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Original Article

Therapeutic efficacy of minimally invasive techniques in shoulder/knee/tibial shaft fractures

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Abstract: Objective: To evaluate the effect of minimally invasive techniques (MITs) on the treatment outcomes and postoperative complications (POCs) of patients with orthopedic trauma. Methods: A total of 103 patients with orthopedic trauma were retrospectively selected and allocated to a control (receiving traditional surgery) and an observation group (receiving MITs). Inter-group comparisons were performed regarding therapeutic efficacy, operation-related indices, postoperative recovery, Short Musculoskeletal Function Assessment (SMFA) scores, modified Barthel Index (MBI), and Visual Analogue Scale (VAS) scores, as well as POCs. Multivariate analysis was conducted to identify independent factors associated with therapeutic efficacy. Results: The observation group demonstrated statistically superior overall therapeutic efficacy and operation-related indices compared with the control group, with lower incidence of POCs. Additionally, patients in the observation group exhibited a greater increase in MBI scores and more significant reductions in SMFA scores at 1 month postoperatively. The VAS scores in the observation group also decreased greatly on postoperative, compared with the control group. Disease duration, VAS, and treatment mode were identified as independent predictors of therapeutic efficacy in patients with orthopedic trauma. Conclusion: Compared with conventional surgery, MITs provide superior clinical efficacy and reduce the incidence of POCs in the management of orthopedic trauma.

Keywords: Minimally invasive techniques, orthopedic trauma, therapeutic efficacy, postoperative complications, influencing factors

Introduction

Orthopedic trauma is primarily caused by traffic accidents, falls, sports-related injuries, assaults, and other emergencies. Severe cases may cause limb dysfunction and even be life-threatening [1, 2]. Clinical treatment of orthopedic trauma follows the principles of reduction, fixation, and functional rehabilitation, and is generally classified into conservative and surgical approaches [3]. Conservative treatment includes manual closed reduction, immobilization with plasters, splints, or braces, pharmacotherapy, and rehabilitation treatment. It is indicated for patients with stable, nondisplaced, or slightly displaced fractures, as well as those who cannot tolerate surgery [4]. For unstable fractures, intra-articular fractures, or neurovascular injury-involved complex traumas, surgical treatment remains the mainstay [5]. Although reduction and internal fixation (ORIF) is a well-established conventional surgical scheme, it carries a relatively high risk of postoperative complications (POCs) such as surgical site infection, malunion, and postoperative swelling [6].

To improve therapeutic outcome in these patients, this study enrolled 103 patients with shoulder, knee, or tibial shaft fractures to evaluate whether minimally invasive techniques (MITs) offers clinical advantages over traditional ORIF. Individualized MIT schemes were applied according to fracture location: shoulder/knee injuries were managed via arthroscopic reduction and internal fixation, while tibial shaft fractures were managed with percutaneous minimally invasive plate osteosynthesis (MIPO) under fluoroscopic guidance [7]. With the assistance of arthroscope, endoscope, and C-arm fluoroscopy, MITs can realize comprehensive exploration and accurate reduction and fixation of the fracture area, while minimizing tissue injury, potentially improving postoperative func-

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tional outcomes compared with traditional open surgery [8, 9]. Moreover, a clear surgical field of vision facilitates accurate lesion positioning and may reduce surgical difficulty [10].

However, systematic comparative studies on the efficacy and incidence of POCs associated with MITs in orthopedic trauma remains limited. Therefore, this study aimed to evaluate the clinical advantages of MITs in the management of orthopedic trauma.

Information and methodology

General data

The study protocol was approved by the Ethics Committee of Beijing TongRen Hospital affiliated to Capital Medical University. In this retrospective study, 103 patients with orthopedic trauma admitted between May 2022 and May 2025 were enrolled. Patients were allocated into a control group (n=50; traditional surgical intervention) and an observation groups (n=53; MITs) according to the treatment they received. The choice of surgical method was determined by fracture type and clinical indications. The observation group included patients with specific fracture types (e.g., tibial shaft fractures, intra-articular knee fractures, and proximal humeral fractures) who were deemed suitable for and received standardized minimally invasive treatment. The control group comprised patients with comparable fractures at the corresponding anatomical sites who underwent traditional open surgery due to complexity or injury characteristics.

