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GENERAL REVIEW

Management of distal humerus fractures

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Abstract
Distal humeral fractures represent approximately 2% of fractures in adults and are often treated operatively to restore stable humeral columns and allow early elbow motion. Diagnosis is made with orthogonal radiographs. The traction view radiograph and computed tomography with three-dimensional reconstruction can be helpful in preoperative planning. Treatment options include: (1) nonoperative management, which is reserved for lower-demand, medically unwell, elderly patients, (2) surgical osteosynthesis, which remains the treatment of choice for most fractures, and (3) prosthetic replacement with either hemiarthroplasty or total elbow arthroplasty, which is indicated for distal complex comminuted fracture patterns in elderly, low-demand patients with poor bone quality. A thorough understanding of the anatomy around the elbow is critical when planning surgical approach and reduction. Controversies exist in the following areas: (1) surgical approach, (2) management of the ulnar nerve, (3) plating technique—parallel versus orthogonal, and (4) whether osteosynthesis or prosthetic elbow replacement is superior in the elderly population.

Keywords Distal humerus fractures · Plating technique · Prosthetic replacement · Trauma · Ulnar nerve management

Introduction

Distal humeral fractures (DHF) are complex injuries that have an estimated incidence of 5.7 per 100,000 persons per year in adults [1], account for 0.5–7% of all fractures, and represent approximately 30% of fractures about the elbow [2]. These fractures occur in a bimodal distribution, peaking early in young patients with high-energy trauma and late in elderly patients with osteoporotic bone resulting from lower-energy falls [2, 3]. DHF tend to occur when the elbow is in a high degree of flexion (more than 110°), compared to the more extended elbow (90° or less) which tends to result in fractures of the olecranon, radial head, or coronoid [4].

Prior to the 1960s, treatment of DHF was predominantly nonoperative. Closed treatment included traction, condylar compression, cuff-and-collar support with early mobilization, reduction and casting, and the "bag of bones" treatment with brief immobilization followed by early mobilization [5]. After the 1960s and the development of the Arbeitsgemeinschaft für Osteosynthesefragen (AO) fracture fixation principles of anatomical reduction, stable fixation, preservation of blood supply, and early mobilization, the number of reports of successful treatment with internal fixation increased.

In patients with good bone quality, operative management is considered the standard of care with plate osteosynthesis (open reduction internal fixation, ORIF). In the elderly, osteoporotic bone, multifragmentary comminution, and very distal fragments provide significant challenges to adequate fixation. Treatment options include osteosynthesis when possible, or prosthetic elbow replacement which has shown promise in prospective comparative trials [6]. Nonoperative management has been recently revisited with reasonable outcomes in elderly patients with medical comorbidities [7].

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Clinical evaluation

Examination includes circumferential inspection to identify sites of open fractures, which are most commonly posterior when present [8]. Open wounds should be cleaned with gentle bedside debridement with administration of antibiotic and tetanus prophylaxis until operative debridement can be performed. Vascular examination is critical, and gentle traction to re-align any deformity may be necessary to normalize the vascular examination. When abnormal, angiography or operative exploration is warranted. Neurological evaluation is necessary as up to 24.8% of bicondylar articular fracture patterns (AO Type C) have associated ulnar nerve symptoms [9].

Diagnosis

Radiographic evaluation should include anteroposterior, oblique, lateral, and traction views of the elbow (Fig. 1). Additional imaging of the limb to the level of the joint above (shoulder) and joint below (wrist) is a common practice to diagnose concomitant injuries, present in up to 17% [2]. The "double arc" sign on the lateral radiograph is suggestive of coronal shear articular fractures. Noncontrast computed tomography (CT) can be valuable in surgical planning (Fig. 2).

Classification

The most commonly used classification system is that of the Orthopaedic Trauma Association (OTA/AO). The column concept [10] divides the distal humerus into two diverging columns, corresponding to the anatomical condyles, which support the trochlea distally (Fig. 3). Restoring this relationship is the goal of surgical fixation.

DHF are divided into: (1) extracapsular fractures of the supracondylar region, (2) intracapsular extra-articular fractures (transcondylar), and (3) intracapsular intra-articular fractures (intercondylar). The intercondylar fractures can be subdivided into: (a) partial articular unicondylar and (b) complete articular bicondylar fractures. These patterns are treated using parallel or orthogonal plating.

More distal fracture variants are less common and include coronal plane shear-type fractures of the capitellum and trochlea. These fractures result from an axial load [11], and the amount of involvement in the posterior condylar region influences fixation requirements and outcomes [12]. Shear fractures without posterior comminution can be treated with screw fixation perpendicular to the fracture line buried deep to the articular cartilage. For fractures with posterior involvement, the addition of a plate to restore the stability of the fractured column is often required [13].

Treatment algorithm

Patient factors including age, medical comorbidities, vocation, and expectations should be considered (Fig. 4) [14].

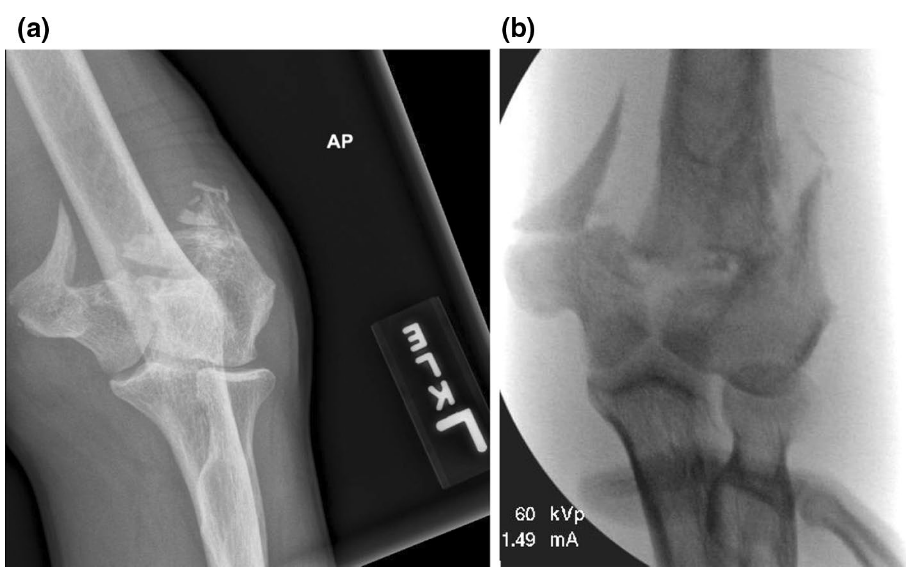


Fig. 1 Radiographic traction view. DHF (AO C-type fracture) showing the injury radiograph (**a**) and the traction film (**b**) highlighting the comminution of the medial and lateral columns. The traction view is helpful when the fracture pattern is multifragmentary and the standard views are difficult to interpret. Courtesy of Marc J. Richard, MD [Durham, NC]

Fig. 2 Computed tomography evaluation of DHF. Plain radiographs (**a**), compared to three-dimensional CT reconstruction (**b**) help delineate the extent of trochlear involvement and comminution of the lateral column. CT is useful in fractures that extend distal to the olecranon fossa. Courtesy of Daphne Beingessner, MD, MSc, FRCSC [Seattle, WA]

Nonoperative management

Nonoperative management is reserved for fractures with no displacement, patients with unstable medical problems, those who are unable to undergo surgical anesthetic, or with advanced dementia, stroke, or paralysis [7, 14]. Nonoperative treatment consists of a brief period of immobilization, less than 21 days, with the elbow in 60° of flexion followed by early gentle motion.

