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Case Report

Treatment of posterolateral tibial plateau fractures with modified Frosch approach: a cadaveric study and case series

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Abstract: This study aimed to investigate the surgical techniques and the clinical efficacy of a modified Frosch approach in the treatment of posterolateral tibial plateau fractures. The standard Frosch approach was performed on 5 fresh-frozen cadavers. The mean bony surface area was measured upon adequate exposure of the proximal tibial cortex. Lateral proximal tibial plate and posterolateral T-plates were placed and the ease of the procedure was noted. In the study, 12 clinical cases of posterolateral tibial plateau fractures were treated via modified or standard Frosch approaches. The outcome was assessed over short to medium follow-up period. Cadaver studies allowed the inspection of the posterolateral joint surface of all specimens from the lateral side. The mean bony surface areas of the exposed lateral and posterolateral tibial plateau were (6.78 ± 1.13) cm^2 and (3.59 ± 0.65) cm^2, respectively. Lateral and posterolateral plates were implanted successfully. Lateral proximal tibial plates were fixed in 10 patients via a modified Frosch approach while posterolateral plates were fixed in 2 patients via a standard Frosch approach. Patients were followed up for 10 to 24 months (average: 15.7 months) and no complications were observed during this period. Based on the Rasmussen knee function score system, the results were recorded as excellent, good, and fair in 6, 4, and 2 patients, respectively. In conclusion, the modified Frosch approach has offers advantages of clear clarity in exposure, convenient for reduction and internal fixation of a fracture, and good positive clinical results over the normal approach.

Keywords: Tibial plateau, fractures, therapeutics, internal fixators, approach

Introduction

The widespread application of computed tomography (CT) shows that intra-articular fractures involving the posterolateral tibial plateau are more common than previously recognized. The incidence of these fractures is approximately 15% of the total tibial plateau fractures [1] and 44% of all bicondylar tibial plateau fractures [2, 3] and are often accompanied by cruciate ligament and lateral meniscus injuries [4]. The clinical outcome is closely related to the successful reduction and fixation of the fracture, as partial reduction and fixation may result in knee flexion instability and significant morbidity [5, 6]. Whether the exposure of the fractured site is adequate or not is one of the key factors that determine the outcome of surgery. However, attaining the required exposure of the posterolateral tibial plateau quadrant is challenging.

Many studies indicate that the treatment of this type of fracture is controversial. This is because this area is often covered by the fibular head and ligamentous structures in the corner region of the popliteus muscle, which makes exposure a challenge. Fibular neck osteotomy approaches could provide a good view of the posterolateral corner of the tibial plateau [7, 8] but could lead to relatively extensive trauma of the soft tissue of the posterolateral corner. A posterolateral approach without fibular osteotomy allows direct reduction and placement of a posterolateral buttress plate [9-13] but the visual control of fracture reduction is limited with a risk of