Eligibility criteria

Inclusion criteria: a diagnosis of traumatic fractures confirmed by X-ray and computerized tomography (CT) examinations [11]; stable physical condition with tolerance to surgery; complete clinical data; fulfillment of surgical indications and receipt of initial treatment at our hospital; normal communication and cognitive function; no mental or psychological disorders.

Exclusion criteria: Lower extremity neurological disorders or joint ankylosis; pathological fractures; open fractures with severe soft tissue injury or infection; severe neurological, hematologic, cardiac, cerebral, or renal diseases; coagulation dysfunction or obesity; malignant tumor; stroke-related hemiplegia, or Parkinson's disease affecting mobility; active infectious diseases; pregnant or lactating.

Treatment methods

Patients in the control group underwent traditional open reduction and internal fixation (ORIF). The anesthesia mode was determined according to fracture characteristics and the patient's condition. After routine disinfection and draping, an open incision was made to fully expose the fracture site. Fracture reduction was performed under direct visualization, followed by temporary fixation with Kirschner wires if necessary. Once satisfactory alignment was achieved, definitive fixation was completed using plates and/or screws. The surgical field was irrigated, a drainage tube was placed when indicated, and the incision was closed in layers and bandaged.

Patients in the observation group received MITs tailored to fracture type. Thorough imaging examinations, including CT, and magnetic resonance imaging [MRI] when necessary, were performed to accurately assess fracture characteristics. General anesthesia or nerve block was employed as appropriate. Some patients were given immobilization with braces or plaster casts pre-operatively. For traumatic fracture of the shoulder joint, a small incision was made inferior to the acromion on the lateral side of the affected limb, and the deltoid muscle was split along its fibers with careful protection of the axillary nerve. After fracture reduction internal fixation was achieved using a locking plate inserted through minimally invasive incisions. Screw placement was completed under fluoroscopic guidance to ensure satisfactory alignment and fixation. For knee joint fractures, the joint cavity was inspected arthroscopically to evaluate concomitant injuries, including meniscal, cartilage, and cruciate ligament lesions. Arthroscopic-assisted reduction and internal fixation was performed. For tibial shaft fractures, a closed reduction approach was adopted, using counter-traction combined with manual reduction, assisted by a C-arm fluoroscopy machine to monitor the reduction situation. After achieving satisfactory reduction, two ~2 cm-long incisions were made at the fracture distal end to achieve deep subcutaneous vein-periosteum separation. A subcutaneous tunnel was then established, and a steel plate was placed on the periosteum surface with concomitant skin marking. Using the MIPO technique, a stab incision was created, through which screws were secured under direct vision. Subsequently, incisions were made at the distal and proximal ends of the fracture, and screws were placed for fixation.

All procedures were conducted under strict aseptic conditions. The incision was closed in layers, and routine postoperative wound care and drainage management were provided.

Detection indicators

Efficacy: Therapeutic efficacy was categorized as markedly effective, effective, or ineffective according to predefined criteria [12]. Markedly effective was defined as complete pain resolution at the injury site with full functional recovery, enabling return to normal life and work; Effective was defined as significant pain relief with occasional pain and essentially restored function without affecting daily activities or work; Ineffective was defined as persistent pain affecting functional exercise, with no functional restoration and impairment of daily life and work. The total effective rate was calculated as the sum of markedly effective and effective cases.

Operation-related indices: Operation time (OT), incision length, and intraoperative blood loss (IBL) were recorded for both patient cohorts.

Postoperative recovery: Patient recovery was assessed by wound healing time, frequency of dressing changes, and length of hospital stay.

