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Treatment of tibial plateau fractures: A comparison of two different operation strategies with medium-term follow up

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ABSTRACT

Background: The objective of this study was to compare the clinical and radiological outcomes of two surgical methods for tibial plateau fractures (TPFs): minimally invasive surgery (MIS) using a double reverse traction repositor and traditional open reduction internal fixation (ORIF).
Methods: From our prospectively collated database, 187 consecutive adult patients with 189 operatively treated TPFs in our level I trauma center were included from January 2015 to March 2018 who had a minimum of three years' follow-up. All cases were performed by the senior surgeon using either MIS (group 1, 84 patients with 84 TPFs) or ORIF (group 2, 103 patients with 105 TPFs). Details of the demographics, injury mechanism, pre- and postoperative follow-up imaging, operative procedures and complications were collected. The final results from the 36-Item Short-Form Health Survey (SF-36), Western Ontario and McMaster Universities Osteoarthritis index (WOMAC) and Hospital for Special Surgery (HSS) were obtained at the final follow-up.
Results: Clinically, significant differences were observed in the WOMAC (pain, $P = 0.001$; stiffness, $P < 0.001$), HSS ($P = 0.003$) and SF-36 ($P = 0.001$). Radiologically, significant intergroup differences were observed in the loss of immediate postoperative reduction rates, secondary loss of reduction rates and signs of osteoarthritis (Kellgren–Lawrence). Two and ten superficial infections in group 1 (2.4%) and group 2 (9.5%), respectively, and 6 lateral popliteal nerve palsy cases occurred (0 MIS, 6 ORIF), with significant intergroup differences.
Conclusion: Our study shows that the MIS using a double reverse traction repositor is promising and safe technique for the TPFs when used for the correct indications.
The translational potential of this article: The current status of using a minimally invasive surgery for the treatment of TPFs have been analyzed and a new method of using a double reverse traction repositor for the treatment of TPFs have been proposed in this study, which updated treatment concept of TPFs.

1. Introduction

Tibial plateau fractures (TPFs) account for 1–2% of all fractures in adults and are typically a consequence of combined axial force and varus or valgus to the knee [1,2]. To restore articular congruity and limb alignment and enable early knee mobilization, surgical treatment is generally recommended for articular displacement or depression greater than 2 mm, condylar widening greater than 5 mm, malalignment greater than 5° or knee instability on full extension [3]. Anatomical reduction and effective fixation of articular fragments are essential for obtaining good knee function and preventing the progression of complications, such as early posttraumatic osteoarthritis, as far as possible [4,5].

Various surgical approaches have been developed for TPFs. Open reduction internal fixation (ORIF) by plates and screws is the most

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commonly used method for TPFs and has achieved good clinical results [6]. However, several pitfalls of ORIF, such as excessive bone damage and soft tissue injury, high infection risk and functional rehabilitation difficulties with delayed activity and scar formation [7]. With technological advancements, many minimally invasive surgery (MIS) techniques for TPFs, such as the balloon technique, arthroscopy and bone tamp, have been performed among orthopedic surgeons [8–11]. However, developing an optimal method that can treat all types of TPFs, maximize improved knee function and prevent the progression of post-traumatic arthritis is difficult.

A novel and promising MIS has been developed for all types of TPFs. The double reverse traction repositor, locking plates and specially designed slot-designed compression bolts were used to achieve reduction and stabilization of the displaced fracture fragments via minimally invasive plate osteosynthesis (MIPO). If there was an obvious depression, the tunnel bone tamp technique was used to reversely reduce and elevate the depressed intraarticular fragments [12,13]. Thus, the objective of this study was to compare the clinical and radiological outcomes of patients with TPFs after treatment utilizing either MIS or ORIF. The authors describe this novel MIS technique, compare with the traditional ORIF, and share the results of this technique with medium-term follow up.

2. Materials and methods

The institutional review board of the ethics committee at our institution approved this study (Theoretical No. 2015-003-1). Signed informed consent was obtained from all patients. All methods were conformed to the ethical standards of the Declaration of Helsinki from 1964. Between January 2015 and March 2018, a total of 513 skeletally mature patients with TPFs who underwent operated treatment were reviewed based on our prospectively level-I trauma center database. The following inclusion criteria were applied: diagnosis of an acute, closed TPF; administration of either the new MIS or ORIF; and minimum of 3 years postoperative imaging data, including preoperative, immediate postoperative and final follow-up computed tomography (CT) scans and control X-ray. The exclusion criteria included: skeletally immature patients; pathological or concomitant ipsilateral multiple fractures; fractures managed by external fixation or other nonoperative means; incomplete patient records; and follow-up shorter than 3 years. In total, 187 patients (189 TPFs) were included and divided into two groups based on surgical methods (group 1, 84 patients (84 TPFs) obtained MIS treatment; group 2, 103 patients (105 TPFs) obtained ORIF treatment). Fig. 1 shows a chart of the trial design.