Pooled data from two Level III studies demonstrated that elderly patients treated nonoperatively were more likely to have an unacceptable result (RR [relative risk] 2.8) compared to those treated operatively [3]. A retrospective study by Robinson et al. compared 273 patients treated operatively to 47 patients treated nonoperatively (Level III) and found a significantly higher rate of nonunion (RR 5.8) and delayed union (RR 4.4) in the nonoperative group [1]. More recently, Aitken et al. reviewed 40 elderly low-demand patients treated with nonoperative measures (Level IV). At short-term follow-up, patients improved Broberg and Morrey scores from 42 points at 6 weeks to 67 points at 3 months. Surviving patients ($n = 20$, 50%) at medium-term follow-up had a mean Disabilities of the Arm Shoulder and Hand (DASH) score of 38 points with 95% of patients having functional elbow range of motion. Union was 53% at one year [15]. Desloges et al. reviewed 32 low-demand, frail, elderly patients with DHF treated nonoperatively. At mean follow-up of 27 months, 19 patients (60%) were available for assessment. Thirteen patients (68%) reported good or excellent subjective outcomes, and a mean Mayo Elbow Performance Score (MEPS) was 90, but the comparison of the injured to uninjured elbow identified significantly worse

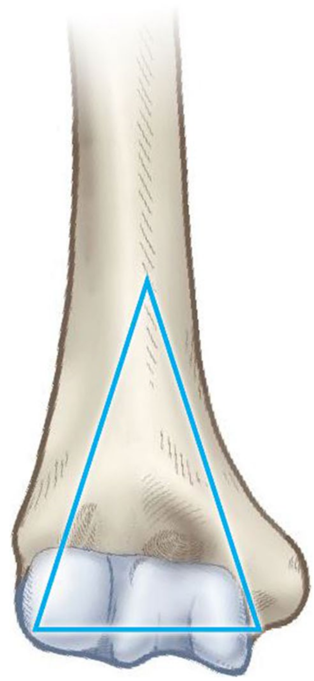


Fig. 3 Distal humeral triangle outlining the medial column, lateral column, and trochlea. Reproduced with permission from ASSH Textbook of Hand Surgery, 2019

range of motion in the injured arm. Union rate at 1 year was 81%, notably higher than comparable reports. The authors concluded that satisfactory outcomes could be obtained with nonoperative management of DHF when selecting lower-demand, medically unwell, elderly patients [7].

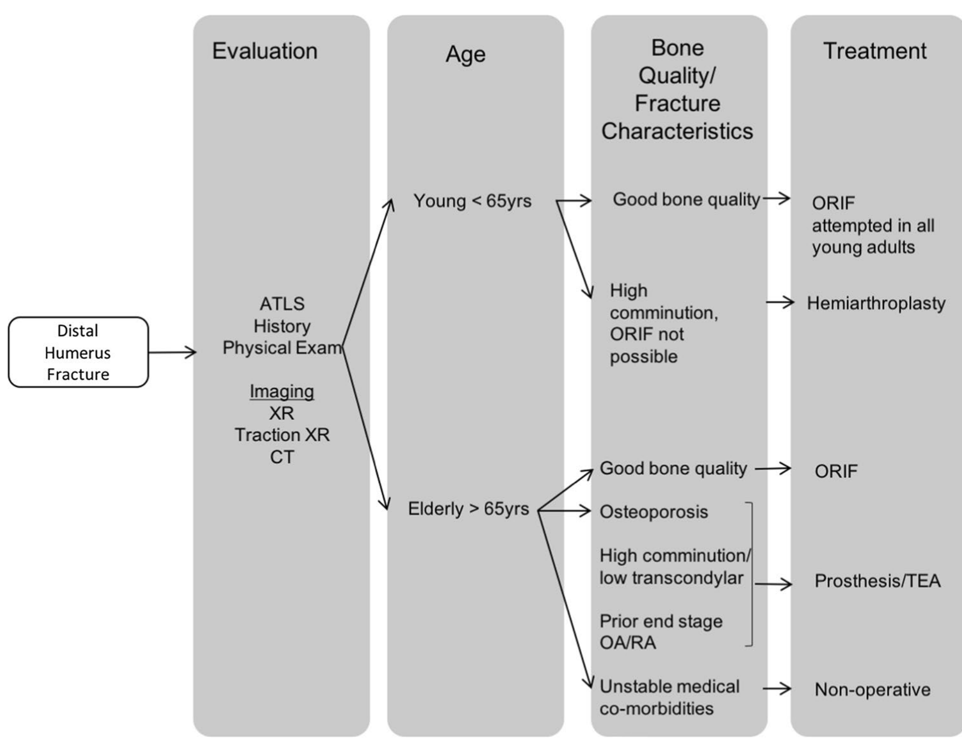
Surgical approaches to the distal humerus

A comprehensive understanding of elbow anatomy is critical (Figs. 5, 6, 7). Surgical approaches depend upon fracture morphology, but comparative analyses between various approaches are limited [3]. A posterior approach variant is commonly utilized for fractures with columnar involvement. The olecranon and triceps are fixed, limiting articular visualization. Posterior approaches are thus divided into: (1) procedures that mobilize the extensor mechanism and (2) those that detach it [16]. Coronal shear fracture patterns, when the posterior columnar stability is intact, can be treated with the lateral column approach. Patient positioning may be supine, lateral, or prone based on surgeon preference, concomitant injuries, and anticipated exposure needs [16, 17].

Universal posterior incision

A posterior midline incision (Fig. 8) from mid-brachium to 4 cm distal to the olecranon tip is made curving radially around the olecranon. The ulnar nerve is isolated, mobilized, and protected as plate fixation of the medial column places it at risk. The radial nerve is not typically identified unless the fracture extends proximally where fixation near the spiral

Fig. 4 Treatment algorithm for treatment of adult DHF. Reproduced with permission from ASSH Textbook of Hand Surgery, 2019



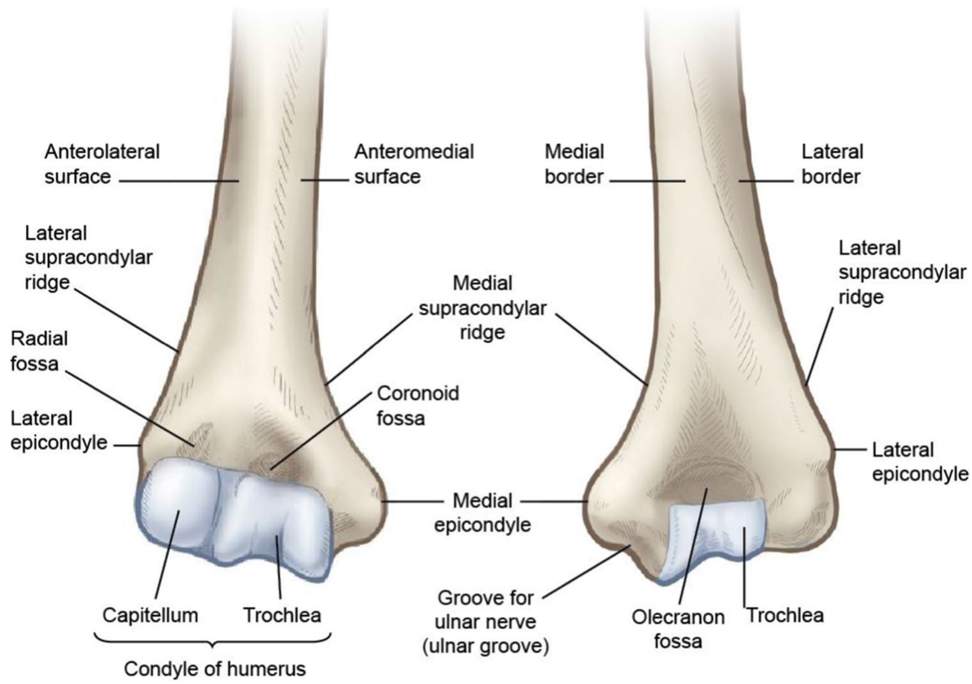


Fig. 5 Osseous anatomy of the distal humerus. Reproduced with permission from ASSH Textbook of Hand Surgery, 2019

groove is necessary [3, 16]. Posterior approach variations are outlined in Table 1.

Outcomes of posterior surgical approaches

Level III comparative evidence in 25 patients failed to show significant differences in functional outcomes between olecranon osteotomy versus the triceps-splitting approach for closed DHF with regard to DASH scores, Short Form-36 (SF36), and muscle strength testing [17]. Reported hardware removal rates can approach 30% in those treated with osteotomy [18, 19]. Open DHF may favor the use of the triceps-splitting approach as one Level III comparative study in 26 patients showed significantly improved DASH and MEPS, postulated to be a result of large tear in the triceps muscle which was incorporated into the triceps split approach [8]. Illical et al. compared elbow motion, extension strength, and DASH scores in 39 patients who underwent either triceps split or paratricipital exposure for extra-articular (AO type A) fractures. The study found a significant decrease in elbow motion and strength in the triceps-splitting group [20].

