Joint Diseases and Related Surgery

Jt Dis Relat Surg
2026;37(x):i-x

ORIGINAL ARTICLE

A comparative analysis of arthroscopy-assisted minimally invasive percutaneous plate osteosynthesis versus open reduction and internal fixation for tibial plateau fractures

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ABSTRACT

Objectives: This study aims to investigate whether arthroscopy-assisted minimally invasive percutaneous plate osteosynthesis (MIPPO) provided more favorable early functional recovery and reduced surgical trauma compared to traditional open reduction and internal fixation (ORIF).

Patients and methods: A total of 84 patients with Schatzker type I-IV tibial plateau fractures treated between January 2021 and January 2024 were retrospectively analyzed. The MIPPO group (n = 41) underwent arthroscopy-assisted reduction plus MIPPO, while the ORIF group (n = 43) received conventional ORIF. Allocation was chronological, with ORIF predominant in the first two years and MIPPO in the latter two years. Operative parameters, postoperative drainage, radiographic outcomes (Rasmussen radiological score), functional recovery (Hospital for Special Surgery [HSS] score), range of motion (ROM), fracture healing time, hospital stay, and complications were compared.

Results: Of a total of 84 patients, 28 were male and 56 were female of 49.4 ± 9.0 (range, 27 to 69) years. The arthroscopy-assisted MIPPO group had significantly longer operative time (96.0 ± 18.2 *vs*. 84.0 ± 13.9 min, $p = 0.001$) but shorter incision length (3.9 ± 0.7 *vs*. 6.2 ± 0.9 cm, $p < 0.001$), less intraoperative blood loss (56.5 ± 9.6 *vs*. 72.6 ± 10.1 mL, $p < 0.001$), and lower postoperative drainage volume (47.1 ± 7.5 *vs*. 59.0 ± 7.0 mL, $p < 0.001$) than the ORIF group. The arthroscopy-assisted MIPPO group also achieved higher Rasmussen radiological scores (15.4 ± 1.4 *vs*. 14.0 ± 1.6, $p < 0.001$) and better HSS scores at one, three, and six months postoperatively (all $p < 0.001$). At six months postoperatively, the MIPPO group also demonstrated significantly improved knee ROM (118.5° ± 8.2° *vs*. 107.3° ± 9.1°, $p < 0.001$), a difference exceeding the clinically meaningful threshold for activities of daily living. However, no significant differences were found in hospital stay ($p = 0.051$), fracture healing time (11.4 ± 1.3 *vs*. 11.1 ± 1.3 weeks, $p = 0.340$), or the excellent-and-good rate of HSS score at final follow-up (95.1% *vs*. 97.7%, $p = 0.746$). Complication rates were similar between the groups ($p = 1.000$).

Conclusion: For Schatzker type I-IV tibial plateau fractures, arthroscopy-assisted MIPPO provides more favorable early functional recovery and radiological reduction quality compared to conventional ORIF, with less surgical trauma and comparable early functional recovery and similar complication rates during follow-up. Although operative time is longer, this minimally invasive approach is a safe and effective option for managing these complex fractures. Its principal advantage is accelerated early recovery, particularly in knee ROM, enabling patients to reach clinically meaningful thresholds for activities of daily living sooner.

Keywords: Arthroscopy, minimally invasive, open reduction and internal fixation, percutaneous plate osteosynthesis, tibial plateau fracture.

Tibial plateau fractures usually result from complex biomechanical forces, most often axial loading combined with varus or valgus stress.[1] In younger patients, such injuries frequently stem from high-energy events like traffic accidents or falls from height, whereas in osteoporotic elderly individuals they often occur after simple falls.[2] These fractures account for approximately 1% to 2% of all adult skeletal fractures and are among the most challenging peri-articular injuries, as they directly involve the primary weight-bearing surface of the proximal tibia.[3] Without precise anatomical restoration, residual articular incongruity or joint instability frequently leads to adverse long-term consequences, including progressive post-traumatic osteoarthritis, chronic pain, and impaired walking ability.[4] Consequently, these fractures impose a considerable clinical and economic burden, often requiring prolonged rehabilitation and substantially reducing quality of life.[5,6]

Received: April 09, 2026
Accepted: June 12, 2026
Published online: July 14, 2026

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Doi: 10.52312/jdrs.2026.2921

Citation: Yan B, Zhang J, Yao W, Li YJ. A comparative analysis of arthroscopy-assisted minimally invasive percutaneous plate osteosynthesis versus open reduction and internal fixation for tibial plateau fractures. Jt Dis Relat Surg 2026;37(x):i-x. doi: 10.52312/jdrs.2026.2921.

