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ORIGINAL ARTICLE

ORIF of Distal Humerus Fractures with Modern Pre-contoured Implants is Still Associated with a High Rate of Complications

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Abstract

Background The purpose of this study was to identify complications after operative treatment of distal humerus fractures with anatomic, pre-contoured, locking distal humeral plates. We hypothesized that these fractures have high complication rates despite the use of these modern implants.

Materials and Methods Between 2010 and 2018, 43 adult patients with a distal humerus fracture underwent open reduction and internal fixation (ORIF) at a Level I trauma center. Pre-operative variables, including medical comorbidities, mechanism of injury, open or closed fracture, AO/OTA fracture classification (Type A, B, or C), and nerve palsy, were recorded. Intra-operative variables including surgical approach, ulnar nerve transposition, and plate configuration were recorded. Anatomic, pre-contoured, locking distal humeral plates were used in all patients. Various plating systems were used based on surgeon preference and fracture pattern. Post-operative complications including infection, nonunion, malunion, painful implants, nerve palsy, heterotopic ossification, stiffness, and post-traumatic arthritis were recorded.

Results Most fractures were Type C (53%). The posterior olecranon osteotomy approach (51%) and parallel plate configuration (42%) were used in most cases. At a mean follow-up of 15 months, the complication rate was 61% (26/43 patients). Among all patients, 49% (21/43 patients) required a reoperation. Elbow stiffness (19%) was the most common complication followed by nerve palsy (16%). There were four fracture nonunions (9%), deep infections (9%), painful implants (9%), post-traumatic arthritis (9%), and heterotopic ossification (9%).

Conclusions Distal humerus fractures treated with ORIF utilizing anatomic, pre-contoured, locking distal humeral plates have a high complication rate, with many requiring reoperation.

Level of Evidence Therapeutic Level IV.

Keywords Distal humerus fracture · Open reduction internal fixation · Complication

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Introduction

Distal humerus fractures comprise of 2% of all fractures and about 30% of all humerus fractures [1]. One-third of distal humerus fractures present as complete articular fractures, classified by the AO/Orthopaedic Trauma Association (OTA) classification as Type C injuries [1]. The elbow joint allows the positioning of the hand in space and is needed to perform activities of daily living involving hygiene and eating. Therefore, fractures of the distal humerus can cause a significant decrease in function. The goal of treatment is to provide painless, functional range of motion of the elbow to allow for functional independence [2].

Open reduction internal fixation (ORIF) of distal humerus fractures has shown satisfactory results; however, the complication rates have been reported as high as 50% [1–35]. Complications include joint contracture or stiffness, nerve palsy, infection, nonunion, malunion, painful implants, heterotopic ossification, and post-traumatic arthritis. Kundel et al. [3] identified factors associated with poor range of motion and return to work after operative treatment of distal humerus fractures. They reported a complication rate of 29%, but did not include painful implants that underwent removal, elbow stiffness, or heterotopic ossification. Robinson [1] showed that high-energy injuries and open fractures were associated with fracture nonunion. Type C fractures were associated with infection. They did not evaluate for elbow stiffness.

The purpose of this study was to identify complications after operative treatment of distal humerus fractures with anatomic, pre-contoured, locking distal humeral plates. We hypothesized that these fractures have high complication rates despite the use of these plates.

Methods

The Institutional Review Board at our institution approved this study. The electronic medical records between August 2010 and January 2018 were searched at our institution's level 1 trauma center. Patients who were greater than or equal to 18 years of age and underwent open reduction internal fixation of a distal humerus fracture were included in the study. The Current Procedural Terminology (CPT) codes for open treatment of a distal humerus fracture (CPT 24,545, 24,546, 24,575, 24,579, and 24,586) were used to identify patients. There were 107 patients who underwent open treatment of a distal humerus fracture during the time period. We excluded patients who had less than 6 months follow-up. There were ten patients who had a complication prior to 6 months, and these patients were not included in the study. Pathologic fractures also were excluded from the study. A total of 43 patients were identified for inclusion in the study.

The patients' age, gender, smoking history, alcohol use, body mass index (BMI), medical comorbidities, medications, other injuries, mechanism of injury, and laterality were recorded. The fractures were characterized as open or closed. Pre-operative nerve palsies were documented. Radiological classification was recorded using the AO/OTA system for fractures of the distal humerus (Type A, Type B, and Type C) [36]. Type A are extra-articular fractures. Type B are partial articular fractures. Type C are complete articular fractures. The number of days from injury to definitive fixation as well as the number of operations before definitive fixation were noted. The surgeries were performed by surgeons from our institution's trauma, hand, or shoulder and elbow service. Surgeon preference and fracture pattern dictated surgical approach, and a uniform technique was not adopted for all cases. The operative notes were reviewed to record the surgical approach, use of bone graft, ulnar transposition, number of plates, and plate configuration, parallel (Figs. 1, 2) or perpendicular (Figs. 3, 4). Various plating systems were used based on surgeon preference and fracture pattern. The more common distal humerus plating systems that were utilized at our institution were Variable Angle–Locking Compression Plate (DePuy Synthes, West Chester, PA) and PERI-LOC (Smith and Nephew, Memphis, TN). The purpose of this study was not to compare different plating systems. Therefore, the specific plating systems utilized in each case were not recorded. However, all cases utilized anatomic, pre-contoured, locking plates of the distal humerus utilizing 3.5 mm and 2.7 mm locking and non-locking screws. For example,

