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DISTAL RADIUS AND WRIST FRACTURES (E SHIN, SECTION EDITOR)

Best Approaches in Distal Radius Fracture Malunions

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Abstract
Purpose of Review Malunion remains a common complication in the treatment of distal radius fractures. The purpose of this review was to discuss the various approaches in planning and surgical management for extra- and intra-articular distal radius malunions.
Recent Findings Several recent studies have reported good results with surgical correction of distal radius malunions utilizing a number of preoperative planning methods and surgical approaches. Three-dimensional models and custom cutting guides have recently become more popular, but their benefit in comparison to other methods remains unclear.
Summary Regardless of preoperative planning method or surgical approach, good results can be achieved with correction of distal radius malunion with careful attention to patient selection, indications, and surgical technique.

Keywords Distal radius · Malunion · 3D modeling · Corrective osteotomy

Introduction

Malunion is a common complication in the treatment of distal radius fractures, especially in unstable patterns treated non-operatively. As with many orthopedic conditions, the radiographic appearance does not always correlate with symptoms and treatment should be directed at symptoms rather than radiographs.

There is no formal classification of distal radius malunions, but a recent paper attempts to define unacceptable healing of distal radius fractures as:

1. Radial inclination < 10°
2. Volar tilt > 20°, dorsal tilt > 20°
3. Radial height < 10 mm
4. Ulnar variance > 2+
5. Intra-articular step or gap > 2 mm [1]

In general, malunion is described as dorsally displaced, volarly displaced, intra-articular, or a combination and the surgical approach varies with the pattern of displacement and planned osteotomy for correction.

For symptomatic patients for whom osteotomy is indicated, the timing of intervention is controversial, but there is some evidence that intervention as early as 6 weeks may be beneficial [2, 3]. Regardless of timing, the goal is to restore both radiocarpal and distal radioulnar joint (DRUJ) congruence to improve pain and function and prevent future arthritis [4]. There are multiple described techniques for achieving this goal.

Pathoanatomy and Indications for Surgery

Malunion of the distal radius results in alterations in biomechanics that lead to functional changes and increased arthrosis at the DRUJ and radiocarpal joint [5•]. Decreased radial inclination changes the position of the carpal tunnel, which alters the angle of the flexor tendons, thereby decreasing their mechanical advantage and resulting in decreased grip strength. Reduced DRUJ space leads to alterations in load transfer, DRUJ pain, and decreased forearm rotation, which increases the risk of DRUJ arthrosis [6–8]. Increased dorsal tilt causes an increase in the force over the distal ulna and dorsal force concentration over both the distal radius and ulna [9]. The resulting changes in alignment can also lead to adaptive dorsal intercalated segment instability (DISI, Fig. 1) and, while less common, carpal instability non-dissociative has also been

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Fig. 1 PA and lateral of a malunited distal radius fracture with some loss of radial height and inclination with significant dorsal tilt and adaptive DISI deformity

described [10]. In addition to these changes from alteration in alignment alone, increased arthrosis and poor outcomes are seen with increased articular incongruity [4, 11].

While malunion can result in multiple changes in mechanics and may ultimately lead to arthrosis, the decision to perform a corrective osteotomy for a distal radius malunion should generally be based on the patient's overall functional capacity and symptoms. Some patients may have severe malunion and degenerative joint disease on plain radiographs but be relatively functional and asymptomatic.

For symptomatic patients, indications for correction include pain, functional limitations, midcarpal instability, disruption of the distal radioulnar joint, and articular incongruity. In symptomatic patients with functional limitations, osteotomy may be contraindicated in the setting of degenerative joint changes, fixed carpal instability, extensive osteoporosis, or patients with decreased baseline functional capacity.

Timing of Osteotomy

Once the decision is made to intervene on malunion of the distal radius, surgery should be performed as soon as possible provided there are no trophic changes, the bone quality is acceptable, and there is adequate wrist function. At 5 to 8 weeks post-fracture, the callus will be immature, but there is an established deformity and nascent malunion with minimal soft tissue contracture, making correction of both the radiocarpal and distal radioulnar joints much easier than at later stages of healing. Not only is correction achieved more easily but there is also often no need for structural bone graft. Furthermore, one study showed that total disability is decreased and patients return to work earlier than those corrected at later stages [2]. After 4 to 6 months of healing, the callus is remodeled and correction becomes much more difficult and increases morbidity for the patient [3].

