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RESEARCH

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Surgical treatment of AO/OTA 41B3 and 41C tibial plateau fractures with a temporary bi-frame fixator combined with the MIPPO technique

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Abstract

Background This study evaluated the clinical effects of the use of a temporary bi-frame fixator in conjunction with minimally invasive percutaneous plate osteosynthesis (MIPPO) for treating AO/OTA 41B3 and 41C tibial plateau fractures (TPFs).

Methods This was a retrospective analysis of 30 patients with TPFs affected by vertical compression seen from October 2019 to October 2020. All patients were treated with a bi-frame fixator to correct the vertical shortening deformity, with the MIPPO technique used after reduction. All patients underwent routine examinations at 1, 3, 6, 12 and 24months postoperatively and then annually. Clinical parameters assessed included the Hospital for Special Surgery score (HSS), number of assistants, intraoperative hemorrhage, intraoperative fluoroscopy frequency, length of hospital stay, and time to fracture healing. Radiographic findings were assessed using Rasmussen scores.

Results All patients had satisfactory fracture reduction on postoperative imaging. The average operating time was 112.03 ± 20.9 min, with 15.79 ± 3.45 fluoroscopic exposures; the average blood loss was 66.63 ± 10.88 mL, the average length of hospital stay was 12.86 ± 5.11 days, and the average fracture healing time was 10.33 ± 1.48 weeks. The mean follow-up time was 23.18 ± 2.59 months. At the last follow-up, the Rasmussen anatomical score was excellent in 22 (75.3%) patients, good in 5 (16.7%), and fair in 3 (10%). The average HSS was 65.7 ± 3.26, 82.26 ± 2.28, and 87.66 ± 2.4 after 1, 6, and 12 months, respectively, and it was 92.56 ± 2.96 at the last follow-up (F = 1073.073, $P < 0.001$). No complications occurred in any patient during follow-up.

Conclusion For AO/OTA 41B3 and 41C fractures of the tibial plateau, the use of a temporary bi-frame fixator combined with the MIPPO technique can correct the compressed displacement, reduce soft tissue damage, and facilitate surgical reduction, which aid the recovery of joint function.

Keywords Tibial plateau fracture, Temporary bi-frame fixator, MIPPO technique, Minimally invasive, External fixator

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Introduction

Tibial plateau fractures (TPFs) are intra-articular fractures with articular surface collapse displacement and split injuries of varying severity [1]. Low-energy trauma such as falls and stumbles may lead to more frequent vertical compression fractures [2]. The gold standard treatment of TPFs is open reduction and internal fixation (ORIF) with locking plates to restore joint consistency and consistent force lines to support the injured limb [3].

The main reduction techniques and apparatus currently used clinically are manual traction, an AO distractor [4, 5], a traction table, Zhang's double reverse traction repositor (DRTR) [6], and preoperative temporary external fixation in staged ORIF treatment [7], The magnitude and direction of manual traction are variable and it cannot maintain long-term reduction, especially in obese and muscular patients. The traction force of a traction table is across the joint, making it difficult to maintain consistency with the direction of the lower limb force line. An AO distractor and Zhang's DRTR require special instruments.

The present study aimed to investigate the clinical results of treatment of temporary bi-frame fixator combined with the MIPPO technique by assessing its postoperative functional and radiological outcomes. We hypothesised that a temporary bi-frame external fixator combined with the MIPPO technique would be useful for surgical treatment of type AO/OTA 41B3 and 41C tibial plateau fractures.

Methods

This study was approved by the Ethics Committee of our hospital. All methods were performed in accordance with the relevant guidelines and regulations. All preoperative evaluations were performed by the same team of physicians.

General Information

In total, 30 patients (16 men and 14 women) with TPFs with AO/OTA 41B3 and 41C plateau fractures i.e. partial articular fractures with a split-depression (41B3) and complete articular fractures (41C) [8], admitted to the hospital between October 2019 and October 2020, were analysed retrospectively.

