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Conversion from Spanning External Fixation to Open Reduction Internal Fixation Contributes to Healing of Soft Tissues and Fractures in Open Distal Humeral Fractures

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Background: Open distal humeral fractures (DHF) often lead to loss of elbow function, thereby seriously affecting patient quality of life. The aim of this study was to evaluate the treatment outcomes of 2 surgical techniques to determine the better method for repairing open DHFs. Both groups were treated with immediate debridement first, and then group I had only internal fixation (IF), while group II underwent initial external fixation (EF) followed by IF surgery.





Material/Methods: This retrospective study included 32 patients who had open DHFs between 2013 and 2018. Twelve patients underwent thorough debridement and temporary EF treatment and converted to IF as the ultimate treatment. Twenty patients were treated with immediate open reduction and internal fixation (ORIF). Data of final treatment outcomes were analyzed at the latest follow-up. A comparative analysis of radiological results, function observations, and complications was performed for the 2 surgical groups.

Results: All DHFs and osteotomized olecranon united after a mean of 5.2 ± 1.21 months. No significant differences were observed in other preoperative demographic data between the 2 groups. Moreover, there was no significant difference in postoperative complications, elbow range of motion, or fracture healing time between the 2 groups.

Conclusions: The evidence provided by our study highlights the efficacy of definitive IF in treating open DHFs, which is recommended whenever possible. Furthermore, the combination of EF and ORIF, according to the type of soft tissue damage, may be a promising treatment option with a low revision rate for patients with open DHFs.

Keywords: **Elbow Joint • Fracture Fixation, Internal • Humeral Fractures**

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Background

Distal humeral fractures (DHF) comprise approximately 2% of all adult fractures and one-third of all humeral fractures [1]. The complex anatomy of elbow articulation, including the distal humerus, proximal ulna, and radial head, leads to complex intra-articular fractures in the distal humerus. The complications accompanying DHFs include elbow stiffness, heterotopic ossification, and loss of elbow function [2,3]. DHFs are frequently the result of high-energy trauma with skin involvement and low-energy trauma in osteoporotic bone [4]. The fundamental goals for the treatment of DHFs are to achieve stable fixation, maintain a viable soft tissue envelope, restore function range of motion, and limit complications [5].

Internal fixation (IF) has shown good outcomes for the complex DHFs with stable fixation and a high rate of union, thus permitting intensive rehabilitation to restore elbow motion [6]. Coblation debridement in treatment with retention of IF is effective for early postoperative infection of extremity fractures, which can avoid second-stage surgery, infectious nonunion, and osteomyelitis [7]. A spanning external fixation (EF) before IF is a safe adjunct providing excellent outcomes by enabling wound care/debridement and soft tissue healing, thus ultimately improving fracture healing [8-10]. A retrospective case study review of 85 humeral fractures, 62 shaft fractures, and 23 extra-articular distal third fractures treated with EF has highlighted EF as a valid treatment method owing to its good outcomes in the stability of reduction, tolerability, healing times, and function recovery [11]. In addition, EF in DHFs in children shows several benefits of avoiding additional injury to the growth plate and enabling careful reduction without interfragmentary compression, with no soft tissue dissection, preserved periosteal blood supply, immediate joint motion, and early weight-bearing; meanwhile, EF ensures primary fracture stability even in the presence of comminution and high adjustment capability [12]. However, the definitive use of EF treatment for fractures is not recommended because this treatment method can also lead to elbow joint stiffness, limit elbow joint activity function, and increase the risk of fracture nonunion or malunion [8,13].

Open reduction and internal fixation (ORIF) is the criterion standard management of DHFs in middle-aged and elderly patients [4,7,14]. The method of fixation depends on the type of fracture, the degree of comminution, and the restoration of columns and articular surface [15]. ORIF treatment for DHFs with an extensor mechanism-on approach can achieve favorable healing, a mean elbow flexion-extension exceeding 100°, and maintenance of 90% of elbow extension strength, relative to that of the contralateral, normal elbow [4]. Spanning the elbow temporarily with a plate as an adjunct to the ORIF method has been demonstrated to be simple and effective in

achieving fracture stability and union and can minimize failure rates after fixation of DHFs [16]. However, a recent systematic review and meta-analysis revealed that complications and reoperations of DHFs after ORIF may be more frequent than previously understood [17].