Traditional management has relied heavily on open reduction and internal fixation (ORIF), which offers excellent direct visualization of the articular surface, enabling accurate reduction and rigid fixation.[7] However, this approach is inherently invasive, requiring extensive soft tissue dissection and a formal arthrotomy. Such exposure compromises periosteal vascularity and devitalizes bone fragments, raising the risks of wound dehiscence, deep surgical site infections, and delayed union or nonunion.[8] In response to these drawbacks, arthroscopic-assisted techniques have gained considerable popularity.[9] The use of arthroscopy provides high-definition visualization of the entire articular surface without a large capsular incision, allowing precise reduction of the joint line while also enabling identification and management of concomitant intra-articular pathologies, such as meniscal tears or cruciate ligament injuries, which occur in a substantial proportion of cases.[10] When combined with minimally invasive percutaneous plate osteosynthesis (MIPPO), this arthroscopic approach is believed to better preserve the biological integrity of the soft tissue envelope. Although the arthroscopic irrigation may wash out the fracture hematoma, the MIPPO technique minimizes additional soft tissue stripping, potentially aiding in recovery.[11] The synergy facilitates early range of motion (ROM), reduces postoperative pain, and shortens hospital stay relative to conventional open procedures.[12]

Recent high-level meta-analyses have established that arthroscopic-assisted reduction and internal fixation (ARIF) and ORIF achieve comparable final functional outcomes, with ARIF showing trends toward faster early recovery.[10,12,13] Huang et al.[12] reported that arthroscopic-assisted percutaneous fixation reduced hospital stay and improved early ROM compared to ORIF for Schatzker types II and III fractures. Tay et al.,[13] in a recent systematic review and meta-analysis of 969 patients, concluded that while ARIF offered advantages in early functional scores and reduced complications, no significant differences persisted at final follow-up. In the present study, we aimed to investigate the early recovery velocity associated with these two surgical approaches within this well-established equivalence framework, specifically for Schatzker type I-IV fractures, with detailed reporting of perioperative parameters and early functional trajectories at one, three, and six months.

PATIENTS AND METHODS

Study design and study population

This single-center, retrospective, comparative study was conducted at Leshan People’s Hospital, Department of Orthopedics between January 2021 and January 2024. Patients who underwent surgical treatment for tibial plateau fractures were screened. Inclusion criteria were as follows: age > 18 years; fresh closed tibial plateau fractures; Schatzker types I-IV; normal knee function of the affected limb before injury; and no vascular or nerve injury. Exclusion criteria were as follows: prior knee surgery; open or pathological fractures; other severe traumatic injuries that might affect postoperative rehabilitation, such as tibiofibular fractures, femoral fractures, compartment syndrome, or poor soft tissue condition; concomitant knee joint diseases including rheumatoid arthritis, tuberculous arthritis, tumors, or deformities; severe medical comorbidities precluding tolerance to surgery; and comorbidities known to affect healing or recovery, such as uncontrolled diabetes mellitus (glycated hemoglobin [HbA1c] > 7.5%) or peripheral arterial disease. Finally, a total of 84 patients who met the inclusion criteria were recruited (Figure 1). A written informed consent was obtained from each patient. The study protocol was approved by the Ethics Committee of Leshan People's Hospital (Date: 25.09.2020, No: LYLL-KY-130). The study was conducted in accordance with the principles of the Declaration of Helsinki.

In this study, no randomization was performed. The allocation to either the MIPPO or ORIF group was chronologically created: the first two years of the study period (between January 2021 and December 2022) predominantly featured ORIF (n = 38/43 ORIF patients), while the latter two years (between January 2023 and January 2024) saw a shift toward the MIPPO technique (n = 36/41 MIPPO patients). All surgeries were performed or directly supervised by two senior orthopedic trauma surgeons, each with over 10 years of experience in arthroscopic and trauma surgery.

Surgical technique

In the MIPPO group, after induction of general anesthesia, patients were placed supine with an electronic pneumatic tourniquet on the proximal thigh. Standard anteromedial and anterolateral portals were established for diagnostic arthroscopy to evaluate intra-articular structural injuries, including fracture fragment displacement, articular surface congruity, meniscal lesions, and

