

CURRENT CONCEPTS REVIEW

Distal Humeral Fractures in Adults

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- ▶ Distal humeral fractures in adults are relatively uncommon injuries that require operative intervention in the majority of cases.
- ▶ Dual plate fixation, with placement of a separate strong plate on each column and orientation of the plates either at 90° or 180° to each other, is indicated for all adult fractures involving both columns of the distal part of the humerus.
- ▶ Acute total elbow arthroplasty is the preferred treatment for elderly patients with a displaced, comminuted, intra-articular distal humeral fracture that is not amenable to stable internal fixation.
- ▶ Displaced coronal shear fractures of the distal humeral articular surface require operative fixation, most typically via a lateral approach.

Distal humeral fractures in adults are complex and technically demanding injuries to manage. Operative intervention is indicated in most cases and is often complicated by difficult exposure, osteoporotic bone, and comminution in the metaphyseal and/or articular region. There is controversy regarding a number of issues pertaining to the management of distal humeral fractures, including the correct operative approach, fixation strategies, the role of total elbow arthroplasty, management of the ulnar nerve, and indications for prophylaxis against heterotopic ossification. This article provides an overview of these issues and others by reviewing the available evidence in the literature on distal humeral fractures and providing graded recommendations.

Epidemiology

Distal humeral fractures have an estimated incidence in adults of 5.7 per 100,000 persons per year¹. These injuries occur in a bimodal distribution, with an early peak in young males, twelve to nineteen years of age, as a result of high-energy trauma, and a second peak in elderly women, with osteoporotic bone, as a result of falls.

In a recent study based on the Finnish National Health Registry, the authors reported a dramatic increase in the annual incidence of distal humeral fractures (from twelve per 100,000 to thirty-four per 100,000) in women sixty years of age or older

during the period of 1970 to 1998². The actual number of low-energy distal humeral fractures in this patient population increased even more dramatically, from forty-two fractures to 224 fractures, over the same time period. These dramatic increases were not sustained over the period from 1998 to 2007, during which the incidence and number of distal humeral fractures stabilized.

These data indicate that, although fractures of the distal part of the humerus are rare in adults, there has been a substantial increase in their number and incidence. The dramatic increases reported in elderly women with potentially osteoporotic bone is of particular note, suggesting that fixation strategies for osteoporotic bone, possibly joint replacement techniques, as well as the management of osteoporosis itself will play important roles in the future management of these injuries.

Classification

Distal humeral fractures involve the supracondylar region of the humerus and/or the articular surface of the distal part of the humerus. They are most commonly classified according to the Orthopaedic Trauma Association/Arbeitsgemeinschaft für Osteosynthesefragen (OTA/AO) classification system (Fig. 1). In this classification system, "A" designates an extra-articular fracture, "B" designates a partial articular fracture, and "C"

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OTA / AO Classification

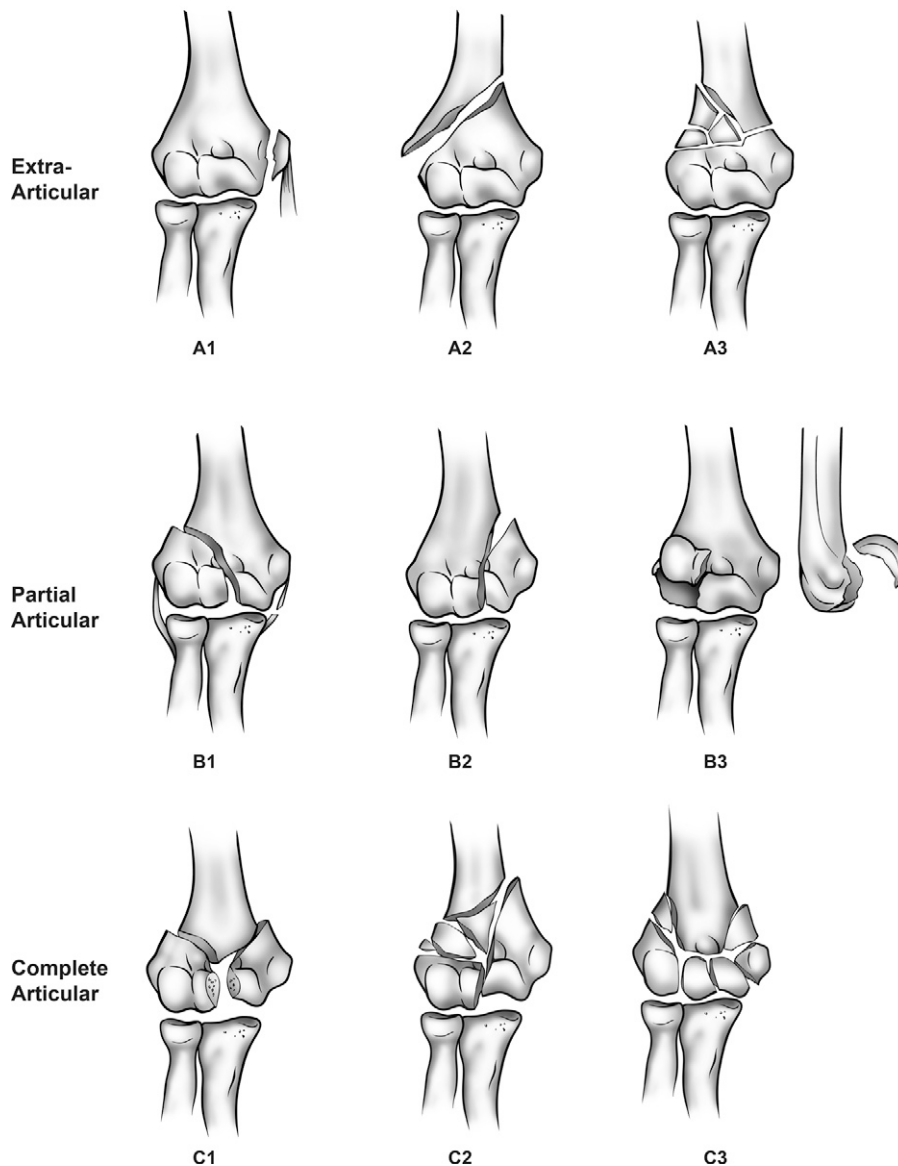


Fig. 1
OTA/AO classification of distal humeral fractures.

indicates an intra-articular fracture in which the articular surface is completely dissociated from the shaft of the humerus. These three types are subdivided with use of the numbers 1, 2, and 3 to indicate increasing degrees of comminution or to further define the location of the fracture. On the basis of epidemiological data from the United Kingdom, the distribution of these fractures has been reported to be 38.7% type A, 24.1% type B, and 37.2% type C¹.

Clinical Assessment and Radiography

The clinical evaluation of a patient with a distal humeral fracture should include careful assessment of the ipsilateral shoulder and wrist, examination of the skin for open wounds, and a detailed

neurovascular examination. A patient with an open distal humeral fracture most commonly has a posterior wound proximal to the elbow joint that was created by protrusion of the humeral shaft through the triceps muscle and posterior skin³. Neurological assessment should include examination of the median, radial, and ulnar nerves. The prevalence of preoperative ulnar nerve symptoms in patients with a type-C fracture of the distal part of the humerus has been reported to be 24.8%⁴.