The aim of this study was to identify a specific approach in treating open DHFs, which offered optimal care to prevent infection and additional soft tissue injury while achieving good elbow movement outcomes.

Material and Methods

Patients

Between 2013 and 2018, 100 patients with DHFs were treated at our institution, of which 40 patients were included in this study as they presented with open DHFs. All fractures were caused by high-energy trauma, including motor vehicle accidents (n=30), falls (n=8), and crush injuries (n=2). We selected the surgical methods based on the general condition of the patients, the degree of wound injury, and the willingness of the patients and their family members. Fifteen patients underwent EF treatment (group I) and 25 patients were treated with ORIF (group II). Sixty patients with open fractures were excluded owing to Gustilo-Anderson grade III type IIIb and IIIc open DHFs, life-threatening complications, or open fractures in adolescents. A total of 3 and 5 patients from each group, respectively, were lost to follow-up before the minimum follow-up period. Twelve patients in group I and 20 patients in group II were available at the latest follow-up, and their data were analyzed for final outcomes. Patient demographic characteristics are shown in **Table 1**.

This study was approved by the local Ethics Committee and followed the ethical standards established in the Declaration of Helsinki. Informed and written consent was provided by the patients or their family members.

Damage Control Orthopedics

The patients were initially evaluated in the Emergency Department (ED) by a senior trauma doctor for open fractures and systemic injuries assessments. Imaging, including computed tomography (CT) of the skull/spine/abdomen/thorax and local fracture imaging by X-ray and CT scan were performed as advised. Primary treatment consisted of fluids, resuscitation, and airway and circulation checks. Limb assessment was performed for distal neuro-vascular deficits. Wounds were rinsed with saline lavage in the ED. Antibiotic prophylaxis was conducted in the ED for contaminated open wounds.

Table 1. Demographics of the 32 patients.

Demographic variable	Group I	Group II	P value
No. of patients	12	20	
Age (y/o)			0.422
Mean (std)	37.6 (10.4)	34 (11.9)	
Sex			0.706
Male (%)	7 (21.9%)	13 (40.6%)	
Female (%)	5 (15.6%)	7 (21.9%)	
The wound classification			0.019
I	0	7	
II	10	13	
IIIA	2	0	
AO classification of fracture types			0.942
C1	3	4	
C2	8	14	
C3	1	2	
CRP before IF (mg/dl)	4.0 (5.92)		
Mean time before admission. H			
Mean (std)	5.8 (2.82)	6 (2.90)	0.879
Mean Hospitalization days			
Mean (std)	13.25 (0.509)	11.75 (0.68)	0.131
Mean follow-up period. Mo			
Mean (std)	28 (5.6)	28.8 (8.0)	0.770

Patients' demographics, wound and fracture classifications, admission time, hospital stay time, follow-up period in a series of 32 patients (mean [standard deviation] or number [percentage]).

Open Wound Grading and Fractures

The wounds of all included patients were classified according to the Gustilo-Anderson system [18]. Group I included 10 patients with open Gustillo grade I or II and 2 patients with open Gustillo grade IIIa distal humerus articular metaphyseal multi-fragmentary fractures. In group II, all 20 patients had open Gustillo grade I or II distal humerus articular metaphyseal multi-fragmentary fractures. Patients with Gustilo-Anderson grades IIIb and IIIc were excluded from the analysis owing to huge variations related to the degree and prognosis of the fractures. The fractures were classified by the Arbeitsgemeinschaft für Osteosynthesefragen (AO) pattern for DHFs [19]. In group I, there were 3 patients with AO type C1, 8 patients with AO type C2, and 1 patient with AO type C3 fractures. In group II, there were 4 patients with AO type C1, 14 patients with AO type C2, and 2 patients with AO type C3 fractures.