Fig. 1 Intra-operative AP fluoroscopic image of a parallel plate configuration for a Type C distal humerus fracture utilizing the Synthes (Depuy Synthes, West Chester, PA) distal humerus plating system

Fig. 2 Intra-operative lateral fluoroscopic image of a parallel plate configuration for a Type C distal humerus fracture utilizing the Synthes (Depuy Synthes, West Chester, PA) distal humerus plating system

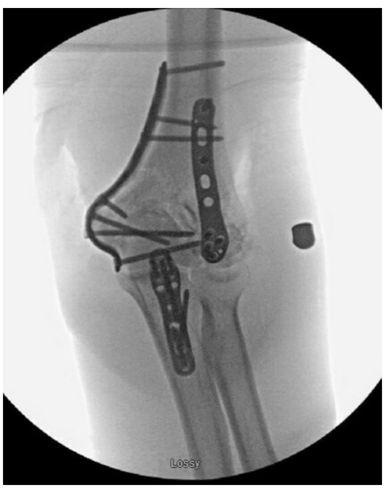

Fig. 3 Intra-operative AP fluoroscopic image of a perpendicular plate configuration and olecranon osteotomy for a Type C distal humerus fracture utilizing the Acumed (Acumed, Hillsboro, OR) distal humerus plating system

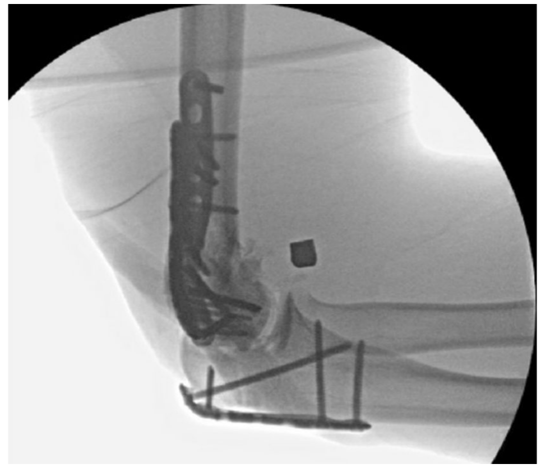

Fig. 4 Intra-operative lateral fluoroscopic image of a perpendicular plate configuration and olecranon osteotomy for a Type C distal humerus fracture utilizing the Acumed (Acumed, Hillsboro, OR) distal humerus plating system

Fig. 5 Synthes (Depuy Synthes, West Chester, PA) Distal Humerus 2.7/3.5 Variable Angle–Locking Compression Plates: posterolateral (top), posterolateral with lateral support (middle), and lateral (bottom)

Figs. 5 and 6 show the pictures of the Synthes distal humeral plates from their surgical technique guide. Intra-operative fluoroscopic images were reviewed, and when applicable, all cases utilized O'Driscoll's principles for optimizing stability of the distal humerus [37]. Based on surgeon's preference, patients were either placed in a long arm posterior splint or allowed for immediate gentle range of motion in a soft dressing after surgery. This immediate range of motion group was defined as the early mobilization group. Patients placed into a splint after surgery began range of motion after their first post-operative visit, at approximately 10–14 days. This was defined as the late mobilization group. All patients were followed for at least 6 months. Radiographs were routinely obtained at all follow-up clinic visits.

Fig. 6 Synthes (Depuy Synthes, West Chester, PA) Distal Humerus 2.7/3.5 Variable Angle–Locking Compression Plates: medial (top) and medial with extension (bottom)

Fig. 7 Pre-operative radiographs of a 72-year-old female with a Type C distal humerus fracture

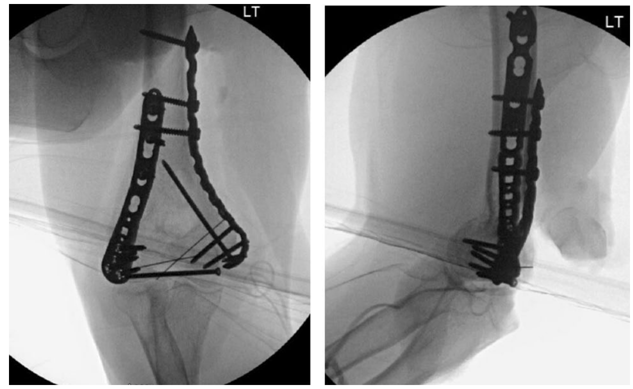

Fig. 8 Intra-operative fluoroscopic images of a 72-year-old female with perpendicular plate fixation using Synthes plates (Depuy Synthes, West Chester, PA) for her distal humerus fracture