Following clinical assessment, anteroposterior and lateral radiographs of the distal part of the humerus should be obtained (Fig. 2). In the setting of articular comminution, the use of computed tomography (CT) scanning with three-dimensional reconstructions can be helpful for classification and preoperative

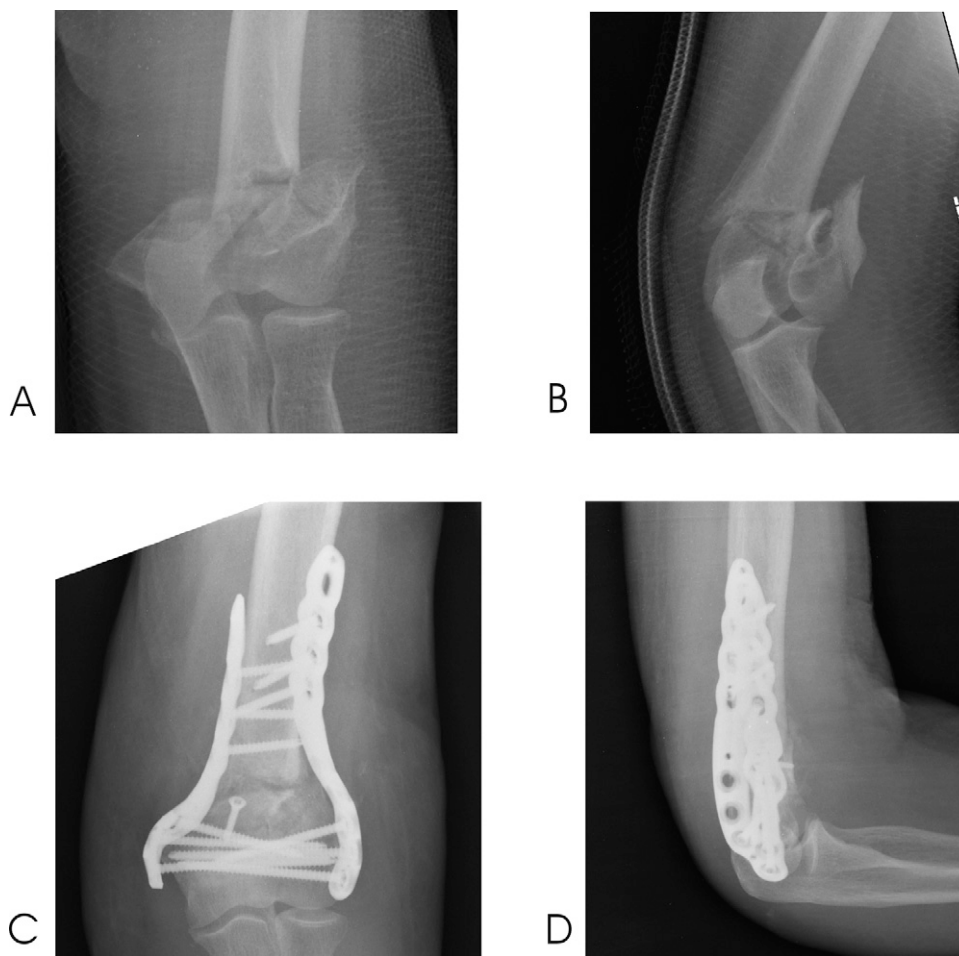


Fig. 2

Radiographs of a seventy-year-old woman with an OTA/AO type-C2 distal humeral fracture. A and B: Pre-operative radiographs. C and D: Six-week follow-up radiographs demonstrating anatomic reconstruction of the articular surface (a paratricipital approach was used) and the use of parallel plate fixation.

planning. Doornberg et al. compared the use of three-dimensional CT reconstructions with the use of two-dimensional CT and radiographs for the classification of distal humeral fractures and treatment decision-making (Level-III evidence)⁵. The authors reported increased interobserver and intraobserver reliability for fracture classification as well as increased intraobserver reliability for treatment decisions with the use of three-dimensional CT. There have been several reports of Level-IV case series in which CT was used, primarily for the evaluation of coronal shear-type fractures of the distal part of the humerus (type B3)⁶⁻⁹.

A Grade-C recommendation can be made for the selective use of CT scanning of fractures of the distal part of the humerus that involve the articular surface, particularly in the setting of articular comminution (Table I).

Nonoperative Treatment

The outcomes of modern operative fixation of distal humeral fractures are such that operative intervention is indicated in most cases. Nonoperative management is reserved for com-

pletely undisplaced fractures, patients who are unable to tolerate anesthesia, and those with advanced dementia. This widely held view is supported by the available evidence, which suggests that operative management of distal humeral fractures is favored over nonoperative management with regard to several outcomes. Two Level-III studies, including one that was based exclusively on patients aged seventy-five years or older, compared functional outcomes between operatively and nonoperatively treated patients ($n = 70$)^{10,11}. We performed a pooled analysis of those two studies, which demonstrated that patients treated nonoperatively are almost three times more likely to have an unacceptable result (RR [relative risk] = 2.8, 95% CI [confidence interval] = 1.78 to 4.4). Another retrospective study, by Robinson et al., compared the results in 273 operatively treated patients with those in forty-seven nonoperatively treated patients (Level-III evidence)¹. The authors reported that nonoperatively treated patients were almost six times more likely to have a nonunion (RR = 5.8, 95% CI = 2.3 to 14.7) and four times more likely to have delayed union (RR = 4.4, 95% CI = 1.6 to 12.0). Numerous, recent Level-IV studies

TABLE I Recommendations for Care

Recommendation	Grade of Recommendation*
There is poor-quality evidence to support the selective use of CT scanning of fractures of the distal part of the humerus that involve the articular surface, particularly in the setting of articular comminution	C
There is fair evidence to support the operative management of all displaced fractures of the distal part of the humerus in patients able to tolerate anesthesia	B
There is poor-quality evidence to support the use of the paratricipital approach for extra-articular or simple intra-articular fractures	C
There is fair evidence to suggest that the use of a triceps-splitting approach leads to functional outcomes similar to those provided by olecranon osteotomy, while potentially avoiding the complications associated with the olecranon osteotomy	B
There is fair evidence to suggest that the use of a triceps-splitting approach leads to functional outcomes that are better than those following an olecranon osteotomy in the treatment of open distal humeral fractures	B
There is fair evidence to support the use of dual plate fixation in either a perpendicular or a parallel configuration for the treatment of distal humeral fractures involving both columns	B
Consideration should be given to the use of a parallel plate configuration, with plates on both columns and at 180° to each other, for comminuted or osteoporotic fractures of the distal part of the humerus	C
There is currently insufficient evidence to recommend for or against the use of locking plates in the management of distal humeral fractures	I
There is poor-quality evidence to recommend the use of CT scanning in the assessment of coronal shear fractures	C
There is poor-quality evidence to recommend ORIF of all displaced coronal shear fractures in patients for whom surgery is suitable	C
There is poor-quality evidence to recommend the use of a lateral approach for the fixation of the majority of coronal shear fractures	C
There is poor-quality evidence to recommend the use of countersunk headless screws, directed anterior to posterior, for the fixation of coronal shear fractures	C
There is fair evidence to suggest that acute total elbow arthroplasty is the preferred treatment for elderly patients (>65 yr old) with a displaced, comminuted, intra-articular distal humeral fracture not amenable to stable internal fixation	B
There is fair evidence to support a recommendation that anterior transposition of the ulnar nerve be performed during the fixation of distal humeral fractures in all patients who exhibited preoperative ulnar nerve symptoms	B
There is insufficient evidence to recommend for or against transposition of the ulnar nerve in patients with a distal humeral fracture who had normal findings on a neurological examination preoperatively	I
There is insufficient evidence to recommend for or against routine prophylaxis against heterotopic ossification following operative fixation of distal humeral fractures	I
There is poor-quality evidence to recommend prophylaxis against heterotopic ossification in patients at particularly high risk for the development of heterotopic ossification, such as those with associated injuries to the central nervous system, a delay in surgical intervention, and surgical procedures prior to definitive fixation	C
There is insufficient evidence to recommend a specific regimen for prophylaxis against heterotopic ossification in patients with a distal humeral fracture	I
There is fair evidence to support the initiation of early range-of-motion exercises (within 14 days) following operative fixation of a distal humeral fracture	B

