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Clinical Observation on the Efficacy of Minimally Invasive Treatment for Comminuted Fractures of Long Bones Using Adjustable Carbon Fiber Three-Dimensional External Fixator-Assisted Closed Reduction and Internal Fixation

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Abstract: *Objective:* To observe the clinical efficacy of minimally invasive treatment for comminuted fractures of long bones using adjustable carbon fiber three-dimensional external fixator-assisted closed reduction and internal fixation, providing practical evidence for clinical treatment. *Methods:* Ninety patients with comminuted fractures of long bones admitted to the orthopedics department of our hospital from January 2024 to January 2026 were selected as the study subjects. They were randomly divided into an observation group and a control group using a random number table method, each with 45 patients. The control group underwent traditional open reduction and internal fixation, while the observation group underwent minimally invasive treatment using adjustable carbon fiber three-dimensional external fixator-assisted closed reduction and internal fixation. Surgical-related indicators (operative time, intraoperative blood loss, hospital stay), fracture healing status (fracture healing time, excellent and good rate of fracture healing), postoperative complications, and limb function recovery before and after treatment were compared between the two groups. *Results:* The observation group had significantly lower operative time, intraoperative blood loss, hospital stay, healing time, and complication rate compared to the control group (all $P < 0.05$). The excellent and good rate of fracture healing in the observation group was significantly higher than that in the control group ($P = 0.013 < 0.05$). At 3 and 6 months after treatment, the Johner-Wruhs scores of both groups were significantly higher than those before treatment, and the scores in the observation group were significantly higher than those in the control group (all $P < 0.001$). *Conclusion:* Minimally invasive treatment for comminuted fractures of long bones using adjustable carbon fiber three-dimensional external fixator-assisted closed reduction and internal fixation offers advantages such as minimal surgical trauma, less intraoperative bleeding, rapid postoperative recovery, good fracture healing, and fewer complications. It effectively promotes limb function recovery in patients, demonstrating definite clinical efficacy and warranting widespread application.

Keywords: Comminuted fracture of long bones; Adjustable carbon fiber three-dimensional external fixator; Closed reduction and internal fixation; Minimally invasive treatment

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1. Introduction

Comminuted fractures of long bones are common orthopedic traumatic injuries, mostly caused by high-energy violence, with the fracture ends fragmented into three or more pieces, often accompanied by soft tissue damage, poor stability, and high treatment difficulty. The core of clinical treatment is to restore anatomical alignment of the fracture ends, provide firm fixation, protect blood supply, promote healing, reduce complications, and maximize the restoration of limb function [1,2]. Although traditional open reduction and internal fixation can achieve precise reduction, it involves significant surgical trauma, substantial blood loss, and is prone to damaging the blood supply, leading to complications such as delayed healing and nonunion, as well as slow postoperative recovery. Minimally invasive closed reduction and internal fixation have gradually been applied due to their minimal trauma and light disruption of the periosteal blood supply. However, they still face challenges in achieving precise reduction and stable fixation for complex fractures, with a continued risk of complications [3]. The adjustable carbon fiber three-dimensional external fixator weighs only one-fifth of traditional metal frames, exhibits good biocompatibility, allows for six-directional fine adjustment of the fracture ends, precisely controls alignment errors, and provides firm three-dimensional fixation. To explore its clinical efficacy, this study compared the effects of minimally invasive treatment using this device-assisted closed reduction and internal fixation with traditional open reduction and internal fixation, and the results are reported as follows.

2. Materials and methods

2.1. General information

Ninety patients with comminuted fractures of long bones admitted to the orthopedics department of our hospital from January 2024 to January 2026 were selected as the study subjects. Inclusion criteria: (1) Diagnosed with comminuted fractures of long bones (femur, tibia, humerus) confirmed by X-ray and CT examinations, with the fracture ends fragmented into three or more pieces; (2) Time from injury to hospital admission ≤ 72 hours; (3) Aged 18 to 65 years, without severe dysfunction of the liver, kidney, heart, or lungs; (4) Without coagulopathy, osteoporosis, malignant tumors, or other diseases; (5) Patients and their families provided informed consent and signed the informed consent form. Exclusion criteria: (1) Open fractures or fractures combined with vascular and nerve injuries; (2) Old fractures or pathological fractures; (3) Patients with mental illnesses or those unable to cooperate with treatment and follow-up; (4) Patients allergic to the materials used in the surgery.