Musculoskeletal function: Musculoskeletal function was evaluated preoperatively and at 1 month postoperatively using the Short Musculoskeletal Function Assessment (SMFA) [13], including the functional impairment index and the distress index. Each domain is scored from 0 to 100, with higher scores indicating more severe functional impairment.

Activities of daily living: The patients' living ability was evaluated pre- and post-operatively using the modified Barthel Index (MBI; 0-100 points) [14], with higher score indicating better functional independence.

Pain intensity: Pain was evaluated using the Visual Analogue Scale (VAS) [15]. The scale ranges from 0 (no pain) to 10 (worst imaginable pain).

POCs: The incidence of POCs, including incision infection, malunion, and postoperative swelling, was recorded, and the overall complication rate was calculated.

Statistical methods

Statistical analyses were performed using SPSS 27.0. Continuous variables were expressed as mean ± standard deviation ($\overline{x}$ ± sd). Between-group comparisons were conducted using the independent-samples *t* test, and within-group (pre- vs. postoperative) comparisons were analyzed using paired *t* test. Categorical variables, presented as n (%), were compared using the χ^2 test. Factors associated with therapeutic efficacy were first screened by univariate analysis and subsequently entered into a multivariate Logistic regression model to identify independent predictors. A *P* value <0.05 was considered statistically significant.

Results

Patients' general information

Inter-group comparison of baseline characteristics revealed no significant differences in sex, age, disease duration, body mass index (BMI), or injury type (P>0.05; **Table 1**), indicating baseline comparability.

Therapeutic efficacy analysis

As shown in **Table 2**, the total effective rate was 88.68% in the observation group, significantly higher than 66.00% in the control group (P=0.006).

Operation-related indices

As shown in **Figure 1**, operation-related indices, including OT, incision length, and IBL were all lower in the observation group compared with the control group (all P<0.05).

Postoperative recovery

As shown in **Figure 2**, wound healing time, frequency of dressing changes, and length of hospital stay were significantly reduced in the observation group compared with the control group (P<0.05).

Table 1. Comparison of baseline characteristics between the two groups

Indicators	Control group (n=50)	Observation group (n=53)	χ^2/t/Z	P
Sex (male/female)	32/18	40/13	1.609	0.205
Age (years)	50.08±5.14	50.36±8.66	0.198	0.843
Disease duration (d)	2.00 (1.75, 3.00)	2.00 (2.00, 3.00)	-1.287	0.198
Body mass index (kg/m^2)	22.54±2.58	22.92±2.06	0.828	0.409
Type of injury (shoulder/knee/tibial shaft fracture)	19/20/11	19/24/10	0.324	0.850

Table 2. Comparison of therapeutic efficacy between the two groups

Indicators	Control group (n=50)	Observation group (n=53)	χ^2	P
Markedly effective	18 (36.00)	24 (45.28)		
Effective	15 (30.00)	23 (43.40)		
Ineffective	17 (34.00)	6 (11.32)		
Overall effectiveness	33 (66.00)	47 (88.68)	7.630	0.006

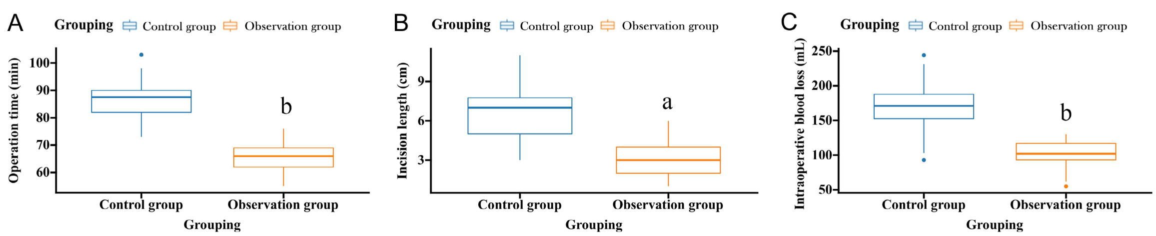

Figure 1. Comparison of operation-related indices between the two groups. A. Inter-group comparison of operation time. B. Incision length comparison. C. Comparative assessment of intraoperative blood loss. Note: [a]P<0.05, [b]P<0.01 vs. control group.