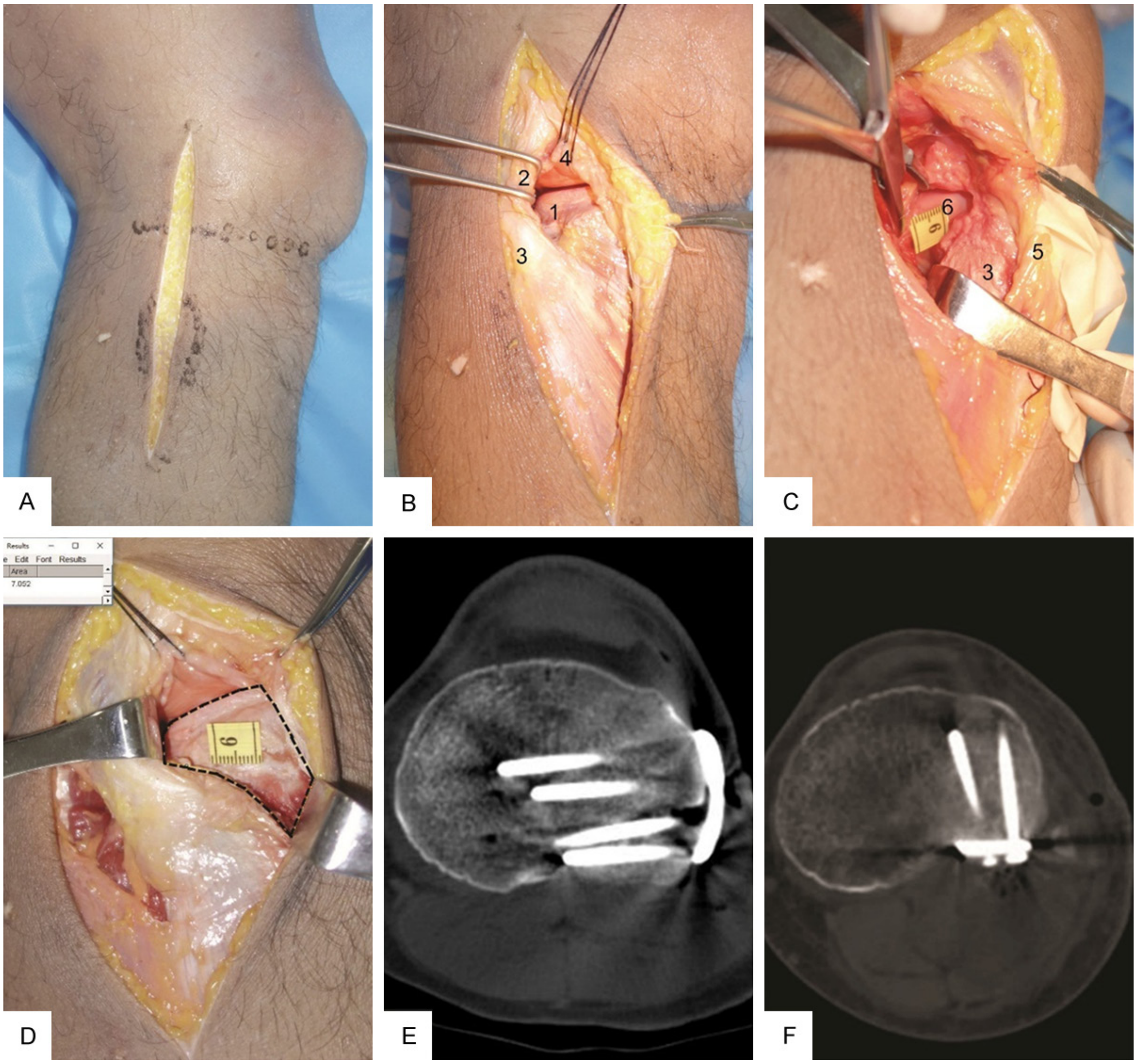

Figure 1. Cadaveric study of new uses of Frosch approach. A: The skin incision; B: Exposure from lateral aspect; C: Exposure from posterolateral aspect. D: Use of calibrated digital photographs to quantify bony exposure using exposure using a measuring device placed directly in the wound, measurement of bony surface area. Dashed line denotes exposed tibial cortex. E, F: CT scan showed that posterolateral tibial plateau was fixed by lateral plate and posterolateral plate respectively via new uses of Frosch approach. The meanings of the number and letters in the figures: 1. Posterolateral tibial plateau from lateral view; 2. Fibular collateral ligament (FCL); 3. Fibular head; 4. Lateral meniscus; 5. Common peroneal nerve; 6. Posterolateral tibial plateau from posterolateral view.

neurovascular damage. The extended anterolateral [14] or supra-fibular-head [15] approaches can provide direct visualization of the posterolateral tibial plateau quadrant; however, this is not in the case of significant posterior cortex rupture.

Frosch et al [16] described a technique using single skin incision with two deep dissection intervals for visualizing the joint surface via lateral arthrotomy, reduction, and plate fixation with the help of a posterolateral approach. The advantages of this approach are sufficient exposure of joint surface and protection of soft tissue and ligamentous structures. However, similar to other posterolateral approaches, this method involves a potential risk of neurovascular damage.

Therefore, we conducted a cadaveric study and developed an approach that involved reduction and lateral plate fixation of the fracture via lateral arthrotomy. We named this novel technique "modified Frosch approach" to distin-

Table 1. General information, operation and outcome details (at final follow-up)

Patient No/Sex	Age (y)	Operation time (min)	Surgical approach**	Follow-up (mo)	Return to work	Rasmussen functional score	Result
1/M	29	90	M	20	Yes	30	Excellent
2/M	35	85	M	24	Yes	19	Fair
3/F	49	80	M	12	Yes	28	Excellent
4/F	41	90	M	15	Yes	28	Excellent
5/M	58	130	S	18	Yes	17	Fair
6/F	46	80	M	15	Yes	30	Excellent
7/F	42	80	M	15	Yes	27	Excellent
8/M	63	125	S	15	Yes	21	Good
9/F	69	75	M	12	Yes	25	Good
10/M	51	75	M	15	Yes	23	Good
11/M	56	80	M	17	Yes	29	Excellent
12/M	43	80	M	10	Yes	25	Good
	48.5 ± 11.6*	89.2 ± 18.6*		15.7 ± 3.8*		25.2 ± 4.3*	

