Functional outcome of internal fixation of complex intraarticular fractures of the distal humerus (OTA-AO type-C) in focus of O'Driscoll criteria for optimized stability

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Introduction
Internal fixation of distal humeral fractures is challenging because of complex anatomy and articular or metaphyseal comminution. Bi-columnar locked plating (orthogonal or parallel) is the standard method of fixation the success of which requires a rigid stable construct to optimize stability. The aim of this retrospective study was to evaluate the outcome of fixation of type-C distal humeral fractures by orthogonal locked plates and to determine the causes of early mechanical failure according to O'Driscoll criteria of optimized fixation stability.
Settings and design
A retrospective study conducted in Benha University Hospital.
Patients and methods
A review of 34 patients with type-C distal humeral fractures fixed with orthogonal anatomical locking plates through the period from 2014 to 2019, and evaluation of their outcome after 24–36 months. Radiographic images were reviewed for O'Driscoll criteria of optimized fixation, and complications were recorded.
Results
Functional outcome was assessed with Mayo elbow performance score. Twenty patients had an excellent outcome, seven patients good and seven fair in whom, O'Driscoll criteria for optimized fixation stability were not met and fixation was revised. All patients showed radiological union of fractures after about 3 months from definitive fixation. Multivariate analysis of the collected data was done by SPSS software to determine the cumulative percent of its factors and its relation with the final outcome.
Conclusion
Internal fixation of type-C distal humeral fractures by anatomically precontoured locking plates must be optimized according to O'Driscoll criteria to avoid early mechanical failure, revision surgery, and to achieve satisfactory functional outcome.

Keywords:
distal humerus, intraarticular fractures, O, 'Driscoll criteria, optimized fixation

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Introduction

Distal humeral fractures account for 0.5–7% of all fractures, 30% of elbow fractures, and 37.2% of them are OTA-AO type-C with a bimodal distribution in young adults and elderly osteoporotic patients. Surgical fixation is a considerable challenge due to the anatomical complexity of bones, and articular or metaphyseal comminution. Conservative treatment and limited internal fixation have poor outcomes. Satisfactory outcome of surgical treatment depends on restoration of the articular congruity and a rigid stable fixation to allow for early mobilization. Bi-columnar plating is the standard method of fixation preferably by anatomically precontoured locking plates in orthogonal (at 90°) or parallel orientation [1–3].

The success of internal fixation depends on the optimization of stability according to the criteria proposed by Shawn W O'Driscoll in 2005 depending on two principles; maximized distal fragment fixation and all distal fragment fixations should contribute to stability with the shaft. These principles can be achieved by technical points related to the fixing screws and plates. In addition, severe metaphyseal comminution and bone loss may require supracondylar shortening and compression fixation [4].

The aim of the current study was to retrospectively assess the outcome of internal fixation of type-C distal humeral fractures by orthogonal plates after a minimum of 2 years, and to determine the causes of

early mechanical failure in focus of O'Driscoll's criteria for optimized fixation stability.

Patients and methods

We retrospectively reviewed patients who had internal fixation of type-C distal humeral fractures in the period from 2014 to 2019 in our department and collected the data of 34 young adult patients who were recalled for follow-up 24–36 months after definitive fixation.The study was conducted after approval from the ethical committee of the department of orthopedic surgery at Banha university hospital. Patients aged under 20 years or over 60 years, patients with associated neurovascular or other upper limb skeletal injuries, patients with open fractures, and those who could not be reached were excluded from the study.

Preoperative elbow radiographic images and computed tomography scan were reviewed for fracture classification. Internal fixation was done in prone position through the triceps-split approach in nine cases and olecranon chevron osteotomy with apex distally in 25 cases. The ulnar nerve was explored till its first motor branch in all cases. Fixation was done by anatomically precontoured locking plates in orthogonal orientation with a posterolateral plate and a medial plate. Fixation proceeded from distal to proximal after reconstruction of the articular surface. No bone graft or bone substitutes were used. The olecranon osteotomy was fixed by a predrilled 6.5 mm intramedullary cancellous screw with a washer.

