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FUNCTIONAL OUTCOME OF A.O. TYPE 'C' FRACTURES OF DISTAL HUMERUS MANAGED SURGICALLY USING BI-COLUMNAR PARALLEL PLATING TECHNIQUE, USING ANATOMICAL DISTAL HUMERAL LOCKING PLATES, IN ADULTS

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ABSTRACT

Background: AO/OTA type 'C' distal humerus fractures are complex intra-articular injuries that require accurate articular reconstruction and stable fixation to restore elbow function. Bicolumnar parallel plating with anatomically contoured distal humeral locking plates provides rigid fixation of both columns and may permit early mobilisation. This study evaluated the functional and radiological outcomes of this technique in adults. **Materials and Methods:** A prospective observational study was conducted on 140 adult patients with AO/OTA type 'C' distal humerus fractures treated surgically using bicolumnar parallel plating with anatomical locking plates. Patients were assessed clinically and radiologically during follow-up. Functional outcome was evaluated using the Mayo Elbow Performance Score (MEPS), elbow range of motion, fracture union, and postoperative complications. Outcomes were also compared among C1, C2, and C3 fracture subtypes. **Results:** The mean age was 44.8 ± 14.7 years, and 63.6% of patients were male. Overall fracture union was achieved in 96.4% of patients, with a mean union time of 15.3 ± 3.7 weeks. The mean final MEPS was 84.6 ± 10.8, and 77.9% of patients achieved excellent or good outcomes. The mean flexion-extension arc was 109.8 ± 17.3°. Type C1 fractures showed significantly better MEPS and range of motion than C3 fractures (P<0.001). Elbow stiffness was the most frequent complication, occurring in 14.3% of patients. **Conclusion:** Bicolumnar parallel plating with anatomical distal humeral locking plates provides high union rates and satisfactory functional outcomes in adult AO/OTA type 'C' distal humerus fractures. Increasing fracture complexity, particularly type C3 injuries, is associated with poorer functional recovery and prolonged union.

INTRODUCTION

Distal humerus fractures are relatively uncommon injuries in adults, but they remain among the most technically demanding fractures around the elbow. Their management is challenging because of the complex three-dimensional anatomy of the distal humerus, the limited amount of bone available for fixation, the close relationship of important neurovascular structures, and the frequent involvement of the articular surface. These fractures show a bimodal age distribution, occurring as a result of high-energy trauma in younger adults and following low-energy falls in elderly individuals with osteoporotic bone. Irrespective of the mechanism of injury, restoration of a painless, stable, and functional elbow requires accurate reconstruction of the articular surface and stable fixation that permits early mobilization.[1]

The AO/Orthopaedic Trauma Association classification categorises distal humerus fractures into type 'A', which are extra-articular; type 'B', which involve part of the articular surface; and type 'C', which are complete articular fractures. In AO type 'C' fractures, the articular component is completely separated from the humeral shaft, with varying degrees of metaphyseal and intra-articular comminution. Type 'C' fractures therefore represent one of the most complex patterns of distal humeral injury. The primary aim of treatment is to restore the trochlea and capitellum anatomically, reconstruct the medial and lateral columns, and achieve sufficient mechanical stability to allow early movement of the elbow.[2] Failure to achieve these objectives may result in malunion, nonunion, post-traumatic arthritis, instability, pain, and substantial restriction of elbow motion.

Historically, conservative management of displaced intra-articular distal humerus fractures was associated with prolonged immobilisation, stiffness, deformity, and poor functional outcomes. With improvements in implant design and surgical techniques, open reduction and internal fixation (ORIF) has become the preferred treatment for most reconstructible intra-articular fractures in active adults.[3] Successful ORIF requires anatomical reduction of the joint surface followed by rigid fixation of both columns. Because the distal humerus functions structurally as two columns supporting an intervening articular segment, fixation of both the medial and lateral columns is considered essential for most AO type 'C' fractures.

Dual plating can be performed using orthogonal (90°–90°) plating and parallel plating configurations. Although satisfactory clinical outcomes have been reported with both techniques, parallel plating has attracted considerable attention because of its ability to provide fixation on both the medial and lateral columns while permitting long interdigitating screws to obtain purchase across the distal fragments. Sanchez-Sotelo et al. described a principle-based parallel-plating technique designed to maximise screw fixation in the distal fragments and increase stability across the supracondylar region. In their series of complex distal humeral fractures, stable fixation and a high rate of fracture union were achieved, supporting the use of parallel bicolumnar fixation for these challenging injuries.[4]

Biomechanical evidence also provides support for parallel plating. A meta-analysis of biomechanical studies by Shih et al. demonstrated that parallel constructs had greater axial stiffness, axial strength, and torsional stiffness than orthogonal constructs in several testing conditions.[5] From a clinical perspective, however, both configurations can provide satisfactory results when properly applied. A systematic review and meta-analysis by Yu et al. found no significant difference between parallel and orthogonal plating in final Mayo Elbow Performance Score, elbow range of motion, or the rate of excellent and good outcomes, although union time was shorter with parallel plating.[6] These findings indicate that the quality of reduction, appropriate implant placement, fracture characteristics, and surgical technique remain important determinants of the final outcome.