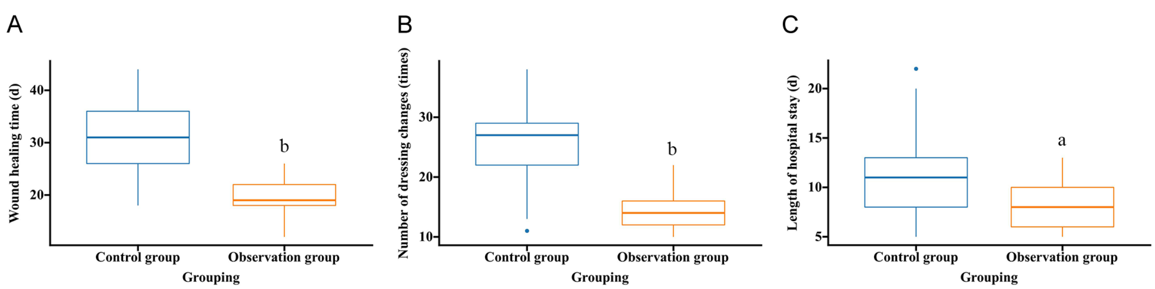

Figure 2. Comparison of postoperative recovery parameters between the two groups. A. Comparison of wound healing time. B. Comparison of dressing change frequency. C. Comparison of length of hospital stay. Note: [a]P<0.05, [b]P<0.01 vs. control group.

Musculoskeletal function

Musculoskeletal function evaluation by the SMFA scale is shown in **Table 3**. No significant inter-group differences were observed in the functional impairment index or distress index scores at baseline (P>0.05). Both groups showed significant postoperative reductions in these scores compared with baseline (all P<0.05), with greater reductions in the observation group (P<0.05).

Activities of daily living and pain

As shown in **Table 4**, preoperative MBI and VAS scores were comparable between the groups (all P>0.05). Post-operatively, MBI scores increased and VAS scores decreased sig-

Table 3. Comparison of musculoskeletal function between the two groups

Indicators	Control group (n=50)	Observation group (n=53)	t	P
Functional impairment index (points)				
Before surgery	45.48±7.41	43.36±7.98	1.395	0.166
After surgery	31.56±7.29	24.85±6.21	5.038	<0.001
Distress index (points)				
Before surgery	46.22±9.03	46.70±9.44	0.263	0.793
After surgery	34.22±7.82	26.40±6.60	5.496	<0.001

Table 4. Comparison of daily living ability and pain between the two groups

Indicators	Control group (n=50)	Observation group (n=53)	Z/t	P
MBI (points)				
Before surgery	29.50±7.63	30.28±5.71	0.590	0.557
After surgery	61.42±6.64	75.19±8.06	9.432	<0.001
VAS (points)				
Before surgery	5.50 (4.00, 7.00)	6.00 (4.00, 7.00)	-0.474	0.636
After surgery	4.00 (3.00, 5.00)	2.00 (2.00, 3.00)	-5.330	<0.001

Note: MBI, modified Barthel Index; VAS, Visual Analogue Scale.

Table 5. Comparison of postoperative complications between the two groups

Indicators	Control group (n=50)	Observation group (n=53)	χ^2	P
Incision infection	3 (6.00)	0 (0.00)		
Malunion	1 (2.00)	0 (0.00)		
Swelling	3 (6.00)	1 (1.89)		
Total	7 (14.00)	1 (1.89)	5.270	0.022

nificantly in both groups (all P<0.05), with more pronounced changes in the observation group (P<0.05).