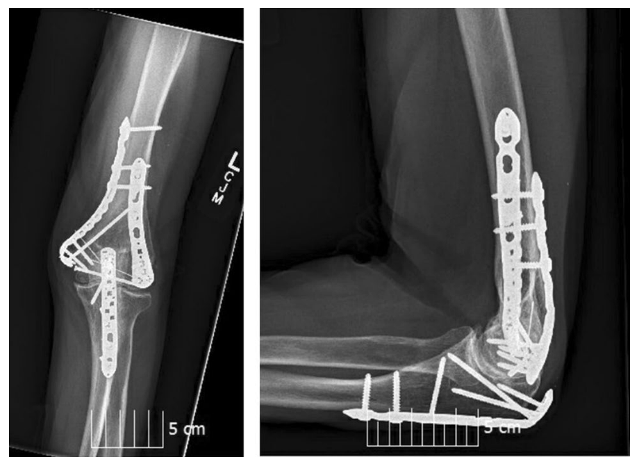

Fig. 9 Post-operative radiographs of a 72-year-old female who is 13-month status post-ORIF distal humerus fracture with olecranon osteotomy. Radiographs showing united distal humerus fracture and olecranon osteotomy

Figure 7 shows the pre-operative radiographs of a 72-year-old female who sustained a closed Type C distal humerus fracture after a ground level fall. She underwent ORIF utilizing a posterior olecranon osteotomy approach. Fracture fixation was achieved with the Synthes (DePuy Synthes, West Chester, PA) distal humerus plating system with a perpendicular plate configuration (Fig. 8). At her final 13-month follow-up, she had no pain, functional range of motion of her elbow, and her radiographs showed a healed distal humerus fracture and olecranon osteotomy (Fig. 9).

Patients' post-operative clinic notes were reviewed for post-operative complications. A superficial infection was defined as wound erythema without purulent drainage, implant failure, or bony changes, and treated with oral antibiotics. A deep infection was characterized as those that required reoperation and had purulence with positive intraoperative cultures. A nonunion was present if the fracture was not clinically or radiographically united after 6 months from definitive fixation or sooner if there was displacement of the fracture due to implant failure (Fig. 10). Implants that were removed due to pain were documented as painful implants (Fig. 11). These patients had healed fractures with pain over their implants and underwent elective removal of implants. Post-operative nerve palsies that were not present pre-operatively were recorded. Heterotopic ossification (Fig. 12) was characterized based on the Hastings and Graham functional classification that was later sub-classified by Viola and Hastings [38, 39]. Joint contracture or stiffness was considered a complication if the patient was unable to obtain functional range of motion. Functional range of motion was defined as 30°–130° of elbow extension and flexion, 55° of forearm pronation, and 65° of forearm supination [40]. Joint contracture or stiffness was also considered a

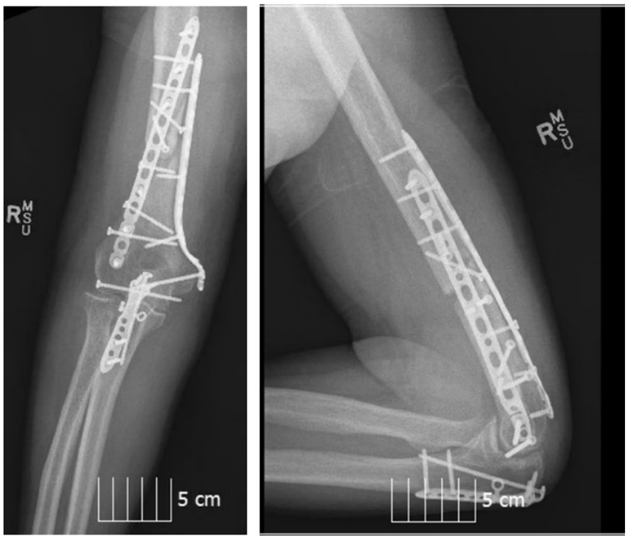

Fig. 10 Post-operative radiographs at 6-month status post-ORIF of a Type C distal humerus fracture utilizing Synthes distal humeral plates. Radiographs show nonunion of the supracondylar humerus fracture with union of the articular segment. The olecranon osteotomy has united

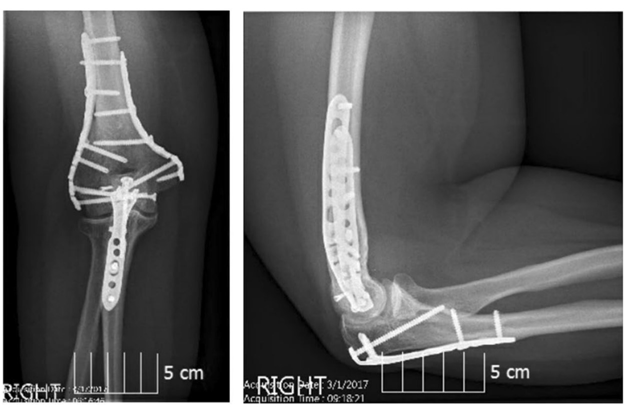

Fig. 11 Post-operative radiographs at 8-month status post-ORIF of a Type C distal humerus fracture utilizing Synthes distal humeral plates. Radiographs show united distal humerus fracture and olecranon osteotomy. Patient had persistent pain over the olecranon plate and underwent removal of implant

complication if the patient required a soft-tissue release or manipulation under anesthesia. Post-traumatic arthritis (Fig. 13) was based on serial post-operative radiographs that showed joint space narrowing, subchondral sclerosis, subchondral cysts, or marginal osteophytes. Complications that required a secondary procedure were recorded.

Descriptive statistics were reported as means and standard deviations for continuous variables and as counts and percentages for categorical variables for pre-operative variables and for overall incidences of specific complications.

