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Clinical Application of Bridging External Fixator Combined with K-Wire Fixation for AO Type C3 Fractures of the Distal Radius

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Abstract

Objective: To compare the clinical efficacy and safety of bridging external fixator combined with K-wire fixation (BEF-KwF), simple bridging external fixator (BEF), and open reduction with volar locking plate internal fixation (IF-VLP) in the treatment of AO type C3 distal radius fractures, and to provide evidence-based support for optimizing treatment strategies for complex distal radius fractures. **Methods:** A retrospective cohort study included 90 patients with AO type C3 distal radius fractures treated at our center from January 2019 to December 2022. They were divided into three groups according to the surgical procedure, with 30 cases in each group: Group A (BEF-KwF), Group B (BEF alone), and Group C (IF-VLP). Perioperative indicators (operative time, intraoperative blood loss, length of hospital stay) were recorded. Patients were followed up at 1, 3, 6, and 12 months postoperatively. Functional recovery was assessed using the Gartland-Werley wrist function score; radiological parameters including palmar tilt, radial inclination, and radial height were measured; and complications were documented. Statistical analysis was performed using SPSS 26.0. Continuous data were expressed as mean ± standard deviation, and comparisons among groups were made using one-way ANOVA or the Kruskal-Wallis H test. Categorical data were compared using the chi-square test. **Results:** There were no statistically significant differences in baseline data (age, sex, cause of injury, fracture type) among the three groups ($P > 0.05$). Intraoperative blood loss in Group A (BEF-KwF) (35.2 ± 12.5 mL) was significantly less

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than that in Group C (105.6 ± 28.3 mL, $P < 0.01$), but showed no significant difference compared with Group B (30.8 ± 10.2 mL, $P > 0.05$). Length of hospital stay in Group A (7.2 ± 2.1 d) was shorter than that in Group C (10.5 ± 3.0 d, $P < 0.05$). At 12 months postoperatively, the excellent-and-good rate of Gartland-Werley score in Group A (93.3%, 28/30) was significantly higher than that in Group B (73.3%, 22/30) and Group C (83.3%, 25/30) ($P < 0.05$). Radiologically, at 6 months postoperatively, Group A showed better palmar tilt (10.2˚ ± 2.1˚), radial inclination (21.5 ± 2.3˚), and radial height (11.0 ± 1.2 mm) compared with Group B (7.5˚ ± 2.5˚, 18.2˚ ± 2.8˚, 8.5 ± 1.5 mm, $P < 0.01$), while no significant differences were found between Group A and Group C ($P > 0.05$). The overall complication rate in Group A (10.0%) was significantly lower than that in Group B (53.3%) and Group C (26.67%) ($P < 0.05$). Group B had high rates of pin tract infection and screw loosening, while Group C had higher incidences of tendon irritation and joint stiffness. **Conclusion:** Bridging external fixator combined with K-wire fixation for AO type C3 distal radius fractures offers the advantages of minimal invasiveness, accurate reduction, and reliable fixation. It is superior to simple external fixation in terms of wrist functional recovery, radiological reduction quality, and complication control, and causes less trauma and enables earlier functional recovery compared with open reduction and volar locking plate internal fixation. It is recommended as one of the priority surgical options for AO type C3 distal radius fractures.

Keywords

Distal Radius Fracture, AO Type C3, External Fixator, K-Wire, Locking Plate

1. Introduction

Distal radius fracture (DRF) is one of the most common fractures, accounting for approximately 25% of pediatric fractures and about 18% of fractures in the elderly [1]. Among them, AO type C3 fracture is defined as "complete intra-articular fracture with multiple comminuted articular fragments and severe metaphyseal comminution" and is usually caused by high-energy injuries [2]. This type of fracture presents great treatment difficulty due to articular surface collapse, metaphyseal bone defect, and severe disruption of the radiocarpal and distal radioulnar joint stability [3]. Even experienced surgeons often face challenges from complications such as reduction loss, traumatic arthritis, and wrist stiffness.

Currently, the treatment strategy for AO type C3 fractures remains controversial [4]. The mainstream surgical options include: (1) Simple bridging external fixator (BEF), which achieves indirect reduction through ligamentotaxis. The technique is simple and causes minimal soft tissue injury, but it is difficult to precisely reduce comminuted articular fragments [5]; (2) Open reduction and volar locking plate internal fixation (IF-VLP) [6], which allows anatomical reduction and rigid internal fixation, but extensive soft tissue dissection may further compromise blood supply, and comminuted fragments often lack screw purchase; (3) Limited open or closed reduction with percutaneous K-wire assisted external fixation [7]. Theoretically, the external fixator provides global support and axial stability, while K-wires can be used to pry and specifically fix key articular fragments. Their combination may achieve complementary advantages of "macro-stability plus micro-precision". However, high-quality clinical studies verifying the exact efficacy of this combined procedure are still lacking.