*A = good evidence from Level-I studies with consistent findings, B = fair evidence from Level-II or III studies with consistent findings, C = poor-quality evidence from Level-IV or V studies with consistent findings, and I = insufficient or conflicting evidence⁸⁹.

on modern techniques of fixation for distal humeral fractures have demonstrated high rates of satisfactory outcomes (47% to 93%), with acceptable rates of complications (19% to 53%)¹²⁻²⁴.

Overall, a Grade-B recommendation can be made for the operative management of all displaced fractures of the distal part of the humerus in patients able to tolerate anesthesia. In patients

for whom anesthesia is deemed to pose too high a risk, conservative treatment with “early mobilization” is appropriate²⁵. This typically involves immobilization of the elbow in 60° of flexion for two to three weeks, followed by gentle range-of-motion exercises.

Operative Approach

Numerous operative approaches for the management of distal humeral fractures have been described. With the exception of approaches described for the fixation of coronal shear fractures (discussed later in this text), these all employ a posterior skin incision with various strategies of working through or around the triceps muscle. Described approaches include the paratricipital (Alonso-Llames)^{26,27}, triceps-reflecting (Bryan-Morrey)²⁸, triceps-reflecting anconeus pedicle (TRAP)²⁹, triceps-splitting^{30,31}, and olecranon osteotomy techniques^{32,33} (Fig. 3). There is controversy regarding the optimal approach for the fixation of distal humeral fractures.

Irrespective of the approach used, the ulnar nerve must always be isolated, mobilized, and protected throughout the

procedure. The nerve is identified proximal to the elbow in the medial intermuscular septum and can be secured with a Penrose drain. The cubital tunnel, proximal fascia of the flexor carpi ulnaris, and articular branch of the ulnar nerve are released, thereby mobilizing the nerve to the level of the first motor branch to the flexor carpi ulnaris (Fig. 4). While there is general agreement about isolation and mobilization of the ulnar nerve, what to do with the nerve at the conclusion of the procedure is a subject of some debate and will be discussed later.

The paratricipital approach avoids violation of the extensor mechanism of the elbow by utilizing medial and lateral windows on either side of the triceps, making it the favored approach for extra-articular fractures (Fig. 5). The major disadvantage of this approach is limited visualization of the articular surface, although visualization is generally adequate for extra-articular fractures and type-C1 and C2 intra-articular fractures^{26,27}. In addition, this approach can be converted to an olecranon osteotomy approach for increased articular exposure

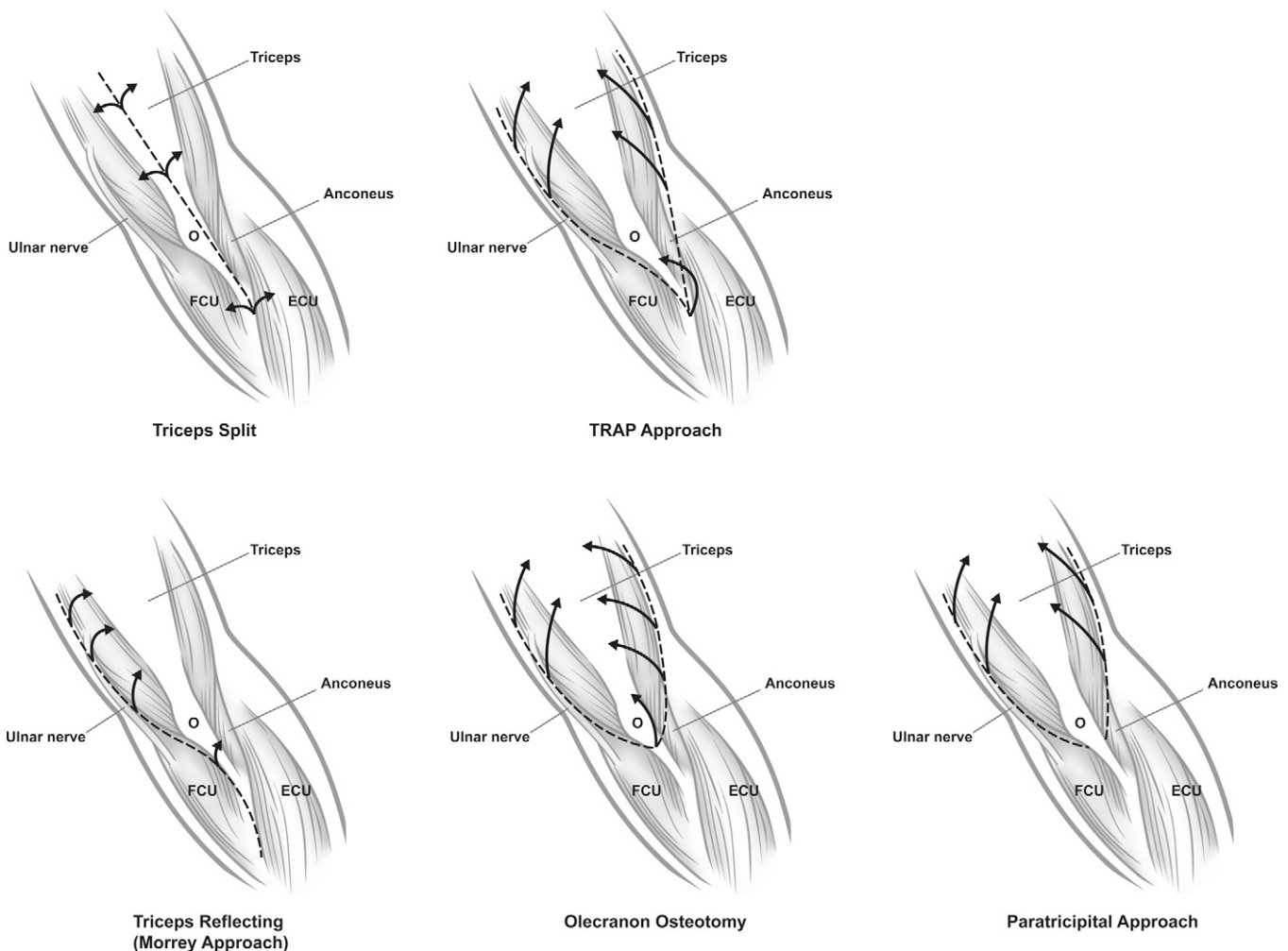


Fig. 3

Schematic illustration of different described operative approaches to the distal part of the humerus (posterior view, right elbow). O = olecranon, FCU = flexor carpi ulnaris, ECU = extensor carpi ulnaris, and TRAP = triceps-reflecting anconeus pedicle.