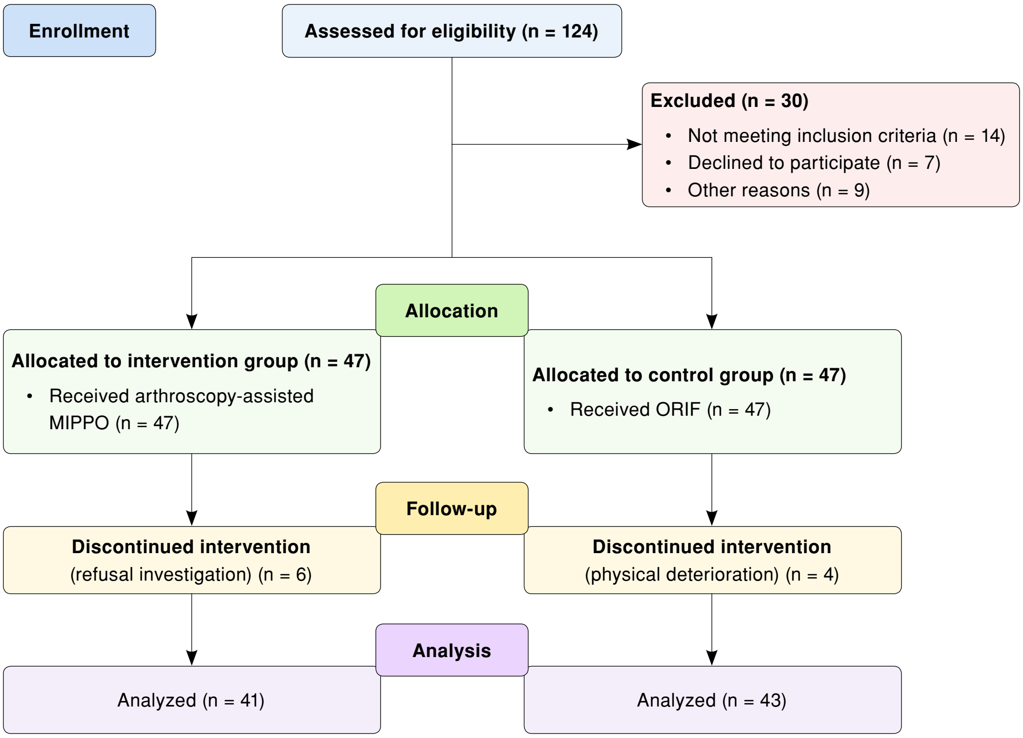

FIGURE 1. Study flowchart.

integrity of the cruciate ligaments. Management of tibial plateau fractures was tailored based on preoperative fracture classification combined with intraoperative findings, with selection of appropriate reduction and fixation methods. For Schatzker type I fractures, anatomic reduction was achieved under direct arthroscopic visualization using extra-articular techniques such as prying, compression, and traction. For Schatzker type III fractures, a targeting device localized the depressed fragment. A 10 × 10 mm cortical window was drilled approximately 30 mm below the tibial plateau depression. Through this window, the depressed articular surface was elevated with an impactor under arthroscopic guidance, and the underlying bone defect was filled with autograft or allograft bone. For Schatzker type II fractures, reduction combined the techniques for type I and type III fractures. After anatomic reduction, provisional fixation was done with Kirschner wires (K-wires). Following confirmation of satisfactory fracture alignment with C-arm fluoroscopy, percutaneous minimally invasive plate fixation was performed using the MIPPO technique. For Schatzker type IV split fractures, a medial or posteromedial incision was made to expose the medial fracture, and reduction was performed using the extra-articular fracture line as a reference. Temporary fixation was achieved with a reduction clamp and one or two K-wires, followed by arthroscopic evaluation of articular surface reduction. If reduction was suboptimal, the clamp was loosened and wires partially withdrawn to manipulate free fragments. Under arthroscopic visualization, the wires combined with the clamp achieved satisfactory articular reduction, after which the K-wires were advanced for definitive fixation. Plate and screw fixation was, then, performed on the medial tibia using MIPPO.

Once satisfactory reduction and fixation of the tibial plateau fracture was confirmed, damaged soft tissues were repaired. Meniscal injuries were managed by primary repair or meniscectomy as appropriate. Collateral ligament injuries underwent primary repair. For cruciate ligament injuries, management was individualized: avulsion fractures of the cruciate ligament insertion with bone fragments amenable to fixation were treated primarily using sutures or suture anchors; cases where the avulsed fragment was not suitable for fixation, as well as complete midsubstance ruptures, were scheduled for delayed autograft reconstruction. After soft tissue repair, knee stability was assessed. A negative-pressure drainage device was placed through the arthroscopic portal, followed by layered wound closure and compression bandaging (Figure 2).