Therefore, this study designed a retrospective cohort trial to systematically compare the clinical and radiological outcomes of BEF-KwF, simple BEF, and IF-VLP in the treatment of AO type C3 fractures, aiming to identify the optimal surgical strategy.

2. Materials and Methods

2.1. Study Design and Ethical Approval

This study was a retrospective cohort study, single-center clinical trial. The study protocol was approved by the Medical Ethics Committee of our hospital (approval No. 2024052203), and all patients signed informed consent forms.

2.2. Inclusion and Exclusion Criteria

Inclusion criteria: (1) Fresh, closed distal radius fracture; (2) AO type C3 fracture (confirmed by preoperative three-dimensional CT reconstruction); (3) Age 18 - 75 years; (4) Time from injury to surgery ≤ 7 days; (5) No other fractures of the ipsilateral upper limb or combined neurovascular injury.

Exclusion criteria: (1) Pathological fracture or open fracture; (2) Concomitant severe osteoporosis (T-score < −3.0); (3) Concomitant severe cardiac, pulmonary, hepatic, or renal insufficiency, or coagulation disorders; (4) Concurrent bilateral distal radius fractures; (5) Previous ipsilateral wrist trauma or surgery; (6) Loss to follow-up or incomplete data.

2.3. Grouping and Surgical Methods

Patients with AO type C3 distal radius fractures who were consecutively admitted to our center between January 2019 and December 2022 and met the inclusion criteria were enrolled. All cases were consecutively included in chronological order of admission without selective exclusion, and a total of 90 patients were ultimately enrolled. According to the actual surgical procedure performed intraoperatively, patients were divided into three groups, with 30 patients in each group: Group A (BEF-KwF), Group B (BEF alone), and Group C (IF-VLP). The selection criteria for each procedure were as follows:

(1) Group A (BEF-KwF): This technique was indicated for fractures with articular surface depression > 2 mm and severely comminuted metaphysis (radiographically assessed as C3.2 or C3.3 subtypes), with dispersed fragments but soft-tissue conditions permitting percutaneous manipulation, aiming to achieve precise articular reconstruction through hybrid fixation.

(2) Group B (BEF alone): This technique was chosen for elderly patients (aged

≥ 70 years) or those with poor general condition unable to tolerate prolonged surgery, severe soft-tissue injury (e.g., Gustilo type I open fracture or accompanied by marked swelling), or relatively less comminuted articular surface where satisfactory reduction was expected by ligamentotaxis.

(3) Group C (IF‑VLP): This technique was applied to patients with good bone quality (bone mineral density T-score ≥ −2.5), large and intact major articular fragments sufficient to provide adequate screw purchase, and a high demand for early functional rehabilitation.

The operative procedures for each group were as follows:

Group A (BEF-KwF): Brachial plexus block anesthesia was administered. Manual traction was applied to correct shortening and displacement. Under C-arm fluoroscopy, two external fixator Schanz pins (diameter 3.0 - 4.0 mm) were inserted into the second metacarpal and the middle part of the radius, respectively. The connecting rod was installed, and adequate distraction was applied to restore radial height. Subsequently, percutaneous prying reduction or limited open reduction (approximately 1 cm) was performed to reduce the collapsed articular fragments, and 2 - 3 K-wires (1.2 - 1.5 mm) were inserted from the radial styloid, dorsal or ulnar side to cross-fix the articular fragments. C-arm fluoroscopy was repeated to confirm an articular step-off < 1 mm, palmar tilt > 10˚, and radial inclination > 20˚. The K-wire ends were bent and left outside the skin. After locking the external fixator, the wrist was maintained in a neutral or slight palmar flexion position.

Group B (BEF alone): The external fixator was inserted in the same manner as in Group A, and closed reduction was achieved by ligamentotaxis. Reduction quality was assessed under C-arm fluoroscopy. If the articular step-off was > 2 mm, repeat traction or compression reduction was attempted. No K-wires were inserted.

Group C (IF-VLP): The Henry approach (volar) was used. The pronator quadratus was incised to expose the fracture site, and the hematoma and interposed soft tissue were debrided. The articular surface and metaphysis were reduced, with temporary K-wire fixation if necessary. A volar locking compression plate (LCP) for the distal radius was placed, and locking screws were inserted into the proximal and distal fragments. C-arm fluoroscopy confirmed adequate reduction and satisfactory screw position. The pronator quadratus was repaired.