The introduction of anatomically contoured distal humeral locking plates has further improved fixation options, particularly in fractures with small distal fragments, metaphyseal comminution, or reduced bone quality. Locking screws create an angular-stable construct and may improve fixation where conventional screw purchase is limited. Anatomically precontoured plates also reduce the requirement for extensive intraoperative plate contouring and allow multiple distal screws to be directed through the medial and lateral columns. Gupta et al. reported favourable clinical and radiological results using distal humerus locking plates, with fracture consolidation achieved in all evaluated patients and excellent or good Mayo Elbow Performance Scores in the majority of cases.[7]

Despite advances in implants and fixation strategies, complications following operative treatment of intra-articular distal humerus fractures remain clinically important. These include elbow stiffness, ulnar neuropathy, heterotopic ossification, infection, nonunion, malunion, implant failure, and the need for secondary surgery. A systematic review and meta-analysis involving more than 2,000 surgically treated elbows demonstrated that complications and reoperations remain substantial following ORIF of articular distal humeral fractures.[8] Consequently, achieving stable fixation that permits early controlled mobilisation is particularly important, as prolonged postoperative immobilisation is a major contributor to loss of elbow movement.

Functional recovery following surgery is determined not only by fracture union but also by restoration of elbow movement, pain relief, strength, stability, and the patient's ability to return to activities of daily living. Outcome measures such as the Mayo Elbow Performance Score (MEPS), Disabilities of the Arm, Shoulder and Hand (DASH) score, range of motion, radiological union, and postoperative complications are therefore commonly used to assess the effectiveness of surgical treatment. Studies focusing specifically on AO type 'C' fractures have demonstrated that satisfactory elbow function can be achieved with double-column fixation when anatomical reconstruction and adequate stability are obtained.[9]

Considering the complexity of AO type 'C' distal humerus fractures and the continuing need to optimize fixation and postoperative elbow function, evaluation of bicolumnar parallel plating using anatomically designed distal humeral locking plates is clinically relevant. The present study therefore aims to assess the functional and radiological outcomes of AO type 'C' fractures of the distal humerus managed surgically using a bicolumnar parallel plating technique with anatomical distal humeral locking plates in adult patients, with particular emphasis on fracture union, elbow range of motion, functional outcome, and treatment-related complications.

MATERIALS AND METHODS

Study Design and Setting

This prospective observational study was conducted in the Department of Orthopaedics at a tertiary hospital in Shahjahanpur, Uttar Pradesh, India. The study included adult patients with AO/OTA type 'C' fractures of the distal humerus who were managed surgically using a bicolumnar parallel plating technique with anatomically contoured distal

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humeral locking plates. The study was carried out over a period of 4 years, from May 2022 to May 2026.

A total of 140 patients fulfilling the predefined eligibility criteria were enrolled consecutively during the study period. All patients were evaluated clinically and radiologically before surgery and were followed prospectively to determine fracture union, elbow range of motion, functional recovery, and postoperative complications.

Study Population

Adult patients presenting with an intra-articular distal humeral fracture classified as AO/OTA type 'C' and considered suitable for operative fixation were screened for inclusion. The diagnosis was established using standard anteroposterior and lateral radiographs of the elbow. Computed tomography with multiplanar and three-dimensional reconstruction was performed when required to define the articular fracture pattern, degree of comminution, and orientation of individual fragments and to assist in preoperative planning.

Inclusion Criteria

Patients were included if they fulfilled all of the following criteria:

1. Age 18 years or older.
2. Closed or Gustilo-Anderson grade I open fracture of the distal humerus.
3. Complete intra-articular distal humerus fracture classified as AO/OTA type 'C'.
4. Fracture considered reconstructible by open reduction and internal fixation.
5. Surgical fixation performed using bicolumnar parallel plating with anatomical distal humeral locking plates.
6. Patients medically fit to undergo surgical intervention.
7. Availability for the planned postoperative clinical and radiological follow-up.
8. Provision of written informed consent.