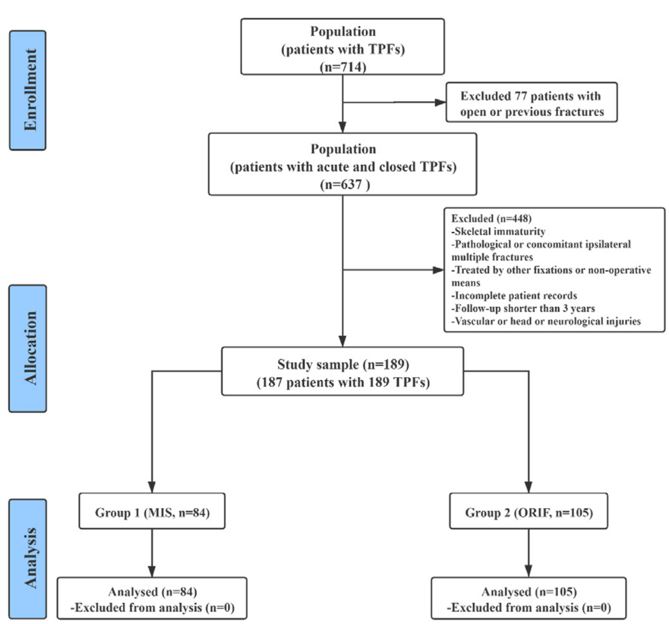

Fig. 1. CONSORT flow diagram of patients included in this investigation.

2.1. Preoperative management

All patients underwent preoperative radiography (anteroposterior (AP) and lateral views) and CT scans (coronal, axial and sagittal views) of the injured knee. According to the imaging data results, the injury severity was graded by the Schatzker and Orthopaedic Trauma Association (OTA) classification systems. When the swelling subsided on the knees, the TPFs were treated surgically.

2.2. Surgical techniques

The supine position and a proximal tourniquet of the affected lower extremity were applied during surgery. If significant intraarticular depression was observed, autogenous bone or allogeneic bone grafts were prepared. The surgical procedures of the two groups were as follows.

For patients in group 1 (MIS), the double reverse traction repositor, tunnel bone tamping method, and specially designed locking plates and slot-designed compression bolts were used for intraoperative reduction and fixation through MIPO [11,13]. (1) The double reverse traction repositor (WEGAO, Wei Hai city, PR China) was composed of a folding scaffold, carbon fiber connecting rods and two U-shaped traction bows. Two 2.5 mm Kirschner wires were inserted through the distal tibia and the supracondylar region of the femur. Then, the 2 traction bows were fixed on the Kirschner wires and tension was applied to the Kirschner wires through the tail rotating rod. The carbon fiber rod connected the proximal traction bow and the folding scaffold over the knee. The distal traction bow was connected with the rotating handle of the scaffold (Fig. 2). Bilateral reverse traction of the affected limb was carried out by rotating the handle of the folding scaffold, which widened the knee joint gap to 8–10 mm to facilitate intraoperative fluoroscopic observation of the reduction. Reverse skeletal traction force applied, parallel to the mechanical axis of the lower extremity was performed via the double reverse traction repositor, and the widened split and depressed TPFs were basically reduced through the squeezing and traction of the soft tissues around the joint. (2) The tunnel bone tamping method was used to