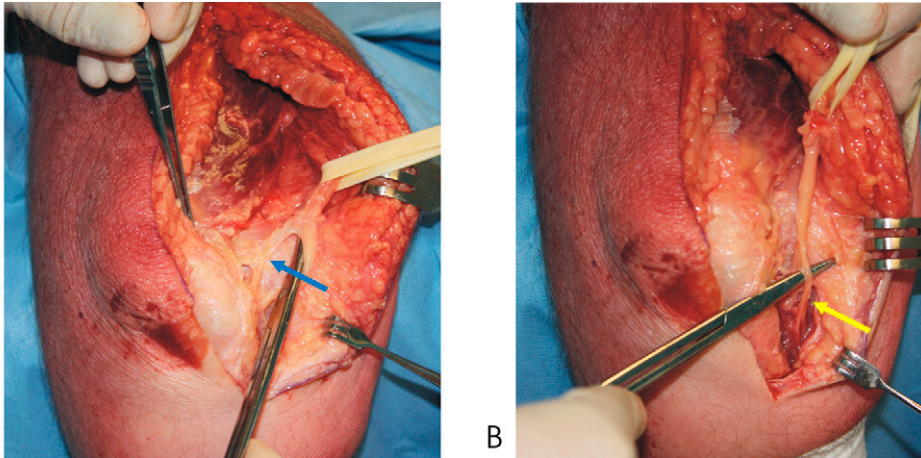


Fig. 4

Cadaveric dissections of approaches to the distal part of the humerus, demonstrating isolation of the ulnar nerve (posterior view, left elbow; Penrose drain placed around the ulnar nerve). *A*: Ulnar nerve dissection, with the blue arrow indicating the articular branch (released). *B*: Ulnar nerve dissection, with the yellow arrow indicating the first motor branch to the flexor carpi ulnaris (preserved).

and facilitates conversion to a total elbow arthroplasty. Satisfactory functional outcomes have been reported with the use of this approach for type-A and type-C1 and C2 fractures (Level-IV evidence)^{26,27}, although we are not aware of any studies comparing this approach with others for distal humeral fractures. Similarly, case series of the triceps-reflecting²⁸ and TRAP²⁹ approaches have been reported (Level-IV evidence), but there is no comparative evidence in the literature on distal humeral fractures.

The triceps-splitting approach involves a midline incision in the triceps fascia with sharp reflection of the triceps insertion off the olecranon, leaving the triceps tendon in continuity with the extensor/flexor fascia (Fig. 6)³⁰. The proximal 1 cm of the olecranon tip is resected to improve visuali-

zation of the articular surface. At the conclusion of the procedure, the triceps tendon is repaired to the olecranon with use of transosseous, nonresorbable sutures.

The olecranon osteotomy approach uses an apex distal, chevron-type osteotomy of the olecranon located 2.5 to 3 cm from the tip of the olecranon, oriented to exit in the so-called bare area of the trochlear groove (Fig. 7). The osteotomy is begun with an oscillating saw and completed with an osteotome. At the conclusion of the procedure, the osteotomy site is fixed with a tension band construct, an intramedullary screw, or a plate.

Anatomic studies have demonstrated that the olecranon osteotomy provides superior visualization of the articular surface³⁴. However, retrospective studies comparing the triceps-splitting

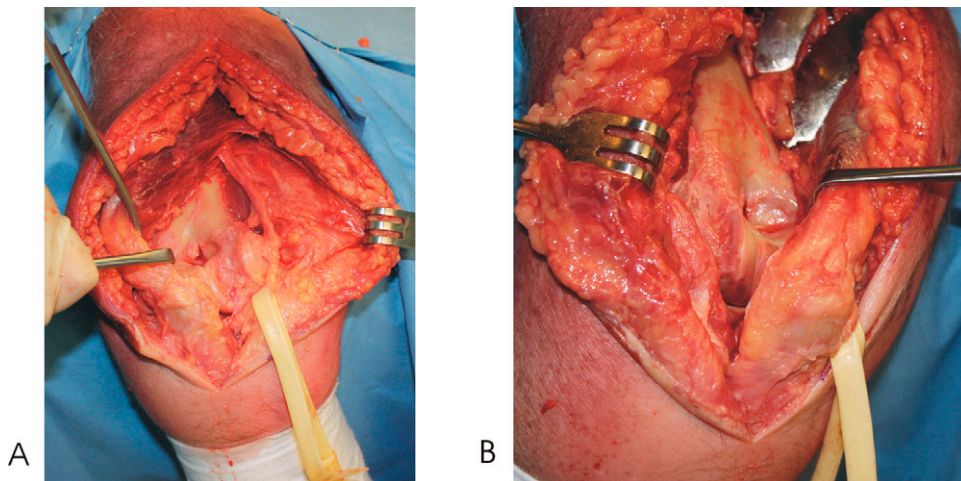


Fig. 5

Paratricipital approach to the distal part of the humerus (posterior view, left elbow; Penrose drain placed around the ulnar nerve). *A*: Medial window. *B*: Lateral window.

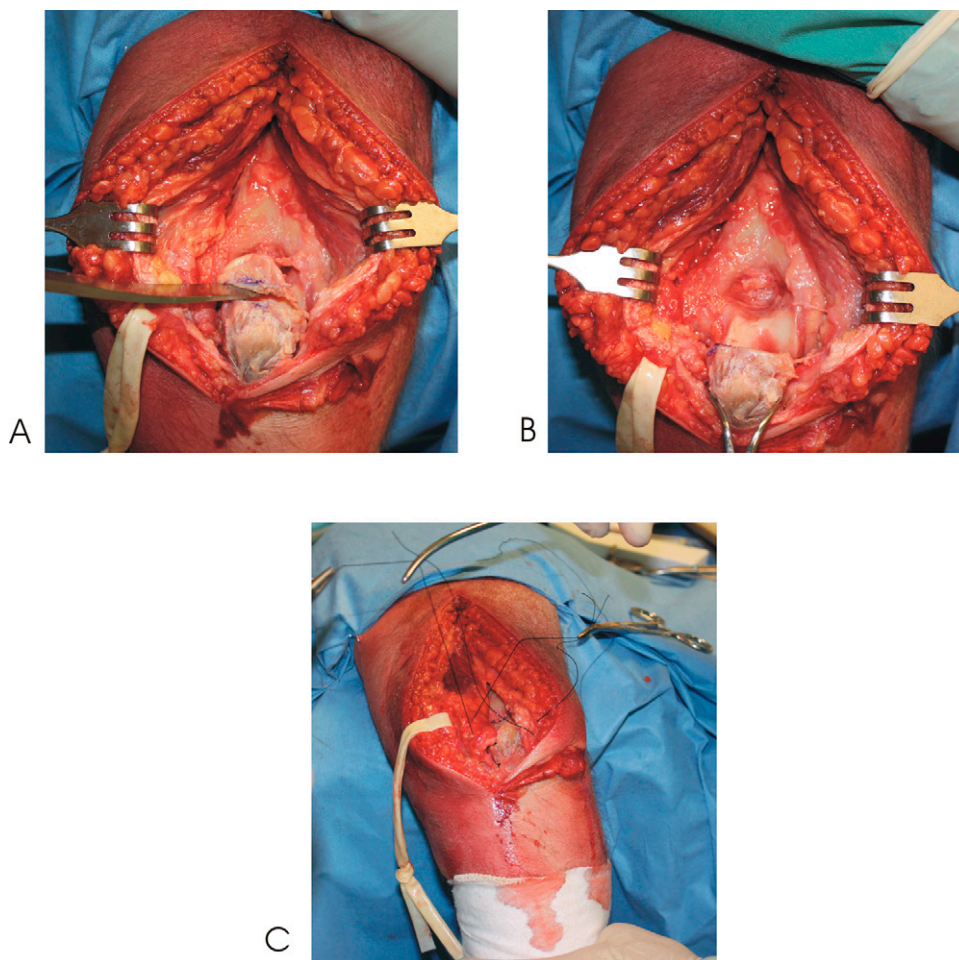


Fig. 6
Triceps-splitting approach to the distal part of the humerus (posterior view, right elbow; Penrose drain placed around the ulnar nerve). *A*: Removal of the olecranon tip to improve visualization. *B*: View of the distal part of the humerus through a triceps-splitting approach. *C*: Reattachment of the triceps tendon with use of transosseous sutures through the olecranon.