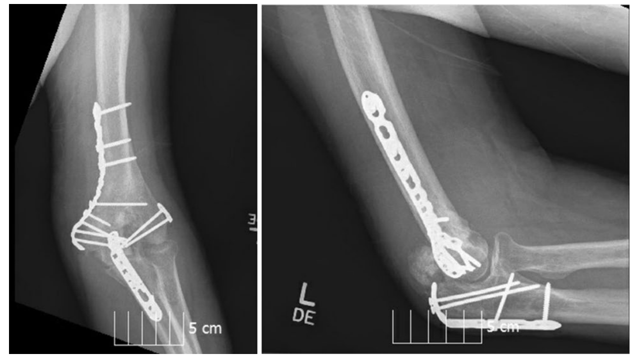

Fig. 12 Post-operative radiographs at 12-month status post-ORIF of a Type B distal humerus fracture utilizing Synthes distal humeral plates. Radiographs show united distal humerus fracture and olecranon osteotomy with formation of heterotopic ossification. Patient underwent excision of heterotopic ossification due to mechanical block to elbow extension and removal of olecranon plate

Fig. 13 Post-operative radiographs at 5-year status post-ORIF of a Type B distal humerus fracture utilizing a Synthes distal humeral plate. Radiographs show a united distal humerus fracture with evidence of post-traumatic osteoarthritis of the ulnohumeral and radiocapitellar joints

Results

A total of 43 patients who underwent ORIF of a distal humerus fracture were included in the study. The average follow-up was 15 months (range 6–55 months). There were 10 patients who had a complication prior to 6 months and were not included in the study. Table 1 shows the demographics and injury characteristics. The majority of patients had Type C distal humerus fractures (23/43, 53.5%). Pre-operative ulnar nerve palsy (6/43, 13.9%) was the most common nerve palsy.

Table 1 Patient demographics and injury characteristics (*n* = 43)

Average age (range; SD)	53 (20–81; 17)
Gender	
Male	21 (48.8%)
Female	22 (51.2%)
Medical comorbidities/medications	
Smoker	10 (23.2%)
Coronary artery disease	5 (11.6%)
Hypertension	15 (34.9%)
COPD	1 (2.3%)
Vitamin D deficiency	2 (4.6%)
RA/SLE	3 (7.0%)
CKD	1 (2.3%)
Hypothyroid	3 (7.0%)
Diabetes	4 (9.3%)
Steroid use	15 (34.9%)
High-energy mechanism	21 (48.8%)
Open fracture	18 (41.9%)
Other ipsilateral extremity injuries	14 (32.6%)
Pre-op nerve palsy	
Ulnar nerve	6 (13.9%)
Ulnar and radial nerves	1 (2.3%)
Ulnar, radial, and median nerves	1 (2.3%)
Fracture classification[a]	
Type A	3 (7.0%)
Type B	17 (39.5%)
Type C	23 (53.5%)

SD standard deviation, *COPD* chronic obstructive pulmonary disease, *RA* rheumatoid arthritis, *SLE* systemic lupus erythematosus, *CKD* chronic kidney disease

[a]AO/OTA fracture classification

Table 2 shows the surgical characteristics. The average number of days from the injury to definitive fixation was 3 days (range 0–14 days). The posterior approach with olecranon osteotomy (22/43, 51.2%) was utilized the most. Parallel plate configuration (18/43, 41.9%) was utilized more than perpendicular plate configuration. A single plate was utilized in five patients and acted as a buttress plate for type B fractures. Early mobilization (10/43, 23.26%) was less common than late mobilization.

Table 3 shows the complications after operative fixation of the distal humerus fractures. There was a total of 35 complications in 26 patients (60.5%). Twenty-one patients (48.8%) required a secondary procedure due to a complication. The most common complication was stiffness (8/43, 18.6%) that resulted in the inability to obtain functional range of motion of the elbow [40]. Four of the eight patients had an open fracture, Type C fracture, and/or an olecranon osteotomy. The early mobilization group demonstrated a higher percentage of developing stiffness (3/10, 30%) compared to the late mobilization group (5/33, 15.2%). Five of the eight patients who had post-operative stiffness underwent a manipulation under anesthesia and/or soft-tissue release.

Table 2 Surgical characteristics of operative fixation of the distal humerus (*N* = 43)

Number of operations prior to definitive fixation	
0	35 (81.4%)
1	3 (7.0%)
2	4 (9.3%)
4	1 (2.3%)
Surgical approach	
Posterior triceps splitting	1 (2.3%)
Posterior triceps sparing	11 (25.6%)
Posterior olecranon osteotomy	22 (51.2%)
Medial only	1 (2.3%)
Lateral only	8 (18.6%)
Ulnar nerve transposition	6 (14.0%)
Number of plates	
1	5 (11.6%)
2	29 (67.4%)
3	2 (4.7%)
Plate configuration	
Parallel	18 (41.9%)
Perpendicular (90–90)	13 (30.2%)
Mobilization	
Early	10 (23.3%)
Late	33 (76.7%)
Bone Grafting	
None	36 (83.7%)
Allograft	7 (16.3%)

Post-operative nerve palsy (7/43, 16.3%) was the next most common complication. The ulnar nerve was involved in all seven patients. One patient also sustained a radial nerve palsy in addition to the ulnar nerve palsy. Only one patient had an ulnar nerve transposition at the time of operative fixation. Four patients underwent a secondary procedure to

Table 3 Complications after operative fixation of the distal humerus

Complications (number of patients)	26 (60.5%)
Required a secondary procedure	21 (48.8%)
Complications (total)	35
Joint contracture/stiffness	8 (18.6%)
Nerve palsy	7 (16.3%)
Bone nonunion	4 (9.3%)
Heterotopic ossification	4 (9.3%)
Post-traumatic arthritis	4 (9.3%)
Deep infection	4 (9.3%)
Painful implant	4 (9.3%)

release the cubital tunnel. The remaining three patients had complete resolution of their symptoms with observation.