Treatment

All patients underwent surgical debridement for primary wound care of the open fractures. After the debridement surgery, the fractures were treated by closed reduction, and 12 patients with high-grade and contaminated injuries had their fractures temporarily fixed by EF. After the overall physiological examination and wound care, IF was selected as the ultimate treatment (Figures 1, 2). We used the olecranon osteotomy approach for DHFs [20,21]. Twenty patients with low-grade injuries were treated with thorough debridement and immediate ORIF. Antibiotics were used in preoperative and postoperative wound care as per our institutional protocols or recommendations. The grade I and II open fractures required coverage by a first-generation cephalosporin for 24 h after wound closure. Grade III open fractures required coverage by a first-generation cephalosporin and an aminoglycoside for 48

to 72 h after initial injury but no longer than 24 h after wound closure [22,23]. The patients undergoing conversion to ORIF were intravenously administered a first-generation cephalosporin (cefazolin, 1 g) within 1 h before skin incision and did not receive additional postoperative antibiotics. C-reactive protein (CRP) levels were measured regularly 2 to 3 days after

EF surgery, and the gradually decreased levels of CRP or levels lower than 30 were used as a reference for the conversion surgery [24,25]. Postoperative infection, heterotopic ossification, and other complications were prevented by using preventive medicine (non-steroidal anti-inflammatory drugs [NSAIDs]) and strengthening the elbow joint function through