and olecranon osteotomy approaches have not shown any significant differences in terms of functional outcomes (Level-III evidence)^{31,35,36}. A retrospective comparison of the two approaches, by McKee et al., showed equivalent outcomes with regard to the Disabilities of the Arm, Shoulder and Hand (DASH) and Short Form-36 (SF-36) scores as well as objective muscle strength testing ($n = 25$ patients)³¹. However, the authors reported that three of eleven patients had a reoperation for removal of the olecranon implant in the osteotomy group (Level-III evidence). Other, Level-IV series of patients treated with olecranon osteotomy have had rates of implant removal ranging from 6% to 30% and rates of nonunion of the olecranon osteotomy site of 0% to 9%^{32,33,37,38}. The triceps-splitting and olecranon osteotomy approaches for the treatment of open distal humeral fractures have also been compared retrospectively³. In that study, of twenty-six patients, the triceps-splitting group had significantly better functional outcomes on the basis of the DASH ($p = 0.05$) and Mayo Elbow Performance Scores

(MEPS) ($p = 0.05$) as well as a trend toward an improved range of motion (Level-III evidence). The authors hypothesized that this effect was due to the fact that open fractures typically were associated with a large tear in the triceps muscle and this tear was easily incorporated into the triceps-splitting approach. This seemed to offer an advantage over sectioning of the extensor mechanism at an adjacent site with an olecranon osteotomy. This study also provided Level-IV evidence that acute plate fixation of open distal humeral fractures was safe and reliable after adequate irrigation and debridement, with only one deep infection developing in the series.

On the basis of the available evidence, a Grade-C recommendation can be made for the use of the paratricipital approach for extra-articular or simple intra-articular fractures. There is fair evidence to suggest that the use of a triceps-splitting approach leads to functional outcomes equivalent to those provided by an olecranon osteotomy while potentially avoiding the complications associated with the olecranon

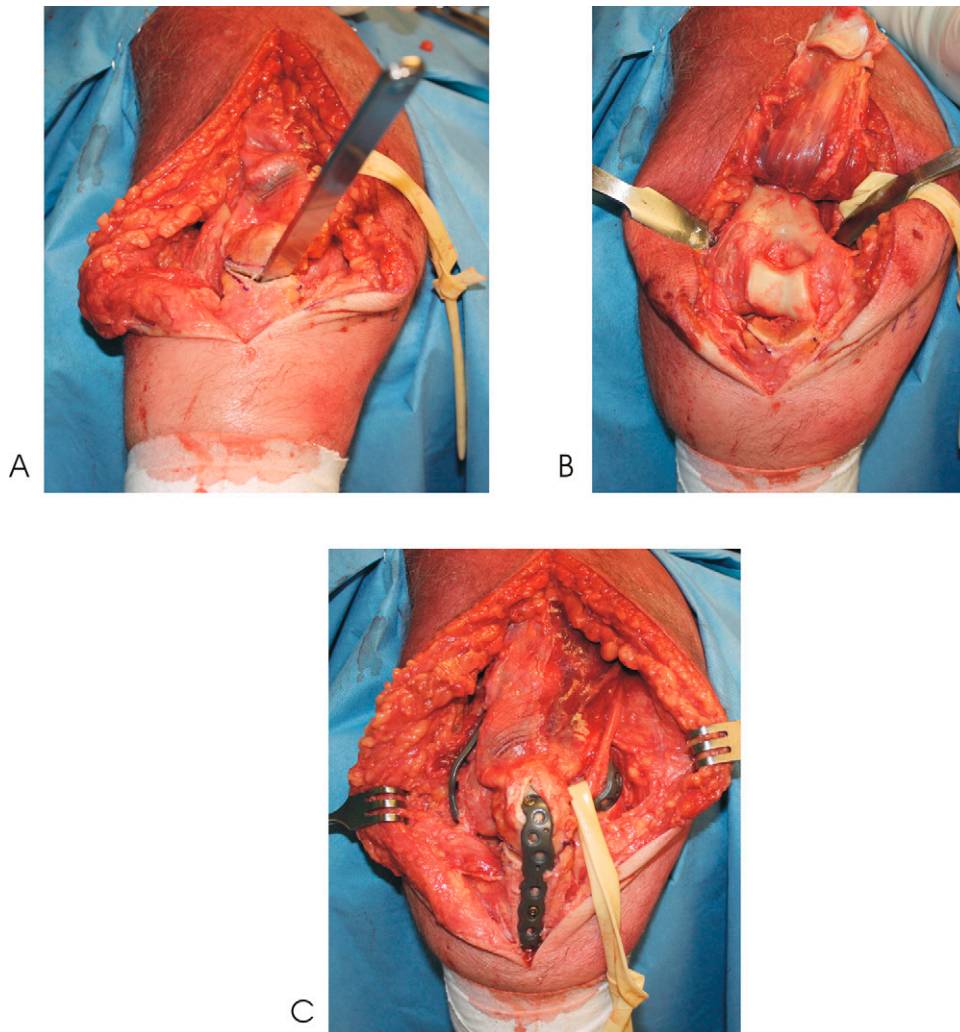


Fig. 7
Olecranon osteotomy approach to the distal part of the humerus (posterior view, left elbow; Penrose drain placed around the ulnar nerve). A: Completion of the olecranon osteotomy with use of an osteotome. B: View of the distal part of the humerus through an olecranon osteotomy approach. C: Plate fixation of the olecranon osteotomy site.

osteotomy, rendering this a Grade-B recommendation. In addition, there is fair evidence to suggest that the use of a triceps-splitting approach leads to improved functional outcomes compared with those following the use of an olecranon osteotomy for the treatment of open distal humeral fractures, rendering this a Grade-B recommendation in that setting.

Plate Fixation

Since the introduction of AO techniques involving dual column plates for the fixation of distal humeral fractures in the 1970s, substantial improvements in surgical outcomes have been observed. The principles of treatment include anatomic articular reduction and rigid fixation with two strong plates. *Strong plates* generally refers to those that are highly rigid and 3.5 mm at a minimum, with the use of one-third tubular plates not recommended. The sequence of fracture reduction typically

involves anatomic reduction and fixation of the articular surface followed by rigid plate fixation of the articular surface to the diaphysis³⁹. In cases of severe comminution of the metaphysis or substantial bone loss in that region, some shortening at the fracture site with maintenance of appropriate alignment of the articular surface is acceptable and can substantially enhance the stability of the fracture, particularly in the setting of osteoporotic bone⁴⁰. Care must be taken to adequately recreate the olecranon fossa or resect a portion of the olecranon tip in order to allow full extension when shortening is carried out. Bone-grafting of the articular surface may be necessary to restore the geometry of a severely comminuted articular surface and usually involves grafting of the trochlea to restore trochlear width when bone loss is present. Otherwise, bone loss is generally associated with open fractures, and bone-grafting is best performed on a delayed basis.