There were four patients who had deep infections that underwent debridement and irrigation. Three of the four patients had an open fracture and one patient required a rotational flap for soft-tissue coverage. All patients had a type C distal humerus fracture. There were four patients who developed fracture nonunion. Two of the patients had a septic nonunion. One patient developed nonunion of the olecranon osteotomy. All patients underwent a secondary procedure to address the fracture nonunion.

There were four patients who developed heterotopic ossification. Three patients had Class IIA heterotopic ossification that underwent capsulotomy, excision of heterotopic ossification, and soft-tissue releases. One patient developed Class IIIA heterotopic ossification and underwent a similar procedure. There were four patients who developed post-traumatic arthritis. Two underwent a secondary procedure. One patient underwent radial head resection arthroplasty. One patient underwent resection arthroplasty of the elbow. There were four patients who had painful implants and underwent the removal of implants.

Discussion

Non-operative treatment of distal humerus fractures has been shown to lead to fracture union but with joint stiffness and poor function or nonunion [1, 8, 41]. Multiple studies have shown satisfactory outcomes with open reduction internal fixation; however, the complication rate has been reported as high as 50% [1–35]. We had a complication rate of 61% in this series (26/43 patients), which is higher than any series reported to date.

Kundel et al. [3] reviewed 99 patients who were treated with open reduction internal fixation of an intra-articular distal humerus fracture. They reported a complication rate of 22%, but did not include painful implants requiring removal or elbow stiffness. Forty-nine percent of patients developed heterotopic ossification in their series. Twenty-four percent of patients had less than 110° of elbow flexion. They identified factors associated with poor range of motion and return to work after operative treatment of distal humerus fractures. The factors included open fractures, type C fractures, polytrauma, ipsilateral extremity injuries, and delayed time to surgery. Robinson et al. [1] reviewed 274 patients who underwent ORIF of the distal humerus. Their overall complication rate was 25%. They had a 3% nonunion rate and 5% infection rate. They showed that nonunion was associated with a high-energy injury, open fractures, and fractures treated non-operatively. Infection was associated with Type C fractures. Post-operative stiffness was not included as a complication.

In our series of 43 patients, the complication rate was 61% with 49% of the cohort requiring a secondary procedure to address the complication. The complication rate is higher than reported in Kundel's and Robinson's studies, because our series included post-operative elbow stiffness and painful implants as a complication. Gofton et al. [13] reviewed 23 patients with type C distal humerus fractures who underwent ORIF. Their complication rate was 48% and did not include elbow stiffness. Athwal et al. [16] reviewed 32 patients who underwent parallel plating for a type C distal humerus fracture. They had a complication rate of 53% at a mean follow-up of 27 months. Doornberg et al. [27] reviewed 30 patients who underwent ORIF for an intra-articular distal humerus fracture with an average follow-up of 19 years. Forty percent required a reoperation during the follow-up period. Eighty percent developed arthrosis.

Post-operative elbow stiffness that resulted in non-functional range of motion was the most common complication in our series (8/43 patients, 18.6%). Morrey et al. [40] defined functional range of motion of the elbow as 30° of extension and 130° of flexion. Sardelli et al. [42] more recently identified functional elbow range of motion for contemporary tasks as 27° of extension and 150° of flexion to reach the back of the neck and to use a cellular telephone while standing. For our study, we used Morrey's definition for functional elbow range of motion. The etiology of elbow stiffness is usually in the posteromedial capsule secondary to capsular fibrosis or heterotopic ossification [43]. Factors that may contribute to post-operative elbow stiffness include prolonged post-operative immobilization, soft-tissue injury, and patient compliance with post-operative rehabilitation [43–45]. Early range of motion and emphasis on post-operative rehabilitation may reduce the risk of post-operative elbow stiffness.

Post-operative nerve palsy was the second most common complication (16%, 7/43 patients). The ulnar nerve was involved in all 7 patients. One patient also sustained a radial nerve palsy in addition to the ulnar nerve palsy. Three cases resolved with observation. Four cases underwent a secondary procedure to address the persistent symptoms. Vazquez et al. [46] retrospectively reviewed 69 patients who underwent ORIF of the distal humerus with and without ulnar nerve transposition. There was a 16% ulnar nerve palsy rate at final follow-up. Transposition of the ulnar nerve did not decrease the development of post-operative ulnar nerve palsy. In their series, age, gender, surgical approach, polytrauma, or open fractures were not associated with ulnar nerve palsy. Chen et al. [47] identified ulnar nerve transposition as an independent variable associated with ulnar neuritis. They did not recommend routine transposition of the ulnar nerve at the time of ORIF.

The current literature reports fracture nonunion after ORIF of the distal humerus to be 0–15% [1, 3–5, 13, 14, 26].