Exclusion Criteria

Patients were excluded in the presence of any of the following:

1. Age below 18 years.
2. Extra-articular or partial articular fractures classified as AO/OTA type A or B.
3. Pathological fractures.
4. Gustilo-Anderson grade II or III open fractures.
5. Previous fracture, deformity, or major surgery involving the affected elbow.
6. Pre-existing severe elbow arthritis or neurological disorder affecting upper-limb function.
7. Fractures requiring primary elbow arthroplasty.
8. Associated vascular injury requiring reconstruction.
9. Polytrauma or associated ipsilateral upper-limb injuries likely to interfere with functional assessment.
10. Patients unable or unwilling to comply with postoperative rehabilitation or follow-up.

Preoperative Assessment

At the time of presentation, a detailed history was obtained regarding age, sex, affected side, dominant limb, mechanism of injury, time from injury to hospital presentation, and associated injuries. Clinical examination included assessment of the condition of the skin and soft tissues, swelling, deformity, distal vascular status, and neurological function, with particular attention to the ulnar, median, and radial nerves.

Standard anteroposterior and lateral radiographs of the affected elbow were obtained in all patients. The fractures were classified according to the AO/OTA fracture classification system into type C1, C2, or C3 based on the degree of articular and metaphyseal comminution. Computed tomography was obtained in complex fracture configurations when additional assessment of articular fragmentation was considered necessary.

Routine preoperative investigations and anaesthetic assessment were performed according to institutional protocol. Temporary immobilisation using an above-elbow posterior slab was provided until definitive surgical fixation.

Postoperative Management and Rehabilitation

Postoperative intravenous antibiotics were administered according to institutional protocol. Analgesics, limb elevation, and measures to reduce postoperative swelling were provided as required. Post operative X-rays of the operated elbow joint were taken by the third post operative day

The operated limb was initially supported in an above-elbow posterior slab and pouch arm sling. Active fingers, wrist, and shoulder mobilisation was encouraged from the immediate postoperative period. Elbow mobilisation was initiated once sutures were removed at 2 weeks post surgery, and the above elbow slab was discontinued.

Active and active-assisted elbow flexion-extension and forearm pronation-supination exercises were progressively introduced under supervision of the physiotherapist and patients were encouraged to continue performing these exercises at home. Heavy lifting and resisted elbow exercises were restricted until radiological evidence of fracture union was observed. Strengthening exercises were subsequently introduced in a graded manner.

Follow-up Assessment

Patients were assessed clinically at approximately 2 weeks where suture removal and elbow range of motion exercises were started. Patients were subsequently assessed clinically and radiologically at 6 weeks, 3 months, 6 months, and 12 months.

At each follow-up visit, patients were examined for pain, wound healing, signs of infection, neurological status, elbow stability, deformity, and implant-related complications. The range of motion of the affected elbow was measured using a standard goniometer. Flexion, extension deficit, and total flexion-extension arc were documented. Forearm pronation and supination were also assessed.

Standard anteroposterior and lateral radiographs were obtained during follow-up to assess fracture alignment, maintenance of reduction, implant position, callus formation, and fracture union.

Assessment of Fracture Union

Radiological union was defined as evidence of progressive bridging callus or trabecular continuity across the fracture site together with disappearance of the fracture line on serial radiographs and absence of clinical tenderness at the fracture site.

Delayed union was considered when satisfactory progression toward union was not evident within the expected healing period but eventual union remained clinically probable. Nonunion was defined according to accepted clinical and radiological criteria, including absence of progressive healing during serial follow-up and persistence of the fracture without evidence of union at an appropriate postoperative interval.

Time to radiological union was recorded in weeks.

Functional Outcome Assessment

The primary functional outcome was assessed using the Mayo Elbow Performance Score (MEPS) at the final follow-up. The MEPS evaluates four domains: pain, range of motion, stability, and ability to perform activities of daily living, producing a total score of 100 points.

Outcomes were classified as:

- **Excellent:** 90-100 points
- **Good:** 75-89 points
- **Fair:** 60-74 points
- **Poor:** <60 points

The final elbow flexion-extension arc was additionally recorded as an objective functional parameter.

Outcome Measures

The **primary outcome measure** was functional outcome at final follow-up as determined by the Mayo Elbow Performance Score.

Secondary outcome measures included:

- Time to radiological fracture union.
- Final elbow flexion.
- Extension deficit.
- Total flexion-extension arc.
- Forearm pronation and supination.
- Proportion of patients achieving excellent or good functional outcomes.
- Relationship between fracture subtype and functional outcome.
- Postoperative complications.
- Requirement for secondary surgical procedures.

Assessment of Complications

All intraoperative and postoperative complications were prospectively documented. Complications specifically evaluated included superficial and deep infection, wound dehiscence, transient or persistent ulnar neuropathy, radial or median nerve dysfunction, elbow stiffness, heterotopic ossification, loss of reduction, implant loosening or failure, symptomatic implant prominence, delayed union, nonunion, malunion, post-traumatic arthritis, and reoperation.