In the ORIF group, after induction of general anesthesia, patients were positioned supine with an electronic pneumatic tourniquet on the proximal thigh. The surgical approach was selected based on fracture location: an anterolateral approach for lateral plateau fractures (Schatzker types I-III) and a medial or posteromedial approach for medial plateau fractures (Schatzker type IV). After capsulotomy, the surgical field was visualized, and fracture reduction was achieved using prying, compression, and traction to restore articular surface congruity. In cases of substantial bone defects, autograft or allograft bone grafting was performed. Intraoperative meniscal or collateral ligament injuries were addressed with primary repair when present, whereas cruciate ligament

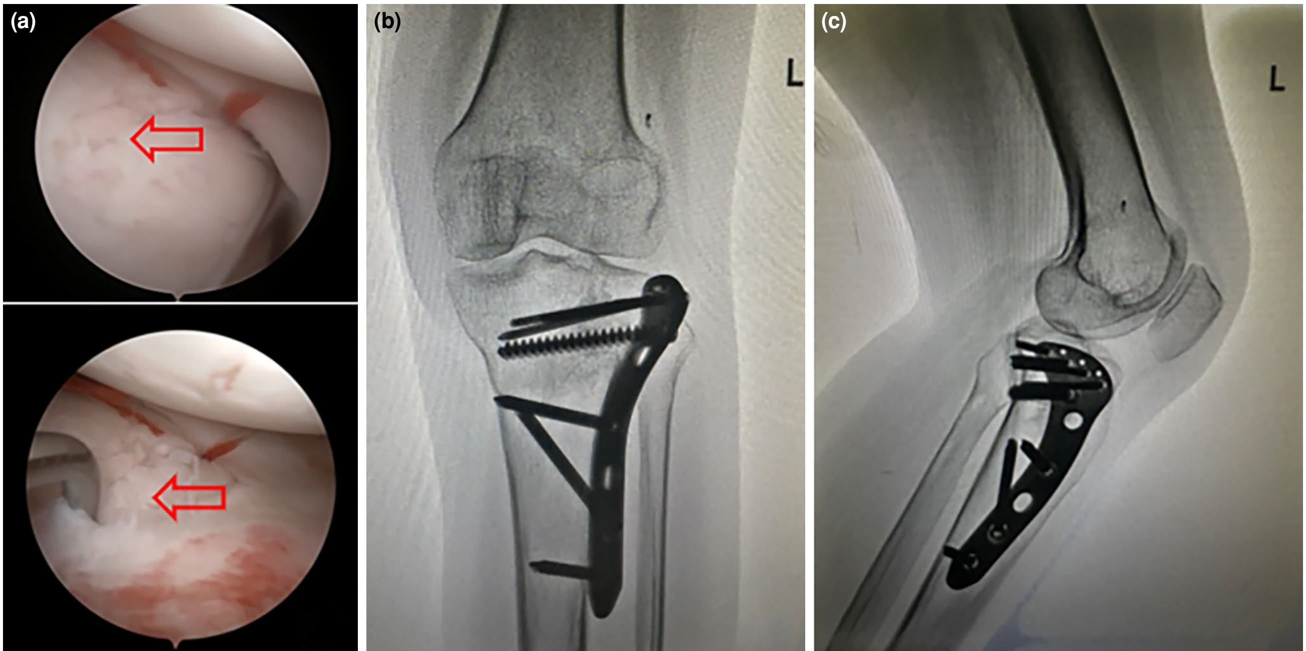

FIGURE 2. A 40-year-old male patient admitted with a left tibial plateau fracture (Schatzker type II) due to a fall, treated with arthroscopy-assisted MIPPO internal fixation. **(a)** Intraoperative arthroscopic view showing an irregular articular surface with obvious fracture displacement. **(b, c)** After MIPPO, the fracture position was well restored.
MIPPO, minimally invasive percutaneous plate osteosynthesis.

FIGURE 3. A 35-year-old male patient admitted with a right tibial plateau fracture (Schatzker type IV) due to a fall, treated with ORIF. **(a)** Intraoperative direct visualization of the exposed fracture ends. **(b, c)** Intraoperative fluoroscopy confirmed satisfactory fracture position. Note: This patient was preoperatively classified as Schatzker type IV (medial plateau fracture). Intraoperatively, unsuspected bicondylar extension was identified, necessitating lateral plating in addition to medial fixation. The lateral plate shown reflects this combined fixation strategy.
ORIF, open reduction and internal fixation.

injuries were reserved for delayed reconstruction. After satisfactory fracture reduction was confirmed, provisional fixation was achieved with K-wires, and adequate fracture alignment was verified by C-arm fluoroscopy (Figure 3).