Postoperatively, the elbow was immobilized in a posterior splint to protect the soft tissues till wounds heal as our department protocol. Intermittent passive range of motion started once wounds were healed in less than 2 weeks after surgery and continued for 2 weeks, followed by gradual active range of motion for 8 weeks. Indomethacin 25 mg 3 times daily for 2 weeks was prescribed to all patients upon discharge. Follow-up radiographic images were taken 2 weeks after surgery and assessed for quality of reduction and stability of fixation according to O'Driscoll criteria, then every 4 weeks to assess union. Cases that showed early failure of fixation 2 weeks after surgery were revised after few days.

The functional outcome was evaluated at the final visit of the patient upon recall by the Mayo elbow performance score (MEPS) that involved four variables: pain, ulno-humeral motion, stability, and ability to perform five activities of daily life. The total score is 5–100 points with 90–100 rated excellent, 75–89 good, 60–74 fair, and less than 60 points poor (Table 1).

Results

Multivariate analysis of the collected data by the IBM-SPSS (IBM-USA-SPSS Statistics IBM - USA. www.ibm.com/products/spss-statistics) software showed that this study included 29 (85%) males and five (15%) females with type-C1 fracture in eight (23.5%) cases, C2 in 11 (32.3%) cases, and C3 in 15 (44%) cases. Nineteen (55.8%) cases had right side fractures and 15 (44%) cases had left side fractures. The mechanism of injury was motor vehicle accident in 22 (64.7%) cases and fall from a height on the elbow in 12 (35.3%) cases.

The triceps-split approach was used in nine (26.4%) cases; eight cases with C1 fractures and one case with C2 fracture, and olecranon osteotomy extensile approach in 25 (73.5%) cases; 15 cases with C3 fractures and 10 cases with C2 fractures.

MEPS was reported excellent in 20 (58.8%) cases, good in seven (20.5%), and fair in seven (20.5%). Good-to-excellent results were reported in 27 (79.3%) cases including the 15 cases with C3 fractures (Table 2, Fig. 1). The mean functional

Table 1 Mayo elbow performance score

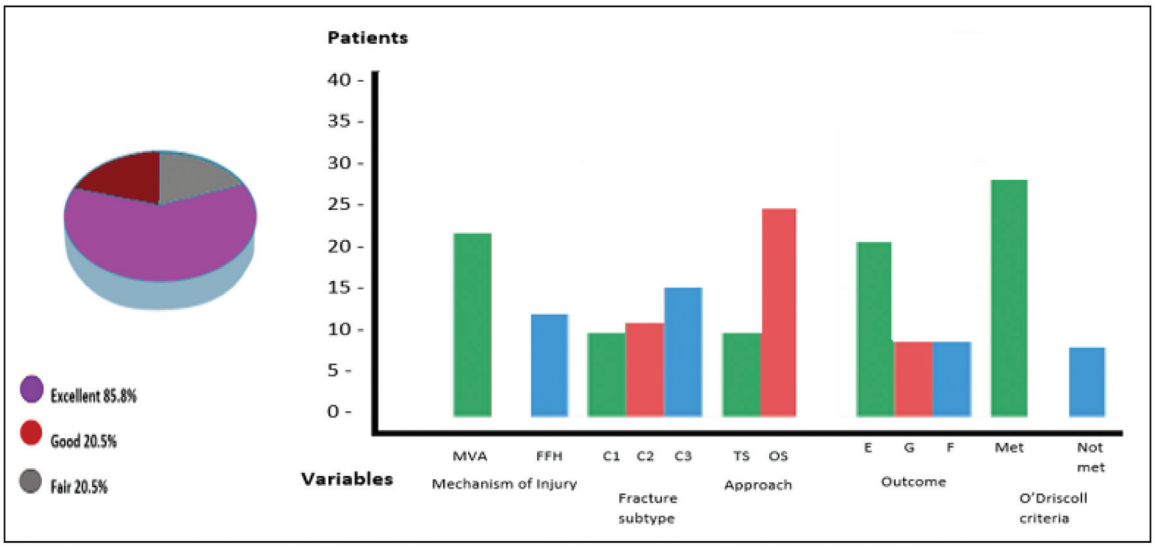
Variables	Points	Definition of points
Pain	45	None: 45. Mild: 30. Moderate: 15. Severe: 0
Motion	20	Arc >100â ° (20). Arc 50–100â ° (15). Arc <50â ° (5)
Stability	10	Stable: 10. Moderate Instability: 5. Gross Instability: 0
Functions of daily activities	25	Comb hair: 5. Feed: 5. Perform hygiene: 5. Don shirt: 5. Don Shoe: 5
Total score	100	Excellent >90. Good: 75–89. Fair: 60–74. Poor <60