Postoperative management: In Groups A and B, the external fixator was worn for 4 - 6 weeks postoperatively. Active wrist motion was started at 4 weeks, and the external fixator was removed at 6 weeks (K-wires were also removed in Group A at 6 weeks). In Group C, passive finger and wrist motion was started early postoperatively, with gradual transition to active motion after 4 weeks. All three groups received routine anti-infective, analgesic, and anti-edema therapy, along with regular rehabilitation guidance.

2.4. Postoperative Management and Rehabilitation Protocol

Given the fundamental differences in the mechanical principles of fixation between the external fixator and the volar locking plate used in the three groups, this study did not adopt a unified standardized rehabilitation protocol for all groups. Instead, we developed corresponding stepwise rehabilitation plans based on the characteristics of each fixation method. Specifically, in Groups A and B, the external fixator was maintained for 4 - 6 weeks postoperatively, during which active flexion and extension of the fingers were allowed to reduce edema. Active wrist flexion and extension were initiated at 4 weeks postoperatively, and after removal of the external fixator and K-wires (in Group A) at 6 weeks, weight-bearing training was gradually increased. In Group C, because the volar locking plate provides immediate rigid internal fixation, passive mobilization of the fingers and wrist was started in the early postoperative period, with a gradual transition to active activities at 4 weeks postoperatively. All three groups received routine anti-infection, analgesic, and anti-edema treatments, as well as regular rehabilitation guidance. The differences in rehabilitation protocols among the groups are inherent to the different fixation modalities rather than being randomized measures in the study design; their potential impact on functional recovery will be analyzed in the Discussion section.

2.5. Outcome Measures

Primary outcome measure:

Wrist joint function: Assessed using the Gartland-Werley wrist function scoring system at 1, 3, 6, and 12 months postoperatively. Grading: 0 - 2 points = excellent, 3 - 8 points = good, 9 - 20 points = fair, >20 points = poor. Excellent and good rate = (excellent + good)/total number of cases × 100%.

Secondary outcome measures:

Perioperative indicators: Operative time (min), intraoperative blood loss (mL), length of hospital stay (days).

Radiological indicators: Anteroposterior and lateral wrist radiographs were taken at 1 week, 3 months, 6 months, and 12 months postoperatively to measure palmar tilt, radial inclination, and radial height (mm).

Complications: Including pin tract infection, screw loosening, tendinitis/tendon rupture, median nerve irritation, traumatic arthritis, joint stiffness, reduction loss, complex regional pain syndrome (CRPS), etc.

2.6. Statistical Analysis

SPSS 26.0 software was used for statistical analysis. Continuous data were first tested for normality using the Shapiro-Wilk test. Data following a normal distribution were expressed as mean ± standard deviation, and comparisons among multiple groups were performed using one-way analysis of variance (ANOVA), followed by pairwise comparisons using the LSD-t test. Non-normally distributed data were expressed as median (interquartile range), and comparisons were made using the Kruskal-Wallis H test. Categorical data were expressed as number of cases (percentage), and comparisons among groups were performed using the chi-square test or Fisher's exact test. A P-value < 0.05 was considered statistically significant.

Regarding the between-group comparison of wrist function, this study prespecified the excellent-to-good rate of the Gartland-Werley score at 12 months postoperatively as the primary analysis endpoint. This time point is sufficient to reflect the final functional status of the wrist after fracture healing and is a well-accepted efficacy evaluation node in this type of research. The follow-up data at 1, 3, and 6 months postoperatively were used only as descriptive process indicators of the dynamic trend of functional recovery, to observe the recovery trajectories of each group. They were not included in the pairwise between-group comparisons of the primary hypothesis testing; therefore, repeated-measures ANOVA or generalized estimating equations (GEE) were not employed for longitudinal inference, in order to avoid interference with the conclusions due to fluctuations in the early follow-up data.

3. Results

3.1. Baseline Patient Data

A total of 90 patients were enrolled, including 47 males and 43 females. The mean age was 51.3 ± 13.6 years (range, 22 - 74 years). Causes of injury included falls in 54 cases, traffic accidents in 28 cases, and falls from height in 8 cases. There were no statistically significant differences among the three groups in terms of age, sex, cause of injury, fracture side, or associated injuries (P > 0.05), indicating comparability (**Table 1**). All patients completed at least 12 months of follow-up, with no dropouts.

Table 1. Comparison of preoperative baseline data among the three groups.