Operative fixation with dual plates was compared with minimal fixation with Kirschner wires or screws in two retrospective Level-III studies (n = 97 patients)^{41,42}. Both studies showed improved functional outcomes following plate fixation. Papaioannou et al. showed that the risk of a poor outcome with the use of Kirschner wires or screws was almost three times higher than the risk with plate fixation (RR = 2.8, 95% CI = 1.5 to 5.1)⁴².

While the evidence supports dual plate fixation for these fractures, there is considerable debate regarding the most appropriate orientation or position of the plate fixation. The main controversy centers around whether plates should be placed on separate columns and perpendicular to each other or in a parallel fashion on the medial and lateral supracondylar ridges (Fig. 8). Shin et al. compared perpendicular and parallel plate fixation in a prospective, randomized study of thirty-five patients (Level-II evidence)²⁴. Although no significant differences were found between the two treatment groups, there were two nonunions in the group managed with perpendicular plate fixation and no nonunions in the group treated with parallel plate fixation. This study may have been underpowered to detect a clinically relevant difference in union rates. Multiple modern case series of patients have shown satisfactory results with perpendicular^{19,20,23,43,44} and parallel^{12-15,17,45} plate fixation techniques (Level-IV evidence). Several biomechanical studies in which a gap model was used to simulate metaphyseal comminution have demonstrated that parallel plate configurations with the plates at 180° to each other are biomechanically superior to perpendicular plates⁴⁶⁻⁴⁸. Some authors have advocated the use of a third plate in the setting of metaphyseal comminution³⁹.

Another area of controversy with regard to plate fixation is the use of locking plates. Locking plates have been shown to provide improved fixation in osteoporotic bone and improved

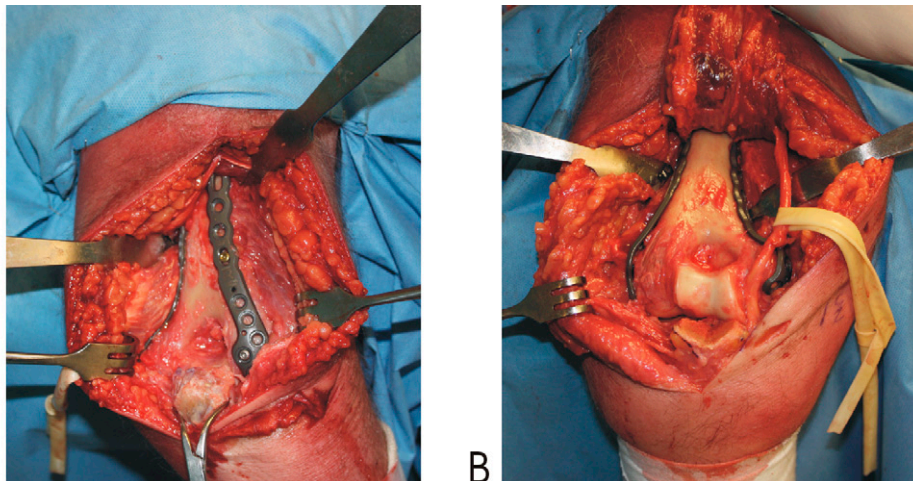
outcomes when used for other periarticular fractures⁴⁹⁻⁵¹. The use of locking plates for distal humeral fractures remains controversial, and the indications for their use are unclear. The high cost of these implants requires that their use be justified by sufficient clinical evidence prior to their application. Two clinical case series on the results of locked plate fixation of distal humeral fractures (n = 52 patients) have been reported^{52,53}. Pooled analysis showed good/excellent results in 79% of the patients, with only a single case of implant failure (Level-IV evidence).

Biomechanical studies have shown that locking plates provided somewhat improved fixation in models of osteoporotic or comminuted distal humeral fractures^{46,54,55}. Despite the lack of available evidence in support of locking plates, many experts believe that their use may be advantageous in the management of comminuted, osteoporotic fractures.

On the basis of the available evidence, several recommendations can be made regarding the use of plate fixation. First, a Grade-B recommendation can be made for the use of dual plate fixation in either a perpendicular or parallel configuration for the treatment of distal humeral fractures involving both columns. Second, a Grade-C recommendation can be made for considering the use of a parallel plate configuration, with plates on both columns and at 180° to each other, for the treatment of distal humeral fractures complicated by comminution or osteoporosis. Finally, there is currently insufficient evidence to recommend for or against the use of locking plates in the management of these fractures, rendering it a Grade-I recommendation.

Coronal Shear Fractures

Isolated coronal plane fractures of the distal humeral articular surface (OTA/AO type B3) are relatively rare, accounting for a small percentage of distal humeral fractures⁵⁶. They represent shear-type injuries involving the capitellum, trochlea, or both.



A
Fig. 8

Plate configurations for distal humeral fractures. **A:** Perpendicular plate fixation via a triceps-splitting approach (posterior view, right elbow; Penrose drain placed around the ulnar nerve). **B:** Parallel plate fixation via an olecranon osteotomy approach (posterior view, left elbow; Penrose drain placed around the ulnar nerve).

It is important to recognize that these injuries can occur in isolation or in association with other fractures of the distal part of the humerus, the radial head, or the olecranon. In addition, they can be associated with concomitant elbow dislocation and ligamentous injuries. Their rarity makes it extremely difficult to study these injuries in a prospective or randomized manner. Therefore, much of the published literature on these fractures is based on retrospective case series (Level-IV evidence).

The most commonly used classification system for coronal shear fractures was originally described by Bryan and Morrey⁵⁶ and later modified by McKee et al.⁵⁷ In this classification system, which is based on radiographs, type I represents a coronal shear fracture of the capitellum (Hahn-Steinthal fracture), type II is an osteochondral lesion of the capitellum (Kocher-Lorenz fracture), type III is a comminuted fracture of the capitellum, and type IV represents a fracture of the capitellum with medial extension encompassing part or all of the trochlea.