Inclusion criteria

(i) Type AO/OTA 41B3 and 41C tibial plateau fractures; (ii) closed TPF; (iii) time from injury to surgery <3 weeks; (iv) normal lower limb function before injury; (v) no other peri-knee fractures.

Exclusion criteria

(i) Patients with other ipsilateral lower extremity injuries and previous lower extremity surgery; (ii) patients with open pathological fractures or severe knee joint degeneration; (iii) patients with severe peripheral nerve injury, vascular injury, or compartment syndrome; (iv) failure to cooperate with surgical treatment and follow-up treatment; (v) patients missing follow-up.

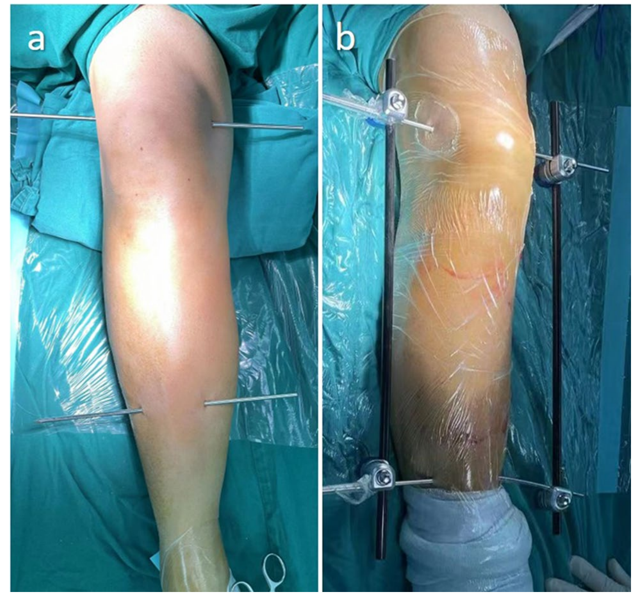

Fig. 1 Installation of temporary intraoperative traction for repositioning. Position the affected supracondylar femur and lower tibial segments, and place two stiemen pins (**a**) connected by external fixators (**b**)

Preoperative preparation

After being admitted, the injury was evaluated via X-rays and computed tomography (CT) three-dimensional reconstruction. Anti-coagulation therapy was given to prevent lower extremity thrombosis. When the skin begins to wrinkle, it can be prepared for surgery. Antibiotics (cefuroxime or clindamycin) were administered 30 min before surgery to minimise the risk of implant-related infection.

Method of operation

The same group of physicians performed all surgeries; 4 patients had general anesthesia, and 26 had mixed spinal-epidural anesthesia. The patient was supine, and standard surgical cleaning and drapery procedures were performed. Two 4.5 mm stiemen pins were inserted into the femoral condyle and distal tibia, and a temporary bi-frame fixator was used to connect the two pins (Fig. 1); such pins can also be placed in selected locations in the distal femur medially, and lower tibial segment laterally, to facilitate single-plane adjustment. The link length is adjusted according to the desired distraction position, and traction is applied to reduce the proximal tibial fragment. The pins may also be used as a temporary bi-frame fixator. C-arm fluoroscopy was used to assess the shortening displacement and alignment after tightening the traction frame and adjusting the reduction position (Fig. 2d, e). In patients with collapsed articular surfaces, the surfaces were reset using top bars. If reduction left a cancellous bone hollow, it was filled with allograft bone (Fig. 2f). The MIPPO technique was used to insert the plate and screw after verifying proper alignment (Fig. 2g, h). Once satisfactory reduction was achieved, the plates and screws were secured, and the external fixator and stiemen pins were removed.

Postoperative management

The patient's limb was elevated to help reduce edema, and they were given standard anti-coagulation and anti-infection treatments postoperatively. Postoperative knee X-rays were used to assess the postoperative quality of the reduction. At 1 day postoperatively, patients were told to perform active and passive functional exercises without weight bearing. The patients began partial weight bearing depending upon fracture healing. Patients could perform full weight bearing at 12 weeks postoperatively.

