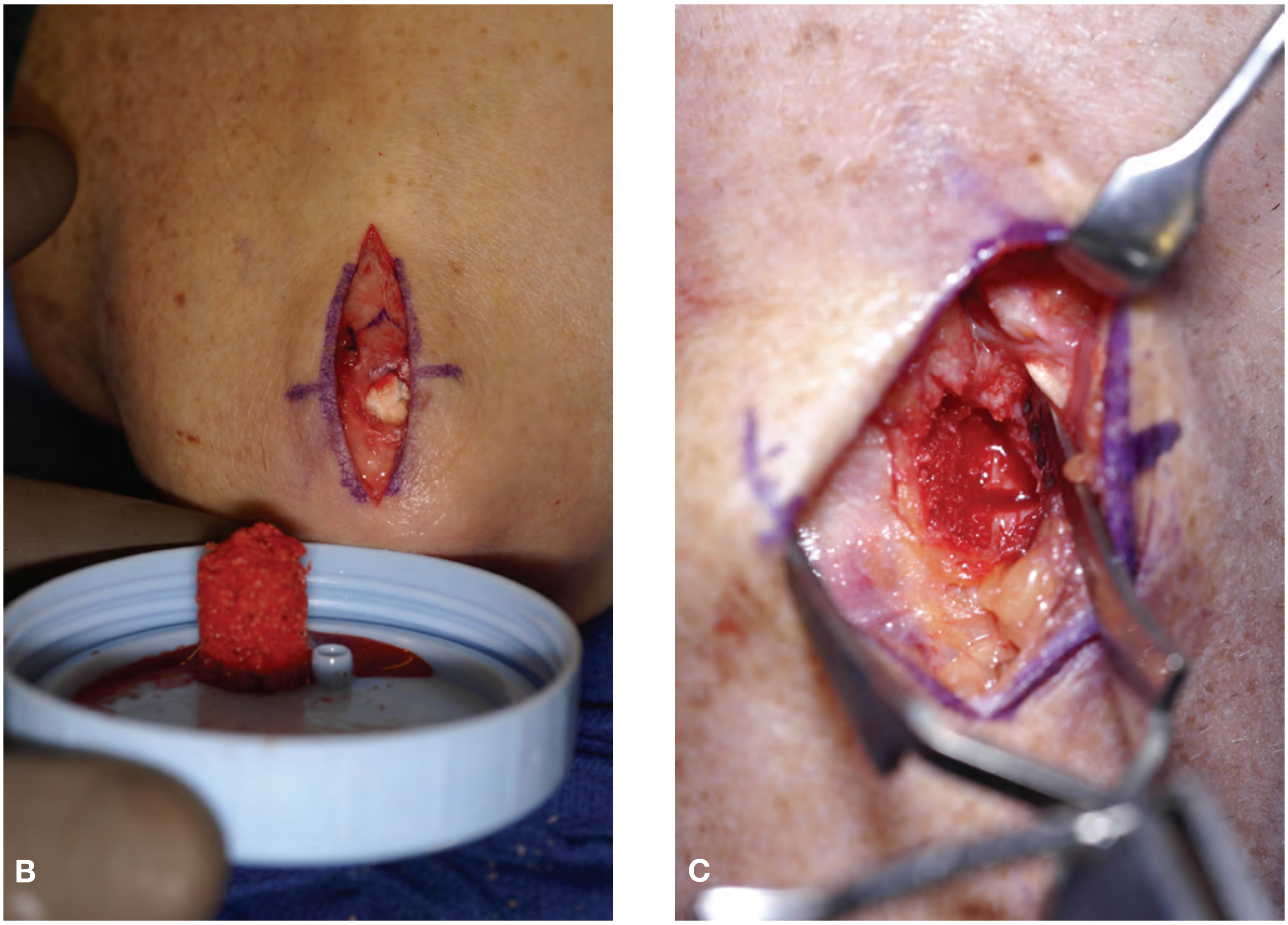
comminution, existing arthrosis, severe osteoporosis, or in patients with low functional demands. In these cases, nonsurgical treatment and future salvage procedures may be better options. Osteotomy is best reserved for simple depressed die-punch fragments, especially of the volar lunate facet.[47,48]