Evaluation of a patient with a coronal shear fracture begins with clinical assessment and radiography. The lateral radiograph is the most illustrative view of this type of fracture, and the appearance of a so-called double-arc sign is pathognomonic of a type-IV fracture with extension into a substantial portion of the trochlea (Fig. 9)⁵⁷. Several Level-IV case series have documented that it is difficult to clearly define coronal shear fractures on the basis of radiographs alone, and the authors of those studies have recommended preoperative CT to better define these injuries^{6,8,9,57}. Watts et al. showed that preoperative radiographs had a sensitivity of 66% and a negative predictive value of 63% for identifying extension beyond the capitellum⁹. On the basis of these studies,

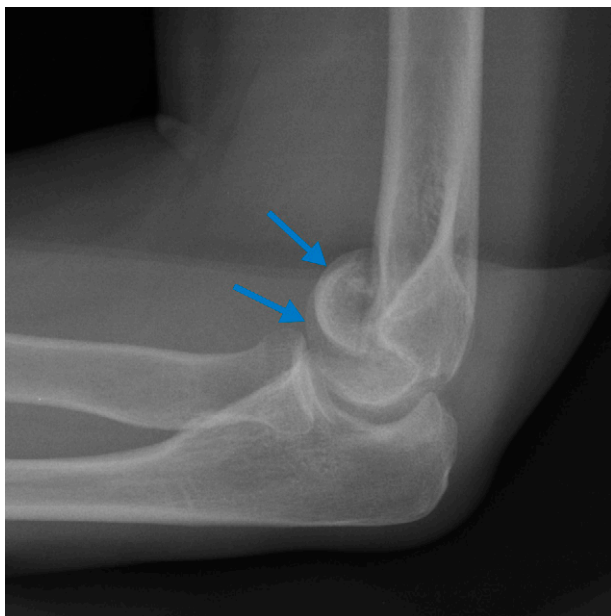


Fig. 9

Lateral radiograph of a fifty-year-old woman with a type-IV coronal shear fracture, demonstrating a double-arc sign. The blue arrows indicate two distinct visible arcs.

a Grade-C recommendation can be made for the use of CT scanning in the assessment of coronal shear fractures.

Suboptimal results in previous series in which coronal shear fractures had been treated with prolonged immobilization or excision, combined with biomechanical evidence showing that capitellar excision in association with ligamentous injury results in substantial elbow instability, have led to a shift toward operative fixation for these injuries⁵⁸⁻⁶¹. Numerous Level-IV case series of coronal shear fractures managed with operative fixation have demonstrated a high proportion of good to excellent results on the basis of the MEPS and mean flexion-extension arcs ranging from 96° to 132°^{8,57,62-69}. Guitton et al. recently reported on the durability of these results at a median of seventeen years⁷⁰. These superior results have been attributed to the fact that surgical fixation allows anatomic reduction with stable fixation and the initiation of early range-of-motion exercises. Despite the improved results of operative fixation, many authors have noted that more complex fracture patterns were associated with poorer functional results^{63,70}. We are not aware of any studies in the literature in which operative fixation of coronal shear fractures was compared with excision or with nonoperative treatment. Overall, a Grade-C recommendation can be made for open reduction and internal fixation (ORIF) of all displaced coronal shear fractures in patients for whom operative treatment is suitable.

A lateral approach has been used in the majority of clinical series of coronal shear fractures treated with ORIF^{8,57,62,64,66,67,69}. Infrequently, medial extension and comminution of coronal shear fractures may result in a separate trochlear fragment that is not accessible from the lateral approach. Authors have advocated a separate medial approach or an olecranon osteotomy in these instances^{62,63,68}. A Grade-C recommendation can be made for the use of a lateral approach for the fixation of the majority of coronal shear fractures. In instances of medial comminution, a separate medial approach or, alternatively, a single approach via an olecranon osteotomy is appropriate.

Multiple fixation strategies have been described in the literature, and there are no comparative clinical studies to suggest improved outcomes with any particular fixation strategy. In most modern series in which coronal shear fractures were treated with operative fixation, countersunk headless screws were used in an anterior-to-posterior fashion, with plate supplementation on the lateral column in instances of comminution extending beyond the articular surface^{8,62,64-69}. There is also biomechanical evidence to suggest that anterior-to-posterior headless screws are biomechanically superior to posterior-to-anterior cancellous screws⁷¹. In addition, anterior-to-posterior screw placement has the potential advantage of avoiding disruption of the posterior soft tissues (which are usually intact) and allowing better preservation of blood supply⁷². Overall, a Grade-C recommendation can be made for the use of countersunk headless screws, directed anterior to posterior, for the fixation of coronal shear fractures.

Total Elbow Arthroplasty

Distal humeral fractures with comminution of the articular surface can be difficult to manage, even in young patients with

excellent bone quality. This challenge increases exponentially in elderly patients with poor bone quality and substantial articular comminution, and surgical outcomes have historically been poor in such patients. This has prompted many authors to investigate, and more recently advocate for, the role of acute total elbow arthroplasty in the management of distal humeral fractures in elderly patients.

In a prospective, randomized, multicenter study, McKee et al. compared ORIF with total elbow arthroplasty for displaced, comminuted, intra-articular fractures of the distal part of the humerus (OTA/AO type C) in forty patients over the age of sixty-five years (Level-II evidence)⁷³. The authors reported better functional outcomes in the total elbow arthroplasty group than in the ORIF group on the basis of DASH scores and MEPS at two years postoperatively. In addition, there was a 25% rate (five of twenty patients) of intraoperative conversion to total elbow arthroplasty in the ORIF group because of extensive comminution and an inability to achieve stable fixation. We identified three retrospective Level-III studies comparing ORIF and total elbow arthroplasty in 256 elderly patients with an intra-articular distal humeral fracture⁷⁴⁻⁷⁶. Pooled analysis of the results suggests that total elbow arthroplasty results in a higher proportion of patients experiencing a good/excellent functional outcome (89% versus 76% in the ORIF group, $p = 0.036$). Complication rates did not differ significantly between the two groups.

We found a single Level-III study in which the outcomes of acute total elbow arthroplasty for distal humeral fractures were retrospectively compared with the outcomes of delayed total elbow arthroplasty following failed ORIF or conservative treatment ($n = 32$ patients)⁷⁷. The authors reported a high rate of good/excellent functional outcomes (in eleven of thirteen patients treated with acute total elbow arthroplasty and eleven of fourteen treated with the delayed procedure) with no significant differences between the two treatment groups. However, the results showed trends toward increased rates of infection, nerve injury, and implant failure in the delayed-treatment group, and the study was likely underpowered to detect clinically relevant differences in the rates of these complications between the groups. Most experts agree that a primary total elbow arthroplasty is dramatically better, with regard to complication rates and ease of operative treatment, than delayed total elbow arthroplasty following failed ORIF for management of a fracture.

While most distal humeral fractures in elderly patients are amenable to ORIF, a substantial subset may not be reconstructable (25% [five] of twenty patients in one study⁷³) and would seem to benefit from acute total elbow arthroplasty. This is particularly relevant to patients with preexisting arthritis of the elbow^{75,76}. It is critical to avoid the use of an olecranon osteotomy for the operative approach when acute total elbow arthroplasty is anticipated or being considered, as this approach compromises fixation of the olecranon component and is contraindicated for total elbow arthroplasty. While the early results of acute total elbow arthroplasty are encouraging, long-term studies evaluating the longevity of total elbow replacements after fracture are lacking. Additionally, many experts are

concerned about the higher rate of infection after total elbow arthroplasty and the subsequent difficulty in managing this complication. Overall, there is fair evidence to suggest that acute total elbow arthroplasty is the preferred treatment for elderly patients (older than sixty-five years) with a displaced, comminuted, intra-articular distal humeral fracture that is not amenable to stable internal fixation, rendering it a Grade-B recommendation.