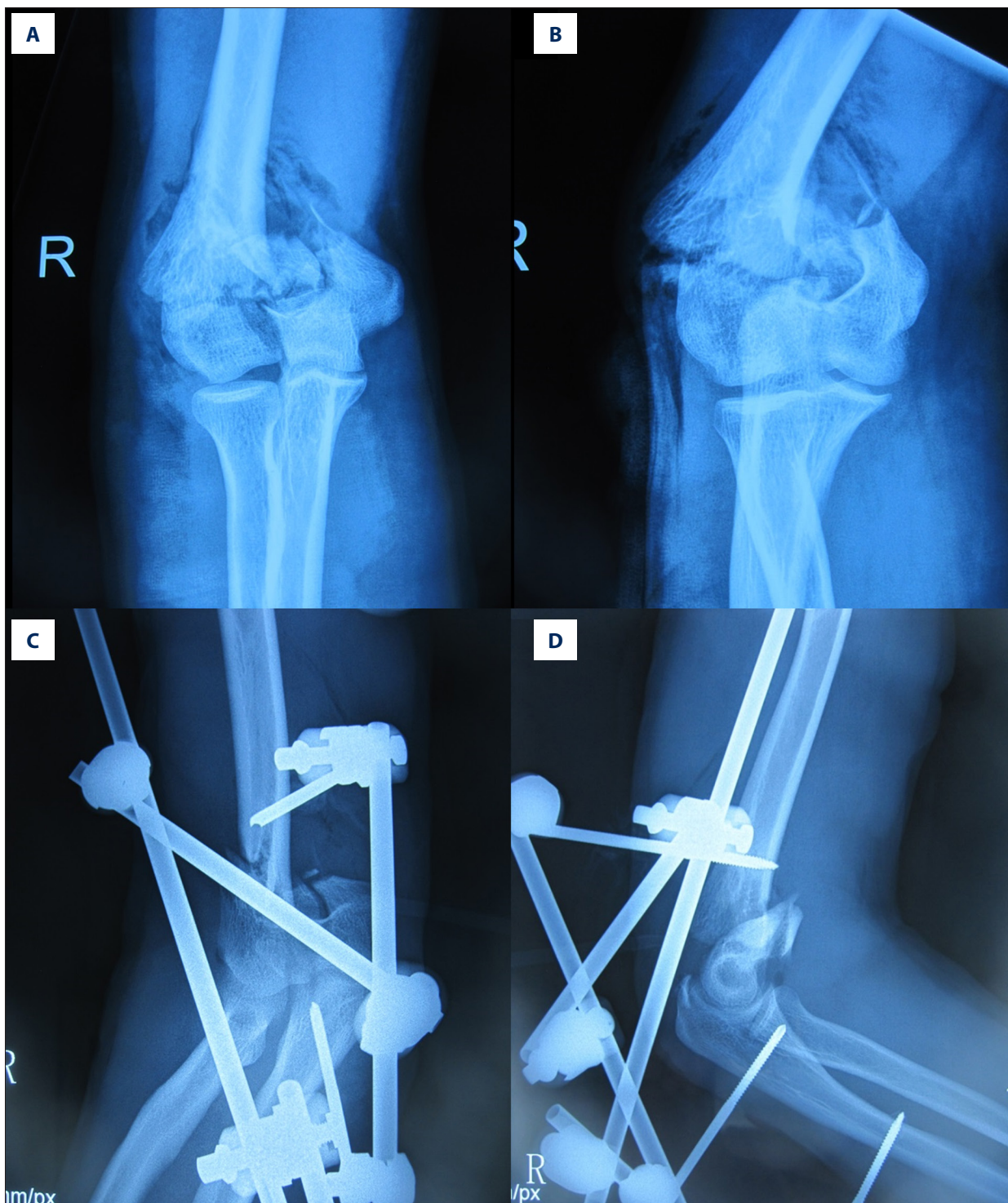




Figure 1. Radiographs from a 35-year-old man who had a grade II open distal humeral fracture in a motor vehicle accident. (A) Anteroposterior and (B) lateral radiographs of AO/OTA type 13-C2 intra-articular fracture of distal humerus on admission. (C) Postoperative anteroposterior and (D) lateral radiographs showing fractures of the distal humeral stabilized by uniplanar external fixation (EF) following debridement. (E) Anteroposterior and (F) lateral radiographs of plate fixation immediately after surgery. EF had been converted to a plate on day 10 after injury. (G) Anteroposterior and (H) lateral radiographs (the internal fixation plates were removed 1 year after plate fixation) showing excellent bony union.



Figure 2. (A) Anteroposterior and (B) lateral images of the injured right elbow showing the well-healed elbow wound when the distal humeral fractures were stabilized by uniplanar external fixation following debridement on day 10 after injury. The red arrow indicates the wound from the motor vehicle accident. Postoperative elbow function. One year after internal fixation, the patient's (C) elbow flexion and (D) extension function images were presented when the elbow joint internal fixation plates were removed.

Table 2. Comparison of 2 types of surgery in elbow joint fracture repairs.

Demographic variable	Group I	Group II	P value
Union time (months)	5.1	5.3	0.773
Complication ratio	8.30%	15%	0.581
Elbow function			
Extension degree			0.898
Mean (std)	11.67 (1.978)	12.0 (1.598)	
Flexion degree			0.633
Mean (std)	123.8 (2.23)	122.3 (2.002)	
ROM			0.75
Mean (std)	112.9 (3.866)	111.3 (3.262)	
MEPS			1.000
Mean (std)	85.0 (10.3)	86.0 (11.0)	
DASH			0.853
Mean (std)	30.2 (19.3)	32.8 (25.0)	

ROM – range of motion; DASH – the Disabilities of Arm, Shoulder and Hand score; MEPS – the Mayo Elbow Performance score.

exercises. The postoperative rehabilitation began with early active-assisted range of motion exercises on the second day after surgery, with the only restrictions being lifting weights or resistance training. Otherwise, there was no limitation to the range of motion. An NSAID (etoricoxib, 90 mg daily) was prescribed for 9 days to prevent heterotopic ossification [26].

Follow-Up and Outcomes

All patients were followed up for a minimum period of 18 months from the date of final ORIF. Radiographs were used after a mean follow-up of 28.8 months to evaluate fracture healing. A thorough physical examination including range of motion was used to evaluate the recovery effects according to the presence of narrowed joint space or early signs of arthritis or heterotopic ossification. When the fractures had healed at approximately 2 years after surgery, the IF devices were removed after a mean of 18 months (12-30 months). Function outcomes were recorded based on assessment by the Mayo Elbow Performance Score (MEPS) and Disabilities of Arm and Shoulder and Hand (DASH) scores.