Elbow stiffness was assessed according to the limitation of the functional arc of motion and the effect on activities of daily living. Any secondary procedure, including implant removal, release for stiffness, treatment of nonunion, or management of infection, was recorded.

Data Collection

All demographic, injury-related, surgical, radiological, and functional data were entered into a structured case-record form. Variables included age, sex, affected side, dominant limb, mechanism of injury, AO/OTA fracture subtype, interval between injury and surgery, surgical approach, operative duration, duration of follow-up, time to fracture union, range of motion, final MEPS, and complications.

Data were checked for completeness and consistency before statistical analysis.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows, version 26.0, IBM Corp., Armonk, NY, USA, or equivalent validated statistical software.

Continuous variables were assessed for normality using the Shapiro-Wilk test and graphical methods. Normally distributed continuous data were expressed as mean ± standard deviation, whereas non-normally distributed data were presented as median and interquartile range. Categorical variables were expressed as frequencies and percentages.

RESULTS

A total of 140 adult patients with AO/OTA type 'C' distal humerus fractures treated surgically using bicolumnar parallel plating with anatomical distal humeral locking plates were included in the final analysis. All patients were assessed clinically and radiologically according to the predefined follow-up protocol.

The mean age of the study population was 44.8 ± 14.7 years, with a predominance of male patients. Road traffic accidents were the most frequent mechanism of injury. AO/OTA type C2 fractures represented the largest fracture subgroup, followed by type C3 and type C1 fractures.

Table 1: Demographic and injury-related characteristics of the study population

Variable	Value
Total number of patients	140
Age, years, mean ± SD	44.8 ± 14.7
Male	89 (63.6%)
Female	51 (36.4%)
Right-sided fracture	78 (55.7%)

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Left-sided fracture	62 (44.3%)
Road traffic accident	78 (55.7%)
Fall	49 (35.0%)
Other mechanisms	13 (9.3%)
AO/OTA type C1	38 (27.1%)
AO/OTA type C2	57 (40.7%)
AO/OTA type C3	45 (32.1%)

Progressive radiological healing was observed in the majority of patients during follow-up. The mean time to radiological union was 15.3 ± 3.7 weeks. A total of 127 patients (90.7%) achieved uncomplicated union within the expected healing period. Eight patients demonstrated delayed union but subsequently achieved union with continued observation and rehabilitation.

At the final follow-up, fracture union had been achieved in 135 of 140 patients (96.4%). Five patients (3.6%) developed nonunion. Maintenance of reduction was satisfactory in most cases, although a small number of patients showed loss of reduction or implant-related problems.

Table 2: Radiological and fracture-healing outcomes

Outcome	Value
Mean time to radiological union, weeks	15.3 ± 3.7
Union within expected period	127 (90.7%)
Delayed union with subsequent healing	8 (5.7%)
Overall union at final follow-up	135 (96.4%)
Nonunion	5 (3.6%)
Loss of reduction	3 (2.1%)
Implant loosening/failure	3 (2.1%)

At final follow-up, the mean elbow flexion was 124.1 ± 10.2°, while the mean extension deficit was 14.3 ± 9.8°. The resulting mean flexion-extension arc was 109.8 ± 17.3°. Mean forearm pronation and supination were 74.5 ± 9.6° and 76.1 ± 8.8°, respectively.

The mean final Mayo Elbow Performance Score (MEPS) was 84.6 ± 10.8 points. According to the MEPS classification, 51 patients (36.4%) achieved an excellent outcome, 58 (41.4%) achieved a good outcome, 23 (16.4%) had a fair outcome, and 8 (5.7%) had a poor outcome. Thus, 109 of 140 patients (77.9%) achieved an excellent or good functional result.

Table 3: Functional outcomes at final follow-up

Functional parameter	Value
Elbow flexion, degrees	124.1 ± 10.2
Extension deficit, degrees	14.3 ± 9.8
Flexion-extension arc, degrees	109.8 ± 17.3
Forearm pronation, degrees	74.5 ± 9.6
Forearm supination, degrees	76.1 ± 8.8
Final MEPS	84.6 ± 10.8
Excellent MEPS (90–100)	51 (36.4%)
Good MEPS (75–89)	58 (41.4%)
Fair MEPS (60–74)	23 (16.4%)
Poor MEPS (<60)	8 (5.7%)
Excellent/good overall outcome	109 (77.9%)

Functional and radiological outcomes demonstrated a significant relationship with fracture complexity. Patients with AO/OTA type C1 fractures had the highest mean MEPS and largest flexion-extension arc, whereas patients with type C3 fractures showed comparatively lower functional scores and longer fracture-healing times.