Parameters assessed

The number of assistants, intraoperative hemorrhage, intraoperative fluoroscopy frequency, length of hospital stay, and time for fracture healing were all noted. The images were assessed using the Rasmussen Reset Anatomy Scale at 1, 3, 6, 12, and 24 months postoperatively [9]. Knee function was evaluated using the Hospital for Special Surgery score (HSS) at 1, 6, and 12 months postoperatively, and at the final follow-up [10]. Postoperative complications were recorded.

Statistical methods

SPSS 27.0 was used to analyse the data. The adherence of data to a normal distribution was checked using the Kolmogorov–Smirnov test. Count data are reported as numbers or percentages, whereas measurement data are expressed as the mean ± standard deviation. Group were compared using ANOVA. The level of significance was set to $p<0.05$.

Results

Thirty patients with Type AO/OTA 41B3 and 41C tibial plateau fractures underwent surgical treatment with a temporary bi-frame fixator combined with the MIPPO technique. The average follow-up period was 23.18 ± 2.59 months. The demographic data are presented in Table 1; there were 16 males and 14 females with an average age of 51.82 ± 8.34 years. The injuries were caused by falls ($n=12$), traffic accidents ($n=9$), and heavy object injuries ($n=9$). The average interval from injury to surgery was 10.14 ± 3.96 days. Average operation time was 112.03 ± 20.9 min, average intraoperative blood loss was 66.63 ± 10.88 mL, and intraoperative fluoroscopy was required an average of 15.79 ± 3.45 times. Postoperative imaging revealed successful reduction and good implant position. The average hospital stay was 12.86 ± 5.11 days.

All patients achieved satisfactory reduction, which was radiographically maintained throughout the follow-up period. The average fracture healing time was 10.33 ± 1.48 weeks. At the last follow-up, the Rasmussen score was excellent in 22 (73.3%) patients, good in 5 (16.7%), and fair in 1 (10.0%).The average postoperative knee HSS score at the last follow-up was 92.56 ± 2.96 (Table 2).

During follow-up, no skin necrosis, deep wound infection, vascular or nerve injury, or osteofascial compartment syndrome occurred. By the last follow-up, no deep infection, nonunion, or malalignment was noted. Arthritis was reported in one patient during follow-up, and this improved with symptomatic treatment.

Discussion

A TPF is one of the most frequent traumatic knee injuries, comprising about 1% of all bone fractures [11]. It is primarily seen in males aged 40–50 years and is often caused by inversion, eversion, or axial trauma [12]. The fracture morphology is related to the mechanism of injury. Following an axial load, the platform will collapse locally under compression or experience simultaneous medial and lateral fractures. The axial force on the knee joint at 90°of flexion is the major contributor to a posterior compression fracture. Anterior compression, which may also affect the back of the platform, is mainly caused by hyperextension of the knee joint when the shank is immobilised [13]. The primary objectives of surgery for these fractures are to restore the collapsed joint surface, lower extremity force lines and height; preserve articular surface stability; and quickly re-establish normal knee mobility [14]. Appropriate fracture reduction is crucial to minimise complications and promote healing.

The gold standard for the treatment of TPF is ORIF [15]. Conventional ORIF has a good operative field but requires the incision of a large amount of soft tissue to achieve a wide exposure. This may increase the risk of soft tissue and neurovascular damage, leading to infection and nonunion [16]. The MIPPO technique is a minimally invasive technique proposed by Krettek et al. [17]. and Wenda et al. [18], and the treatment principles are avoidance of exposure of the fracture end, gentle soft tissue exposure, small incisions, indirect reduction, minimal hardware application, maximal preservation of the blood supply to the fracture end and surrounding tissues, and reduction of soft tissue injury, thus providing a good microenvironment for fracture healing. Over the past 30 years, the MIPPO technique has become a safe and reliable technique that has been applied to fractures of the humerus, clavicle, distal tibia, and calcaneus [19],