Postoperative management

Ice packs were applied to the affected limb, which was kept elevated. On the first postoperative day, patients initiated quadriceps isometric exercises and active and passive ankle ROM exercises. Once radiographic imaging confirmed satisfactory implant positioning, continuous passive motion (CPM) was initiated for passive knee mobilization. Partial weight-bearing with crutches started at 10 weeks postoperatively, and full weight-bearing was permitted after radiographic confirmation of fracture healing at 12 weeks. The standardized hospital discharge criteria required the patient to have pain controlled with oral analgesics, ability to perform straight leg raise, independent transfer from bed to chair, and afebrile status for 24 h. For patients with midsubstance tears of the anterior or posterior cruciate ligament, delayed ligament reconstruction was performed after recovery of basic knee flexion-extension function and bone healing.

Outcome measures

Baseline demographic and clinical characteristics including age, sex, American Society of Anesthesiologists (ASA) class, operative time (defined as time from skin incision to skin closure), incision length, intraoperative blood loss (calculated as the volume in the suction canister minus irrigation fluid used, plus the increase in weight of surgical gauze, assuming 1 g ≈ 1 mL; we acknowledge that this method has measurement error, particularly in arthroscopic cases where irrigation fluid dilutes blood), postoperative drainage volume, intra-articular soft tissue injuries, hospital stay, fracture healing time (defined as radiographic evidence of bridging callus on three of four cortices on anteroposterior and lateral views, reported in weeks), and incidence of postoperative complications were recorded. Posteroanterior and lateral knee radiographs were obtained on the first postoperative day to assess reduction quality using the Rasmussen radiological scoring system (maximum 18 points, higher scores indicate better reduction quality).[14] Functional recovery was evaluated with the Hospital for Special Surgery (HSS) knee scoring system,[15] with scores collected at one, three, and six months postoperatively. Knee ROM was measured using a standard long-arm goniometer by a blinded physical therapist at one, three, and six months postoperatively. Knee stiffness was defined as flexion < 100° or extension deficit > 10° at three months postoperatively. The rate of excellent and good HSS knee scores at the final follow-up was also calculated for both groups, where an HSS score of > 85 was considered excellent, 70-85 good, 60-69 fair, and < 60 poor.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 26.0 software (IBM Corp., Armonk, NY, USA). Normality of continuous variables was assessed with the Shapiro-Wilk test. Continuous data were presented in mean ± standard deviation (SD) or median (min-max), while categorical data were presented in number and frequency. Between-group comparisons were performed using the independent samples t-test. Categorical variables were compared using the chi-square test or Fisher exact test. Ordinal data between the groups were compared using the Mann-Whitney U rank-sum test. A p value of < 0.05 was considered statistically significant.

RESULTS

Of a total of 84 patients, 28 were male and 56 were female with a mean age of 49.4 ± 9.0 (range, 27 to 69) years. Baseline characteristics were well balanced between the two groups, including sex, age, body mass index, affected side, injury cause, Schatzker classification, and time from injury to definitive surgery (all $p > 0.05$, Table I). The mean time from injury to surgery showed a trend toward longer delay in the study group, but did not reach statistical significance (3.7 ± 0.8 *vs.* 3.3 ± 0.9 days, $p = 0.052$).

As shown in Table II, the arthroscopy-assisted MIPPO group had significantly longer operative time (96.0 ± 18.2 *vs.* 84.0 ± 13.9 min, $p = 0.001$). On the other hand, incision length was significantly shorter in the study group (3.9 ± 0.7 *vs.* 6.2 ± 0.9 cm, $p < 0.001$). Intraoperative blood loss and postoperative drainage volume were also statistically significantly reduced in the arthroscopy-assisted MIPPO group (56.5 ± 9.6 *vs.* 72.6 ± 10.1 mL, $p < 0.001$; and 47.1 ± 7.5 *vs.* 59.0 ± 7.0 mL, $p < 0.001$, respectively). The ASA class did not significantly differ between the groups ($p = 0.405$).

The mean postoperative Rasmussen radiological scores were significantly higher in the arthroscopy-assisted MIPPO group (15.4 ± 1.4 *vs.* 14.0 ± 1.6, $p < 0.001$). The mean hospital stay was slightly shorter in the study group (7.3 ± 1.5 *vs.* 8.2 ± 2.2