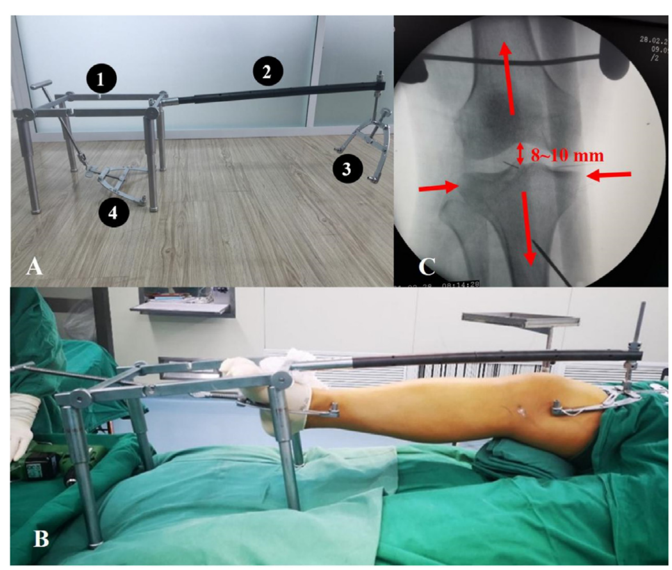

Fig. 2. Introduction and application of the double reverse traction repositor. A, the major components. ① folding scaffold; ② carbon fiber connecting rod; ③ and ④ two U-shaped traction bows; B, the general view of the intraoperative application; C, anteropotential X-ray view of the knee after applying bidirectional traction.

reset the intraarticular fracture fragment of the tibial plateau if there was significant depression (step-off > 2 mm). A 2.5 mm Kirschner wire is used to locate the depressed area of the intraarticular fracture. A power-driven trephine was used to make a cortical bone window at the proximal tibia, and a bony tunnel was created to insert a special metal tamp. A series of retrograde impacts were carried out with a hammer and cylindrical metal tamps of different diameters to the depressed articular fragments, which were gradually pushed upward to bring them back into place [14]. After reduction, the remaining bone tunnel cavity was filled with bone grafts (Fig. 3). (3) Specially designed medial and lateral locking plates and slot-designed compression bolts (WEGO, Wei Hai city, PR China) were used to fix the fracture through MIPO depending on the position of the depressed articular fragments (Schatzker types I - III were fixed with a single plate through an anterolateral approach, Schatzker type IV was fixed with a single plate through a medial approach, and Schatzker types V - VI were fixed with double plate through dual approach) (Fig. 4). The special slot-designed compression bolt can increase the close connection between fracture fragments by increasing the transverse pressure to maintain the reduction effect pressure [12,13]. Intraoperative C-arm fluoroscopy was performed again to confirm the reduction, complete hemostasis was performed, and the wound was closed.

For patients in group 2 (ORIF), the fracture ends were exposed through conventional anterolateral, medial, or dual incisions. After incision, Kirschner wire and reduction forceps were used to reduce the split fractures under direct vision and to elevate the depressed articular surface (if it existed) from the existing fracture line. Autologous or allogeneic bone grafts were used as fillers for the postoperative residual cavities. Patients in group 2 used the same plates and screws as those in group 1 except without a compression bolt (Fig. 5). Layered wound closure was performed after intraoperative fluoroscopy.

2.3. Postoperative management and evaluations

An identical postoperative rehabilitation program was applied to all patients in the two groups. Immediate postoperative reduction was assessed on AP and mediolateral X-ray and CT scans of the knee on the second day after surgery. Continuous passive motion was started on the postoperative first day. Weight bearing activity was restricted during the first 8 weeks. Partial weight bearing activity with a gradual increase was allowed if a union was confirmed both clinically and radiologically at approximately 10–12 weeks. All patients were evaluated radiographically, and routine postoperative radiographs, including AP and lateral views, were performed at 1, 2, 3 and 6 months and then yearly for at-least 3 years. Knee CT scans were obtained at the final follow-up.

The primary outcome measurements included the functional and radiographic outcomes. Hospital for Special Surgery (HSS) and 36-Item Short-Form Health Survey (SF-36) scores were obtained at the last follow-up to assess knee function and health. The HSS and SF-36 scores are scaled from 0 to 100, with higher scores indicating greater function and better outcomes, respectively [15]. The Western Ontario and McMaster Universities Osteoarthritis index (WOMAC) score and Kellgren–Lawrence (K-L) classification were used to evaluate the degree of arthritis. Higher HSS and SF-36 scores and lower WOMAC and K-L grades indicate improved outcomes. These scales have been extensively tested for reliability and validity [16]. Normally, patients are evaluated in person by the operating clinician. Three radiographic parameters, namely, the time of fracture healing and the rates of immediate postoperative reduction loss and secondary reduction loss, were evaluated by 2 independent blinded reviewers based on the X-ray films and CT scans taken immediately after surgery and at the final follow-up. Immediate postoperative reduction loss was defined as an intraarticular step-off of 2 mm or more, plateau widening of 5 mm or more, medial tibial plateau angle (MTPA) $\geq 95^\circ/\leq 80^\circ$, or posterior slope angle (PSA) $\geq 15^\circ/<-5^\circ$ based on immediate postoperative radiographs and CT scans. Compared to the immediate postoperative radiographs and CT scans, an intraarticular step-off greater than 3 mm, plateau widening greater than 5 mm and malalignment increased 5° at the final follow-up were defined as secondary loss of reduction. In addition, bony union was defined as a union of at-least 3 cortices in AP and lateral views on follow-up radiographs [13].