Note: *Value are expressed as mean ± SD; **surgical approach, M: modified Frosch approach; S: standard Frosch approach.

guish it from the standard Frosch approach. We propose the modified Frosch approach for the reduction and fixation of posterolateral tibial plateau fractures. Further, this approach can provide simple and effective exposure of the fractured site with rigid raft support for a depressed articular surface.

Materials and methods

Ethics statement

The study was approved by the institutional review board of Wenzhou Integrated Traditional Chinese and Western Medicine Hospital Affiliated to Zhejiang Chinese Medical University. All study participants provided written informed consent prior to enrollment in the study.

Cadaveric study

Five fresh-frozen cadaveric lower extremities were used in the study. No specimen had signs of prior surgery, injury, abnormality, or disease of the knee or proximal tibia. The mean age of the donors at the time of death was 61.2 ± 13.3 years (range: 48-81 years). All procedures were performed under the direct supervision of an orthopedic trauma surgeon.

The specimen was placed in a lateral decubitus position to simulate patient position. Each lower extremity was dissected using a standard Frosch approach [16]. A longitudinal incision was made starting 3 cm above the joint line and followed the fibula in a distal direction for approximately 15 cm. Lateral arthrotomy was performed first. An incision was made in the iliotibial tract and the dorsal fibers were detached from Gerdy's tubercle. The coronary ligament of the meniscus was cut and the fibular collateral ligament (FCL) was mobilized, exposing the joint surface with varus and internal rotation of the knee. The common peroneal nerve was exposed upon lateral exposure. The lateral gastrocnemius was retracted medially. The soleus was detached from the dorsal surface of the proximal fibula and retracted distally and medially. The popliteus muscle was dissected and retracted upward to gain access to the posterolateral tibial plateau. At the conclusion of each dissection, the exposed tibial plateau was observed and photographed from a position that offered maximum subjective bone visibility. The bony surface area (cm^2) was calculated from calibrated digital photographs using ImageJ software (NIH, Bethesda, MD, USA) [17-19] (**Figure 1A-D**).

Lateral proximal tibial plate (LCP Proximal Tibial Plate 3.5, Synthes Inc., Switzerland) was placed laterally with screws and a precontoured 3.5-mm T-plate was placed posterolaterally with screws. The ease of the procedures was noted. Computed tomography was performed to determine if the plate and screw positions were suitable (**Figure 1E**, **1F**).

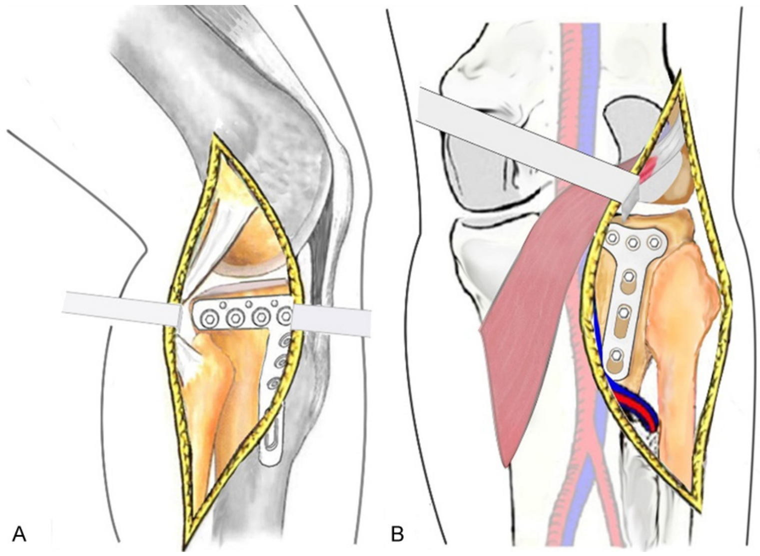

Figure 2. Schematic diagram showing the position of the plate. A: Proximal tibial plate is placed at larteral of tibial plateau over the fibular head; B: Precontoured T-plate is placed at posterolateral of tibial plateau via the same skin incision.