Patients were randomly divided into an observation group and a control group using a random number table method, with 45 patients in each group. In the observation group, there were 25 males and 20 females, aged 22 to 63 years, with an average age of 42.35 ± 8.76 years; the fracture sites were 18 femurs, 17 tibias, and 10 humeri. In the control group, there were 24 males and 21 females, aged 20 to 65 years, with an average age of 43.12 ± 8.95 years; the fracture sites were 17 femurs, 18 tibias, and 10 humeri. There were no statistically significant differences in general information such as gender, age, and fracture site between the two groups ($P > 0.05$), indicating comparability.

2.2. Treatment methods

The control group underwent traditional open reduction and internal fixation. Patients received general anesthesia or epidural anesthesia, with a lateral decubitus position for femoral fractures and a supine position for others. An appropriate incision was made based on the fracture site, and the skin was incised layer by layer to the periosteum. The surrounding soft tissues were dissected to expose the fracture ends, and hematomas, bone fragments, and incarcerated tissues were cleared. After reduction with forceps, fixation was achieved using plates, screws, or intramedullary nails. Fluoroscopy confirmed firm alignment before the incision was irrigated, sutured, and a drainage tube was placed.

The observation group underwent minimally invasive treatment using adjustable carbon fiber three-dimensional external fixator-assisted closed reduction and internal fixation. After anesthesia, patients were placed in a supine position, and routine disinfection and draping were performed. Manual closed reduction of the fracture ends was performed under fluoroscopic guidance using a C-arm X-ray machine. Based on the fracture condition, an appropriate external fixator was selected, and 2–3 entry points were chosen near the proximal and distal ends of the fracture. Percutaneous pinning was performed for fixation, and the frame was installed and fine-tuned until satisfactory fracture alignment was achieved. Fluoroscopy confirmed the position before the frame was fixed.

Subsequently, for femoral and tibial fractures, minimally invasive intramedullary nail fixation was performed by making a 1–2 cm small incision to establish a medullary canal, inserting an intramedullary nail, and locking it in place. For humeral fractures, minimally invasive fixation with a mini-plate was performed by inserting the plate and screws through a subcutaneous tunnel, without the need for a drainage tube.

Both groups received antibiotics for 3–5 days postoperatively to prevent infection, along with symptomatic pain relief and swelling reduction. Early functional exercises were guided, and regular X-ray reviews were conducted to monitor fracture healing. In the observation group, the tightness of the external fixator could be adjusted 4–6 weeks postoperatively. Both groups gradually initiated weight-bearing exercises based on healing progress.

2.3. Observation indicators

2.3.1. Surgical-related indicators

The operative time (from the onset of anesthesia to the end of surgery), intraoperative blood loss, and hospital stay were recorded for both groups.

2.3.2. Fracture healing status

Regular postoperative X-ray reviews were conducted to record the fracture healing time (from the end of surgery to the appearance of continuous callus on X-ray, with a blurred fracture line and the patient able to bear normal weight). The healing quality was evaluated using the excellent and good rate: excellent indicated anatomical alignment and normal function; good indicated good alignment and basic functional recovery; fair indicated acceptable alignment but delayed healing; poor indicated poor alignment and abnormal healing. The excellent and good rate = (number of excellent + good cases) / total number of cases × 100%.

2.3.3. Postoperative complications

The occurrence of postoperative complications, including infection, delayed fracture healing, nonunion, internal fixation loosening, and joint stiffness, was observed and recorded in both groups. The complication rate was calculated as the number of complication cases / total number of cases × 100%.

2.3.4. Limb function recovery

The Johner-Wruhs score [4] was used to evaluate limb function before treatment, and at 3 and 6 months after treatment. This score includes aspects such as pain, deformity, joint range of motion, limb length, and functional recovery, with a total score ranging from 0 to 100. A higher score indicates better limb function recovery.