Lateral column approach

The lateral approach (Fig. 9) is indicated when visualization of the anterior distal humeral articular surface is needed, as in coronal shear-type fractures. Skin incision may be lateral, directly over the extensor carpi ulnaris–anconeus (Kocher) interval, or posterior raising a lateral adipocutaneous flap prior to proceeding to the Kocher interval. Dissection proceeds distally along the radial neck with the forearm pronated to protect the posterior interosseous nerve (PIN) [21]. The LCL can be reflected off its origin with the anconeus to allow hinging the joint in varus on the intact medial collateral ligament (MCL). If performed, the LCL must be repaired to its isometric origin with either transosseous fixation or suture anchors to prevent posterolateral rotatory instability.

Management of the ulnar nerve

Controversy remains regarding the optimal handling of the ulnar nerve after surgical fixation of DHF. It is a common practice in posterior approaches to mobilize and protect the nerve for the duration of surgical fixation. Post-fixation, the nerve is either returned it to its native position or transposed anteriorly.

A recent meta-analysis analyzed five retrospective studies (Level IV evidence) comprising 366 DHF treated surgically with either in situ management or anterior transposition of the ulnar nerve (Table 2). One hundred and eighty-seven patients were treated with in situ management compared to 179 who underwent transposition. The incidence of ulnar neuritis in all cases was 19%. The meta-analysis found a higher incidence of ulnar neuropathy in the transposition group (23.5%) compared to the in situ group (15.3%), and the authors concluded that transposition of the ulnar nerve during surgical treatment of DHF does not have a positive effect with regard to ulnar nerve symptoms postoperatively [22].

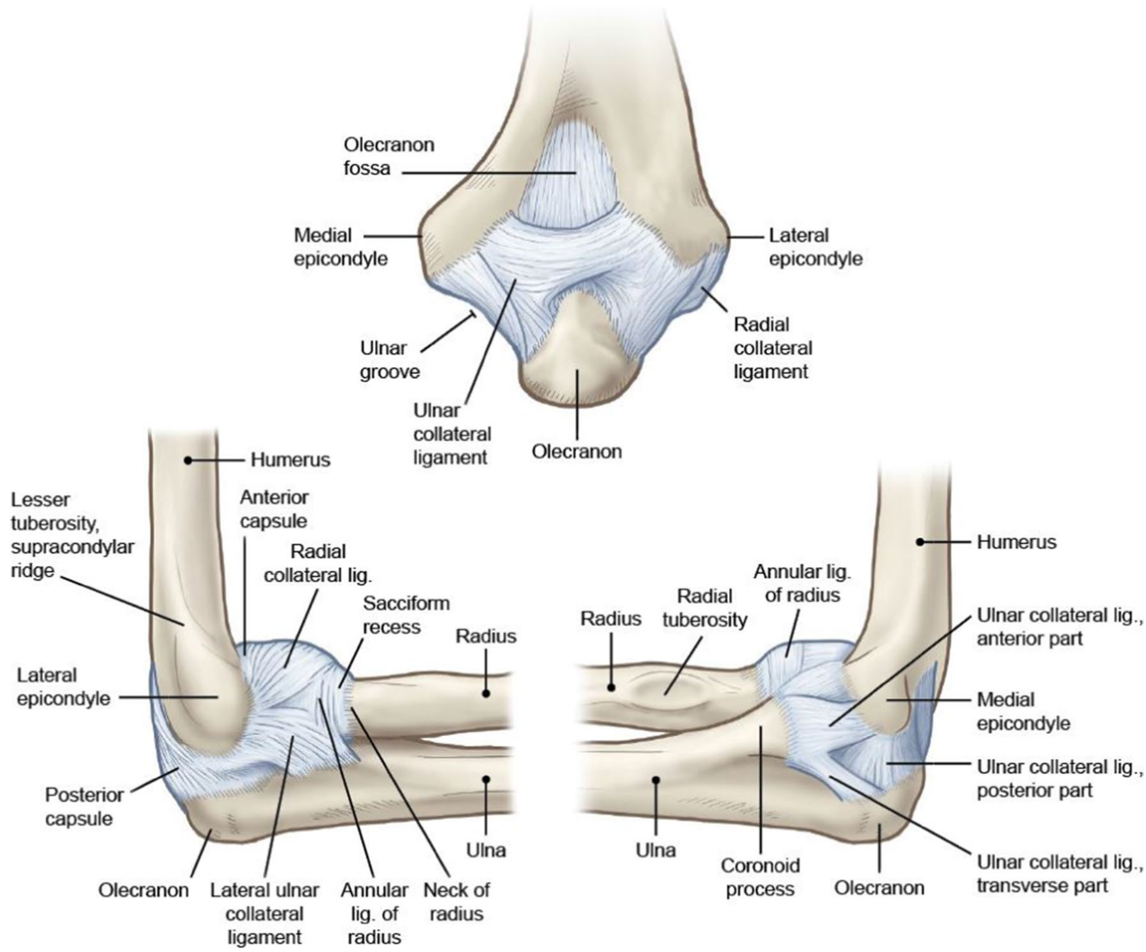


Fig. 6 Ligamentous anatomy of the distal humerus. Top: posterior view ligamentous anatomy of the elbow. Left: lateral collateral ligamentous complex components: lateral ulnar collateral ligament, radial collateral ligament, annular ligament. Right: medial collateral ligamentous complex anatomy comprised of three bundles: anterior, posterior, and transverse. Reproduced with permission from ASSH Textbook of Hand Surgery, 2019

Operative goals and technique

Fixation principles and technique are outlined in Supplemental Table and Figs. 10, 11, 12, 13, 14. Stable fixation requires rigid columnar fixation with strong plates, typically of 3.5 mm diameter. Restoration of the olecranon fossa–tip relationship is necessary to achieve elbow extension [3]. Attention to screw length, orientation, and articular penetration is critical to ensure unrestricted articular integrity.

Plating configuration

Operative fixation with dual plates has proven superior to fixation with K-wires or screws alone with respect to functional outcomes [27], but debate remains on the ideal plating configuration—parallel versus orthogonal. Parallel plating has shown biomechanical superiority when the cortical contact is absent or when locked plating is used [28]; however, clinical outcomes in published case series (Level IV evidence) have reported satisfactory results with both techniques [29, 30].

Shin et al. compared orthogonal to parallel plate fixation in a prospective randomized comparative study of 35 patients and found no significant differences in clinical outcomes or range of motion between treatment groups (Level II evidence). Two nonunions developed in the orthogonal plating group, but the study was underpowered to detect a difference in this outcome [31].

Lee et al. similarly compared orthogonal versus parallel plating in a prospective randomized trial of 67 patients (Level II evidence). This trial also found no differences between the two groups with regard to clinical outcomes, operating time, time to union, or complication rates. No nonunions occurred [32].

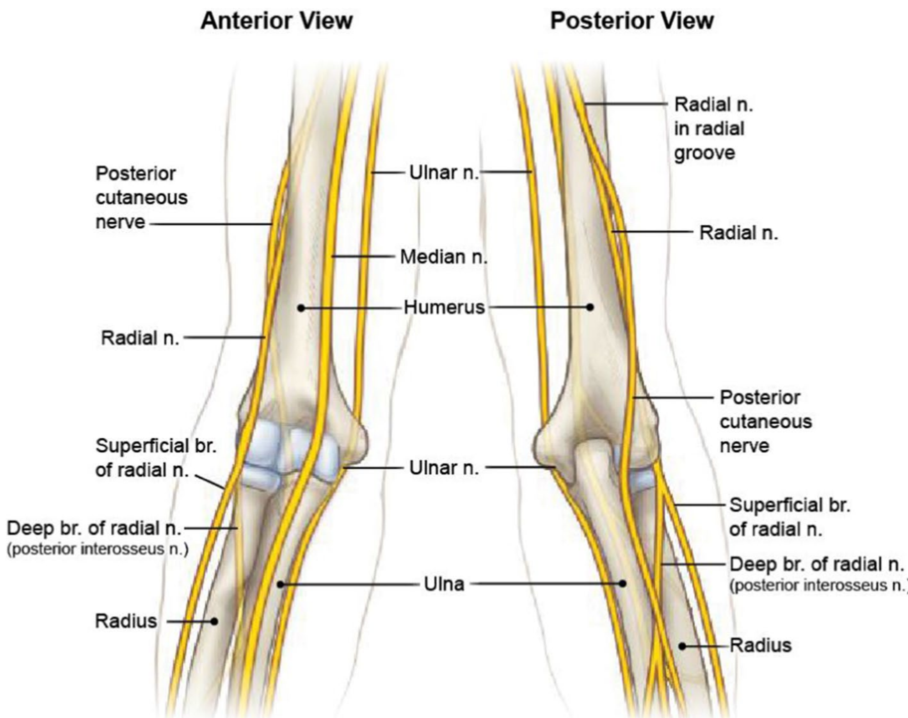


Fig. 7 Neuroanatomy of the elbow. Anatomic relationships of the neuroanatomy around the elbow shown from an anterior view and posterior view. Reproduced with permission from ASSH Textbook of Hand Surgery, 2019