Patients and methods

Between May 2012 and July 2015, 12 cases of posterolateral tibial plateau fractures were treated by open reduction and plate fixation via standard and modified Frosch approaches. Exclusion criteria were undisplaced, open, and pathological fractures, fracture extension into the medial part of the posterior column, neurovascular injuries of the lower extremity, and the osteofascial compartment syndrome. The patients comprised 7 males and 5 females, with an average age of 48.5 years (range, 29-69 years) (**Table 1**). The causes of injury included 6 road traffic accidents, 4 accidental falls from height, and 2 from other causes. None of the patients sustained a neurovascular injury. Cases were assessed preoperatively by X-ray radiographs, CT, and three-dimensional (3D) reconstructions. The mean interval between the time of injury and the surgery was 4.6 days (range, 2-8 days). Surgeries reported in this study were led and performed by an experienced orthopedic surgeon.

Surgical technique

Patients underwent surgery under spinal or general anesthesia. The patients were placed in a lateral position with the injured limb maintained in a slightly flexed position; the knee was supported with a thick pad. A thigh tourniquet was inflated before skin incision. With the patient placed in a lateral position, a longitudinal incision was made in the skin and superficial tissue, following which the iliotibial tract was incised and retracted anteriorly. The coronary ligament of the meniscus was cut and the FCL was retracted posteriorly. Varus and internal rotation of the knee for exposure of the posterolateral tibial plateau enabled the assessment of the fracture. Impacted and depressed articular segments were elevated below the fragments or through a small lateral rectangular cortical window. The resultant metaphyseal void was grafted with a bone taken from the iliac crest or the bone bank. The fragments were temporarily fixed using K-wires and 3.5-mm L-shaped lateral tibial LCP and screws (**Figure 2A**). In case the manipulation of the posterolateral fragments was unsuccessful using this modified approach, a standard Frosch approach was used. The visual control of fracture reduction was achieved by lateral arthrotomy, as described previously, and the posterolateral fragments were manipulated from the dorsal side. A precontoured T-plate was placed after radiologic control of fracture reduction was regained (**Figure 2B**).

Postoperative management and follow up

Post-surgery, the use of a continuous-passive-motion (CPM) machine and physical therapy with emphasis on muscle strengthening activities was prescribed daily for several hours. Gentle active joint motion was also encouraged. The inclusion of weight-bearing activities depended on the radiographic evidence of fracture healing; it was typically initiated after 12 weeks of the operation. Patients were followed up at 1, 2, 3, 6, and 12 months after the operation. Standard X-ray and physical examinations were performed at each follow-up visit. The Rasmussen functional score system [20] was used to evaluate the condition of the patients