Few published reports exist on the optimal surgical techniques for intra-articular osteotomies. In general, these describe similar overall strategies in that the original fracture lines are recreated as precisely as possible with an osteotome or fine oscillating saw, fibrocartilage and callus are resected to expose the true articular edges, and the articular fragments are reapproximated and fixed using K-wires, screws, plates, or a combination of these (Fig. 5). Any remaining bony defects are filled with bone graft. The approach used can vary, but generally aims to expose the side with the greatest deformity. Dorsal approaches permit direct visualization of the articular surface via a capsulotomy; in volar approaches, where the radiocarpal ligaments are left intact, the surface is observed through the fracture. Intra-operative fluoroscopy is essential for additional evaluation. Reported results with these procedures indicate favorable outcomes in experienced hands.[49] Ring et al. reported on a series of 23 patients and described symptomatic and functional improvement following intra-articular osteotomy, although they noted that normal wrist anatomy and function are only rarely restored.[50] Whether later development of arthrosis is avoided remains to be seen.[29]

Ulnar-sided interventions, mentioned briefly above, may be required in some instances. In select malunion cases where

Figure 3: **A)** Limited dorsal approach exposing the dorsal defect. **B)** Cancellous autogenous graft obtained from the ipsilateral olecranon process. **C)** Bone graft packed into the dorsal defect.



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an isolated radial axial shortening deformity is present with no concomitant radial or volar inclination abnormality, an ulnar-sided procedure alone (eg, an ulnar shortening osteotomy) may adequately address the pathology by restoring normal ulnar variance. DRUJ dysfunction in the form of incongruity or instability may also necessitate an ulnar-sided intervention, provided it is not simply secondary to extra-articular malunion of the radius. Several procedures have been proposed to treat this dysfunction. The Darrach procedure may be appropriate for marked increased ulnar variance and ulnocarpal abutment in older patients with limited functional demands, in whom the decreased grip strength often seen as a result of the procedure is well-tolerated. The Sauvé-Kapandji technique, on the other hand, may be more appropriate for younger patients, although persistent pain following this procedure has been reported and it is more technically demanding.[51]

Graft Choices

A number of graft choices have been proposed to address the gap created by opening wedge osteotomies. Prior to the advent of fixed-angle plating constructs, structural cortico-cancellous bone graft, obtained most commonly from the iliac crest had been preferred. These grafts possessed the capacity to bear load, which provided considerable stability to the overall construct, albeit at the cost of often significant donor site morbidity and possible size mismatch between the graft and the recipient site. With volar fixed-angle plating now available, the plate itself provides structural support, and nonstructural cancellous autograft can be used with comparable results. The graft and can be easily obtained from the ipsilateral olecranon with minimal donor site morbidity (Fig. 3B).[52]

More recently, cancellous allograft and commercially available bone substitutes including calcium phosphate and carbonated hydroxyapatite have been compared to autogenous graft in the setting of corrective osteotomy with comparable healing rates.[53–57] Alternative substitutes also include porous tantalum wedges, which provide an osteoconductive, structurally sound scaffold for bone ingrowth and have been used extensively in hip and knee arthroplasty. Bone morphogenic proteins have also been studied preliminarily in this context.[58]