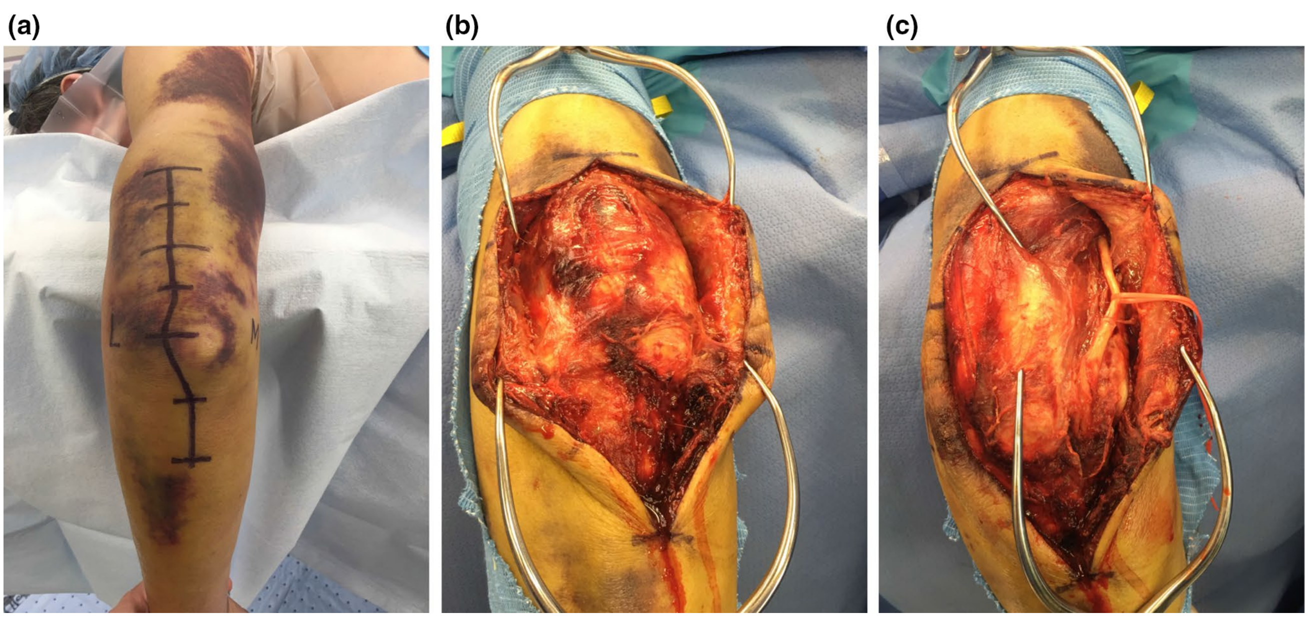


Fig. 8 Universal posterior approach. **a** A posterior midline incision is made curving radially around the olecranon. **b** Full-thickness flaps are elevated off of the triceps fascia. **c** The ulnar nerve is identified, gently mobilized, and protected with a vessel loop. Courtesy of Marc J. Richard, MD [Durham, NC]

Management of bone loss

Bone loss may be present owing to comminution and high-energy mechanisms [33]. Supracondylar-level bone loss may be treated with metaphyseal shortening up to 2 cm with the minimal impact on elbow biomechanics [34]. The diaphyseal fracture fragment is contoured to match the end of the articular segment, restoring rotational, coronal, and sagittal alignment. Metaphyseal

Table 1 Posterior approaches to the distal humerus

	Indication	Technique	Considerations
Paratricipital	Supracondylar fractures Transcondylar fractures Intercondylar intra-articular fractures without significant comminution AO type C1 and C2 intra-articular fracture patterns	Dissection performed medial and lateral to the triceps Mobilize triceps off of the distal humerus, medial, and lateral intermuscular septae Triceps reflected medial and lateral keeping insertion intact to visualize fracture fragments	Least disruptive to the extensor mechanism Limited visualization of the articular surface Allows for conversion to TEA or olecranon osteotomy
Triceps split	Supracondylar fractures Transcondylar fractures Intercondylar intra-articular fractures	Triceps may be split from spiral groove to the proximal fourth of the ulna, leaving the triceps tendon in continuity with the extensor fascia laterally and flexor fascia medially Proximal 1 cm of olecranon tip can be resected to improve visualization Elbow flexion improves visualization Closure: extensor mechanism fascia repaired with interrupted nonabsorbable sutures anchored via olecranon bone tunnels	Olecranon remains intact and blocks articular visualization Intact proximal ulnar articular surface acts as a template for reduction in the distal humeral articular surface May be used in TEA but can preclude loss of extension strength, though not significantly different from other exposures [8]
Lateral paraolecranon	Supracondylar fractures Transcondylar fractures Intercondylar intra-articular fractures without significant comminution AO type C1 and C2 intra-articular fracture patterns	Merges paratricipital with triceps-splitting approach Triceps is split between the lateral expansion and central triceps tendon Lateral triceps retracted laterally as a single unit with anconeus off of the lateral distal humeral column Medial triceps is elevated from the medial intermuscular septum off the distal humerus Medial triceps is mobilized medially and laterally (similar to paratricipital approach)	Maintains majority of the triceps insertion on the olecranon with improved exposure by splitting the lateral triceps musculature Central insertion of triceps onto the olecranon is not violated
Olecranon osteotomy	Supracondylar fractures Transcondylar fractures Intercondylar intra-articular fractures Severe intra-articular comminution AO type C1, C2, C3 intra-articular fracture patterns	Broad, obtuse, apex distal chevron osteotomy made at bare spot of proximal ulnar semilunar notch (2.5–3 cm distal to olecranon tip) Olecranon attached to triceps is reflected proximally, elevating the medial triceps off its osseous origin Osteotomy site secured using a templated plate and pre-drilled screw holes for fixation	Best visualization of articular surface Does not allow easy conversion to TEA Osteotomy creates possible complication site Nonunion rate 0–9% with conventional methods of fixation (Level IV) [18]. 6–30% require removal of symptomatic hardware [18]
Bryan–Morrey TRAP	May be used for fixation of DHF and TEA Subperiosteal or osteoperiosteal elevation of the distal extensor mechanism with the periosteum Repair after osteosynthesis is made with nonabsorbable sutures via olecranon bone tunnels [16]		