Preoperative Planning

Prior to performing a corrective osteotomy, a well thought out preoperative plan is a must. In the ideal scenario, this plan is based on radiographic measurements of the opposite wrist including ulnar inclination, ulnar variance, and volar tilt [12]. With these goals in mind, preoperative plans may range from hand drawings to three-dimensional (3D) computer-assisted plans with cutting jigs custom made for the patient [13••, 14, 15].

Once the goals of osteotomy have been established, there are several types that may be utilized to achieve correction. While some may be performed through a pure rotational osteotomy, failure to recognize combined rotational and translational deformities will lead to an incomplete correction [16].

Surgical Treatment

The goal of surgical treatment of distal radius malunion should focus on reorientation of the articular surface to restore normal load transmission and reestablish normal carpal kinematics and DRUJ function.

When treating distal radius malunions, it must first be established whether the malunion is extra- or intra-articular. While extra-articular malunions are most commonly the result of non-operative management, intra-articular malunion commonly results from both a failure to recognize potentially unstable articular disruptions in non-operatively treated distal radius fractures and insufficient reduction and fixation in surgical treatment.

Extra-articular Patterns

Extra-articular malunions can generally be corrected through a volar approach with either a volar plate or Kirschner wires for fixation. There is often enough bone in the distal segment to achieve correction in both the coronal and sagittal planes via this approach. If longitudinal correction is also needed, this can also be achieved with a volar plate. Many different techniques that utilize this approach have been described. The simplest method is a distal osteotomy and fixed angle correction with a volar plate, which is most useful for an extra-articular fracture with a dorsal angulation deformity. However, by fixing the volar plate to the distal segment in a position that accounts for the desired correction prior to making the osteotomy, correction in multiple planes can be achieved (Fig. 2). Opening or closing wedge osteotomies

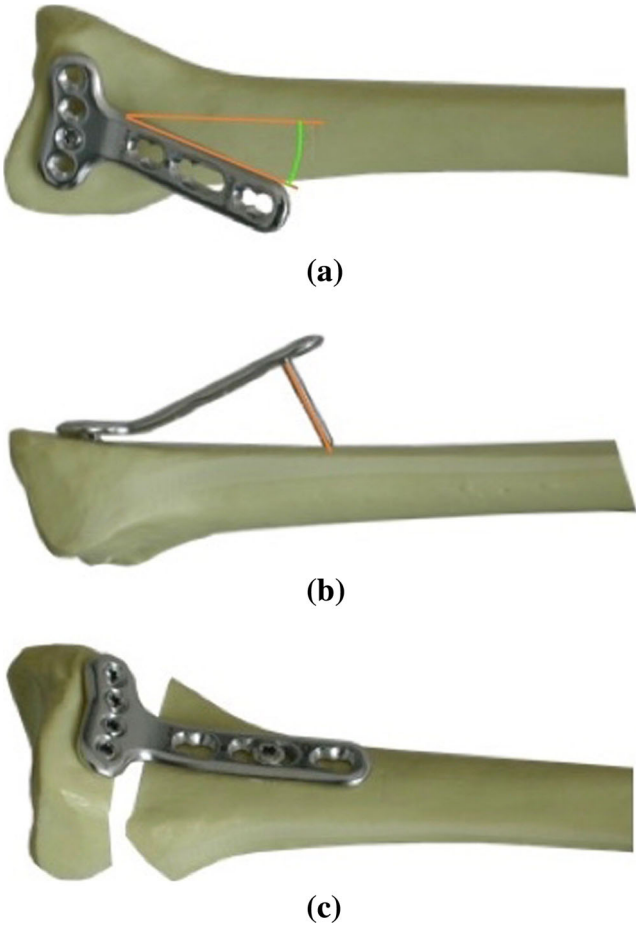

Fig. 2 Fixing the plate to the distal malunited segment in a manner that takes the desired correction into account allows correction in the coronal (**a**) and sagittal (**b**) planes, restoring anatomy through a single approach and osteotomy (**c**)

can be used depending on the situation and any gaps can be filled with interpositional bone graft if needed [17]. For cases where bone graft is likely to be needed, Mathew and Garcia-Elias recently described an anterolateral approach which allows for correction and bone graft harvest through a single incision, which may decrease trauma to surrounding tendons as well as the morbidity of two incisions [18].