The secondary outcome parameters were the surgery-related information and complication rate, and they included operation record information, days in hospital, time of follow-up, and postoperative complications. All adverse postoperative events including infection, deep

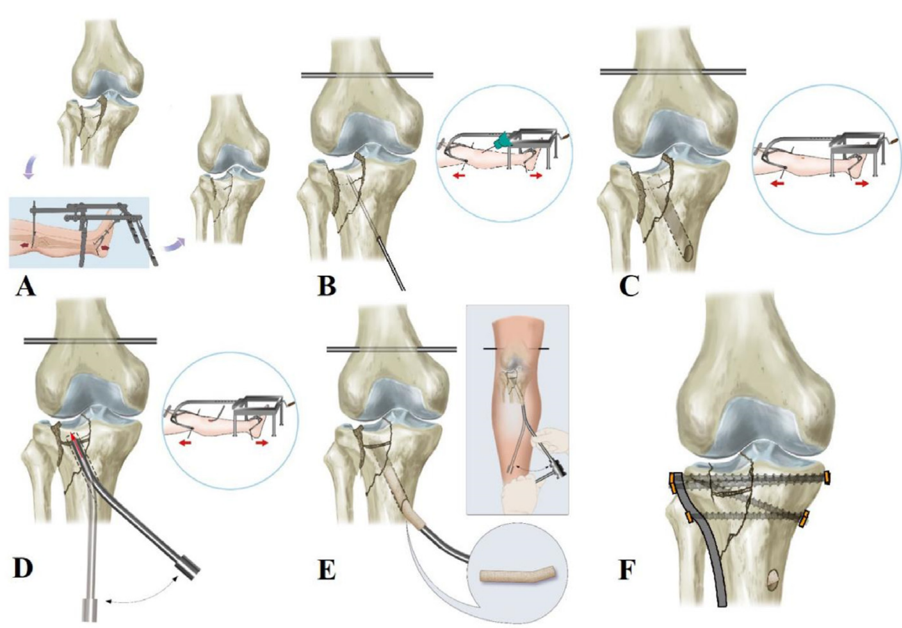

Fig. 3. The procedure of MIS used double reverse traction repositor for TPFs. A, double reverse traction repositor was applied to the patient with TPF (Schatzker type II); B, a 2.5 mm Kirschner wire was used to locate the depressed area; C, a power-driven trephine was used to create a bony tunnel; D, metal tamps were used to push the depressed fragments upward; E, the remaining cavity was filled with bone grafts; F, lateral lock plate and slot-designed compression bolt were used to fix the fracture.

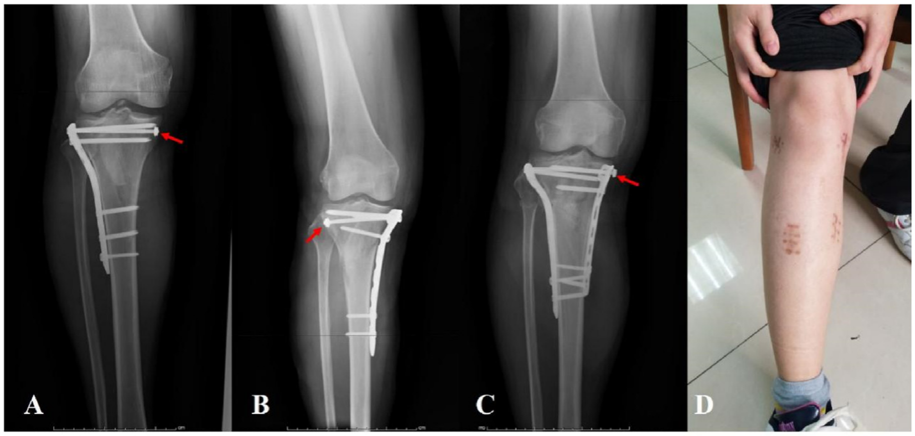

Fig. 4. Anteropotential X-ray views and incision photograph of different types of TPFs after treating with MIS. A, Schatzker types I - III (single lateral plate); B, Schatzker type IV (single medial plate); C, Schatzker types V - VI (double plate); D, incision photograph one year follow-up after surgery (The red arrows indicate the slot-designed compression bolts).