Table 2 Outcome on Mayo elbow performance score and complications

Data	*n* (%)
MEPS	
Excellent (score 92–98)	20 (5 C1, 7 C2, 8 C3) (58.8)
Good (score 78–85)	7 (C3) (20.5)
Good-to-excellent	27 (5 C1, 7 C2, 15 C3) [79.3% (14.7% C1, 20.5% C2, 44% C3)]
Fair (score 64–72)	7 (3 C1, 4 C2) [20.5% (8.8% C1, 11.7% C2)]
Complications	10 (29.4)
Metalwork prominence	3 (8.8)
Heterotopic ossification	3 (8.8)
Wound infection	2 (5.8)
Ulnar neuropathy	2 (5.8)

MEPS, Mayo elbow performance score.

Figure 1



Statistical analysis of the multi-variables and final Outcome on MEPS.

score was 81 points (range, 64–98). The mean flexion–extension arc was 107° (range, 85–130°). The mean pronation arc was 73.5° (range, 65–82°) and supination arc was 75° (70–80°). The lower range of motion was reported in the seven cases with fair outcome, in whom, three were type-C1 (8.8%) and four were type-C2 (11.7%), and showed early mechanical fixation failure that necessitated revision of fixation after about 2 weeks from the first surgery.

No cases of malunion or nonunion of the distal humeral fracture or the olecranon osteotomy were reported and no arthritic changes were noted in all cases at the final visit. Minor complications were reported in 10 (29.4%) cases: three (8.8%) cases with a fair score had heterotopic ossification, two (5.8%) cases had wound infection (one of them had fair score) that was cured with culture-specific antibiotic and wound care, three (8.8%) cases with a fair score had prominent medial plate that did not require plate removal, and two (5.8%) cases with good-to-excellent score had temporary ulnar nerve neuropathy that improved within 2 months (Table 2).

Discussion

The goals of surgical treatment of complex distal humeral fractures are anatomical reduction of the articular surface, rigid stable bi-columnar fixation, and management of metaphyseal comminution or substantial bone loss. Controversy exists regarding the proper surgical approach, methods of fixation, plate configuration, ulnar nerve management, heterotopic ossification prophylaxis, and the role of primary total elbow arthroplasty in elderly patients [1–3].

Studying the advantages of distal humeral locking plates biomechanically, Schwartz and colleagues and Shin and colleagues found no significant difference in stiffness between orthogonal and parallel locking plates but lower resistance to axial compression with orthogonal plates and lower resistance to torsion with parallel plates. O'Driscoll stated that parallel locking plates are as strong as or stronger than orthogonal orientation. Stoffel and colleagues demonstrated higher compression and rotation stability with parallel plates in osteoporotic cadaveric bones. Arnander and colleagues reported higher sagittal bending stiffness with the parallel configuration. Some authors advocate placement of a third plate to increase stability with metaphyseal comminution [3–8]. Korner *et al.* [9] reported best stiffness with orthogonal locking plates compared with conventional reconstruction plates.

In addition, orthogonal plating has the advantages of placing the most distal screws on the posterolateral plate to capture coronal capitellar fractures and a posterolateral instead of a lateral plate avoiding more lateral dissection to explore the radial nerve. Several studies have reported favorable clinical outcomes with both configurations of locking plates and recommended plate placement based on fracture configuration [2,10–12].

Complications after fixation of distal humeral fractures are related to the strategy of treatment, articular surface injury, and the natural history of elbow injury in general with a degree of stiffness commonly encountered [2]. The possibility of having multiple surgeries mandates optimization of fixation stability in the first surgery to avoid complications of several operations. In our retrospective study, the flexion–extension arc was reported less in the seven cases with fair outcome, although they were type-C1 and type-C2 fractures, because of early mechanical failure that necessitated revision of fixation with subsequent soft tissue complications and prolonged immobilization since injury (Fig. 2). Heterotopic ossification may occur in 0–21% of cases usually without functional deficit. Radiation therapy or a NSAID are often used for prophylaxis in high-risk patients [10,13]. In the current study, three cases with a fair score developed grade-II heterotopic ossification after revision of fixation. No cases with nonunion or malunion of fracture were noted in our study. Helfet *et al.* [14] reported 2–10% nonunion rate after ORIF of distal humeral fractures; 98% healed after fixation revision and 29% required additional surgery for soft tissue complications and prominent hardware. Ulnar neuropathy may be due to the initial injury (24.8%) or iatrogenic injury during surgery (0–12%). McKee *et al.* [15] reported good-to-excellent nerve recovery after neurolysis and transposition during revision surgery after failed elbow fixation. Anterior transposition is recommended during fixation in patients with preoperative nerve symptoms but no sufficient evidence recommends transposition in patients without preoperative symptoms [3,10,12,15]. In our study, the ulnar nerve was explored and mobilized but not transposed in all cases. Two cases with type-C3 fractures and good outcome reported postoperative temporary ulnar neuropathy that recovered within 2 months after surgery.