TRAP triceps-reflecting anconeus pedicle, *TEA* total elbow arthroplasty

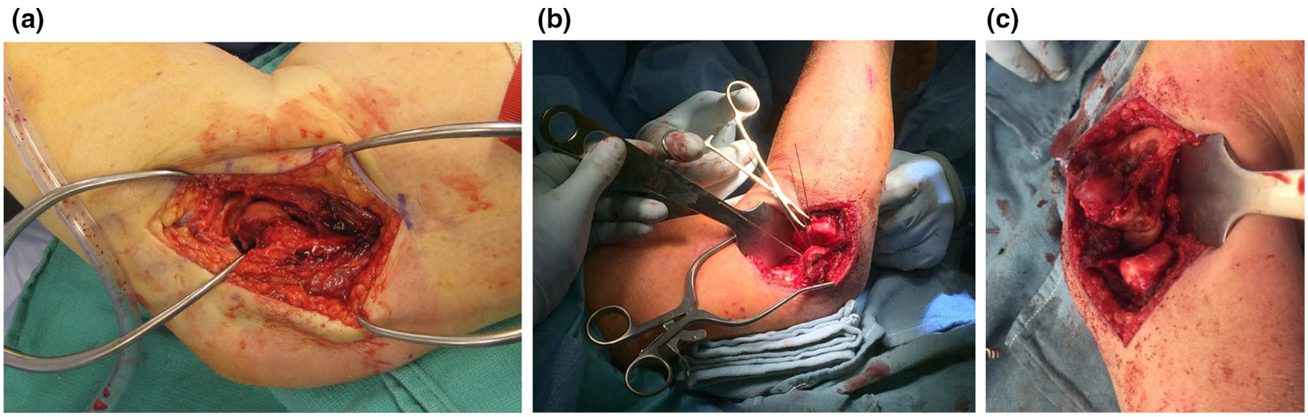


Fig. 9 Lateral column approach. **a** The lateral column approach is shown utilizing the ECU–anconeus (Kocher) interval to access the radiocapitellar joint and lateral humeral column. Capsular violation from the injury can be exploited for exposure. Effort is made to preserve the lateral collateral ligament (LCL) insertion by making the deep incision from the lateral epicondyle toward the equator of the radial head [13]. **b** The capitellum is assessed and found to have a significant comminution. **c** Release of the LUCL enables the elbow to hinge on the intact MCL, allowing for provisional fixation with K-wires and definitive fixation with headless compression screws. *Note* The PIN typically traverses 5.6 cm distal to the capitellum through supinator with the forearm in pronation (not shown) [21]. If posterior lateral column exposure is needed for columnar plate application, the triceps may be elevated posteriorly. A. Courtesy of Marc J. Richard, MD [Durham, NC]: B, C. Courtesy of Douglas P. Hanel, MD [Seattle, WA]: C)

Table 2 Outcomes related to the management of the ulnar nerve. Reproduced with the publishers permission from the ASSH Textbook of Hand Surgery, 2019 Chapter 40

Study	Level of evidence	Management		Postoperative ulnar neuritis		
		In situ	Transposed	In situ	Transposed	Total
Ruan et al. [9]	Retrospective comparative Level III	14	15	6* (43%)	3* (20%)	9 (31%)
Chen et al. [23]	Retrospective comparative Level III	89	48	8** (9%)	16** (33%)	24 (18%)
Vazquez et al. [24]	Retrospective comparative Level III	22	47	4 (18%)	7 (14%)	11 (16%)
Wiggers et al. [25]	Retrospective Level IV	50	57	6 (12%)	11 (19%)	17 (16%)
Worden and Ilyas [26]	Retrospective comparative Level III	12	12	4 (33%)	5 (42%)	9 (38%)
Shearin et al. [22]	Meta-analysis Level IV	187	179	28 (15%)	42 (23%)	70 (19%)

*, ** $p < 0.05$

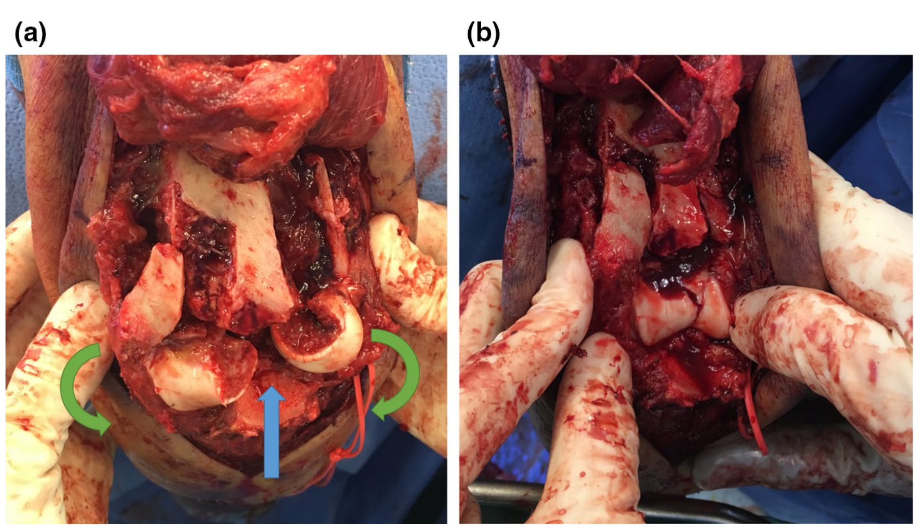


Fig. 10 Deforming forces in DHF. **a** The olecranon produces axial impaction into the trochlea (blue arrow). The muscular deforming forces of the common extensor origin on the lateral epicondyle (left) and the flexor pronator mass on the medial epicondyle (right) produce a rotatory deformity of the fracture fragments anterior (green arrows). **b** The reduction maneuver counteracts these forces. Courtesy of Marc J. Richard, MD [Durham, NC] (color figure online)

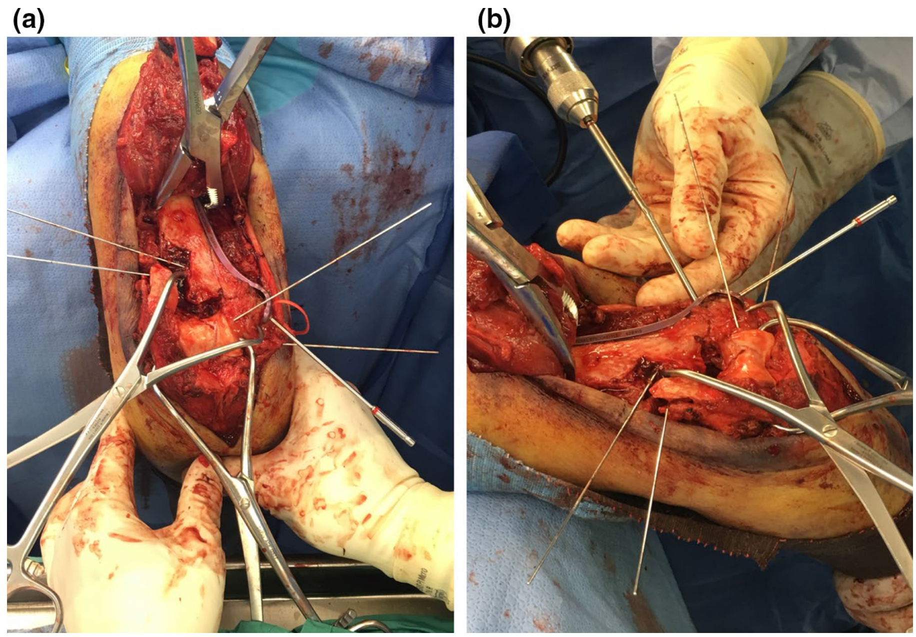


Fig. 11 Provisional fixation techniques for DHF. A combination of provisional fixation can be utilized including K-wire fixation, pointed reduction clamps, and drill bits (**a**, **b**) to maintain fracture reduction during definitive fixation. Courtesy of Marc J. Richard, MD [Durham, NC]

shortening causes loss of the olecranon, radial, and coronoid fossae limiting elbow motion. To compensate, bone is removed from the posterior humeral diaphysis to recreate an olecranon fossa. The anterior fossae remain absent, but the articular segment is fixed in slight anterior translation to accommodate of the coronoid and radial head in flexion [33].

Comminuted DHF may require bone grafting when impaction is present. Cancellous bone graft can be used to support subchondral articular fracture fragments. Central trochlear articular comminution and bone loss can be reconstructed with structural bone grafting to restore trochlear stability [33]. Severe bone loss with significant contamination is treated with debridement, local antibiotic placement, and external fixation until soft tissue stabilization occurs and delayed bone grafting can be performed, typically at 6–8 weeks.

Outcomes

Outcomes following the fixation of DHF are summarized in Table 3. Differences exist between studies in terms of fracture pattern, research design, plating configuration, use of locking screw construct, patient-reported outcomes, and systematic standardized collection of objective outcomes measurements. The advent of rigid fixation with a multiple plate construct has increased union rates and allowed for restoration of functional arc of motion.

Complications of surgical management

Infection

Deep infection rates range from 0 to 9% [8, 17, 19]. Management requires debridement of nonviable tissue and assessment of fracture consolidation. If the fracture is stable with adequate consolidation, the implant is removed and antibiotic therapy guided by deep tissue cultures. When the fracture is unstable without its supporting internal fixation, culture-specific antibiotic therapy continues until fracture consolidation occurs and fixation can be removed.

Nonunion

Recent studies using modern fixation principles have demonstrated excellent union rates from 90 to 100% (Level IV evidence) [19, 48]. When nonunion occurs, it typically is located at the metadiaphyseal region due to the watershed area at this level [49]. Management involves revision fixation and bone grafting. Other causes of nonunion including infection, nutritional, and smoking status, and nonmodifiable factors such as underlying endocrine conditions should be addressed.