2.4. Statistical methods

Data analysis was performed using SPSS 27.0 statistical software. Measurement data were expressed as mean ± standard deviation (SD), and comparisons between groups were made using independent sample t-tests. Count data were expressed as [*n* (%)], and comparisons were made using the χ^2 test. A *P*-value < 0.05 was considered statistically significant.

3. Results

3.1. Comparison of surgical-related indicators between the two groups

The operative time, intraoperative blood loss, and hospital stay in the observation group were significantly lower than those in the control group (all $P < 0.001$). See **Table 1**.

Table 1. Comparison of surgical-related indicators between the two groups

Group	Operation time (min)	Intraoperative blood loss (ml)	Hospital stay (d)
Observation group (n = 45)	68.45 ± 10.23	89.36 ± 15.78	7.62 ± 1.85
Control group (n = 45)	95.78 ± 12.56	186.54 ± 20.31	11.35 ± 2.42
t	11.318	25.353	8.196
P	<0.001	<0.001	<0.001

3.2. Comparison of fracture healing status between the two groups

The fracture healing time in the observation group was significantly shorter than that in the control group ($P < 0.001$); the excellent and good rate of fracture healing in the observation group was significantly higher than that in the control group ($P = 0.013 < 0.05$). See **Tables 2** and **3**.

Table 2. Comparison of fracture healing time between the two groups

Group	Fracture healing time (weeks)	t	P
Observation group (n = 45)	12.35 ± 1.76	11.019	<0.001
Control group (n = 45)	16.89 ± 2.13		

Table 3. Comparison of the excellent and good rate of fracture healing between the two groups [*n* (%)]

Group	Excellent	Good	Fair	Poor	Excellent + good rate (%)	χ^2	P
Observation group (n = 45)	28 (62.22)	15 (33.33)	2 (4.44)	0 (0.00)	43 (95.56)	6.154	0.013
Control group (n = 45)	18 (40.00)	17 (37.78)	7 (15.56)	3 (6.67)	35 (77.78)		

3.3. Comparison of the incidence of postoperative complications between the two groups

The incidence of postoperative complications in the observation group was significantly lower than that in the control group ($P < 0.05$). See **Table 4**.

Table 4. Comparison of the incidence of postoperative complications between the two groups [*n* (%)]

Group	Infection	Delayed fracture healing	Nonunion	Internal fixation loosening	Joint stiffness	Total incidence rate (%)	χ^2	*P*
Observation group (*n* = 45)	1 (2.22)	1 (2.22)	0 (0.00)	0 (0.00)	0 (0.00)	2 (4.44)	4.050	0.044
Control group (*n* = 45)	3 (6.67)	2 (4.44)	1 (2.22)	2 (4.44)	1 (2.22)	8 (20.00)		

3.4. Comparison of the recovery of limb function between the two groups before and after treatment

Three and six months post-treatment, the Johner-Wruhs scores of both groups showed a significant increase compared to pre-treatment levels, with the observation group achieving significantly higher scores than the control group (both $P < 0.001$). See **Table 5**.

Table 5. Comparison of Johner-Wruhs scores between the two groups before and after treatment

Group	Before treatment	3 months after treatment	6 months after treatment
Observation group (*n* = 45)	42.35 ± 5.78	78.45 ± 6.32	91.23 ± 4.15
Control group (*n* = 45)	43.12 ± 5.96	65.36 ± 7.18	80.57 ± 5.26
t	0.616	9.173	10.671
P	0.540	<0.001	<0.001

4. Discussion

Comminuted fractures of long bones pose significant clinical challenges due to severe fragmentation of the fracture ends, poor stability, and frequent association with soft tissue injuries. The key to improving treatment outcomes and promoting patient recovery lies in ensuring accurate fracture reduction and stable fixation while minimizing surgical trauma and preserving the periosteal blood supply. Traditional open reduction and internal fixation (ORIF) can achieve precise reduction of fracture ends, but it involves long surgical incisions, extensive trauma, and the need to strip a large amount of soft tissue and periosteum during surgery, which can easily damage the blood supply to the fracture site, leading to complications such as delayed fracture healing and nonunion. Additionally, the prolonged postoperative recovery period affects the restoration of limb function, limiting its clinical application to some extent [5,6].