POCs

As presented in **Table 5**, the overall incidence of complications, including incision infection, malunion, and postoperative swelling, was significantly lower in the observation group than that in the control group (P<0.05).

Factors associated with therapeutic efficacy

Based on the therapeutic outcomes, patients were classified into an ineffective group (n=23) and an effective group (n=80). Univariate analysis (**Table 6**) showed that therapeutic efficacy was not significantly associated with sex, age, injury type, or MBI (P>0.05), but was significantly associated with disease duration, BMI, VAS score, and treatment mode (P<0.05).

Variables with statistical significance in univariate analysis were entered into a multivariate model (**Table 7**), and the results identified disease duration (Odds Ratio [OR]=3.242, 95% Confidence Interval [CI]: 1.090-9.646), VAS (OR=3.182, 95% CI: 1.014-9.983), and treatment mode (OR=4.824, 95% CI: 1.557-14.940) as independent predictors of therapeutic efficacy (all P<0.05), whereas BMI was not statistically significant (P>0.05). Specifically, disease duration ≥3 days, VAS score ≥6, and traditional open surgery were associated with an increased risk of ineffective treatment.

Discussion

This study included 103 patients with orthopedic trauma to comparatively evaluate the clinical efficacy of MITs and traditional open surgery, demonstrating significant clinical advantages of MITs.

First, MITs were associated with superior efficacy compared with traditional procedures,

Table 6. Univariate analysis of factors associated with ineffective treatment outcomes in patients with traumatic fractures

Indicators	Ineffective group (n=23)	Effective group (n=80)	χ^2	P
Sex			1.149	0.284
Male	14 (60.87)	58 (72.50)		
Female	9 (39.13)	22 (27.50)		
Age (years)			0.120	0.729
<50	11 (47.83)	35 (43.75)		
≥50	12 (52.17)	45 (56.25)		
Disease duration (d)			5.063	0.024
<3	8 (34.78)	49 (61.25)		
≥3	15 (65.22)	31 (38.75)		
Body mass index (kg/m^2)			4.875	0.027
<22	5 (21.74)	38 (47.50)		
≥22	18 (78.26)	42 (52.50)		
Type of injury			2.407	0.300
Shoulder joint	6 (26.09)	32 (40.00)		
Knee joint	10 (43.48)	34 (42.50)		
Tibial shaft fracture	7 (30.43)	14 (17.50)		
Functional impairment index (points)			0.199	0.656
<45	10 (43.48)	39 (48.75)		
≥45	13 (56.52)	41 (51.25)		
Distress index (points)			2.921	0.087
<47	8 (34.78)	44 (55.00)		
≥47	15 (65.22)	36 (45.00)		
MBI (score)			3.553	0.059
<30	14 (60.87)	31 (38.75)		
≥30	9 (39.13)	49 (61.25)		
VAS (score)			4.133	0.042
<6	6 (26.09)	40 (50.00)		
≥6	17 (73.91)	40 (50.00)		
Treatment mode			7.630	0.006
Minimally invasive technique	6 (26.09)	47 (58.75)		
Conventional surgery	17 (73.91)	33 (41.25)		

Note: MBI, modified Barthel Index; VAS, Visual Analogue Scale.

Table 7. Multivariate analysis of factors associated with ineffective treatment outcomes in patients with traumatic fractures

Indicators	B	SE	Wald	P	OR	95% CI
Disease duration (d)	1.176	0.556	4.470	0.034	3.242	1.090-9.646
Body mass index (kg/m^2)	1.050	0.590	3.167	0.075	2.859	0.899-9.090
VAS (points)	1.157	0.583	3.935	0.047	3.182	1.014-9.983
Treatment mode	1.574	0.577	7.443	0.006	4.824	1.557-14.940

Note: OR, Odds Ratio; 95% CI, 95% Confidence Interval; VAS, Visual Analogue Scale.

aligning with the report by Hernández-Vaquero et al. [16]. The superior efficacy of MITs may be attributed to the smaller incisions, improved intraoperative visualization, and reduced soft tissue disruption, all of which facilitate a thorough understanding of the patient's injury, thus maximizing therapeutic efficacy and surgical outcomes. Additionally, patients treated with MITs exhibited shorter OT, smaller incision, and less IBL. Similarly, Wang et al. [17] reported that, compared with conventional dynamic hip screws for femoral intertrochanteric fractures, MITs significantly reduced OT, incision length, and blood loss.