When the DRUJ must be addressed as well, a closing wedge osteotomy and concomitant ulnar head shortening osteotomy or ulnar head prosthesis has been described [19]. For more complex corrections involving the DRUJ, biplanar closing wedge osteotomies and Darrach resection can be performed [20].

Intra-articular Patterns

While many extra-articular malunions are relatively straightforward to correct, intra-articular malunions are generally more complex and require close attention to the fracture pattern as well other patient factors when considering correction. The treating surgeon should also take into account chronicity, the extent of cartilage damage, and the condition of the soft tissues, as well as the presence of fixed carpal malalignment or limited residual wrist and finger motion. Patients with severe cartilage damage, radiographic degenerative changes, chronic synovitis, significant soft tissue and capsular contractures, fixed carpal malalignment, or complex fracture patterns are not likely to benefit from corrective osteotomies. These patients may be candidates for other salvage procedures however, including limited carpal fusions such as radioscapholunate or radiolunate [21].

Careful preoperative evaluation of the patient with intra-articular malunion is essential for a successful correction. This often includes comparative plain radiographs and computed tomography (CT) as well 3D reconstruction [22]. While 3D reconstruction is more expensive, it may help with the surgeon's understanding of the fracture pattern. Furthermore, these reconstructions that can be used for 3D preoperative planning may lead to better patient-reported outcome measures [13••].

Multiple techniques for correction are possible and range in complexity and necessary planning. The most conventional technique utilizes an arthrotomy and outside-in correction [22]. More recently, some authors have described and advocated for inside-out arthroscopic-assisted techniques and argue that this allows for better delineation of the original fracture plane, resulting in correction without the possibility of creating secondary fractures on the already damaged articular surface [23, 24•]. Good results have been reported in small series with this technique [25].

Combined Patterns

For malunions that involve both extra- and intra-articular components, there is no standard surgical approach, but extra care should be taken in preoperative planning to identify the original fracture lines and resulting deformity as closely as possible. This can be accomplished with the use of a combination of radiographs, CT, and magnetic resonance imaging (MRI). For very complex fractures, these images can be used to create 3D models for visualization and preoperative practice of the intended osteotomies.

With recent advances in 3D printing, several institutions have begun to use in-house 3D printers for planning various operations. Several studies have been published on the use of 3D printing in planning for correction of a malunited distal radius and a recent meta-analysis by Keizer et al. shows that several groups have achieved good radiographic and functional outcomes with the use of 3D printing [26]. Furthermore, some companies are beginning to expand offerings for virtual reduction and plating and even patient specific cutting guides for very complex malunions (Fig. 3, Materialise, Leuven, Belgium). However, to our knowledge, no study has yet been performed comparing 3D planning with other planning methods for treatment of distal radius malunions, so the added benefit of this technique is not yet clear.

Regardless of method, thoughtful planning and execution can yield good results for correction of combined extra- and