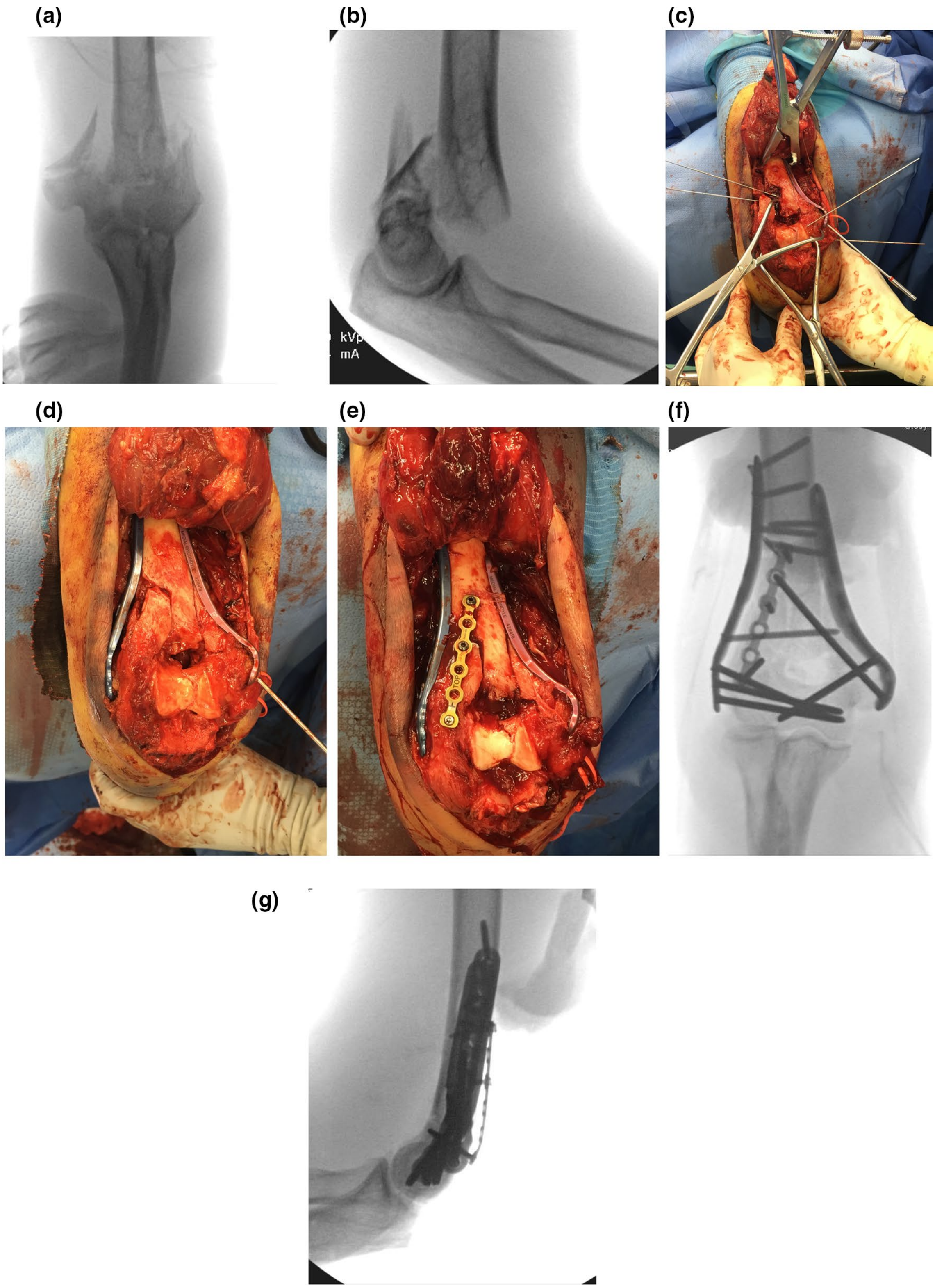


Fig. 12 Case 1, fixation DHF. **a**, **b** Injury radiographs of an adult male who sustained a DHF treated with parallel plating osteosynthesis. **c** An olecranon osteotomy was performed and provisional fixation simplified the fracture pattern from an AO C-type to an A-type with definitive fixation of the articular surface initially. The medial column was then built to the intact articular surface, followed by **d** the lateral column fixation. **e** Addition of a third plate allowed buttress of the metaphyseal comminution. **f**, **g** Final radiographs. Courtesy of Marc J. Richard, MD [Durham, NC]

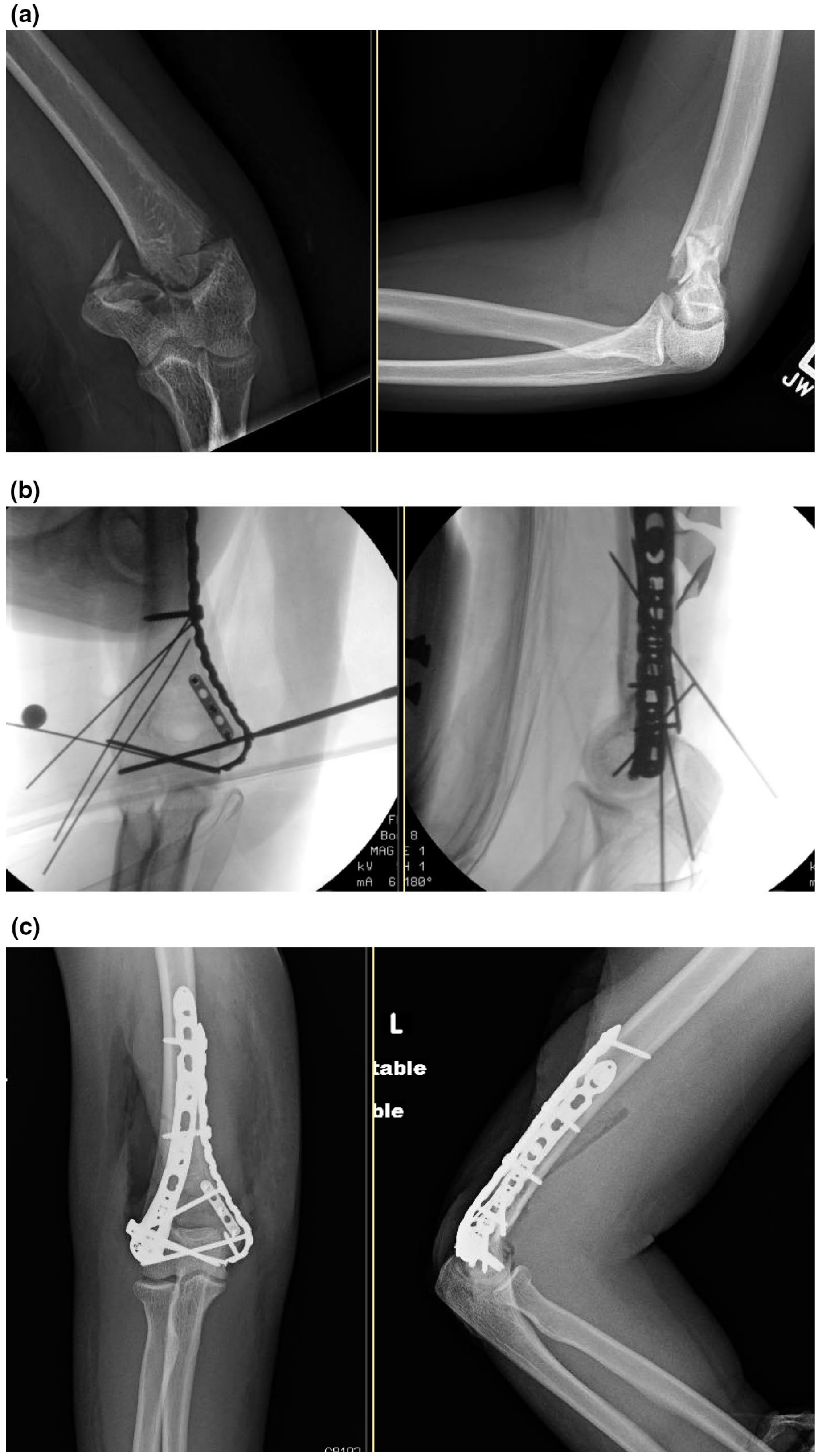


Fig. 13 Case 2, fixation DHF. **a** Injury radiographs of a young adult female who sustained a DHF treated with orthogonal plating osteosynthesis. **b** Provisional stabilization allowed fixation of the medial column followed by the articular surface, transitioning the fracture from an AO C-type to a B-type. Note the provisional fixation with the 2.0-mm plate along the posteromedial column to allow metaphyseal fracture reduction, not interfering with medial column plate placement. The articular surface was then compressed with independent screws and stabilized with screws locked to the medial plate. **c** The lateral column was stabilized with a posterolateral plate and periarticular locking screws. Courtesy of Daphne Beingessner, MD, MSc, FRCSC [Seattle, WA]