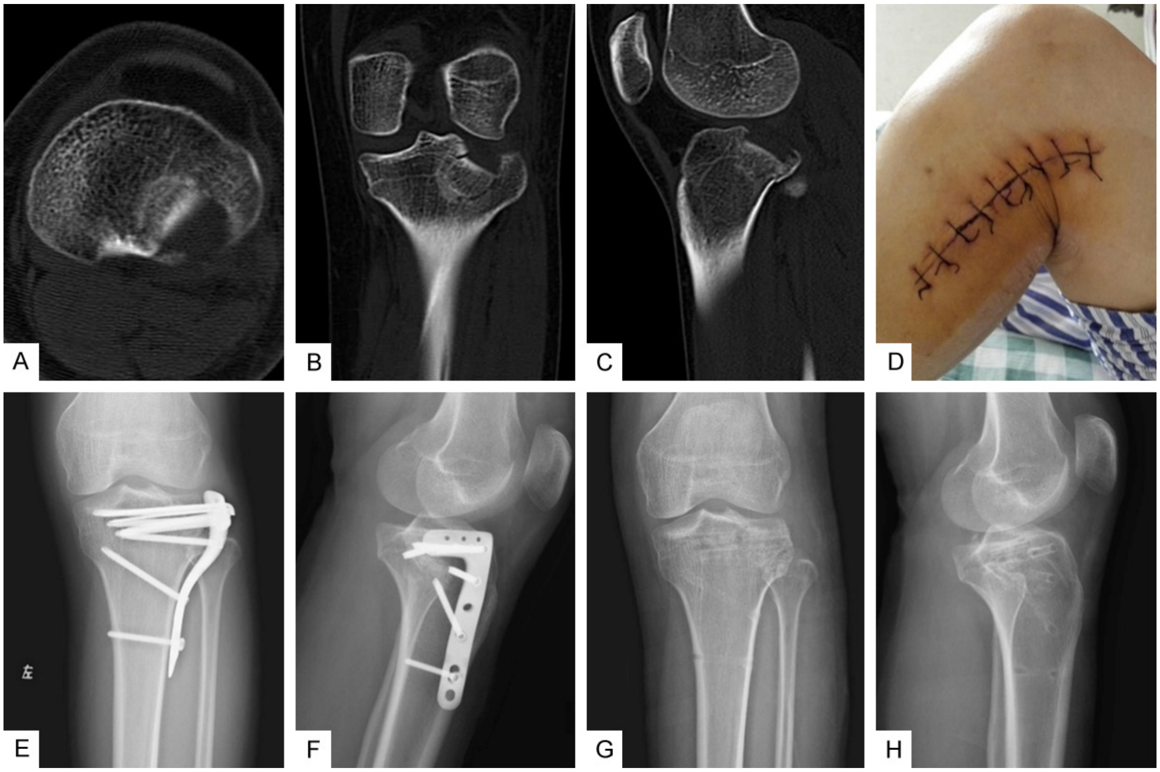

Figure 3. A 29-year-old female patient suffering from posterolateral tibial plateau fracture induced by road traffic accidents. A-C: Preoperative CT scan showed obviously posterolateraltibial plateau fracture; D: The postoperative incision is shown; E, F: Anteroposterior and lateral x-ray images of satisfied reduction of posterolateral tibial plateau fracture via new uses of Frosch approach after surgery; G, H: The Internal fixation has been removed 2 years after operation when the anteroposterior and lateral X-ray images indicated the fracture had healed and no varus or valgus deformity of knee joint occurred.

after surgery. The total maximum score possible is 30 points; 27 to 30 points, excellent; 20 to 26 points, good; 10 to 19 points fair, and less than 9 points, poor.

Statistical analysis

Statistical analyses were performed using SPSS 17.0 statistical software (SPSS Inc., Chicago, IL, USA). A paired Student t-test was used to determine the difference between the mean values. Data were expressed as mean ± standard deviation (SD). Test results with $P<0.05$ were considered significant.

Results

Cadaveric study

The mean bony surface areas upon lateral and posterolateral exposures were recorded as (6.78 ± 1.13) cm^2 and (3.59 ± 0.65) cm^2, respectively; a significant difference was noted between the two groups ($P<0.01$). The dorsal side of the iliotibial band attachment, the lateral and posterolateral articular surfaces, and the posterior wall of the posterolateral tibial plateau were exposed through a lateral interval. The exposure gained on the lateral tibial plateau was sufficient to allow the placement of the L-shaped plate. The transverse arm of the L-shaped plate was placed above the fibular head and the 3.5-mm locking screws from the plate transverse arm were able to fix the posterolateral tibial plateau. The 3.5-mm T-plate and screws were placed through the posterolateral interval.

Clinical evaluation

Clinically, 10 cases were treated with 3.5-mm LCP placed at the lateral tibial plateau via a modified Frosch approach and 2 cases were treated with a 3.5-mm T-plate placed at the posterolateral tibial plateau via a standard Frosch approach. All patients were followed up for 10 to 24 months (average: 15.7 months).

There were no complications of incisional infection or necrosis. None of the cases had common peroneal nerve or anterior tibial artery injury. All patients showed bone union without obvious collapse of the articular surface, loosening, or breakage of implants, and varus or valgus deformity of the knee. At the time of the final assessment, the average Rasmussen functional score was 25.2 ± 4.3, which included the scores of excellent, good, and fair in 6, 4, and 2 patients, respectively (**Figure 3** and **Table 1**).

Discussion

Given the anatomic barriers of the fibular head and the fibular collateral ligament, it is difficult to expose the posterolateral tibial plateau and its management of its fracture remains controversial and challenging. A traditional anterolateral approach is often sufficient for treating fractures of the lateral tibial plateau. However, for fractures extending into the posterolateral corner behind the fibular head, this approach does not provide complete visualization of the posterior articular surface, resulting in difficulty in fracture reduction and implant placement and an increased risk of iatrogenic injury of the popliteal vessels by K-wire or screw placement [21]. Previous authors [7, 8] introduced transfibular approaches for posterolateral tibial plateau fractures, which allow an optimal overview of the posterolateral tibia plateau. However, this method may also result in considerable trauma to the posterolateral corner soft tissue caused by the extended exposure. In addition, there is a higher risk of injury to the peroneal nerve along with a risk of developing pseudarthrosis at the osteotomy site [12, 22]. Yu et al [23] described an anterolateral approach involving the partial removal of the fibula head but sacrificed certain important normal structures for the sake of fracture reduction and fixation.