The triceps-split approach was used in nine cases (eight C1 and one C2), whose results were good-to-excellent except three C1 cases whose results were fair as they had more complications. The olecranon osteotomy was used in 25 cases (15 C3 and 10 C2), whose results were good-to-excellent except four C2 cases that had fair

Figure 2

Early failure of fixation. (A) Preoperative. (B) Postoperative. Note short screws and no subchondral screws. (C) Early mechanical failure after 2 weeks. (D) Revision of fixation with longer plates and interdigitating screws.

results. It was observed that the 25 cases operated through olecranon osteotomy had better functional outcome than those operated through the triceps-split approach but the difference was not statistically significant (P=0.658). The triceps-split approach can avoid the complications of olecranon osteotomy and has equivalent functional outcomes; however, olecranon osteotomy is often necessary with more complex fractures [3]. Coles *et al*. [16] and Ring *et al*. [17] reported, respectively, 29.5 and 26% of symptomatic olecranon hardware that required removal. Nonunion of chevron osteotomy is rare (0–9%) with a stable compressive fixation [18]. The 25 olecranon osteotomies in the current study were fixed with an intramedullary screw, all of them united and no patient complained of screw prominence.

Union rate of distal humeral fractures fixed with double-locking plate approaches 89–100% with a rigid stable fixation by strong bi-columnar plates [19–21]. In the current study, we did not find a relation between time-to-union and the final outcome (P=0.0652). All cases (either primary or revision fixation) united within 3 months after definitive fixation and no bone graft or bone substitute was used.

Rigid stable fixation permits early mobilization within 14 days after fixation and can achieve a mean flexion–extension arc of 99–112°. Many surgeons prefer immediate postoperative mobilization after rigid stable fixation [1,12]. Patients in our study started a range of motion exercises once their wounds healed as the protocol of our department. The seven cases with a fair outcome had a relatively longer period of immobilization between injury and definitive fixation revision. This delay in rehabilitation together with the soft tissue injury of double surgeries led to a decrease in their flexion arc more than the rest of cases.

The functional outcome after complex distal humeral fracture fixation on MEPS is 84–100% good-to-excellent in several studies. The mean DASH score ranged from 18.5 to 46.1 in multiple studies and patients usually regain 70–75% of their flexion–extension strength, indicating mild-to-

Figure 3

Type-C3 fracture with optimized primary fixation. (A) Preoperative. (B) Postoperative. Note long interdigitating screws, subchondral screws, and fixation through all holes of the plates. (C) Follow-up after 4 months showing union of fracture and olecranon osteotomy.

Table 3 Comparison of outcome with other studies on Mayo elbow performance score

Study	Number of cases	Mean follow up (months)	MEPS: good to excellent	Mean flexion–extension arc	Complications
Huang *et al*. [10]	19	97	100%	112â °	11%
Doornberg *et al*. [11]	30	228	91%	106â °	14%
Sanchez-Soteb *et al*. [12]	34	24	85%	99â °	22%
Current study	34	30	79.3%	107â °	29.4%

MEPS, Mayo elbow performance score.

Table 4 O'Driscoll criteria for distal humeral fractures optimized fixation stability

Criteria related to screws	Criteria related to bi-columnar plates
1. All screws through a plate	Parallel better than orthogonal
2. Engage a bone fragment on te opposite side	2. Compressing fracture at the supracondylar area
3. As long as possible and as many as possible	3. Strong and stiff to resist bending and breaking
4. Engage as many articular fragments as possible	4. Linked together through bone (creating an arch)
5. Interdigitate with opposite screws (create a fixed angle construct)	

moderate residual impairment [20,22,23]. We used the MEPS for its simplicity and reported good-to-excellent results (Fig. 3) in 27 (79.3%) cases and fair results in seven (20.5%) cases, who had more complications and less range of motion that affected the activities of daily life.