Statistical Analysis

Data were analyzed and compared between the 2 groups. We developed a spreadsheet for data entry, including demographic data, surgical treatment, patient outcomes, complications, and other patient-specific information. Descriptive statistics were presented as frequencies and percentages (categorical variables) or as mean±standard deviation (continuous variables). The categorical data were analyzed using the chi-squared test, and the continuous data were analyzed using *t* test. *P*<0.05

was considered statistically significant. The Fisher exact test was used under circumstances of fewer patients in groups of interest. The data were processed using SPSS 22.0 statistical software (IBM Corp, Armonk, NY, USA).

Results

A retrospective review was performed on 32 patients (20 men and 12 women; mean age: 35.41±11.67 years) with open DHFs at our institution. Of these patients, 12 (7 men and 5 women, mean age: 37.6±10.4) underwent procedure 1, and 20 (13 men and 7 women, mean age: 34±11.9) underwent procedure 2 (Table 2). All patients were available at the latest follow-up for radiological and function assessment. Most of the injuries were associated with high-energy trauma, with road traffic accidents accounting for 75% of injuries in the 32 patients. There were 3 patients with fall injuries in group I and 5 patients with fall injuries in group II, both accounting for 25% of the patients in these groups. Associated systemic or multi-organ injuries were noted in 5 patients. Mean CRP levels before IF were 4±5.92 mg/dL in group I.

In function evaluation at 12 months following surgery, patients in group I achieved greater elbow range of movement for flexion-extension (111.3±3.262 degrees vs 112.9±3.866 degrees for group II; *P*=0.75). There were no differences between the 2 groups in terms of MEPS (85±10.3 vs 86±11 in group II; *P*=1.0) or DASH scores (30.2±19.3 vs 32.8±25 in group II; *P*=0.853).

Duration of hospital stay in group I was 13 (10-15) days vs 12 (8-18) days in group II (*P*=0.0664), which was not significantly

different. In addition, patients of group I (5 [3.5-7] months) achieved similar fracture union to that of group II (5 [3.5-8] months) ($P=0.773$).

All DHFs and osteotomized olecranon united after a mean of 5.2 ± 1.21 months. Only 1 case of heterotopic ossification occurred in group I. Three patients developed postoperative complications, including heterotopic ossification (2 patients) and elbow stiffness (1 patient) in group II, and 1 patient's elbow motion was still seriously affected 1 year after the elbow injury, thus requiring arthroscopy to remove an abnormal bone mass and release the joint.

Discussion

The best choice of surgical methods for the treatment of severe open humeral fractures has been controversial for several decades. Previous case reports of open DHFs have demonstrated favorable outcomes using definitive ORIF to achieve good elbow function [27-29]. In the present study, we clarified the importance of EF as a primary procedure for the stabilization and prevention of further soft tissue injury and as a spanning fixator for wound management until it was appropriate to convert to ORIF [24].

The results obtained in the present investigation revealed that, at function evaluation at 12 months following surgery, patients treated with EF exhibited greater elbow range of movement for flexion-extension than did patients treated with ORIF. The most common complications of open fractures are wound infection and nonunion [28]. A previous study showed that patients with distal radius fractures in an EF group exhibited better grip strength than did those in the volar locking plate group, with a mean difference of 12.48 ($P<0.01$) after 3 months and 4.54 after 6 months [30]. Another study showed that, compared with ORIF, EF resulted in a relatively higher incidence rate of superficial infection, malunion, and nonunion, yet a lower rate of unplanned hardware removal; however, no difference was detected in terms of deep infection, reduction, clinical evaluation, post-traumatic arthrosis, and union time [31]. Much in agreement with this, the present study demonstrated that patients undergoing EF treatment showed similar fracture union to those undergoing ORIF treatment. In addition, a previous study reported a significant difference between ORIF and EF combined with limited internal fixation (EFLIF) groups regarding hospital stay, reduction results, screw loosening, and traumatic arthritis; specifically, EFLIF led to decreased hospital stay and intraoperative blood loss after surgery, while ORIF had better outcomes for reduction, incidence of screw loosening, and post-traumatic arthritis [32].