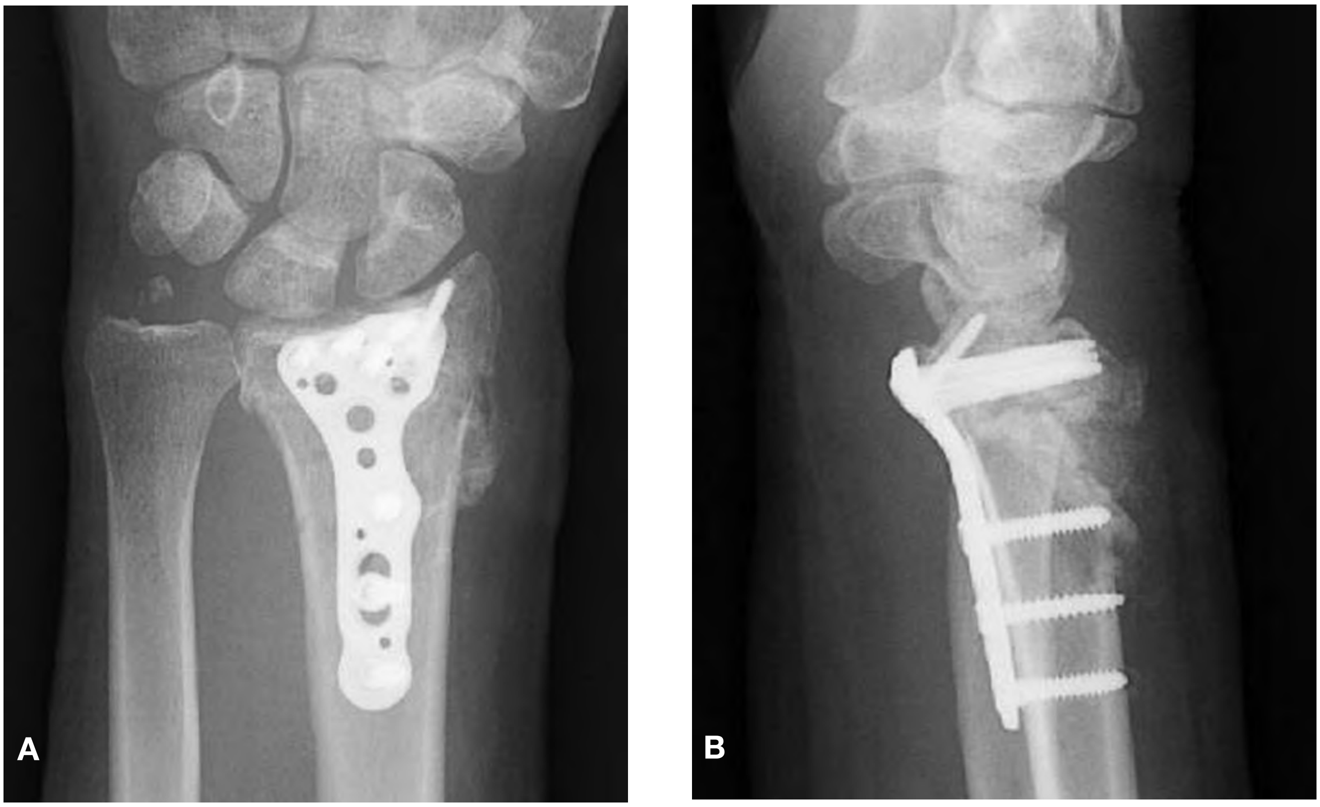

Figure 4: **A)** PA and **B)** lateral postoperative radiographs showing plate position, correction of radial angulation and shortening, and good fill of the cancellous autograft.

The advantages of these substitutes include decreased operative time and reduced donor site morbidity, although the cost of the grafting substitute must be considered.[59] Further study is needed before these substitutes can be unequivocally recommended.

Future Directions

The treatment of distal radius malunions continues to evolve as new technologies are introduced. While long-term studies regarding these technologies are still lacking, initial reports suggest promising results.

The increasing versatility of CT scanning with the availability of 3-dimensional reconstructions has made computer-assisted techniques for treating malunions feasible. As described by Athwal et al., one strategy for using computer-assisted technology involves obtaining CT scans of both the injured and uninjured upper extremity. A computer program can be used to create an osteotomy in the virtual malunited radius and align the osteotomized fragment to the contralateral side. The location of the osteotomy and the magnitude and direction of the correcting displacement are recorded. The surgeon can use this computer model to guide the intraoperative osteotomy and appropriately position the distal fragment. The system therefore facilitates in-depth preoperative planning as well as intraoperative guidance. Initial reports have shown good clinical results with this technique; whether the results are significantly better than those obtained with traditional techniques has yet to be determined.[3,60,61]

Arthroscopically-assisted techniques have been described in the primary treatment of distal radius fractures with articular involvement, with cited advantages including the ability to directly visualize and reduce articular fragments and to evaluate and potentially treat ligamentous pathology in a less invasive fashion than traditional open techniques. Some groups have attempted to extend this experience to the treatment of distal radius malunions.[62–64] Del Piñal et al. reported on 11 patients with intra-articular malunions treated with arthroscopically guided osteotomies and fixation with mean follow-up of 32 months. In their patients, all stepoffs were corrected by arthroscopic and radiographic evaluation; however, 4 of 11 patients had residual gaps (<2 mm). Clinical outcomes were comparable to results of open treatment.[65] Though this initial report seems promising, longer studies are needed to assess the impact on the development of later stage radiocarpal arthrosis.[66]

Figure 5: **A)** Preoperative PA radiograph and **B)** CT scan and coronal reconstruction image demonstrate an intra-articular malunion with stepoff of the lunate facet. **C)** Postoperative PA films following intra-articular osteotomy and fixation with a volar plate, showing correction of the intra-articular stepoff.

Summary

The incidence of symptomatic distal radius malunions is expected to increase over the next 2 decades. Treating these deformities is challenging, but should generally lead to favorable outcomes in the hands of surgeons familiar with wrist anatomy and biomechanics, and in the context of appropriate preoperative planning.[67] However, reconstruction does not restore anatomy or function to that of the normal wrist, and the prevention of malunion through appropriate initial treatment remains the optimal strategy.[68]

Figure 5: *(Continued)*

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