TABLE I
Demographic and clinical data of patients

	MIPPO group (n = 41)		ORIF group (n = 43)		
Variables	n	Mean ± SD	n	Mean ± SD	*p*
Age (year)		49.2 ± 8.7		49.7 ± 9.4	0.828
Sex					0.280
Male	16		12		
Female	25		31		
BMI (kg/m^2)		22.5 ± 2.4		22.2 ± 2.2	0.675
Side of the affected limb					0.666
Left	21		20		
Right	20		23		
Cause of injury					0.850
Low-energy violent	18		18		
High-energy violent	23		25		
Schatzker's classification					0.752
I	15		18		
II	8		8		
III	16		13		
IV	2		4		
Time from injury to definitive surgery (days)		3.7 ± 0.8		3.3 ± 0.9	0.052
Soft tissue injury					0.815
Normal	26		28		
Meniscus injury	7		9		
Cruciate ligament injury	4		4		
Collateral ligament injury	4		2		

MIPPO, minimally invasive percutaneous plate osteosynthesis; ORIF, open reduction and internal fixation; SD, standard deviation; BMI, body mass index. Statistical methods: Continuous variables were compared using independent samples t-test and presented as mean ± SD. Categorical variables were compared using chi-square or Fisher exact test and presented as n. Low-energy violence: falls from standing height or simple falls. High-energy violence: traffic accidents, falls from height > 1.5 meters, or direct crush injuries

days), but the difference did not reach statistical significance ($p = 0.051$). Fracture healing time was comparable between the groups (11.4 ± 1.3 *vs.* 11.1 ± 1.3 weeks, $p = 0.340$). Follow-up duration was similar between the groups (16.1 ± 3.6 *vs.* 16.5 ± 4.0 months, $p = 0.639$) (Table III).

The mean HSS scores at one, three, and six months postoperatively were consistently higher in the arthroscopy-assisted MIPPO group than in the ORIF group (35.7 ± 2.2 *vs.* 27.8 ± 2.2, 47.4 ± 1.8 *vs.* 38.7 ± 2.2, and 81.1 ± 2.7 *vs.* 64.5 ± 2.4, respectively; all $p < 0.001$, Table IV). The differences at one

TABLE II
Surgical-related parameters

	ASA classification	Operative time (min)	Incision length (cm)	Intraoperative blood loss (mL)	Postoperative drainage volume (mL)
Groups	n (I/II/III)	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
MIPPO group (n = 41)	7/26/8	96.0±18.2	3.9±0.7	56.5±9.6	47.1±7.5
ORIF group (n = 43)	5/33/5	84.0±13.9	6.2±0.9	72.6±10.1	59.0±7.0
p	0.001	< 0.001	< 0.001	< 0.001	0.405

ASA: American Society of Anesthesiologists; SD, standard deviation; MIPPO, minimally invasive percutaneous plate osteosynthesis; ORIF, open reduction and internal fixation.

and three months exceed the minimal clinically important difference (MCID) for the HSS score. However, at final follow-up, the excellent-and-good rate of HSS score showed no significant difference between the two groups (95.1% *vs.* 97.7%, $p = 0.746$). Knee ROM was also significantly improved in the MIPPO group at all postoperative time points (Table V). The 11.2° difference at six months (118.5° ± 8.2° *vs.* 107.3° ± 9.1°) was clinically meaningful: 107° could leave patients struggling with advanced activities of daily living (e.g., squatting, stair negotiation), whereas 118.5°

TABLE III
Comparison of postoperative Rasmussen radiological scores, hospital stay and fracture healing time

	Rasmussen radiological scores	Hospital stay (days)	Fracture healing time (weeks)	Follow-up time (months)
Groups	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
MIPPO group (n = 41)	15.4 ± 1.4	7.3 ± 1.5	11.4 ± 1.3	16.1 ± 3.6
ORIF group (n = 43)	14.0 ± 1.6	8.2 ± 2.2	11.1 ± 1.3	16.5 ± 4.0
p	< 0.001	0.051	0.340	0.639

ASA: American Society of Anesthesiologists; SD, standard deviation; MIPPO, minimally invasive percutaneous plate osteosynthesis; ORIF, open reduction and internal fixation.

TABLE IV
Comparison of the HSS score at 1, 3, and 6 months postoperatively and the excellent and good rate of the HSS score at last follow-up

	One month after surgery	Three months after surgery	Six months after surgery	Excellent and good rate of the HSS score
Groups	%	Mean ± SD	Mean ± SD	Mean ± SD
MIPPO group (n = 41)	95.1	35.7 ± 2.2	47.4 ± 1.8	81.1 ± 2.7
ORIF group (n = 43)	97.7	27.8 ± 2.2	38.7 ± 2.2	64.5 ± 2.4
p	0.746	< 0.001	< 0.001	< 0.001

HSS, Hospital for Special Surgery; SD, standard deviation; MIPPO, minimally invasive percutaneous plate osteosynthesis; ORIF, open reduction and internal fixation.