Our results were consistent with the literature with a nonunion rate of 9% (4/43 patients). Robinson et al. [1] showed that nonunion was associated with high-energy mechanism, open fractures, and fractures treated non-operatively. Claessen [7] showed that nonunion was associated with smoking, obesity, diabetes mellitus, and Charlson comorbidity index. Our rates of heterotopic ossification, deep infection, painful implants, and post-traumatic arthritis were consistent with the literature [3, 4, 12–15, 21, 22, 26, 30, 32]. Foruria et al., Abrams et al., and Ilahi et al. evaluated heterotopic ossification after operative fixation of distal humerus fractures [48–50]. They concluded that head injury, delayed definitive fixation more than 48 h, and use of bone graft was associated with heterotopic ossification.

This study had several limitations. Most of the limitations were related primarily to the inherent weaknesses of a retrospective review, including loss to follow-up of 60% of patients (64/107 patients) and varying surgical techniques and plating systems. The sample size was also small and post hoc power analyses of the modifiable factors indicated that we were only powered to detect very large differences in complication rates (~40–50%) for these factors and would have likely needed nine-to-ten times more cases to find statistically significant differences. Therefore, we were unable to identify modifiable or non-modifiable risk factors for each complication. This study does not report functional outcomes after ORIF of distal humerus fractures, e.g., pain or elbow functional scores. However, the purpose of this study was to report complications and not functional outcomes.

In conclusion, we found that distal humerus fractures treated with ORIF using anatomic, pre-contoured, locking distal humeral plates at our institution were associated with a high rate of complications with about half of patients requiring a secondary procedure. Patients should be educated about the potential complications and chance of a secondary procedure after definitive fixation.

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Compliance with Ethical Standards

Conflict of interest Dr. Hassan Mir has the following disclosures: AAOS Council on Advocacy: Board or committee member, AAOS Diversity Advisory Board: Board or committee member, AAOS Healthcare Systems Committee: Board or committee member, AO Trauma North America: Research support, AOA Leadership/Fellowship Committee: Board or committee member, Core Orthopaedics: Stock or stock Options, FOT Research Committee: Board or committee member, JAAOS Consultant Reviewer: Editorial or governing board, JBJS Consultant Reviewer: Editorial or governing board, Journal of Orthopaedic Trauma Associate Editor: Editorial or governing board, OrthoGrid: Stock or stock Options, OsteoSynthesis, The JOT Online Discussion Forum Editor: Editorial or governing board, OTA Education Committee: Board or committee member, OTA International Digital Editor: Editorial or governing board, Smith & Nephew: Paid consultant; Research support, Trice Medical: Paid consultant, Zimmer: Paid consultant. Dr. Jason Nydick has the following disclosures: Axogen: Paid consultant; Paid presenter or speaker, Checkpoint surgical: Paid presenter or speaker, DePuy, A Johnson & Johnson Company: Paid consultant; Paid presenter or speaker, Journal of Hand Surgery—American: Editorial or governing board, Mission Surgical: Paid consultant, Trimed: Paid consultant. Shaan Patel, Evan Horowitz, Carson Smith, Adil Ahmed, and Katheryne Downes do not have any disclosures. All authors contributed to the conception and design of the study, data analysis, manuscript writing, and editing.

Ethical standard statement The authors certify that they have obtained all appropriate patient consent forms.

Informed consent For this type of study informed consent is not required.

References

1. Robinson, C. M., Hill, R. M., Jacobs, N., Dall, G., & Court-brown, C. M. (2003). Adult distal humeral metaphyseal fractures: epidemiology and results of treatment. *Journal of Orthopaedic Trauma, 17*(1), 38–47.
2. Varecka, T. F., & Myeroff, C. (2017). Distal Humerus Fractures in the Elderly Population. *Journal of American Academy of Orthopaedic Surgeons, 25*(10), 673–683.
3. Kundel, K., Braun, W., Wieberneit, J., & Rüter, A. (1996). Intraarticular distal humerus fractures. Factors affecting functional outcome. *Clinical Orthopaedics and Related Research, 332*, 200–208.
4. Jupiter, J. B., Neff, U., Holzach, P., & Allgöwer, M. (1985). Intercondylar fractures of the humerus. An operative approach. *The Journal of Bone and Joint surgery. American Volume, 67*(2), 226–239.
5. Pereles, T. R., Koval, K. J., Gallagher, M., & Rosen, H. (1997). Open reduction and internal fixation of the distal humerus: functional outcome in the elderly. *Journal of Trauma, 43*(4), 578–584.
6. Obert, L., Ferrier, M., Jacquot, A., et al. (2013). Distal humerus fractures in patients over 65: complications. *Orthopaedics and Traumatology: Surgery and Research, 99*(8), 909–913.
7. Claessen, F. M., Braun, Y., Peters, R. M., Kolovich, G. P., & Ring, D. (2015). Plate and screw fixation of bicolumnar distal humerus fractures: factors associated with loosening or breakage of implants or nonunion. *The Journal of Hand Surgery, 40*(10), 2045–2051.e2.
8. Zagorski, J. B., Jennings, J. J., Burkhalter, W. E., & Uribe, J. W. (1986). Comminuted intraarticular fractures of the distal humeral condyles. Surgical vs. nonsurgical treatment. *Clinical Orthopaedics and Related Research, 202*, 197–204.
9. Reising, K., Hauschild, O., Strohm, P. C., & Suedkamp, N. P. (2009). Stabilisation of articular fractures of the distal humerus: early experience with a novel perpendicular plate system. *Injury, 40*(6), 611–617.
10. Gabel, G. T., Hanson, G., Bennett, J. B., Noble, P. C., & Tullos, H. S. (1987). Intraarticular fractures of the distal humerus in the adult. *Clinical Orthopaedics and Related Research, 216*, 99–108.
11. Letsch, R., Schmit-neuerburg, K. P., Stürmer, K. M., & Walz, M. (1989). Intraarticular fractures of the distal humerus. Surgical treatment and results. *Clinical Orthopaedics and Related Research, 241*, 238–244.
12. Tyllianakis, M., Panagopoulos, A., Papadopoulos, A. X., Kaisidis, A., & Zouboulis, P. (2004). Functional evaluation of comminuted intra-articular fractures of the distal humerus (AO type C). Long