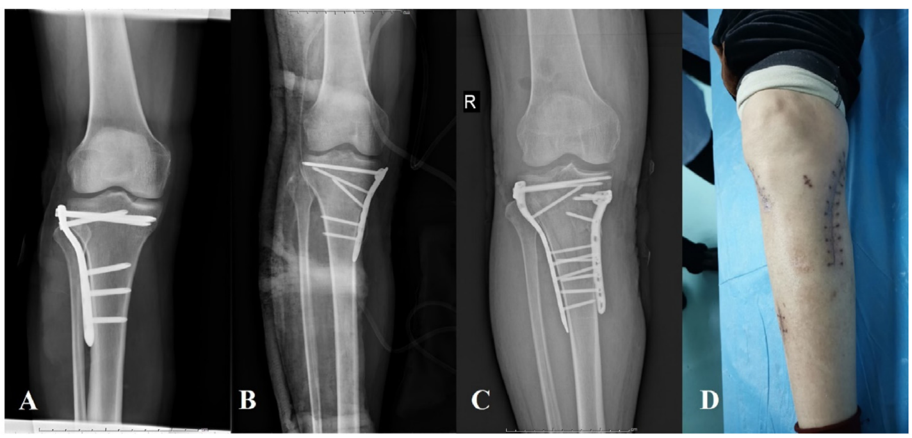

Fig. 5. Anteropotential X-ray views and incision photograph of different types of TPFs after treating with ORIF. A, Schatzker types I - III (single lateral plate); B, Schatzker type IV (single medial plate); C, Schatzker types V - VI (double plate); D, incision photograph one year follow-up after surgery.

vein thrombosis (DVT), lateral popliteal nerve palsy, chronic regional pain syndrome, compartment syndrome, nonunion and lysis of adhesions, were recorded contemporaneously. Superficial infections were defined as subcutaneous tissues infections. Deep infections were defined as any infections requiring surgical debridement. Nonunion was defined as absence of any signs of union at 6 months after surgery. Deep vein ultrasound of the lower extremity was used to detect the presence of DVT. Lateral popliteal nerve palsy was defined as the inability to dorsiflexion of the foot or toe and the loss or loss of skin sensation on the dorsum of the foot due to damage to the common peroneal nerve [17].

2.4. Statistical analysis

IBM SPSS statistics version 22.0 software (IBM Inc., Chicago, IL) was used for the statistical analyses. Continuous variables are presented as the mean values ± standard deviation (SD) and range, and categorical variables are expressed as numbers and percentages (%). If the continuous variables were normally distributed, independent samples Welch's *t*-tests were used; otherwise, Mann–Whitney U tests were used. Categorical variables were determined using the Chi-square test or Fisher's test, as appropriate. In addition, continuous data with skewed distributions were categorized by the reference values. $P < 0.05$ was considered significant.

3. Results

3.1. Patient characteristics

After application of the exclusion criteria, a total of 187 patients (189 knees, left 103 and right 86) out of 513 patients with TPFs meeting our screening criteria were included in the analysis, including 140 men and 47 women aged between 18 and 72 years (mean age: 44.7 ± 11.9 years). Of these, 106 patients with TPFs (56.1%) were caused by high-energy injuries, and 11, 70, 16, 19, 45, and 28 were Schatzker I, Schatzker II, Schatzker III, Schatzker IV, Schatzker V, and Schatzker VI, respectively. The mean follow-up time was 54.2 ± 10.4 months. According to the relevant surgical information, 84 patients (84 TPFs, 44.4%) treated by MIS were included in group 1, and 103 patients (105 TPFs, 55.6%) who underwent ORIF were included in group 2. The demographic data, injury mechanism and fracture characteristics were not significantly different between the two groups in this study (Table 1).

3.2. Main outcome measurements

Table 2 shows that MIS was a satisfactory technique for the treatment of TPFs in terms of clinical outcomes, immediate postoperative reduction

Table 1
Comparison of the patient demographics and injury characteristics for each group.