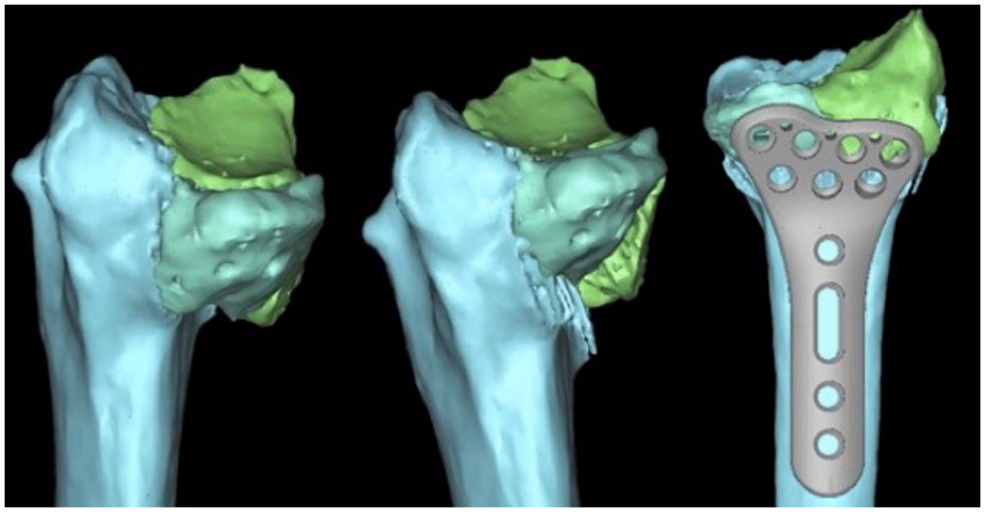

Fig. 3 Virtual reduction and plating of a complex intra-articular distal radius malunion. These tools provide a detailed preoperative plan for complicated cases (Materialise, Leuven, Belgium)

intra-articular distal radius malunions. In a study by Buijze et al., 18 patients who underwent correction for combined malunion were evaluated at an average of 78 months after osteotomy and were found to have significant improvements in range of motion and grip strength with 72% excellent results in the Mayo Modified Wrist Score. These results are comparable to those for isolated extra- or intra-articular distal radius corrective osteotomy [27]. Despite their complexity, correction of combined distal radius malunion is a good surgical option in the right patient.

Bone Graft

When bone graft is needed to fill defects left by corrective osteotomy, there are multiple options available to the treating surgeon. The results of non-structural and structural grafts have been shown to be similar both radiographically and functionally [28].

Non-structural graft options include cancellous autograft, allograft bone chips, demineralized bone matrix, coral, and calcium pellets. However, while outcomes may be similar overall, this assumes that non-structural grafts are used in combination with implants that are designed to maintain stable corrections of the distal fragment throughout the time required for bony healing—i.e., fixed angle plates or external fixators, but not Kirschner wires. Non-structural grafts are therefore ideal for corrective osteotomies in osteopenic bone or nascent malunions with immature callus where rigid fixation is otherwise utilized [29].

Structural grafts include corticocancellous autograft or allograft and calcium cements. The benefit of corticocancellous grafts is that they can be shaped and interposed in the defect, which restores cortical continuity and therefore increases intrinsic stability, which reduces the need for stronger implants in cases where bone quality is adequate. However, these grafts do take slightly longer given the time needed for proper shaping for fit. While calcium cements cannot be used in this manner, they do provide structural stability once set (Fig. 4).

Complications

While rare, as with initial treatment of distal radius fractures, a major complication of distal radius osteotomy is extensor pollicis longus (EPL) tendon rupture. In a study by Rivlin et al., six cases of EPL rupture after osteotomy and volar plate fixation who underwent tendon reconstruction were reviewed. The average time to tendon rupture was 10 weeks after surgery. A review of the intraoperative findings and radiographs showed exuberant dorsal callus formation in four of six cases, screw tip

Fig. 4 PA and lateral of a distal radius malunion corrected with a volar plate. The bone defect was filled with a calcium cement, which provides structural support once set

prominence in one case, and a prominent Lister's tubercle and dorsal bone spur that resulted from the osteotomy in one case [30]. As with primary fixation of distal radius fractures, close attention to bony prominences and screw length may help prevent some, but not all instances of this complication.

Conclusions

When treating distal radius fractures non-operatively, careful attention should be paid to alignment, as malunion remains the most common complication of non-operative treatment of unstable extra-articular fractures. While intra-articular malunion most commonly results from failure to recognize a potentially unstable articular disruption, it also occurs from insufficient reduction and fixation in surgical treatment.

When malunion does occur, osteotomy can improve function and carpal kinematics as well as improve external appearance in severe extra-articular malunion. In the setting of intra-articular malunion, early correction should be pursued to restore the integrity of the joint before the onset cartilage damage and in some cases prior to the onset of symptoms.

Complications and failures are commonly the result of either technical errors or poor selection of patients who have degenerative changes, trophic disturbances, partial joint stiffness, severe osteoporosis, or fixed carpal malalignment. Good results can be achieved with careful patient selection and surgical technique with the correct indications.

Compliance with Ethical Standards

Conflict of Interest Brady T. Evans declares no potential conflicts of interest.

Jesse B. Jupiter reports stock in OHK Co. and is a speaker for Aptis Co. and Dupuy-Synthes.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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