TABLE V
Comparison of knee ROM postoperatively

	One month after surgery	Three months after surgery	Six months after surgery
Groups	%	Mean ± SD	Mean ± SD
MIPPO group (n = 41)	85.4° ± 7.5°	102.1° ± 8.6°	118.5° ± 8.2°
ORIF group (n = 43)	72.6° ± 8.1°	89.3° ± 9.2°	107.3° ± 9.1°
p	< 0.001	< 0.001	< 0.001

ROM, range of motion, SD, standard deviation; MIPPO, minimally invasive percutaneous plate osteosynthesis; ORIF, open reduction and internal fixation.

TABLE VI
Complications

	MIPPO group (n = 41)		ORIF group (n = 43)		
Complications	n	%	n	%	*p*
Deep vein thrombosis	2	4.9	1	2.3	0.611
Superficial infection	0	0	1	2.3	1.000
Knee stiffness	1	2.4	2	4.7	1.000

MIPPO, minimally invasive percutaneous plate osteosynthesis; ORIF, open reduction and internal fixation.

could provide a biomechanical buffer for normal kinematic function.

The overall complication rate was low in both groups (7.3% [3/41] in MIPPO group *vs.* 9.3% [4/43] in ORIF group). No significant differences were observed for deep vein thrombosis (4.9% *vs.* 2.3%, $p = 0.611$), superficial infection (0% *vs.* 2.3%, $p = 1.000$), or knee stiffness (2.4% *vs.* 4.7%, $p = 1.000$) (Table VI).

DISCUSSION

In the present study, we investigated whether arthroscopy-assisted MIPPO provided more favorable early functional recovery and reduced surgical trauma compared to traditional ORIF. Our study results showed that the arthroscopy-assisted minimally invasive approach offered benefits including smaller incisions, reduced perioperative blood loss, better radiological reduction quality (with the caveat of small magnitude and lack of reliability analysis), and faster early functional recovery, while achieving comparable short-term outcomes (functional recovery at one, three, and six months postoperatively) and complication rates assessed at a mean follow-up of 16 ± 3.8 months. The reductions in intraoperative blood loss (mean difference 16.1 mL) and postoperative drainage volume (mean difference 11.9 mL), while statistically significant, seem to be clinically non-significant. These small absolute differences are unlikely to influence transfusion requirements, hemodynamic stability, or recovery milestones. These findings are consistent with the growing body of evidence favoring arthroscopic-assisted techniques for selected tibial plateau fractures.[10,12,13]

Recent meta-analyses have demonstrated that ARIF and ORIF achieve comparable final functional outcomes. Tay et al.[13] pooled data from 969 patients and found no significant differences in HSS scores or Knee Society scores at final follow-up, although ARIF showed trends toward better early functional outcomes. Huang et al.[12] reported that arthroscopic-assisted percutaneous fixation significantly reduced hospital stay and improved early ROM compared to ORIF for Schatzker types II and III fractures. Our study provides granular confirmation of these early recovery benefits, specifically documenting HSS and ROM trajectories at one, three, and six months, while demonstrating that final excellent-and-good rates do not differ. Thus, the primary contribution of the arthroscopy-assisted MIPPO technique is accelerated early recovery, not superior long-term outcomes.

Considering clinically meaningful ROM difference, the 11.2° difference in knee ROM at 6 months (118.5° *vs.* 107.3°) exceeded the MCID for knee flexion in post-traumatic settings, supporting the clinical relevance of this early functional advantage. Kinematic studies indicate that approximately 110° of knee flexion is required for stair negotiation and 120° for squatting and rising from a low chair. In the ORIF group, the mean ROM of 107.3° left a substantial portion of patients straddling a critical kinematic threshold, potentially struggling with advanced activities of daily living and requiring compensatory movements from the hip and lumbar spine. In contrast, in the MIPPO group, the mean ROM of 118.5° provided a comfortable biomechanical buffer for normal function. This finding provides a compelling clinical argument for considering the arthroscopy-assisted MIPPO technique when early return to full functional independence is a priority.

For trade-offs and clinical decision-making, the arthroscopy-assisted MIPPO technique required significantly longer operative time (96.0 *vs.* 84.0 min, $p = 0.001$). This difference reflects the time needed for diagnostic arthroscopy, management of concomitant soft tissue injuries, and percutaneous fixation. The longer operative time carries implications for operating room scheduling, anesthesia exposure, and cost. Additionally, the technique has a learning curve; all surgeries in this study were performed by experienced arthroscopic surgeons, and outcomes may differ in lower-volume centers. Clinicians must weigh the three-month functional head start against these added costs, operative time, and learning curve requirements. For patients who prioritize rapid return to high-demand activities, the arthroscopy-assisted approach may be justified; for lower-demand patients or those with significant medical comorbidities, the conventional ORIF approach remains a safe and effective option.