Variable	Group A (n = 30)	Group B (n = 30)	Group C (n = 30)	P-value
Age (years)	52.1 ± 14.2	50.9 ± 13.5	51.8 ± 13.0	>0.05
Sex (male/female)	16/14	15/15	16/14	>0.05
Right-side fracture (cases)	18	19	17	>0.05
Traffic/high-energy injury (cases)	13	14	12	>0.05
Concomitant ulnar styloid fracture (cases)	22	21	23	>0.05

3.2. Comparison of Perioperative Indicators

The results showed that there were no significant differences between Group A and Group B in terms of operative time and intraoperative blood loss, but both groups were significantly superior to Group C, and the differences were statistically significant (P < 0.01). For comparisons among multiple groups, the LSD-t test (equal variances assumed) was used. Regarding the length of hospital stay, Groups A and B were shorter than Group C (P < 0.05). See **Table 2** for details.

Table 2. Comparison of perioperative indicators among the three groups.

Variable	Group A (n = 30)	Group B (n = 30)	Group C (n = 30)	P-value
Operative time (min)	58.6 ± 12.3	42.5 ± 9.7*	85.3 ± 18.4#	<0.001
Intraoperative blood loss (mL)	35.2 ± 12.5	30.8 ± 10.2	105.6 ± 28.3#	<0.001
Length of hospital stay (d)	7.2 ± 2.1	6.8 ± 1.9	10.5 ± 3.0#	<0.001

Note: *P < 0.05 compared with Group A; #P < 0.001 compared with Group A.

3.3. Wrist Joint Functional Recovery

According to the pre-specified analytical protocol of this study, the 12-month postoperative Gartland-Werley score served as the primary efficacy endpoint. At each follow-up time point (1, 3, and 6 months), the mean Gartland‑Werley scores in Group A showed a trend of superiority over Groups B and C. However, because the data at these early time points were mainly used to describe the recovery process rather than for primary endpoint comparisons, pairwise intergroup statistical tests were not performed at each time point. The distribution of functional scores and the excellent-to-good rates at 12 months postoperatively for each group are detailed in Table 3.

Table 3. Distribution of Gartland-Werley functional scores at 12 months postoperatively [n (%)].

Group	Excellent	Good	Fair	Poor	Excellent and good rate (%)
Group A	20 (66.7)	8 (26.67)	2 (6.7)	0 (0)	93.3
Group B	12 (40.0)	10 (33.3)	5 (16.7)	3 (10.0)	73.3
Group C	15 (50.0)	10 (33.3)	3 (10.0)	2 (6.7)	83.3

3.4. Comparison of Complications

Complication type	Group A (n=30)	Group B (n = 30)	Group C (n = 30)
Pin tract infection	2 (6.7)	6 (20.0)	0 (0)
Screw loosening	0 (0)	4 (13.3)	0 (0)
Tendon irritation/tendinitis	0 (0)	0 (0)	3 (10.0)
Joint stiffness	1 (3.3)	3 (10.0)	3 (10.0)
Reduction loss > 5˚	0 (0)	2 (6.7)	1 (3.3)
CRPS (Complex Regional Pain Syndrome)	0 (0)	1 (3.3)	1 (3.3)
Total	3 (10.0)	16 (53.3)	8 (26.67)

4. Discussion

In this retrospective cohort study, we systematically compared for the first time the efficacy of three mainstream surgical procedures for AO type C3 distal radius fractures. The results showed that bridging external fixator combined with K-wire fixation (BEF-KwF) not only achieves satisfactory radiological reduction quality but also offers significant advantages of minimal invasiveness, low blood loss, low complication rates, and excellent wrist functional recovery.

4.1. Treatment Difficulties of AO Type C3 Fractures

The core pathological features of AO type C3 fractures are "articular comminution, metaphyseal bone defect, and loss of axial stability" [8]. Traditionally, anatomical reduction and rigid internal fixation are considered the gold standard, making volar locking plates a common choice [9]. However, in our clinical practice, we found that for C3 fractures with severe metaphyseal comminution and bone fragments lacking screw purchase, plate fixation alone often fails to achieve "rigid fixation", and the extensive soft tissue dissection may further compromise blood supply, increasing the risks of nonunion, implant failure, and joint stiffness.

4.2. Mechanical Advantages and Clinical Significance of the Combined Fixation Technique

The external fixator restores radial length and radiocarpal alignment through a distraction-compression mechanism, complying with the principle of "relative stability" and facilitating callus formation [10]. However, its drawback is the inability to directly reduce collapsed articular fragments. Relying solely on ligamentotaxis for type C3 fractures often leaves an articular step-off > 2 mm, which is an independent risk factor for traumatic arthritis [11].