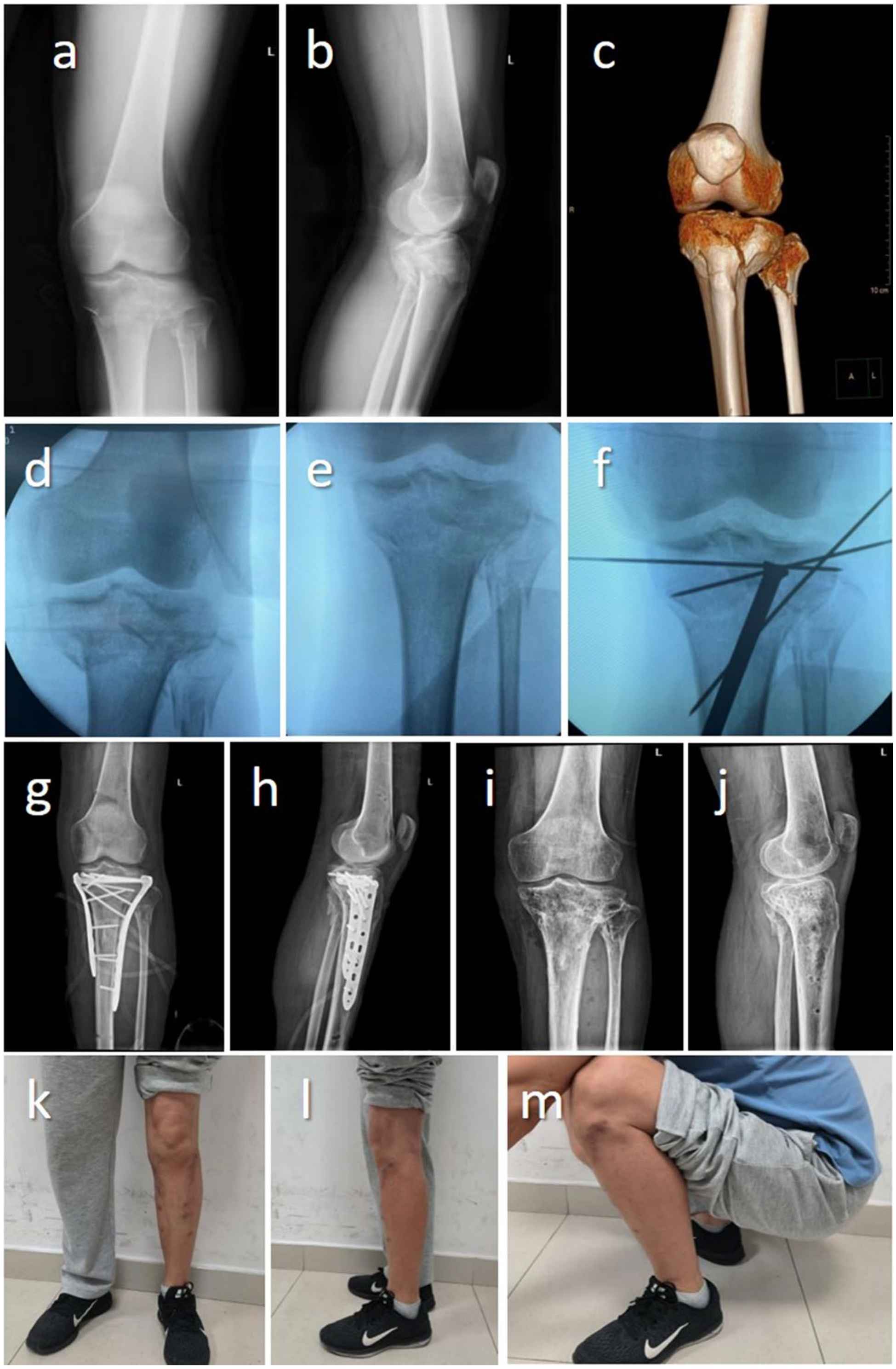

Fig. 2 A middle-aged male with Type AO/OTA 41C2 tibial plateau fractures. Preoperative X-ray and three-dimensional CT reconstruction show a AO/OTA 41C2 TPF. (**a**–**c**) Preoperative X-rays and CT images. (**d**) The fractured end of the tibial plateau before installing the traction fixator was altered by its insertion. (**e**) The vertical shortening deformity of the fracture was corrected after traction repositioning using a temporary bi-frame fixator. (**f**) The collapsed articular surface was repositioned by applying the MIPPO technique with a nail bar and was temporarily fixed with stiemen pins. (**g**–**j**) Postoperative X-ray films and internal fixation removal. (**k**–**m**) Postoperative functional recovery