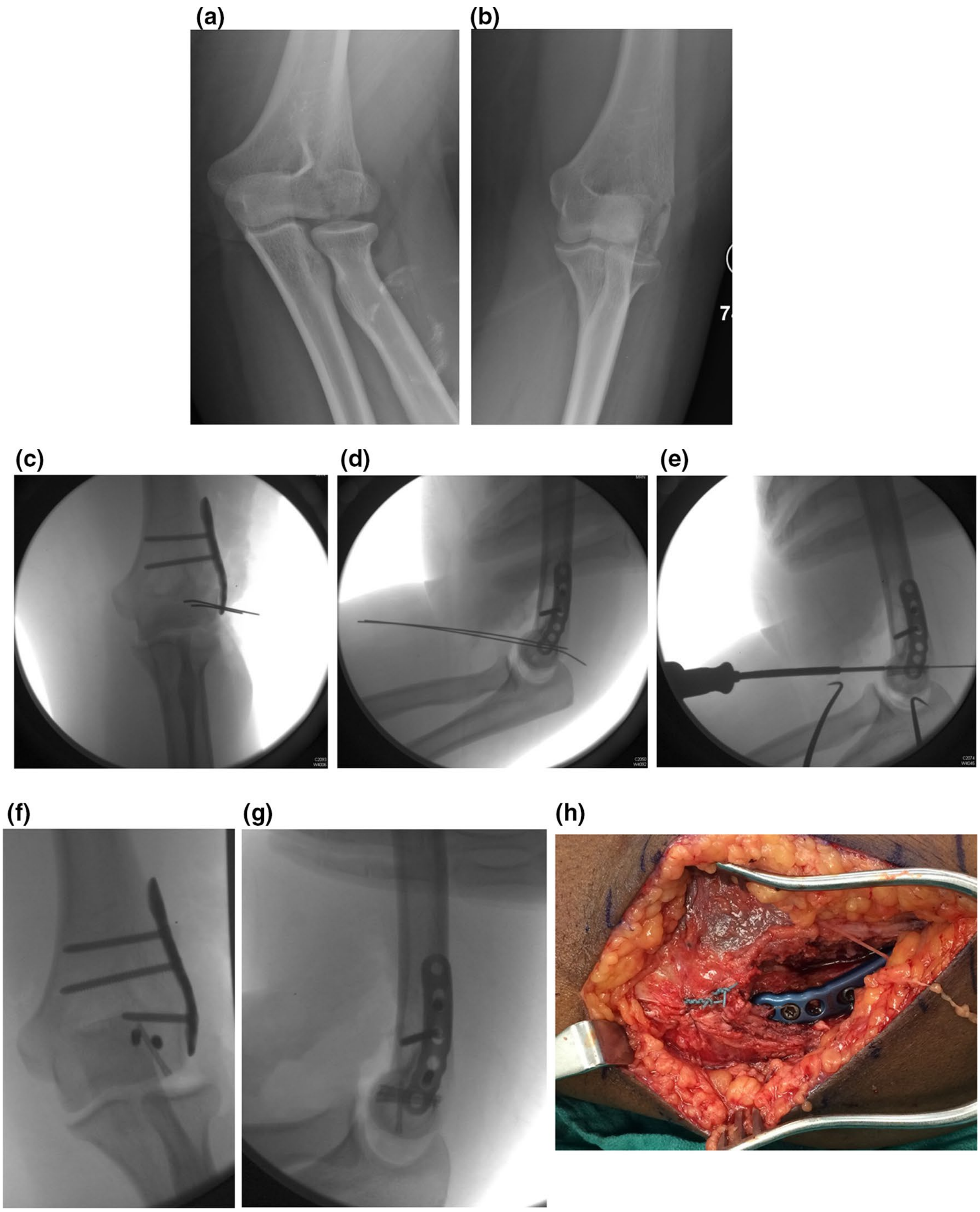


Fig. 14 Case 3, fixation of capitellum fracture with associated posterior comminution. **a**, **b** Injury radiographs identify a comminuted capitellum fracture with metaphyseal comminution. **c**, **d** Provisional fixation with an antiglide plate and K-wires provide anatomical alignment. **e** The provisional K-wires are over-drilled and replaced with headless compression screws in an anterior-to-posterior direction. **f**, **g** A locking screw is added through the plate for additional fixation of the capitellum fragment in the setting of metaphyseal comminution. **h** Closure of the LUCL. Courtesy of Marc J. Richard, MD [Durham, NC]

Stiffness

All DHF are associated with some degree of motion loss, most notably with extension. Intrinsic and extrinsic causes include articular incongruity, adhesions, capsular contractures, loose bodies, and prominent hardware [2]. Despite this, most studies report restoration of functional activity (Table 3).

Table 3 Outcomes of DHF fixation. Reproduced with the publishers permission from the ASSH Textbook of Hand Surgery, 2019 Chapter 40

Study	N	Follow-up	Mean age	Fracture type/plating	Outcomes	ROM arc	Complications
Intercondylar fractures							
McKee et al. [8]	26	51 mo	44	13 C	DASH 23.7 60% satisfactory MEPS	97	1/26 nonunion 4/26 delayed union 1/26 radial nerve palsy 3/26 reoperation
McKee et al. [17]	25	37 mo	47	13 C	DASH 20	108	1/25 nonunion 1/25 malunion 3/25 ulnar neuritis 6/25 reoperation
Pajarinen et al.[35]	21	25 mo	44	13 C	56% satisfactory OTA	107	2/21 nonunion 1/21 infection 2/21 reoperation
Gofton et al. [19]	23	45 mo	53	13 C 90 nonlocking	DASH 12 87% satisfactory MEPS	122	1/23 nonunion 1/23 infection 1/23 AVN 6/23 reoperation
Soon et al. [36]	15	12 mo	43	13 B and C	86% satisfactory MEPS	109	1/15 nonunion 2/15 ulnar neuritis 3/15 implant failure 4/15 reoperation
Sanchez-Sotelo et al. [37]	32	24 mo	58	13 C 180 locking	83% satisfactory MEPS	98	1/34 nonunion 2/34 infection 9/34 reoperation
Atalar et al. [38]	21	28 mo	47	13 C 180 locking	DASH 7.6 MEPS 86	90	0/21 nonunion 1/21 infection 7/21 reoperation
Schmidt-Horlohe et al. [39]	31	12 mo	50	13 C 90 locking	DASH 24 MEPS 87.2	102	0/31 nonunion 0/31 infection 5/31 reoperation
Flinkkila et al. [40]	47	19 mo	60	13 C 180 locking	DASH 26 MEPS 88	123	n/a nonunion 1/47 infection 13/47 reoperation
Kural et al. [41]	24	28 mo	47	13 C	DASH 21.9 91% satisfactory	104	0/24 nonunion 1/24 infection 2/24 reoperation
Capitellum and trochlear fractures							
Dubberley et al. [12]	28	56 mo	43	13 B and C Headless compression screws, cancellous screws, +/− plate	MEPS 91 SF36 46P, 50 M	119	3/28 nonunion 11/28 reoperation
Singh et al. [42]	14	58 mo	33	13 B Headless compression screws	MEPS 100% satisfactory	124	3/14 nonunion 0/14 AVN
Giannicola et al. [43]	15	29 mo	47	13 B Headless compression screws, ex-fix	MEPS 98	127	0/14 nonunion 1/14 infection 3/14 reoperation
Mighell et al. [44]	18	26 mo	45	13 B Headless compression screws	ASES 83.1 B-M 93.3	128	0/18 nonunion 3/18 AVN 3/18 HO 0/18 infection 0/18 reoperation
Brouwer et al. [45]	30	34 mo	49	13 B and C Headless compression screws +/− plate	B-M 85	115	8/18 nonunion (if posterior comminution present)
Heck et al. [46]	15	59 mo	36	13 B and C fine-threaded wires	DASH 11 ASES 92 B-M 91 MEPS 90	124	0/15 nonunion
Bilsel et al. [47]	18	44 mo	45	13 B and C Headless compression screws	DASH 15 MEPS 87	124	1/18 HO 0/18 AVN

mo months, *DASH* Disabilities of the Arm, Shoulder and Hand Score, *OTA* Orthopaedic Trauma Association Score, *MEPS* Mayo Elbow Performance Score, *ASES* American Shoulder and Elbow Surgeons Elbow Assessment, *B-M* Broberg–Morrey Score, *AVN* avascular necrosis, *HO* heterotopic ossification, *SF 36* Short Form-36 (*P*—physical component, *M*—mental component), *TEA* total elbow arthroplasty, *ROM arc* range of motion arc in flexion–extension