Complications of Distal Humeral Fractures

Ulnar Nerve

Distal humeral fractures are often complicated by injury to the ulnar nerve due to either the original injury or the operative intervention. There is controversy regarding the management of the ulnar nerve during operative intervention, with some authors recommending routine anterior transposition and others recommending in situ decompression alone. Ruan et al. prospectively randomized twenty-nine patients with a distal humeral fracture and preoperative ulnar nerve symptoms to either anterior subcutaneous transposition of the ulnar nerve or in situ decompression (Level-II evidence)⁴. The results showed significantly improved outcomes in the transposition group, with complete nerve recovery in twelve of fifteen patients in that group versus eight of fourteen patients treated with decompression alone ($p < 0.05$). Chen et al. performed a retrospective analysis of patients who had had either in situ release of the ulnar nerve alone or anterior transposition following ORIF (Level-III evidence)⁷⁸. They included patients with normal ulnar nerve function on preoperative examination as well as those with preoperative ulnar nerve symptoms. They found a 33% rate of ulnar neuritis postoperatively in the transposition group (sixteen of forty-eight patients) versus a 9% rate in the group without transposition (eight of eighty-nine patients) ($p = 0.0003$), suggesting a lack of benefit from transposition of the nerve. Vazquez et al. retrospectively reviewed the results in two groups of patients with no preoperative ulnar nerve symptoms who were treated with transposition or no transposition (Level-III evidence)⁷⁹. They reported an overall 20% rate of documented ulnar nerve dysfunction (fourteen of sixty-nine patients) postoperatively, with no significant differences between the two groups. The authors concluded that anterior transposition of the nerve was not protective in their analysis. Several Level-IV studies have demonstrated rates of ulnar neuropathy ranging from 0% to 12.5% after routine anterior subcutaneous transposition in patients in whom the ulnar nerve had been normal preoperatively^{4,12,17,24,38,80}. Doornberg et al. reported the twelve to thirty-year results of surgical treatment of a distal humeral fracture with no transposition of the ulnar nerve⁸¹. Of the thirty patients evaluated, only one had symptoms of ulnar nerve dysfunction at the time of final follow-up (Level-IV evidence). The literature on this topic remains somewhat conflicting, and the management of the ulnar nerve following ORIF of a distal humeral fracture in patients who had normal findings on a neurological examination preoperatively remains an unresolved issue.

Overall, a Grade-B recommendation can be made for anterior transposition of the ulnar nerve during the fixation of distal humeral fractures in all patients who exhibit preoperative ulnar nerve symptoms. There is insufficient evidence to recommend for or against transposition of the ulnar nerve in patients with a distal humeral fracture who have normal findings on neurological examination preoperatively, rendering it a Grade-I recommendation.

Heterotopic Ossification

Heterotopic ossification can cause important limitations in elbow motion and function when it occurs following operative intervention for distal humeral fractures. The indications for prophylaxis against heterotopic ossification after surgical management of a distal humeral fractures are controversial, with some authors recommending routine prophylaxis and others recommending selected use of prophylaxis in certain patients with risk factors for the development of heterotopic ossification.

Gofton et al. retrospectively reviewed the prevalence of heterotopic ossification in two groups of patients who had undergone operative treatment of a distal humeral fracture: one in which prophylaxis had not been used and one in which prophylaxis with indomethacin had been used for six weeks ($n = 23$ patients)³⁸. Five of the twelve patients who had not received prophylaxis developed heterotopic ossification, whereas only two of the eleven who had received indomethacin did. The difference between the groups was not significant, although, with the number of patients evaluated, the study was likely underpowered to detect a clinically relevant difference in the development of heterotopic ossification. Authors of modern studies of operative fixation of distal humeral fractures in which routine prophylaxis of heterotopic ossification was not used have reported rates of clinically relevant heterotopic ossification ranging from 0% to 21%^{10-13,17,82}. Pooled analysis of the data from these studies ($n = 239$ patients) demonstrates an overall 8.6% rate of symptomatic heterotopic ossification when



Fig. 10

Radiographs of a sixty-year-old male physician with early fixation failure of a type-C2 fracture due to inadequate fixation. A and B: Radiographs made two weeks after the initial surgery showing fixation failure. The arrow shows a loose screw in the soft tissues. C and D: Three-month follow-up radiographs demonstrating revision ORIF with use of a parallel plate construct.

routine prophylaxis was not used (Level-IV evidence). The authors of two recent Level-IV studies have reported on routine prophylaxis against heterotopic ossification in series of distal humeral fractures treated operatively. In one study, Shin et al. used an initial dose of radiation therapy on postoperative day one, followed by two weeks of indomethacin²⁴. The authors reported a rate of symptomatic heterotopic ossification of 3% (one of thirty-five patients), with a nonunion rate of 6% (two of thirty-five patients). Liu et al. used six weeks of Celebrex (celecoxib) for routine prophylaxis and reported a 3% rate of clinically symptomatic heterotopic ossification (one of thirty-two patients), with no nonunions⁸³. The potential benefits of prophylaxis with nonsteroidal anti-inflammatory drugs (NSAIDs) against heterotopic ossification must be weighed against the known potential for these medications to increase nonunion rates⁸⁴.

Risk factors that have been reported in the literature to substantially increase the risk of development of heterotopic ossification in association with a distal humeral fracture include central nervous system injury⁸⁵, delay in operative intervention⁸², and surgery prior to definitive fixation¹⁷.

Overall, there is insufficient evidence to recommend for or against routine prophylaxis against heterotopic ossification following operative fixation of distal humeral fractures (Grade-I recommendation). A Grade-C recommendation can be made for the use of prophylaxis against heterotopic ossification in patients at particularly high risk for the development of heterotopic ossification. There is insufficient evidence to recommend a specific regimen for prophylaxis against heterotopic ossification for patients with a distal humeral fracture (Grade-I recommendation).

Nonunion, Elbow Stiffness, and Functional Outcomes

Modern studies of dual plate fixation of distal humeral fractures have demonstrated excellent union rates ranging from 89% (sixteen of eighteen patients)³⁶ to 100% (sixteen of sixteen patients)¹³ (Level-IV evidence). However, failing to adhere to the principles of rigid fixation with a strong plate on each column can dramatically increase nonunion rates (Fig. 10). When a nonunion does occur, it can be reliably treated with revision ORIF, bone-grafting, and selective elbow release⁸⁶. On the basis of modern series in which patients were treated with rigid fixation and early range-of-motion exercises, a mean

flexion-extension arc of 99° to 112° can be expected (Level-IV evidence)^{17,19}. Several retrospective series have highlighted the importance of early range-of-motion exercises with respect to functional outcome and the final arc of flexion (Level-III evidence)^{36,42,87,88}. A Grade-B recommendation can be made for initiating early range-of-motion exercises (within fourteen days) following operative fixation of a distal humeral fracture.

With respect to functional outcomes, authors of recent studies have reported 84% to 100% rates of good/excellent outcomes on the basis of the MEPS (Level-IV evidence)^{17,43}. Mean DASH scores following operative treatment of distal humeral fractures in modern series have been reported to range from 18.5 to 46.1, indicating mild to moderate residual impairment (Level-IV evidence)^{13,53}. In addition, objective strength testing has shown that patients typically regain 70% to 75% of their flexion and extension strength relative to the strength on the uninjured side (Level-IV evidence)^{31,53}.

Overview

The literature on distal humeral fractures largely comprises Level-III or IV studies. In addition, the few comparative studies that have been reported have often been underpowered to detect clinically relevant differences between treatment groups. Therefore, decision-making regarding the management of distal humeral fractures must be based on a combination of the best available evidence, surgeon preference and comfort, and informed discussions with the patient. There is clearly a need for prospective, multicenter, large-scale trials to aid surgical decision-making in the future regarding the treatment of distal humeral fractures. ■

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