term results in twenty-six patients. *Acta Orthopaedica Belgica, 70*(2), 123–130.

13. Gofton, W. T., Macdermid, J. C., Patterson, S. D., Faber, K. J., & King, G. J. (2003). Functional outcome of AO type C distal humeral fractures. *The Journal of Hand Surgery, 28*(2), 294–308.
14. Pajarinen, J., & Björkenheim, J. M. (2002). Operative treatment of type C intercondylar fractures of the distal humerus: results after a mean follow-up of 2 years in a series of 18 patients. *Journal of Shoulder and Elbow Surgery, 11*(1), 48–52.
15. Gupta, R., & Khanchandani, P. (2002). Intercondylar fractures of the distal humerus in adults: a critical analysis of 55 cases. *Injury, 33*(6), 511–515.
16. Athwal, G. S., Hoxie, S. C., Rispoli, D. M., & Steinmann, S. P. (2009). Precontoured parallel plate fixation of AO/OTA type C distal humerus fractures. *Journal of Orthopaedic Trauma, 23*(8), 575–580.
17. Greiner, S., Haas, N. P., & Bail, H. J. (2008). Outcome after open reduction and angular stable internal fixation for supra-intercondylar fractures of the distal humerus: preliminary results with the LCP distal humerus system. *Archives of Orthopaedic and Trauma Surgery, 128*(7), 723–729.
18. Saragaglia, D., Rouchy, R. C., & Mercier, N. (2013). Fractures of the distal humerus operated on using the Lambda® plate: report of 75 cases at 9.5 years follow-up. *Orthopaedics and Traumatology: Surgery and Research., 99*(6), 707–712.
19. Schmidt-horlohé, K. H., Bonk, A., Wilde, P., Becker, L., & Hoffmann, R. (2013). Promising results after the treatment of simple and complex distal humerus type C fractures by angular-stable double-plate osteosynthesis. *Orthopaedics and Traumatology: Surgery and Research, 99*(5), 531–541.
20. Ring, D., & Jupiter, J. B. (1999). Complex fractures of the distal humerus and their complications. *Journal of Shoulder and Elbow Surgery, 8*(1), 85–97.
21. Henley, M. B., Bone, L. B., & Parker, B. (1987). Operative management of intra-articular fractures of the distal humerus. *Journal of Orthopaedic Trauma, 1*(1), 24–35.
22. Huang, T. L., Chiu, F. Y., Chuang, T. Y., & Chen, T. H. (2005). The results of open reduction and internal fixation in elderly patients with severe fractures of the distal humerus: a critical analysis of the results. *Journal of Trauma, 58*(1), 62–69.
23. Erpelding, J. M., Mailander, A., High, R., Mormino, M. A., & Fehringer, E. V. (2012). Outcomes following distal humeral fracture fixation with an extensor mechanism-on approach. *Journal of Bone and Joint Surgery. American Volume, 94*(6), 548–553.
24. Liu, J. J., Ruan, H. J., Wang, J. G., Fan, C. Y., & Zeng, B. F. (2009). Double-column fixation for type C fractures of the distal humerus in the elderly. *Journal of Shoulder and Elbow Surgery, 18*(4), 646–651.
25. Luegmair, M., Timofiev, E., & Chirpaz-cerbat, J. M. (2008). Surgical treatment of AO type C distal humeral fractures: internal fixation with a Y-shaped reconstruction (Lambda) plate. *Journal of Shoulder and Elbow Surgery, 17*(1), 113–120.
26. Simone, J. P., Streubel, P. N., Sanchez-sotelo, J., & Morrey, B. F. (2014). Low transcondylar fractures of the distal humerus: results of open reduction and internal fixation. *Journal of Shoulder and Elbow Surgery, 23*(4), 573–578.
27. Doornberg JN, Van duijn PJ, Linzel D, et al. (2007). Surgical treatment of intra-articular fractures of the distal part of the humerus Functional outcome after twelve to thirty years. *Journal of Bone and Joint Surgery. American Volume, 89*(7), 1524–1532.
28. Aslam, N., & Willett, K. (2004). Functional outcome following internal fixation of intraarticular fractures of the distal humerus (AO type C). *Acta Orthopaedica Belgica, 70*(2), 118–122.
29. Kaiser, T., Brunner, A., Hohendorff, B., Ulmar, B., & Babst, R. (2011). Treatment of supra- and intra-articular fractures of the distal humerus with the LCP Distal Humerus Plate: a 2-year follow-up. *Journal of Shoulder and Elbow Surgery, 20*(2), 206–212.
30. Muzaffar, N., Bhat, K., Ahmad, R., Wani, R., & Dar, M. (2014). Functional results after osteosynthesis of distal humeral fractures with pre-contoured LCP system. *Ortopedia, Traumatologia, Rehabilitacja, 16*(4), 381–385.