The complications rate after distal humeral fixation varied among studies in relation to the outcome score used. Gofton and colleagues reported 48% minor complications that resolved without further surgery in cases fixed with orthogonal plates on DASH and American Shoulder and Elbow Surgeons scores. Huang and colleagues, Doornberg and colleagues, and Sanchez-Soteb and colleagues reported 100, 91, and 85% good-to-excellent results and 11, 14, and 22% complications rates, respectively, on MEPS [10–12,15,19]. The collected data in our study showed that the good-to-excellent functional outcomes were close to that of Sanchez-Soteb and colleagues, and less than those of Huang and colleagues and Doornberg and colleagues, but we reported more complications because we included cases with minor complications that resolved without additional surgery (Table 3).

Early mechanical failure may occur in 7–27% of complex distal humeral fracture fixation and typically occurs at the supracondylar area but immediate postoperative radiographs cannot predict it [24]. Predisposing factors of this pitfall are poor fixation techniques, bone defects/weakness, improper rehabilitation, and early shoulder abduction creating shearing stresses on medial soft tissues through the elbow [25]. O'Driscoll proposed two principles to avoid early mechanical failure: maximize the fixation in distal fragment and all distal fragment fixations should participate in construct stability with the shaft. These principles can be achieved through certain technical points (Table 4), in addition to supracondylar shortening that may be required in cases with metaphyseal comminution [4].

In the current study, the seven cases with fair outcome had early loss of fixation 2 weeks after surgery; meanwhile, the postoperative radiographs were accepted. The causes of failure were found to be not related to the fracture subtype (three C1 and four C2) but were explained according to O'Driscoll criteria to be due to suboptimal fixation stability. In those seven cases who did not meet O'Driscoll criteria the pitfalls were the distal screws were short, did not engage the opposite fragment or articular fragments, and not all the distal holes of the plates were filled with screws. The proximal parts of the plates, especially the medial one, were fixed with one or two screws to the shaft, which was insufficient for stability even in the presence of a lateral plate (Fig. 2). Union was reported in those cases within 3 months after revision of fixation with stability optimized according to O'Driscoll criteria. The other 27 cases who met O'Driscoll criteria had good-to-excellent outcome with their fixation optimized by long interdigitating screws filling all the holes of both plates, which were fixed to the shaft with three to four screws and the optimized fixation of the distal fragment (Fig. 3). No metaphyseal shortening or bone grafting was performed in cases with metaphyseal comminution because of good bone quality.

It is worth mentioning that in cases with type-C3 fractures, awareness of the complexity of the

articular fractures should lead the surgeon to do all the efforts to first reconstruct the articular surface, followed by long-segment fixation by longer plates and as many screws as possible into the shaft. The less severe C1 and C2 fracture types may convince and mislead the surgeon that the fixation is enough with less metalwork and less soft tissue dissection; meanwhile, it is not an optimized fixation and early mechanical failure may occur.

The proposed points of strength of this study are the application of the criteria of optimized fixation stability in 79.3% of the studied cases and the follow-up of the final outcome after at least 2 years. The 27 cases who met the criteria of optimized fixation stability after one surgery had satisfactory good-to-excellent functional outcome.

The weak points in the current study are the small number of reviewed cases, the different occupations and daily activities among patients, the use of two different surgical approaches, and the delay of about 2weeks after surgery to initiate postoperative rehabilitation.

Conclusion

The success of fixation of type-C distal humeral fractures in the middle age group depends on the rigidity of the implants on their proper technical application to optimize fixation stability to prevent early mechanical failure that mandates revision surgery. The use of anatomically precontoured distal humeral locking plates through applying the technical points proposed by O'Driscoll to optimize fixation stability is important and must be followed by trauma surgeons dealing with such fractures to avoid early mechanical failure of fixation and subsequent revision of surgery. More studies with a higher level of evidence are required to highlight any other factors or surgical steps that could improve the outcome of these complex fractures.

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Conflicts of interest

There are no conflicts of interest.

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