The mean MEPS was 89.1 ± 8.3 in type C1 fractures, 85.4 ± 9.7 in type C2 fractures, and 79.9 ± 12.4 in type C3 fractures (P<0.001).

Similarly, the mean elbow flexion-extension arc decreased progressively with increasing fracture complexity, from 118.2 ± 12.9° in the C1 group to 100.8 ± 18.2° in the C3 group (P<0.001).

Excellent or good MEPS outcomes were observed in 92.1% of type C1 fractures, 82.5% of type C2 fractures, and 60.0% of type C3 fractures, demonstrating a statistically significant association between fracture subtype and functional outcome (P=0.001).

Table 4: Comparison of outcomes according to AO/OTA fracture subtype

Outcome	C1 (n=38)	C2 (n=57)	C3 (n=45)	P value
Mean MEPS	89.1 ± 8.3	85.4 ± 9.7	79.9 ± 12.4	<0.001
Flexion-extension arc, degrees	118.2 ± 12.9	111.3 ± 15.4	100.8 ± 18.2	<0.001
Time to union, weeks	13.7 ± 2.4	15.1 ± 3.1	17.1 ± 4.2	<0.001

Excellent outcome	18 (47.4%)	22 (38.6%)	11 (24.4%)	—
Good outcome	17 (44.7%)	25 (43.9%)	16 (35.6%)	—
Fair outcome	3 (7.9%)	8 (14.0%)	12 (26.7%)	—
Poor outcome	0	2 (3.5%)	6 (13.3%)	—
Excellent/good outcome	35 (92.1%)	47 (82.5%)	27 (60.0%)	0.001

Continuous variables were compared using one-way analysis of variance or an appropriate non-parametric test. Categorical outcomes were compared using the chi-square test or Fisher's exact test, as appropriate. A P value <0.05 was considered statistically significant.

Postoperative complications were documented throughout the follow-up period. Elbow stiffness was the most frequent complication, occurring in 20 patients (14.3%). Transient postoperative ulnar neuropathy occurred in 11 patients (7.9%), with spontaneous or conservative-treatment-related recovery in most cases. Persistent ulnar neuropathy was observed in 3 patients (2.1%).

Superficial surgical-site infection occurred in 6 patients and was successfully managed with wound care and antibiotics. 2 patients developed deep infection requiring additional intervention. Heterotopic ossification was detected radiologically in 7 patients.

5 patients developed nonunion, while 3 experienced loss of reduction or implant failure. Symptomatic implant prominence was reported in 8 patients. 9 patients (6.4%) required a secondary surgical procedure for complications including nonunion, infection, symptomatic hardware, or persistent elbow stiffness.

Table 5: Postoperative complications

Complication	Number of patients	Percentage
Elbow stiffness	20	14.3
Transient ulnar neuropathy	11	7.9
Persistent ulnar neuropathy	3	2.1
Superficial infection	6	4.3
Deep infection	2	1.4
Heterotopic ossification	7	5.0
Nonunion	5	3.6
Loss of reduction/implant failure	3	2.1
Symptomatic implant prominence	8	5.7
Post-traumatic arthritis	6	4.3
Secondary surgical procedure	9	6.4

Overall, bicolumnar parallel plating using anatomical distal humeral locking plates resulted in a 96.4% final fracture-union rate, with 77.9% of patients achieving excellent or good MEPS outcomes. Increasing fracture complexity was significantly associated with a lower functional score, reduced elbow range of motion, and prolonged time to fracture union. Type C3 fractures demonstrated the least favourable outcomes compared with C1 and C2 fractures.

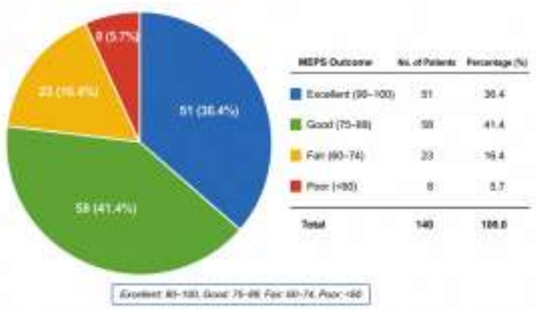

Figure 1: Distribution of functional outcomes according to the Mayo Elbow Performance Score following bicolumnar parallel plating of AO/OTA type C distal humerus fractures

Figure 1 illustrates the distribution of functional outcomes based on the Mayo Elbow Performance Score (MEPS) among 140 patients with AO/OTA type 'C' distal humerus fractures treated using bicolumnar parallel plating. Good functional outcomes were observed in 58 patients (41.4%), while 51 patients (36.4%) achieved excellent outcomes. Fair outcomes were recorded in 23 patients (16.4%), and only 8 patients (5.7%) had poor functional results. Overall, 77.9% of patients achieved excellent or good outcomes, indicating satisfactory postoperative functional recovery in the majority of patients following parallel bicolumnar fixation.