The present study also found that only 1 case of heterotopic ossification occurred in patients treated with EF, while 3

patients reported postoperative complications, including heterotopic ossification (2 patients) and stiff elbow (1 patient) in response to ORIF treatment. Recent findings suggest that EF is safe and effective for the definitive treatment of the anterior ring in unstable pelvic fractures and has a high proportion of excellent outcomes, regardless of the type of fracture, and a low complication rate [33]. A previous report on the function outcomes and complications after ORIF for acute DHF AO/OTA type 13 C2 and C3 with a minimum 2-year follow-up showed that the median flexion/extension and supination/pronation arcs were 120 degrees and 160 degrees, respectively; 8 complications were found in 7 patients, and 4 of them required reoperation owing to fracture pseudoarthrosis or elbow stiffness [14]. A prior prospective clinical evaluation showed that 7 cases with displaced both-column fractures of the acetabulum developed postoperative complications, including subcutaneous hematoma in 2, wound infection in 2, and heterotopic ossification in 3, when treated by ORIF with cerclage wiring; none of these complications had an adverse effect on the clinical outcome, and all the cases had excellent final outcomes [34].

Skeletal stabilization is conducted by the temporary EF at the first debridement. After the conversion operation from EF to ORIF, the fractures are firmly fixed, and patients can perform early function exercises. The temporary EF can reduce the initial surgical trauma compared with definitive IF, since trauma and surgeries lead to an inflammatory response [24]. Meanwhile, EF is recommended for fractures with serious injuries in the soft tissues to avoid intramedullary infection [35]. These data were consistent with our study, in which EF allowed for debridement and wound care, while the health of the patients as well as the soft tissues were stabilized for ORIF surgery. In addition, previously published literature has indicated that, compared with individual EF treatment, combined fixation of EF with limited IF is an effective and safe alternative for the management of open tibial diaphyseal fractures, as it can provide superior initial reduction and better stability as well as decrease the risk of inferior alignment and delayed union without increasing the risk of infection [36,37]. The present study provided evidence suggesting that EF in combination of ORIF, according to the type of soft tissue damage, can be an effective treatment for patients with open DHFs, with a low revision rate.

One limitation of this pilot retrospective study was selection bias, whereby patients with lower Gustilo-Anderson grades of open injuries were advised to receive ORIF as the primary treatment. These patients carried a lower risk for local or systemic complications after primary ORIF surgery, and hence this approach was appropriate without increasing the risk of soft tissue damage or extensive surgery. Owing to the retrospective design, this study was restricted to assess objective range of motion and function scores reported by patients during

follow-up. Future prospective studies with larger sample sizes are required to validate the early benefits of EF in offering immediate stabilization, pain relief, and ease of surgical conversion from EF to ORIF. This is a no-difference study according to the statistical results. A possibility of difference might be present; however, this difference did not reach statistical significance owing to the small sample size.

Conclusions

The evidence provided by our study highlights the potential of EF as a primary treatment for all open fractures around the elbow, despite an insignificant statistical difference. The EF treatment prior to conversion to ORIF led to fewer complications, easier wound care, and improved patient health. Undoubtedly, ORIF is the definitive treatment option to restore elbow function as evidenced by the findings from this

study and the published literature review. Meanwhile, we advocate primary EF in selected patients to achieve optimal fracture healing and wound repair.

Ethics Approval and Consent to Participate

The study was approved by the Ethics Committee of Tongji Medical College, Huazhong University of Science and Technology. Each author certifies that the conduct of the investigation conformed with ethical principles. Written informed consent to participate in the study was obtained from each patient.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors, who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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