Table 1 Basic patient information and result

Variables		N(%)	Mean	SD
Demographics	Age	-	51.82	8.34
	Sex (M/F)	16/14 (53.33%)		
Mode of injury	Fall	12 (40%)		
	Heavy object injuries	9 (30.00%)		
	Traffic accidents	9 (30.00)		
AO/OTA classification	41 B3	13 (43.3%)		
	41 C1	3 (10.0%)		
	41 C2	8 (26.7%)		
	41 C3	6 (20.0%)		
Hospital	Operating time (min)	-	112.03	20.9
	Intraoperative fluoroscopy frequency (times)	-	15.79	3.45
	Bleeding volume (mL)	-	66.63	10.88
	Hospital stay (days)	-	12.86	5.11
Results	Follow-up (months)	-	23.18	2.59
	Fracture healing time (weeks)	-	10.33	1.48
Rasmussen score	Excellent	22 (73.3%)		
	Good	5 (16.7%)		
	Fair	3 (10.0%)		

MIPPO is superior to traditional fixation. It reduces periosteal stripping, preserves the fracture hematoma, and minimises the risk of iatrogenic trauma. Compared to ORIF, MIPPO has the advantages of lower rates of infection, delayed union, deformity, and plate loosening, but it is associated with malalignment, more intraoperative fluoroscopy, and longer operating times [20], To address the disadvantages of the MIPPO technique, traction is used to reduce the fracture during surgery, such as with an AO distractor or Zhang's DRTR.

For a TPF with initial changes due to vertical compression, assisted reduction is often performed using manual traction, a traction table, temporary external fixation in ORIF staging treatment, or other traction devices, such as a circular traction stent [21] and DRTR. Manual traction is not continuously steady and relies on the operator's ability and the assistance of helpers, which can easily lead to loss of reduction following repositioning [22]. The trans-articular effects of a traction table may cause the traction line to be improperly aligned with the axis of the lower extremity, which can result in an inverted or valgus deformity and clinical complications such as soft tissue contusion, compartment syndrome, and neurological injury [23, 24]. The treatment of a TPF with a preoperative external fixator poses a high risk of infection and reoperation, and has high nursing costs [25]. The positive culture rate of external fixation nails is high, and the overlap of external fixation nails with internal fixation readily leads to deep infection [26]. Additionally, careful disinfection of the external fixator is required if it is to be retained for traction in internal fixation [27]. To realign the fractured ends more effectively, Wang et al. used DRTR to achieve the maximum bidirectional traction force focusing on the tibial plateau, while correcting and continually maintaining the force line [28]. The AO distractor was initially applied to femoral fractures, and its distraction was uniplanar. It is impossible to reduce the medial or lateral tibial plateau individually; this requires special instruments [5]. The combination of DRTR and MIPPO has positive clinical outcomes. Compared to a traction bed, it is less expensive and has fewer complications [6, 28]. However, DRTR requires additional equipment that costs 40,000 yuan or nearly $5,000 US [24]; there are few reports on the use of DRTR in TPF, and more studies are needed to prove its feasibility [29].

The device used in this study significantly affected the traction reduction of the deformity of medial and lateral plateau vertical compression fractures. Because it offers more stable, long-lasting, symmetrical traction on the tibia, the external fixator used in this study reduces the destabilising factors that may arise with manual traction, reduces the reliance on the surgeon's clinical experience, and is effective at reducing the difficulty of the subsequent reduction and fixation. Compared with external fixation in staged treatment, intraoperative external fixation reduces the risk of pin track and deep infection, as well as the number of surgeries and nursing costs. Compared with Zhang's DRTR and a traction table, fixator installation is quick, sampling is simple, and the cost is minimal. There is no need to purchase additional devices, making it easier to use in hospitals. The operative technique is simple, and the learning cycle is short, allowing beginners to master this technology quickly.