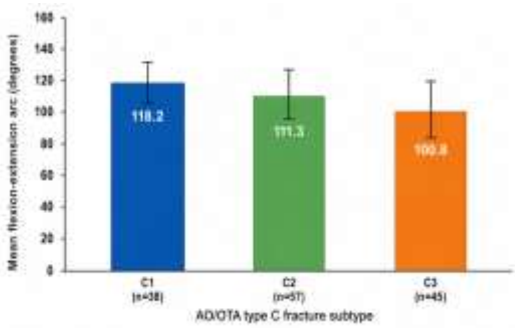

Figure 2: Comparison of mean elbow flexion-extension arc according to AO/OTA type C fracture subtype at final follow-up

Figure 2 compares the mean elbow flexion-extension arc among patients with AO/OTA type C1, C2, and C3 distal humerus fractures at final follow-up.

Patients with type C1 fractures achieved the greatest mean flexion-extension arc of 118.2 ± 12.9°, followed by 111.3 ± 15.4° in type C2 fractures and 100.8 ± 18.2° in type C3 fractures. The difference among the three fracture subtypes was statistically significant (P<0.001). These findings indicate a progressive reduction in postoperative elbow range of motion with increasing fracture complexity, with type C3 fractures showing the least favourable functional recovery.

DISCUSSION

The management of AO/OTA type 'C' distal humerus fractures remains challenging because successful treatment requires simultaneous restoration of the articular surface, reconstruction of the medial and lateral columns, stable fixation, preservation of the surrounding soft tissues, and early postoperative mobilisation. The present study evaluated the functional and radiological outcomes of 140 adult patients with AO/OTA type 'C' fractures treated using bicolumnar parallel plating with anatomical distal humeral locking plates. The main findings were a final fracture union rate of 96.4%, a mean Mayo Elbow Performance Score (MEPS) of 84.6 ± 10.8, and excellent or good functional outcomes in 77.9% of patients. The mean flexion-extension arc was 109.8 ± 17.3°. Increasing fracture complexity was associated with significantly poorer functional outcome, reduced elbow movement, and prolonged union time, with type C3 fractures demonstrating the least favourable results.

The mean age of the study population was 44.8 years, and 63.6% of patients were male. Road traffic accidents accounted for 55.7% of injuries, while falls accounted for 35.0%. This demographic profile reflects the substantial contribution of high-energy trauma to intra-articular distal humerus fractures in relatively younger adults. Gofton et al. evaluated functional outcomes after operative fixation of AO type 'C' fractures and demonstrated that although satisfactory functional recovery can be achieved, residual loss of motion and strength may persist even following successful fracture reconstruction.[10] The predominance of type C2 and C3 fractures in the present series further highlights the complexity of the injuries encountered.

One of the most important findings of the present study was the high fracture union rate. Overall union was achieved in 135 of 140 patients (96.4%), and the mean time to radiological union was 15.3 ± 3.7 weeks. Only five patients developed nonunion. These findings support the ability of bicolumnar parallel plating to provide adequate mechanical stability for fracture healing. Atalar et al. reported solid union in all 21 patients treated using the parallel plate technique for complex distal humerus fractures.[11] Similarly, Theivendran et al. achieved union in all patients treated with precontoured anatomical parallel plates and reported no hardware failure.[12] These findings are consistent with the principle that fixation of both columns combined with multiple distal screw purchase can create a sufficiently stable construct to maintain reduction until fracture healing occurs.

The functional results observed in the present study were also satisfactory. The mean final MEPS was 84.6 ± 10.8, with 36.4% of patients having an excellent result and 41.4% having a good result. Thus, almost four out of every five patients achieved an excellent or good functional outcome. Atalar et al. reported a mean MEPS of 86.1 ± 12.6 following parallel plate fixation, which is comparable to the value observed in the present study.[11] Lan et al., in a comparative study of type 'C' distal humeral fractures, reported a mean MEPS of 86.1 in patients treated with parallel plating and an excellent or good outcome in approximately 90% of cases.[13] Although the proportion of excellent or good results in their study was somewhat higher than the 77.9% observed in the present study, differences in fracture complexity, sample size, patient characteristics, surgical technique, and duration of follow-up may explain the variation.