The interpretation of the present findings should take into account the potential influence of concomitant meniscal and cruciate ligament injuries Patients undergoing delayed cruciate ligament reconstruction or meniscal repair have fundamentally different functional recovery trajectories than those with isolated fractures. Due to the small sample size (n = 84), multivariate regression was not feasible, creating an omitted-variable bias that confounds attribution of functional outcomes solely to the osteosynthesis technique. Consequently, the observed differences in HSS scores and ROM may have been influenced, at least in part, by concomitant soft tissue injuries and their management. Nevertheless, a sensitivity analysis restricted to patients with isolated fractures without meniscal or ligament treatment demonstrated directionally similar between-group differences, although statistical significance was not reached, likely due to the limited sample size. Larger studies with sufficient statistical power and multivariate adjustment are needed to further clarify the independent contribution of surgical technique to postoperative functional recovery.

The mean Rasmussen radiological score in the MIPPO group (15.4) fell within the "Good" tier (13–15 points) of the Rasmussen scale and was statistically higher than that in the ORIF group (14.0). However, this 1.4-point difference corresponds to sub-millimeter improvements in articular depression or condylar widening. Given that we did not perform inter- or intra-observer reliability analysis for the Rasmussen scores, this small difference should be interpreted with caution and is likely clinically non-significant. Thus, while arthroscopy may provide enhanced visualization of the articular surface, the practical advantage in radiographic reduction quality remains uncertain.

Several limitations should be acknowledged. First, the retrospective, non-randomized design with chronological allocation (ORIF predominantly in early period, MIPPO in later period) introduces potential confounding from the surgical learning curve and evolution of perioperative care protocols. Second, we did not perform an a priori power analysis, and the sample size ($n = 84$) is relatively modest. Third, the follow-up period (mean 16 ± 3.8 months) is short-term by orthopedic standards; we could not assess the development of post-traumatic osteoarthritis, which typically requires longer observation. Fourth, the inclusion of patients with concomitant meniscal and ligamentous injuries creates omitted-variable bias; due to small sample size, we could not perform multivariate regression to isolate the effect of the osteosynthesis technique. Fifth, we did not perform second-look arthroscopy or routine postoperative magnetic resonance imaging (MRI) to evaluate cartilage healing or meniscal repair status. Sixth, the study included only Schatzker types I-IV fractures; the findings may not be generalizable to more complex patterns (types V and VI). Seventh, a learning curve is associated with arthroscopic-assisted techniques; our results were achieved by experienced arthroscopic surgeons and may differ in lower-volume centers. Eighth, our method of estimating intraoperative blood loss (suction canister minus irrigation fluid plus gauze weight) has measurement error, particularly in arthroscopic cases where irrigation fluid dilutes blood. Ninth, we did not perform reliability analysis for Rasmussen radiological scores. Finally, the complication p values were recalculated using the Fisher exact test and are no longer statistically significant for any individual complication type; the study was underpowered to detect differences in rare events.

In conclusion, for Schatzker type I-IV tibial plateau fractures, arthroscopy-assisted MIPPO provides more favorable early functional recovery and radiological reduction quality compared to conventional ORIF, with less surgical trauma and comparable early functional recovery and similar complication rates during follow-up. Although the operative time is longer, this minimally invasive approach represents a safe and effective treatment option. Its principal advantage is accelerated early recovery, particularly in knee ROM, enabling patients to reach clinically meaningful thresholds for activities of daily living sooner. The decision to adopt this technique should balance these early functional benefits against the longer operative time, technical learning curve, and additional costs. Future prospective, randomized studies with longer follow-up and appropriate adjustment for concomitant soft tissue injuries are warranted to further evaluate the long-term effectiveness of this approach.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: B.Y.: Conception and design, drafting of the article; J.Z.: Collection and assembly of data, statistical expertise; W.Y.: Analysis and interpretation of the data; Y.J.L.: Critical revision of the article for important intellectual content. All authors read and approved the final manuscript.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

AI Disclosure: The authors declare that artificial intelligence (AI) tools were not used, or were used solely for language editing, and had no role in data analysis, interpretation, or the formulation of conclusions. All scientific content, data interpretation, and conclusions are the sole responsibility of the authors. The authors further confirm that AI tools were not used to generate, fabricate, or 'hallucinate' references, and that all references have been carefully verified for accuracy.

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