With the advancement of minimally invasive orthopedic techniques, closed reduction and internal fixation (CRIF) has gradually replaced traditional ORIF as an important method for treating long bone fractures. This approach does not require extensive stripping of soft tissue and periosteum, resulting in less surgical trauma and intraoperative blood loss, effectively protecting the blood supply to the fracture site and promoting fracture healing [7]. However, in the treatment of comminuted fractures of long bones, due to the severe fragmentation of the fracture ends, manual closed reduction cannot precisely control the alignment of the fracture ends, and the fixation stability is insufficient, making it prone to issues such as fracture end displacement and loosening of internal fixation, which affect treatment outcomes.

The adjustable carbon fiber three-dimensional external fixator is a novel minimally invasive fixation device. Made of carbon fiber material, it offers advantages over traditional metal external fixators, including lighter weight, better biocompatibility, and corrosion resistance. It also features multi-directional adjustment capabilities, enabling six-directional fine-tuning of the fracture ends, precisely controlling alignment errors within 0.5 mm, while providing firm three-dimensional fixation support to effectively maintain the stability of the fracture ends and prevent displacement [8]. When combined with CRIF, it can fully leverage the advantages of both approaches: CRIF achieves minimally invasive fixation of the fracture ends, reducing surgical trauma; the adjustable carbon fiber three-dimensional external fixator assists in precise reduction, enhances fixation stability, and dynamically adjusts the fixation force according to the fracture healing process, achieving dynamic fixation. This balances “stability” and “healing,” promoting callus growth through moderate stress stimulation and shortening the fracture healing time.

The results of this study showed that the observation group had significantly shorter operative time, less intraoperative blood loss, and shorter hospital stay compared to the control group, indicating that minimally invasive treatment with the adjustable carbon fiber three-dimensional external fixator assisting CRIF results in less surgical trauma, less intraoperative bleeding, and faster postoperative recovery in patients. This is attributed to the fact that this approach does not require extensive stripping of soft tissue and involves simpler surgical procedures [9]. The observation group also had a significantly shorter fracture healing time and a higher excellent and good rate of fracture healing compared to the control group, suggesting that this treatment regimen effectively promotes fracture healing and improves the quality of fracture healing. This is because the adjustable carbon fiber three-dimensional external fixator can precisely reduce the fracture ends, provide firm fixation, protect the blood supply to the fracture site, and dynamically adjust the fixation force to promote callus growth. In contrast, traditional ORIF delays fracture healing due to damage to the periosteal blood supply.

In terms of postoperative complications, the observation group had a significantly lower complication rate compared to the control group. The observation group only experienced one case of infection and one case of delayed fracture healing, while the control group had various complications such as infection, delayed fracture healing, nonunion, loosening of internal fixation, and joint stiffness. This is because minimally invasive treatment with the adjustable carbon fiber three-dimensional external fixator assisting CRIF causes less trauma and damage to soft tissue and periosteum, reducing the occurrence of complications such as infection and joint stiffness. Additionally, the firm three-dimensional fixation prevents fracture end displacement and reduces complications such as loosening of internal fixation and nonunion [10]. Furthermore, the good biocompatibility of carbon fiber material significantly reduces the incidence of skin allergies and local inflammation compared to traditional steel structure brackets, further reducing the risk of complications.

5. Conclusion

In terms of limb function recovery, the Johner-Wruhs scores of the observation group were significantly higher than those of the control group at 3 and 6 months after treatment, indicating that this treatment regimen effectively promotes the recovery of limb function in patients. This is because this approach involves less trauma and faster postoperative recovery, allowing patients to engage in functional exercises early. Additionally, the high quality of fracture healing reduces factors affecting limb function such as malunion and joint stiffness. In contrast, traditional ORIF affects functional exercises and leads to poor limb function recovery due to slow postoperative recovery and multiple complications.

In summary, minimally invasive treatment of comminuted fractures of long bones with the adjustable carbon fiber three-dimensional external fixator assisting CRIF offers advantages such as less surgical trauma, less intraoperative bleeding, faster postoperative recovery, better fracture healing, and fewer complications. It effectively promotes the recovery of limb function in patients and has definite clinical efficacy, making it worthy of promotion and application.

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Disclosure statement

The author declares no conflict of interest.

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