Schmidt-Horlohé et al. investigated anatomically precontoured angular-stable double plates in type 'C' distal humerus fractures and reported a mean MEPS of 85 points, closely resembling the mean score in the present study. They observed excellent or good outcomes in 92% of evaluated fractures.[14] Their findings provide additional support for the use of anatomically designed locking implants, which may be especially beneficial when distal fragments are small or bone quality is compromised. Angular-stable fixation allows the plate and screws to function as a fixed-angle construct, reducing dependence on friction between the plate and bone and potentially increasing stability in comminuted fracture patterns.

The recovery of elbow movement is an important determinant of patient satisfaction and the ability to perform routine activities. In the present study, the mean final elbow flexion was 124.1 ± 10.2°, the mean extension deficit was 14.3 ± 9.8°, and the mean flexion-extension arc was 109.8 ± 17.3°. Atalar et al. reported mean flexion of approximately 118° in patients treated using parallel plating, while the mean total range of motion was approximately 90°.[11] Lan et al. reported a mean flexion-extension arc of approximately 100° in their parallel plating group.[13] Schmidt-Horlohé et al. reported an extension-flexion range of approximately 105° following angular-stable double plating.[14] Therefore, the mean motion arc achieved in the present study compares favourably with several previously published series.

Stable fixation is particularly important at the elbow because prolonged immobilisation may rapidly result in capsular contracture and loss of movement. Anatomically contoured parallel locking plates allow stable fixation of both columns and facilitate the initiation of controlled postoperative mobilisation. Jagadish et al. similarly reported approximately 80% excellent or good MEPS outcomes following bicolumnar plating and emphasised the importance of stable fixation and early elbow mobilisation for recovery of function.[15] The 77.9% excellent/good outcome rate observed in the present study is therefore broadly consistent with their findings.

A clinically important observation in the present study was the significant influence of fracture subtype on postoperative outcome. Mean MEPS decreased from 89.1 ± 8.3 in type C1 fractures to 85.4 ± 9.7 in C2 fractures and 79.9 ± 12.4 in C3 fractures (P<0.001). Similarly, the mean flexion-extension arc declined from 118.2° in C1 fractures to 100.8° in C3 fractures. Only 60.0% of patients with C3 fractures achieved excellent or good outcomes compared with 92.1% of patients with C1 fractures.

This progressive deterioration in outcome with increasing fracture complexity is clinically plausible. Type C3 fractures are characterised by extensive articular and metaphyseal comminution, producing smaller fragments and making anatomical reconstruction more difficult. Greater surgical exposure may also be required, potentially increasing soft-tissue trauma and postoperative fibrosis. Furthermore, severe comminution can reduce the available area for screw purchase and may compromise the biological environment required for fracture healing. Bhayana et al., in a prospective series of 94 AO type ‘C’ fractures treated using parallel plating, demonstrated that these injuries can achieve satisfactory outcomes but remain associated with a substantial complication burden because of their inherent complexity.[16]

The relationship between fracture complexity and healing was further demonstrated by the progressive increase in union time. Mean union occurred at 13.7 ± 2.4 weeks for C1, 15.1 ± 3.1 weeks for C2, and 17.1 ± 4.2 weeks for C3 fractures (P<0.001). The prolonged healing observed in C3 fractures may reflect extensive metaphyseal comminution, greater periosteal disruption, increased surgical manipulation, and occasionally less favourable bone contact. These results emphasise that successful management of C3 fractures requires careful preservation of viable fragments and soft-tissue attachments in addition to mechanically stable fixation.

Despite favourable union and functional outcomes, complications remained clinically relevant. The most frequent complication was elbow stiffness, affecting 14.3% of patients. Elbow stiffness following distal humerus fracture fixation is multifactorial and may result from the initial articular injury, capsular fibrosis, prolonged immobilisation, heterotopic ossification, pain, and repeated surgical manipulation. In the multicentre study by Han et al., limitation of functional elbow motion was common after plate fixation, illustrating that stiffness remains a major concern even when fracture union is achieved.[17] Their study further demonstrated that complications after distal humerus ORIF should not be regarded solely as implant-related problems because neurological symptoms, heterotopic ossification, infection, and post-traumatic degenerative changes can also influence long-term function.

Ulnar nerve dysfunction represents another recognised complication because of the nerve's close anatomical relationship with the medial column and the need for its mobilisation during surgical exposure and plate placement. In the present study, transient ulnar neuropathy occurred in 7.9% of patients, while persistent neuropathy was recorded in 2.1%. Bhayana et al. identified ulnar nerve neuropathy as the most frequent complication in their series of type ‘C’ fractures treated with parallel plating.[16] Han et al. reported postoperative ulnar nerve symptoms in approximately 15% of their multicentre cohort.[17] The somewhat lower rate observed in the present study may relate to careful identification and protection of the nerve, differences in fracture severity, surgical technique, or the criteria used to define postoperative neuropathy.