Variable	Group 1	Group 2	P value
Patients	n = 84	n = 103	
Age (year), mean ± SD (range)	45.0 ± 12.1 (19–72)	44.4 ± 11.8 (18–65)	0.699
Sex (male), n (%)	60, (71.4)	78, (75.7)	0.506
BMI (kg/m^2), mean ± SD (range)	26.3 ± 3.1 (19.2–34.0)	26.5 ± 3.3 (18.5–37.2)	0.781
Affected side (left), n (%)	47, (56.0)	63, (61.2)	0.471
Tobacco smoker (yes), n (%)	15, (17.9)	21, (20.4)	0.662
Alcohol use (yes), n (%)	9, (10.7)	16, (15.5)	0.335
Hypertension (yes), n (%)	16, (19.0)	16, (15.5)	0.526
Diabetes (yes), n (%)	9, (10.7)	13, (12.6)	0.687
Injury mechanism, n (%)			0.315
High energy	51, (60.7)	55, (53.4)	
Low energy	33, (39.3)	48, (46.6)	
ASA score, n (%)			0.731
I	12, (14.3)	17, (16.5)	
II	51, (60.7)	65, (63.1)	
III or above	21, (25.0)	21, (20.4)	
TPFs	**n = 84**	**n = 105**	
Schatzker classification, n (%)			0.784
Type I	3, (3.6)	8, (7.6)	
Type II	32, (38.1)	38, (36.2)	
Type III	9, (10.7)	7, (6.7)	
Type IV	9, (10.7)	10, (9.5)	
Type V	19, (22.6)	26, (24.8)	
Type VI	12, (14.3)	16, (15.2)	
OTA/AO Classification, n (%)			0.244
41-B1	9, (10.7)	14, (13.3)	
41-B2	10, (11.9)	6, (5.7)	
41-B3	34, (40.5)	43, (41.0)	
41-C1	14, (16.7)	10, (9.5)	
41-C2	4, (4.8)	11, (10.5)	
41-C3	13, (15.4)	21, (20.0)	
Coronal fracture (yes), n (%)	20, (23.8)	29, (27.6)	0.553
Comminution of fractures (yes), n (%)	28, (33.3)	33, (31.4)	0.781

TPFs, tibial plateau fractures; SD, standard deviation; BMI, Body Mass Index; ASA, American Society of Anesthesiologists; OTA, Orthopedic Trauma Association.

and postoperative long-term maintenance of reduction in this study. Clinically, significant differences were observed in the WOMAC score (pain, $P = 0.001$; stiffness, $P < 0.001$), HSS score (94.4 ± 6.5 vs. 86.2 ± 11.5, $P = 0.003$) and SF-36 score (90.1 ± 7.6 vs. 81.0 ± 13.2, $P = 0.001$). Radiologically, there were no significant inter-group differences for loss of immediate postoperative reduction rate (11.9% vs. 16.2%, $P = 0.403$). There were significant inter-group differences for secondary loss of reduction rate (17.9% vs. 35.2%, $P = 0.008$), signs of osteoarthritis (K-L grade) ($P = 0.037$) and time of fracture healing ($P < 0.001$).

3.3. Secondary outcome measurements

MIS presented obvious advantages for the treatment of TPFs in terms of the days from injury to operation (5.6 ± 2.3 vs. 6.8 ± 2.9, $P = 0.008$), duration of operation ($P < 0.001$), intraoperative blood loss ($P < 0.001$) and days in hospital (14.6 ± 4.2 vs. 16.6 ± 6.2, $P = 0.015$) compared to the ORIF technique (Table 2). Two and ten superficial infections occurred in group 1 and group 2, respectively (2.4% vs. 9.5%, $P = 0.045$), and 6 lateral popliteal nerve palsy cases were observed (0 vs. 6, $P = 0.026$), with significant intergroup differences. No significant differences in the other complications including deep infection, deep vein thrombosis, chronic regional pain syndrome, compartment syndrome, nonunion and lysis of adhesions were noted between the two groups (Table 3). All the relevant symptoms disappeared after conventional treatment.

Table 2
Operating information and clinical results of two groups.