Regarding postoperative recovery, MITs were associated with shorter wound healing time, fewer dressing changes, and accelerated hospital discharge. These findings may be explained by the limited soft tissue trauma and preservation of periosteal blood supply associated with minimally invasive approaches, which are conducive to fracture healing and functional rehabilitation. Consistently, MITs have been reported to improve postoperative rehabilitation in spinal trauma compared to traditional open surgery [18]. Complementary to our findings, Panero et al. [19] observed that MITs in traumatic thoracolumbar fractures shortened hospitalization duration and reduced transfusion-related costs, although the total hospitalization cost was comparable between the techniques.

In the SMFA-based assessment, MITs were associated with greater improvements in both the functional impairment index and the distress index, indicating superior restoration of musculoskeletal function. This benefit may stem from the reduced IBL and soft tissue disruption, which help preserve periarticular structures and maintain joint stability, thereby facilitating postoperative functional recovery. In the report by Wang et al. [20], minimally invasive treatment for tibial plateau fractures outperformed traditional ORIF in pain relief and joint function recovery, supporting our conclusions. In addition, patients treated with MITs demonstrated superior functional independence and less pain. Sun et al. [21] reported that MIT for rib fractures contributed to shortened incision length and hospital stay, while providing greater postoperative pain alleviation, corroborating our results. MITs for type II fragility fractures of the pelvis have been shown to significantly improve patients' quality of life compared to conservative treatment [22], further supporting the results obtained in this study. Regarding safety, the incidence of POCs, including incision infection, malunion, and swelling, was lower in the MIT group than that in the control group. This advantage may be related to limited surgical trauma and better preservation of local blood supply, which are conducive to fracture healing and may reduce complication rates. Tsai et al. [23] likewise reported a lower incidence of POCs in patients with vertical pelvic and sacral fractures treated with MITs.

Finally, univariate and multivariate analyses identified disease duration ≥3 d, preoperative VAS ≥6, and the adoption of traditional open surgery as independent risk factors for increased risk of ineffective treatment. Research specifically addressing determinants of overall therapeutic efficacy in patients with orthopedic trauma remains limited. However, previous studies have examined factors influencing postoperative rehabilitation compliance in patients with traumatic fractures. The report points out that intense pain during exercise, rehabilitation environment, self-efficacy, and patients' education and income levels are independent influencing factors affecting adherence to rehabilitation training after traumatic fractures [24].

This study has several limitations. First, relatively small sample size and single-center design may limit the generalizability of the findings. Future multi-center studies with larger and more diverse populations are warranted to validate the results. Second, long-term efficacy and prognosis were not evaluated. Extended follow-up (e.g., 3-5 years) would provide more comprehensive evidence regarding the sustained clinical benefits of MITs. Finally, cost-benefit analysis was not performed. Incorporating economic evaluations in future studies may further clarify the clinical value of MITs.

Conclusion

Collectively, MITs for orthopedic trauma management demonstrate distinct clinical advantages over conventional ORIF. MITs contribute to significant improvement in therapeutic efficacy, reduced surgical trauma, enhanced postoperative recovery, better musculoskeletal function and functional independence, while reducing postoperative pain and maintaining high safety. A disease course ≥3 days, a VAS score ≥6, and treatment with traditional open surgery were identified as independent predictors of ineffective treatment.

Disclosure of conflict of interest

None.

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