The traction line of the DRTR is concentrated in front of the affected limb, while the traction at the opposite end is an indirect force (Fig. 3). In comparison, the ends of the temporary bi-frame fixator are fixed at the femoral condyle and distal tibia, respectively, and traction reduction is performed directly on the fracture end; this provides continuous stable traction during the operation

Table 2 Knee HSS scores of the included patients

	1 month postoperatively	6 months postoperatively	12 months postoperatively	Last follow-up*	F	P
HSS Score	65.7 ± 3.26	82.26 ± 2.28	87.66 ± 2.4	92.56 ± 2.96	1073.073	< 0.001

*Compared with 1 month postoperatively

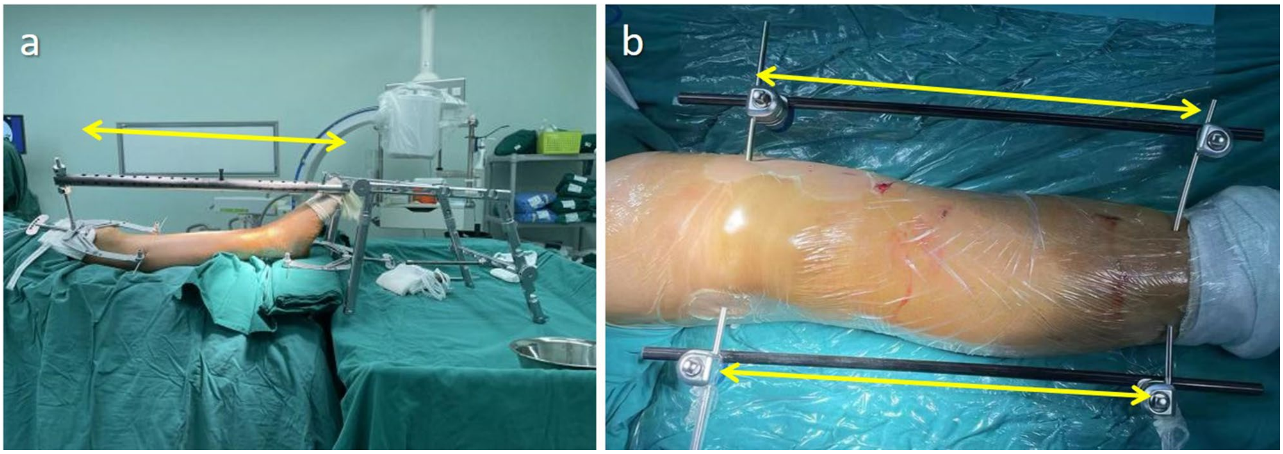

Fig. 3 Difference between the use of a DRTR and an external fixator in TPF traction. (**a**) The traction force of Zhang's DRTR is applied "indirectly" to the anterior tibia; (**b**) that of our external fixator is applied "directly" to the medial and lateral tibial plateau

while correcting the impaction and shortening the displacement caused by vertical compression in the closed state through skeletal traction, ligament displacement, and soft tissue compression [6]. It applies the same traction as the tibial axis and achieves good reduction. During the operation, traction pins can be added according to the fracture characteristics to assist reduction and reduce the fracture more effectively. The method can better correct the vertical shortening deformity of the fracture directly and effectively restore the normal alignment of the lower limbs.

The external fixator minimises additional surgical harm to the soft tissues of the broken end. It reasonably preserves the blood supply of the folded end, since it does not directly affect the soft tissues in the wounded region. In our study, all patients had good bleeding control (66.63±10.88 mL) and short operating times (112.03±20.9 min). There was no skin necrosis or deep wound infection during follow-up, which was lower than the 10% and 8%, respectively, reported in a recent study [30]. The frame offers sufficient traction while providing ideal circumstances for using MIPPO, which significantly decreases the frequencies of soft tissue problems, infections, and bone discontinuities [20]. Using an external fixator in conjunction with MIPPO helps ensure proper repositioning while minimising harm to the surgical site and facilitating healing. Our patients achieved osseous healing at 10.33±1.48 weeks postoperatively. At the final follow-up, the Rasmussen score was satisfactory, at 91.7%, similar to that reported by Biggi et al. [31]and Raza et al. [32] The HSS score improved from 65.7±3.26 at 1 month postoperatively to 92.56±2.96 at the last follow-up. Our study showed that this method can achieve satisfactory fracture healing and the desired joint mobility and function.