Variable	Group 1	Group 2	P value
Patients	**n = 84**	**n = 103**	
Time from injury to operation (days), mean ± SD (range)	5.6 ± 2.3, (1–14)	6.8 ± 2.9, (1–15)	0.008*
Anesthetization, n (%)			0.103
Intraspinal	34, (40.5)	54, (52.4)	
General	50, (59.5)	49, (47.6)	
Duration of operation (minutes), n (%)			<0.001*
1-120	71, (84.5)	48, (46.6)	
>120	13, (15.5)	55, (53.4)	
Intraoperative blood loss (ml), n (%)			<0.001*
1-200	58, (69.0)	36, (35.0)	
201-400	22, (26.2)	50, (48.5)	
>400	4, (4.8)	17, (16.5)	
Days in hospital (days), mean ± SD (range)	14.6 ± 4.2, (6–26)	16.6 ± 6.2, (7–32)	0.015*
Follow-up (months), mean ± SD (range)	52.7 ± 7.0, (36–71)	55.4 ± 12.5, (36–74)	0.080
§SF-36 score, mean ± SD (range)	90.1 ± 7.6 (68–99)	84.0 ± 13.2 (35–98)	0.001*
TPFs	**n = 84**	**n = 105**	
Bone grafting (yes), n (%)	38, (45.2)	41, (39.0)	0.391
Implant removal (yes), n (%)	36, (42.9)	51, (48.6)	0.434
Fracture healing time (months), n (%)			<0.001*
1-3	71, (84.5)	39, (37.1)	
4-6	13, (15.5)	62, (59.0)	
>6	0, (–)	4, (3.8)	
Loss of immediate postoperative reduction, n (%)	17, (20.2)	47, (44.8)	<0.001*
Secondary loss of reduction, n (%)	15, (17.9)	37, (35.2)	0.008*
†Plateau widening (>5 mm)	7, (8.3)	24, (22.9)	0.009*
†Articular step-off (>3 mm)	5, (6.0)	19, (18.1)	0.013*
†MTPA (>5°)	2, (2.4)	10, (9.5)	0.045*
†PSA (>5°)	4, (4.8)	11, (10.5)	0.149
§Signs of osteoarthritis (K-L), n (%)			0.037*
Grade 1	6, (7.1)	9, (8.6)	
Grade 2	4, (4.8)	19, (18.1)	
Grade 3	2, (2.4)	6, (5.7)	
Grade 4	1, (1.2)	1, (1.0)	
§WOMAC score, mean ± SD (range)	3.5 ± 8.4 (0–50)	7.1 ± 13.1 (0–64)	0.078
Pain	0.3 ± 0.8 (0–4)	1.6 ± 3.0 (0–14)	0.001*
Stiffness	0.3 ± 0.8 (0–5)	1.3 ± 2.1 (0–8)	<0.001*
Function	2.8 ± 7.0 (0–48)	4.2 ± 9.0 (0–64)	0.372
§HSS score, mean ± SD (range)	94.4 ± 6.5 (69–100)	89.2 ± 11.5 (54–100)	0.003*

TPFs, tibial plateau fractures; SD, standard deviation; MTPA, medial tibial plateau angle; PSA, posterior slope angle; K-L, Kellgren–Lawrence; WOMAC, Western Ontario and McMaster University Osteoarthritis Index; HSS, Hospital for Special Surgery; SF-36, 36-Item Short-Form Health Survey; † represents the changes of parameters between immediate postoperation and final follow-up; § represents the parameters evaluated at the final follow-up; * represents that $P <$ 0.05.

4. Discussion

As with any intraarticular fracture, the ultimate goal of treatment are great functional outcomes, well-aligned congruous joints, painless restoration of full motion and symptomatic posttraumatic arthritis prevention [18]. Several methods and surgical techniques, such as ORIF and MIS techniques (the balloon technique, arthroscopy and bone tamp), have been applied to the treatment of TPFs [8–11]. Previously, the emergence of ORIF was promising for the treatment of TPFs and achieved good results. However, a number of drawbacks, such as large trauma, infection, nonunion, pain, stiffness, poor reduction and traumatic arthritis, cannot be ignored [6,8,10,11]. Extensive dissection of the soft

Table 3
Complications including surgery for two groups of patients with tibial plateau fractures followed to 3 years.

Variable	Group 1 (TPFs, n = 84)	Group 2 (TPFs, n = 105)	*P* value
Superficial infection, n (%)	2, (2.4)	10, (9.5)	0.045*
Deep infection, n (%)	0, (0)	2, (1.9)	0.203
DVT, n (%)	7, (8.3)	11, (10.5)	0.618
Lateral popliteal nerve palsy, n (%)	0, (0)	6, (5.7)	0.026*
Chronic regional pain syndrome, n (%)	0, (0)	1, (1.0)	0.370
Compartment syndrome, n (%)	0, (0)	0, (0)	1.000
Nonunion, n (%)	0, (0)	2, (1.9)	0.203
Lysis of adhesions, n (%)	0, (0)	3, (2.9)	0.118

TPFs, tibial plateau fractures; DVT, deep vein thrombosis; * represents that $P < 0.05$.

tissue envelope may be the main cause of these complications. In a study on the ORIF technique, 20% of patients developed superficial or deep infections despite acceptable functional outcomes [19]. Up to 50% of complications have been reported to be related to soft tissue [20]. In addition, Kim et al. [21] found that the rate of reduction loss was as high as 29.0% in TPFs treated with ORIF, and was higher in bicondylar TPFs (34.5%).