In Group A of this study, K-wires were inserted percutaneously or through a limited open approach, achieving "targeted reduction and fixation" of the free articular fragments. As a form of "internal fixation bridge", K-wires together with the external fixator constitute a "hybrid fixator" system, whose shear and compression stiffness approaches or even exceeds that of volar plates, making it particularly suitable for comminuted fractures. Our radiological results also confirmed that the articular reduction quality in Group A at 6 months postoperatively was significantly better than that in the simple BEF group and comparable to that in the plate group, demonstrating the effectiveness of the "macro-stability plus micro-precision" strategy.

4.3. Functional Recovery and Complication Analysis

In this study, the excellent-and-good rate of wrist function in Group A at 12 months postoperatively was as high as 93.3%, significantly superior to that in Group B (73.3%) and Group C (83.3%). The reasons are analyzed as follows: (1) precise articular reduction lays the foundation for good function; (2) the minimally invasive approach avoids tendon adhesion and scar formation, allowing earlier mobilization. Notably, although the plate group (Group C) had a higher excellent-and-good rate than the external fixator group, it was still lower than that of the combined group. This may be related to flexor tendon irritation in some patients due to the volar approach, and insufficient early postoperative activity because of pain and swelling [12]. In contrast, Group A achieved stable fixation with K-wires, and active motion could be started after removal of the external fixator at 4 weeks postoperatively, resulting in superior functional rehabilitation.

It should be particularly noted that the postoperative rehabilitation protocols were not completely identical among the three groups—due to the presence of the external fixator, active wrist motion was deliberately delayed until 4 weeks postoperatively in Groups A and B, whereas Group C was allowed early passive motion after plate fixation. Superficially, this difference seems to favor Group C (earlier mobilization); however, the 12-month excellent-to-good rate in Group C (83.3%) remained significantly lower than that in Group A (93.3%) in this study. This suggests that the differences in rehabilitation protocols did not offset the limitations on active motion imposed by flexor tendon irritation and early postoperative pain resulting from soft-tissue dissection via the volar approach in Group C. In other words, the advantages of Group A derived not only from earlier "active motion" (initiated after removal of the external fixator) but also, more importantly, from the intrinsic protection of the wrist flexor/extensor tendon apparatus afforded by the minimally invasive procedure. Therefore, although the non-standardization of rehabilitation protocols might objectively interfere with early (1- to 3-month) functional scores to some extent, at the long-term time point of 12 months postoperatively—when all rehabilitation programs had been completed and patients in all groups had resumed daily activities—the differences in functional outcomes were primarily determined by the biological and mechanical characteristics of the surgical procedures themselves, rather than by variations in the rehabilitation schedules. We have listed this difference in rehabilitation protocols as one of the inherent limitations of this study.

In terms of complications, Group B had a pin tract infection rate as high as 20%, which is associated with prolonged external fixator retention, pin-bone interface micromotion, and inadequate patient care. In Group A, K-wire augmentation enhanced stability, reduced pin-track micromotion, and paradoxically lowered the infection rate (6.7%). Tendon irritation (10%) in Group C is a unique complication of locking plates; poor screw placement or a plate placed too distally can lead to attrition or even rupture of the extensor or flexor tendons, potentially requiring revision surgery.

4.4. Clinical Significance and Limitations of This Study

This study provides a clinical recommendation: for AO type C3 distal radius fractures, especially those with severe articular comminution where a plate cannot achieve adequate purchase, priority should be given to bridging external fixator combined with K-wire fixation. This procedure has a moderate learning curve, can be performed in primary hospitals, and does not require expensive internal fixation materials.

This study also has limitations: (1) The sample size is relatively small (30 patients per group). Although it meets statistical requirements, rare complications (e.g., tendon rupture) may not be detected. (2) As a retrospective study, standardized measurements and between-group comparisons of refined objective indicators of fracture severity—such as initial articular step-off height, radial shortening distance, metaphyseal comminution volume score, and soft-tissue injury grade—were not performed preoperatively. Although all cases were classified as AO type C3 and there were no significant between-group differences in general data including age, sex, and injury mechanism, these unquantified preoperative factors may directly influence the difficulty of intraoperative reduction and postoperative radiological outcomes, and thus the possibility of residual confounding bias cannot be excluded. (3) No subgroup analysis was performed regarding the specific K-wire insertion route (radial vs. dorsal) or the number of K-wires. (4) All surgeries were performed by the same team, so the generalizability of the results needs to be validated by multicenter studies.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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