For patients with posterior column fracture of the tibial plateau, the medial and lateral columns are first reduced and immobilised as described above [33]. Usually, anatomic reduction of AO/OTA 41B3 and 41C TPFs are achieved by traction of a temporary bi-frame external fixator [34]. If the reduction of the posterolateral plateau is still unsatisfactory, a bone tamp can be used to reduce the fracture trans-osseous tunnel, and bone grafting can be implanted to fill the bone defect (Fig. 4). For posterior medial and anterior lateral double incision, there are many methods for fixing posterolateral plateau TPFs including the use of anterolateral lag screws, anteromedial-to-posterolateral fixation [35], a WAVE posterior proximal tibia plate [36], or a posteriorly placed barrel hoop plate [37].

It is necessary to assess the patient's bone quality preoperatively, to avoid iatrogenic fractures (by using appropriate distraction during surgery) and prevent excessive traction force. To avoid injury to the vascular nerves around the femoral condyle and ankle joint, the stiemen pins must be implanted carefully during surgery; they should be placed from medial to lateral in the proximal femur and from lateral to medial in the distal tibia. To avoid intra-articular placement, place the pins 5 cm above the ankle [38, 39]. There is an angle of 86°–89° between a line tangent to the proximal tibia and the mechanical axis of the tibia, *i.e.* the medial proximal tibial angle [40, 41]. According to the anatomical characteristics of tibial varus, the traction force of the lateral fixator should be increased during the operation, resulting in "excessive traction" of the lateral plateau. This improves the reduction of the lateral tibial plateau and better restores the normal anatomical alignment of the lower limbs. If the fracture reduction is not satisfactory, additional pins can be installed at the site and adjusted to perform reduction using the same technique.

This study has several limitations. First, it was a retrospective, uncontrolled study. We examined radiological and clinical measures that could help us assess the