Recently, arthroscopy-assisted screw fixation has been promoted as a method of indirectly reducing TPFs and precisely managing intraarticular pathologies. However, the majority of included patients had Schatzker type I-III fractures. A study by Siegler et al. [22] showed that 46% of the patients with Schatzker type II fractures developed osteoarthritis during long-term follow-up. Typically, the MIPO technique is mainly applied to split or nondepressed TPFs, and the balloon technique and bone tamp are mainly used to reduce depressed fracture fragments [9,13]. Thus, it is urgent to find a safe, minimally invasive, effective and suitable treatment for all types of TPFs.

We designed a new MIS method for clinical practice that uses a novel lower limb traction device combined with specially designed metal bone tamps and compression bolts to facilitate closed reduction fixation for all types of TPFs. Initially, this traction device was primarily used for closed reduction and fixation of femoral shaft fractures, and achieved good results [23]. Based on the theory that application of a suitable external compressive stress to the bones could stimulate the natural repair ability of the tissues in the body, the axial traction and transverse pressure of the novel device can lead to the regeneration of bones and other tissues, eventually resulting in the natural reconstruction of the microcirculation and promoting rapid fracture healing [24]. The result of our study also confirmed that fracture healing time was more shorter in the novel device group than in the ORIF group ($P < 0.001$).

In this study, better knee function and physical and mental health were obtained for the patients treated with MIS compared with the ORIF; thus, MIS would greatly increase the final HSS score (94.4 vs. 86.2) and SF-36 score (90.1 vs. 81.0). Satisfactory function outcomes were associated with the minimally invasive approach and better quality of reduction. All patients in group 1 received the MIPO technique, which resulted in a lower incidence of soft-tissue problems and complications and achieved better outcomes than ORIF. Additionally, MIPO can reduce postoperative pain and enable early mobilization, which improves articular nutrition and promotes fracture healing. It would reduce the incidence of joint adhesion and stiffness because of less scar formation [11]. The WOMAC score and K-L grade also confirmed this point, as shown in Table 2 of our study. The mean WOMAC score was significantly lower in group 1 ($P = 0.001$), especially for pain and stiffness, and the incidence of arthritis was significantly lower in group 1 than group 2 (15.5% vs. 33.4%, $P = 0.037$), thus indicating lower signs of arthritis development. In our study, we found that the MIS treatment effectively reduced the secondary reduction loss rate (from 35.2% to 17.9%) compared with ORIF. From the perspective of long-term reduction maintenance, MIS played an important role in preventing platform widening, articular surface reduction and MTPA loss, which may be related to the application of double reverse traction repositor, specially designed metal bone tamps and compression bolts.

In addition, the use of MIS with a double traction device significantly reduced the mean time from injury to operation, mean time of operation, mean intraoperative blood loss, mean days in hospital, and postoperative complications. No cases of deep infection, lateral popliteal nerve palsy, chronic regional pain syndrome, or nonunion occurred in patients in group 1. MIS had obvious advantages in preventing superficial infection (2.4% vs. 9.5%, $P = 0.045$) and lateral popliteal nerve palsy (0% vs. 5.7%, $P = 0.026$). All these findings might be due to the minimally invasive advantages of our novel approach.

Some limitations to this study should be noted. First, the effect of bone quality on the loss of reduction was not evaluated, and it was difficult to evaluate bone mineral density in all patients. However, the age, sex, BMI, or injury mechanism did not significantly differ between the two groups, which may be sufficient to support the results of the study. Second, due to incomplete MRI examinations, possible intra-articular pathologies were not evaluated. Finally, CT scans can more accurately assess fracture union and reduction loss, but it is impractical to preform CT scans at every follow-up. Thus, knee CT scans were only performed before surgery, immediately postoperation, and at the final follow-up, to assess the presence of reduction loss.

5. Conclusion

In summary, TPFs are intraarticular fractures that usually necessitate the least invasive treatment possible. MIS with a double reverse traction repositor is a satisfactory technique for the treatment of TPFs, and it shows better clinical and radiological outcomes, is less invasive, presents faster surgical opportunities and has fewer complications than ORIF.

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Ethical approval

The institutional review board of the ethics committee at our institution approved this study (Theoretical No. 2015-003-1).

Declaration of competing interest

All authors declare that they have no conflict of interest.

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