31. Mckee, M. D., Wilson, T. L., Winston, L., Schemitsch, E. H., & Richards, R. R. (2000). Functional outcome following surgical treatment of intra-articular distal humeral fractures through a posterior approach. *Journal of Bone and Joint Surgery. American Volume, 82-A*(12), 1701–1707.
32. Soon, J. L., Chan, B. K., & Low, C. O. (2004). Surgical fixation of intra-articular fractures of the distal humerus in adults. *Injury, 35*(1), 44–54.
33. Helfet, D. L., & Schmeling, G. J. (1993). Bicondylar intraarticular fractures of the distal humerus in adults. *Clinical Orthopaedics and Related Research, 292*, 26–36.
34. Clavert, P., Ducrot, G., Sirveaux, F., Fabre, T., & Mansat, P. (2013). Outcomes of distal humerus fractures in patients above 65 years of age treated by plate fixation. *Orthopaedics and Traumatology: Surgery and Research, 99*(7), 771–777.
35. John, H., Rosso, R., Neff, U., Bodoky, A., Regazzoni, P., & Harder, F. (1994). Operative treatment of distal humeral fractures in the elderly. *Journal of Bone and Joint Surgery. British Volume, 76*(5), 793–796.
36. Muller, M. E. (1991). The comprehensive classification of fractures of long bones. In M. E. Muller, M. Allgower, R. Schneider, et al. (Eds.), *Manual of internal fixation* (3rd ed., pp. 118–150). Berlin: Springer-Verlag.
37. O'driscoll, S. W. (2005). Optimizing stability in distal humeral fracture fixation. *Journal of Shoulder and Elbow Surgery, 14*(1 Suppl S), 186S–194S.
38. Hastings, H., & Graham, T. J. (1994). The classification and treatment of heterotopic ossification about the elbow and forearm. *Hand Clinics, 10*(3), 417–437.
39. Viola, R. W., & Hastings, H. (2000). Treatment of ectopic ossification about the elbow. *Clinical Orthopaedics and Related Research, 370*, 65–86.
40. Morrey, B. F., Askew, L. J., & Chao, E. Y. (1981). A biomechanical study of normal functional elbow motion. *Journal of Bone and Joint Surgery. American Volume, 63*(6), 872–877.
41. Riseborough, E. J., & Radin, E. L. (1969). Intercondylar T fractures of the humerus in the adult. A comparison of operative and non-operative treatment in twenty-nine cases. *Journal of Bone and Joint Surgery. American Volume, 51*(1), 130–141.
42. Sardelli, M., Tashjian, R. Z., & Macwilliams, B. A. (2011). Functional elbow range of motion for contemporary tasks. *Journal of Bone and Joint Surgery. American Volume, 93*(5), 471–477.
43. Park, M. J., Chang, M. J., Lee, Y. B., & Kang, H. J. (2010). Surgical release for posttraumatic loss of elbow flexion. *Journal of Bone and Joint Surgery. American Volume, 92*(16), 2692–2699.
44. Galano, G. J., Ahmad, C. S., & Levine, W. N. (2010). Current treatment strategies for bicolumnar distal humerus fractures. *Journal of American Academy of Orthopaedic Surgeons, 18*(1), 20–30.
45. Koh, K. H., Lim, T. K., Lee, H. I., & Park, M. J. (2013). Surgical release of elbow stiffness after internal fixation of intercondylar fracture of the distal humerus. *Journal of Shoulder and Elbow Surgery, 22*(2), 268–274.
46. Vazquez, O., Rutgers, M., Ring, D. C., Walsh, M., & Egol, K. A. (2010). Fate of the ulnar nerve after operative fixation of distal humerus fractures. *Journal of Orthopaedic Trauma, 24*(7), 395–399.
47. Chen, R. C., Harris, D. J., Leduc, S., Borrelli, J. J., Tornetta, P., & Ricci, W. M. (2010). Is ulnar nerve transposition beneficial during open reduction internal fixation of distal humerus fractures? *Journal of Orthopaedic Trauma, 24*(7), 391–394.

48. Ilahi, O. A., Strausser, D. W., & Gabel, G. T. (1998). Post-traumatic heterotopic ossification about the elbow. *Orthopedics., 21*(3), 265–268.
49. Foruria, A. M., Lawrence, T. M., Augustin, S., Morrey, B. F., & Sanchez-sotelo, J. (2014). Heterotopic ossification after surgery for distal humeral fractures. *The Bone and Joint Journal, 96-B*(12), 1681–1687.
50. Abrams, G. D., Bellino, M. J., & Cheung, E. V. (2012). Risk factors for development of heterotopic ossification of the elbow after fracture fixation. *Journal of Shoulder and Elbow Surgery, 21*(11), 1550–1554.