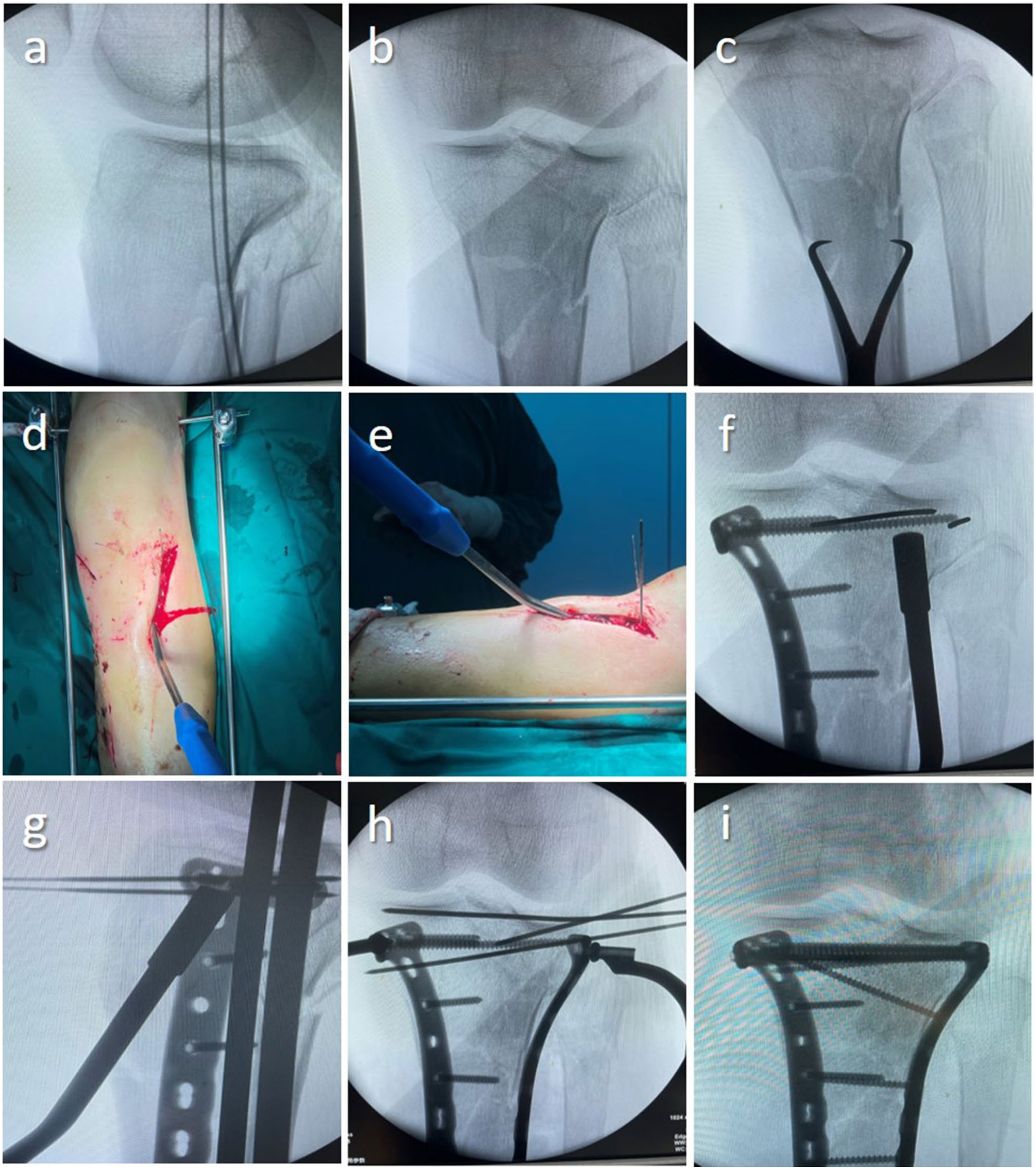

Fig. 4 Preoperative X-ray showing an AO/OTA 41C2 TPF involving the posterior column. (**a**-**b**) A temporary bi-frame fixator, with limited incision and reduction and a bone tamp were used during the operation. (**c**-**g**). After fracture reduction, plates was inserted for fixation. (**h**-**i**)

short-term efficacy of this technique. Second, the sample was small; large, prospective, randomised controlled trials and comparative studies should be conducted to assess the radiological findings, clinical efficacy, and postoperative complications of a temporary bi-frame fixator combined with MIPPO in the treatment of Type AO/OTA 41B3 and 41C TPFs.

Conclusions

A temporary bi-frame fixator can provide continuous stable traction in Type AO/OTA 41B3 and 41C TPFs with changes due to vertical compression. The method can reduce and fix vertical compression TPFs with the least amount of tissue disruption and better safeguard the blood supply of the soft tissues at the surgical site.

Abbreviations

MIPPO	Minimally Invasive Percutaneous Plate Osteosynthesis
TPFs	Tibial Plateau Fractures
HSS	Hospital for Special Surgery score
ORIF	Open Reduction and Internal Fixation
DRTR	Double Reverse Traction Repositor
CT	Computed Tomography

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None.

Author contributions
XS.L&JL.W Designed the study, Wrote the text, analyzed and confirmed the data, Approved the final version for submission. L.Y&LB.H: Cases collected, Collected and analyzed the data and approved the final version for submission. JF.H: Designed the study, Wrote the text, Prepared the figures, Approved the final version for submission.

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Data availability
The datasets supporting the conclusion are available upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee of Zhongshan Hospital of Traditional Chinese Medicine Affiliated to Guangzhou University of Traditional Chinese Medicine (No.2023ZSZY-LLK-027). Written informed consent was obtained from all patients.

Consent for publication
All patients consented to the publication of the case details.

Competing interests
The authors declare no competing interests.

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