Previous studies demonstrated posterolateral approaches without osteotomy that involved various types of skin incisions for direct visualization of the fragment and rigid fixation with a buttress plate [9-13]. Nevertheless, only limited exposure of the posterolateral plateau can be obtained through these approaches [24]. It is also extremely difficult to extend these approaches. Additional incision is often needed when tibial plateau fractures involve the posterolateral and lateral columns simultaneously. Although many other approaches have been developed for posterolateral tibial plateau fractures, the available area for exposure and fixation remains unsatisfactory [14, 15]. Chen et al [14] successfully used the extended anterolateral approach and lateral supporting plate to achieve anatomic reduction and fixation of posterolateral tibial plateau fractures. It was stated that this approach could provide excellent visualization of the posterolateral tibial plateau quadrant and the plate could be positioned more posteriorly as compared with that possible with an anterolateral approach. Hu et al [15] obtained good clinical outcomes using a similar method of anterolateral supra-fibular-head approach. These approaches are not suitable for a significant posterior cortex rupture and posterolateral cortical wall requiring reconstruction.

In 2010, Frosch et al [16] introduced a posterolateral approach; the advantages of the approach are the protection of soft tissue and ligamentous structures, the ability to dispense with fibular osteotomy, and the preservation of soft tissue around the posterolateral fragments. However, although the method can provide relatively good exposure of the joint surface, similar to that obtained through other posterolateral approaches [9-13], the potential risk to neurovascular structures with posterolateral exposure and plate placement remains [16, 25].

Frosch contended that manipulation and fixation of the posterolateral fragments was seldom successful using lateral arthrotomy alone [16]. However, according to our study, similar to the extended anterolateral [13] and anterolateral supra-fibular-head approaches [14], our method includes a certain amount of space above the head of the fibula. With varus and internal rotation of the knee, the entire posterolateral joint surface could be visualized via lateral arthrotomy using the Frosch approach. The development of advanced internal fixation materials allows raft plate fixation to be commonly used in the treatment of tibial plateau fractures. In our cadaveric study and clinical application, the 3.5-mm L-shaped lateral proximal tibial LCP could be placed on the tibial plateau with ease. The transverse arm of the

L-shaped plate can be placed very close to the posterior cortical wall through the superior fibular head space and can provide rigid raft support for the depressed articular surface. In our case series, most posterolateral fragments could be reduced and fixed with a lateral plate using the modified approach. For cases where the posterolateral cortical wall is severely fractured, reduction and fixation of the posterolateral fragments may be unsuccessful with the modified approach. Therefore, it is convenient to perform posterolateral exposure via the same skin incision, as described by Frosch, and use the direct posterolateral plate if required.

The ideal indication for a modified Frosch approach is isolated posterolateral tibial plateau fracture, especially a complex fracture that involves both the posterolateral and anterolateral parts of the tibia plateau. According to our results, there are several advantages to this new approach. First, it offers direct surgical exposure and provides an effective method for the treatment of posterolateral tibial plateau fractures. Second, this method does not damage any important soft tissue or ligamentous structures, thereby protecting the stability of the knee. In addition, lateral arthrotomy is safe and simple and allows for a reduced operative time. If lateral arthrotomy is inadequate as a stand-alone procedure, it is easy to perform posterolateral exposure according to the standard Frosch approach. However, there are also some disadvantages to this approach. Since only the dorsal side of the iliotibial band attachment can be observed anterolaterally, this approach is not suitable for fractures that extend to the anterior tibial plateau. Similar to other posterolateral approaches, potential injury risks to the inferolateral geniculate and anterior tibial arteries and the common peroneal nerve with a posterolateral exposure remain a matter of concern [25].

This study has certain limitations. First, the lack of a control group, a small number of patients in the study, and the short-term follow-up should be addressed in the future. Second, a further random control study is necessary to determine the effectiveness of the technique.

In conclusion, the modified Frosch approach provides excellent exposure of the posterolateral and lateral tibial plateaus. The approach is safe and enables easy placement of a lateral plate for the management of posterolateral and lateral fragments. Further, it is easy to perform posterolateral exposure through the same skin incision.

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Disclosure of conflict of interest

None.

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