Heterotopic ossification

A pooled analysis from 239 patients demonstrated an overall rate of symptomatic heterotopic ossification (HO) to be 8.6% [3]. A more recent retrospective review (Level IV evidence) of 89 patients found 41% of patients with symptomatic HO, typically coursing along the MCL [50]. HO was associated with significant loss of extension and overall decreased flexion–extension arc less than 100°. Eight percentage of patients (7/89) required surgical excision of HO. The authors found a significant association with head injury, delayed internal fixation, and the use of bone graft or substitute [50]. High-energy injuries and open fractures are also associated with HO.

Treatment for symptomatic HO is controversial but typically involves surgical excision, possible removal of hardware, capsulectomy, debridement of the olecranon, coronoid and radial fossae, and adjunct radiation or nonsteroidal anti-inflammatory medication. Shin et al. evaluated the use of routine prophylaxis against HO in a retrospective review of patients with DHF treated with radiation therapy (three doses of 200 centigray) followed by 2 weeks of indomethacin (75 mg daily). The authors found a 3% rate of symptomatic HO and a nonunion rate of 6% [31]. Liu et al. reported a 3% rate (1/32) of symptomatic HO and no nonunions when using a 6-week course of celecoxib (200 mg daily) for prophylaxis after DHF fixation [51].

Posttraumatic osteoarthritis and avascular necrosis

Development of arthritis or avascular necrosis is the other complication related to surgical treatment of DHF. Management with conversion to soft tissue arthroplasty in younger patients or prosthetic elbow replacement in older patients can be considered [14].

Ulnar neuritis

Ulnar neuropathy is reported in approximately 19% of patients treated surgically for DHF [22]. Symptoms can be addressed with neurolysis and anterior transposition of the ulnar nerve [14].

Prosthetic replacement

Indications

Indications for prosthetic elbow replacement for DHF include complex comminuted fracture patterns in elderly low-demand patients with poor bone quality. Treatment options include distal humerus hemiarthroplasty and total elbow arthroplasty (TEA), though currently the hemiarthroplasty is not approved for use in the USA. Prosthetic replacement is contraindicated for acute management of open fractures or in patients with chronic infection. Patients should be counseled about the postoperative restrictions of 5–10 lb and no repetitive lifting more than 1–2 lb [52]. In general, TEA should be avoided in patients under 50 years old as high rates of early mechanical failure (54%) at mean follow-up of 3.2 years and 82% complication rate have been reported [52].

Total elbow arthroplasty

TEA may offer improved function in elderly low-demand patients with comminuted DHF and poor bone quality [6]. It is also the treatment of choice for patients with preexisting inflammatory arthropathy of the elbow who sustain DHF [2]. Disadvantages of TEA include lifelong weight restrictions to the extremity as well as risks of prosthetic loosening, fracture, infection, and poor longevity [2]. Olecranon osteotomy should be avoided if the surgeon is considering TEA as a salvage option as fixation of the olecranon with the adjacent implant becomes problematic.

The outcomes of TEA for the treatment of DHF are summarized in Table 4. McKee et al. completed a prospective, randomized, multicenter study comparing ORIF with TEA for displaced, comminuted, intra-articular fractures in 60 patients older than 65 years of age (Level II evidence). The study found improved functional outcomes (DASH and MEPS) at 2 years postoperatively in the TEA group. This trial had a 25% intraoperative crossover rate from ORIF to TEA given the extent of fracture comminution found intraoperatively [6]. Pooled analysis of 256 elderly patients from three retrospective studies (Level III evidence) favored TEA to have a good or excellent functional outcome (89%) compared to ORIF (76%) ($p = 0.036$) [3]. Githens et al. performed a systematic review and meta-analysis of 27 studies comprising 563 patients with an average follow-up of 3.8 years who underwent either ORIF or TEA. The authors found no significant difference in functional outcomes (flexion arc and MEPS) between patients treated with ORIF compared to TEA. The TEA group had higher overall complication rates (38% vs. 33%) and infection (4% vs. 2%), but the differences were not significant. The ORIF group had a higher reoperation rate (9% vs. 6%), but this too did not reach a statistical significance. There were no differences in neuropraxia, superficial wound complications, or HO [53].

Both ORIF and TEA are reasonable treatment options with benefits and risks to each strategy. Despite notable complication rates with each option, functional outcomes are good to excellent in most patients.

Table 4 Outcomes of ORIF vs TEA in management of DHF. Reproduced with the publishers permission from the ASSH Textbook of Hand Surgery, 2019 Chapter 40

ORIF versus total elbow arthroplasty (TEA)

Study	*N*	Follow-up	Mean age	Fracture type/treatment	Outcomes	ROM arc	Complications
Frankle et al. [54]	24	57 mo	73	13 C 12 ORIF 12 TEA	Satisfactory outcomes 67% ORIF 100% TEA	ORIF 80 TEA 105	*ORIF* 3/12 reoperation *TEA* 1/12 hardware complication 2/12 infection 3/12 reoperation
Jost et al. [55]	16	49 mo ORIF 66 mo TEA	59	13 A, B, C 6 ORIF 10 TEA	MEPS ORIF 93 MEPS TEA 96	ORIF 107 TEA 107	*ORIF* 0/6 nonunion 3/6 reoperation *TEA* 1/10 infection 3/10 reoperation
McKee et al. [6]	42	24 mo	77	13 C 15 ORIF 25 TEA	MEPS ORIF 73 DASH ORIF 38 MEPS TEA 86 DASH TEA 34	ORIF 95 TEA 107	*ORIF* 1/15 nonunion 1/15 HO 6/15 ulnar neuritis 4/15 reoperation *TEA* 1/25 deep infection 3/25 HO 3/25 reoperation
Egol et al. [56]	20	15 mo	76	13 B, C 11 ORIF 9 TEA	MEPS ORIF 85 DASH ORIF 32 MEPS TEA 79 DASH TEA 30	ORIF 98 TEA 92	*ORIF* 1/11 nonunion 2/11 reoperation *TEA* 4/9 loosening 1/9 reoperation
Ellwein et al. [57]	19	26 mo ORIF 20 mo TEA	73	13 C 11 ORIF 8 TEA	MEPS ORIF 82 DASH ORIF 45 MEPS TEA 94 DASH TEA 26	ORIF 99 TEA 111	*ORIF (RR 4.4 maj comp)* 4/11 implant failure 1/11 screw perforation *TEA* 1/8 ulnar neuritis 0/8 implant failure 1/8 infection

ORIF open reduction internal fixation, *HO* heterotopic ossification, *TEA* total elbow arthroplasty, *mo* months, *MEPS* Mayo Elbow Performance Score, *ROM arc* range of motion arc in flexion–extension, *RR* relative risk

Rehabilitation

Gentle active motion exercises guided by a therapist are started between 2 and 5 days postoperatively, providing that there are no wound issues. Strengthening exercises may begin after fracture consolidation, typically around 10–12 weeks. If a functional arc of motion (30°–130°) is not achieved, dynamic splinting, static progressive splinting, or surgical contracture release may be considered [58, 59].

Future directions

DHF are challenging to manage. Advances in plate design and surgical fixation principles have improved functional outcomes in patients treated surgically. Future studies should prospectively compare surgical exposures with regard to patient outcomes. Additionally, there is a need for more high-level comparative studies between ORIF and TEA in terms of functional outcomes, longevity, complications, and cost. Long-term outcomes data are needed in the area of hemiarthroplasty and TEA for patients with DHF.

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Compliance with ethical standards

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