The infection rate in the present series was relatively low, with superficial infection occurring in 4.3% and deep infection in 1.4% of patients. Deep infection following distal humerus surgery is particularly important because of the limited soft-tissue envelope over the posterior elbow and the presence of extensive internal fixation. Han et al. reported both superficial and deep infections following ORIF, although the absolute rates were relatively low.[17] Careful soft-tissue handling, appropriate antibiotic prophylaxis, meticulous wound closure, and avoidance of unnecessary periosteal stripping remain important in reducing this complication.

Nonunion occurred in 3.6% of patients in the present study. This rate is comparable with the 4.1% nonunion rate reported by Han et al. following plate fixation of adult distal humerus fractures.[17] The relatively high overall union rate in the present cohort suggests that parallel locking plate fixation was capable of maintaining stability through the healing period in most patients. Nevertheless, nonunion remains possible, particularly in highly comminuted fractures, patients with impaired bone biology, extensive soft-tissue damage, or inadequate mechanical stability.

Heterotopic ossification was identified in 5.0% of patients. Atalar et al. reported heterotopic ossification in seven of their 21 patients, although only two required excision because of severe limitation of motion.[11] Han et al. also reported a higher incidence of radiographically detected heterotopic ossification in their multicentre series.[17] The lower rate in the present study may reflect differences in injury severity, diagnostic criteria, follow-up duration, and whether clinically insignificant radiographic ossification was systematically included.

Symptomatic implant prominence was observed in 5.7% of patients, and 6.4% underwent a secondary surgical procedure. Theivendran et al. reported that some patients required implant removal because of pain and prominence despite successful union.[12] This remains relevant in distal humeral fixation because plates are positioned in an anatomically superficial region with relatively limited soft-tissue coverage. Anatomically contoured plates may reduce but cannot completely eliminate implant-related irritation.

The comparison of parallel and orthogonal plating remains an area of ongoing investigation. Govindasamy et al., in a prospective randomised study, found satisfactory outcomes with both parallel and perpendicular plating and did not demonstrate clear superiority of one technique in terms of clinical outcome.[18] Similarly, Lan et al. reported comparable functional results between the two configurations.[13] These observations indicate that plate orientation alone is unlikely to determine treatment success. Anatomical articular reduction, reconstruction of both columns, adequate distal screw purchase, preservation of fracture biology, and early rehabilitation are probably more important than the configuration of the plates in isolation. Nevertheless, parallel placement has the practical advantage of permitting multiple long distal screws to pass from each column into the opposite side of the reconstructed articular block, potentially improving fixation in small or comminuted distal fragments.

The findings of the present study therefore support the use of bicolumnar parallel plating with anatomical distal humeral locking plates as an effective reconstructive strategy for adult AO/OTA type 'C' distal humerus fractures. The high union rate, satisfactory mean MEPS, and functional motion achieved in most patients indicate that this technique can provide a stable construct capable of supporting fracture healing and postoperative rehabilitation. However, the poorer results in C3 fractures demonstrate that implant selection alone cannot overcome the biological and mechanical challenges associated with severe articular comminution.

Strengths and Limitations

An important strength of the present study is the relatively large sample of 140 patients treated using a defined fixation strategy, allowing meaningful assessment of functional outcomes across the C1, C2, and C3 fracture subgroups. The simultaneous evaluation of radiological union, objective elbow movement, MEPS, and postoperative complications provides a comprehensive assessment of treatment outcome.

Several limitations should also be acknowledged. The study was observational and did not include a control group treated with orthogonal plating or another fixation technique. Consequently, superiority of parallel plating over alternative constructs cannot be established from the present findings. Outcomes may also have been affected by variations in fracture morphology, bone quality, rehabilitation compliance, and other patient-related factors. In addition, longer follow-up may identify late complications such as progressive post-traumatic arthritis, persistent neurological symptoms, or delayed requirement for implant removal. Future prospective comparative studies with standardised rehabilitation protocols and patient-reported outcome measures would further clarify the long-term benefits of anatomical parallel locking plate fixation.

CONCLUSION

Bicolumnar parallel plating using anatomically contoured distal humeral locking plates provides a reliable method for the surgical management of AO/OTA type 'C' distal humerus fractures in adults. In the present study, this technique achieved a high overall fracture union rate of 96.4%, with 77.9% of patients obtaining excellent or good functional outcomes according to the Mayo Elbow Performance Score. The mean final elbow flexion-extension arc was satisfactory, indicating good restoration of functional elbow movement in the majority of patients.

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