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# Treatment of tibial plateau fractures involving the posterolateral column using the extended anterolateral approach

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**Abstract**

To summarize the surgical technique and clinical effects of the extended anterolateral approach for the treatment of Schatzker type II and Schatzker type V/VI involving the posterolateral column tibial plateau.

From January 2015 through December 2018, 28 patients with tibial plateau fractures involving the posterolateral column were included in the study. Among them, 16 patients were Schatzker type II treated using an extended anterolateral approach with lateral tibial locking compression plate fixation. Twelve patients were Schatzker type V or VI treated using an extended anterolateral combined with a medial approach using lateral tibial locking compression plate plus medial locking compression plate fixation. All cases were followed up for 15 to 31 months, with an average follow-up of $22.5 \pm 3.7$ months. During the follow-up, the tibial plateau angle (TPA), lateral posterior angle (PA) and Rasmussen radiological criteria were used to evaluate the effect of fracture reduction and fixation; the Hospital for Special Knee Surgery score and the range of motion were used to evaluate knee function. Additionally, the Lachman and knee Valgus (Varus) stress tests were used to evaluate anteroposterior and lateral stability of the knee.

All fractures healed. At the 12-month follow-up, the Schatzker type II group revealed a mean TPA of $86.38 \pm 3.92°$, a mean PA of $7.43 \pm 2.68°$, and a mean Rasmussen radiological score of $16.00 \pm 2.06$ points. The Schatzker type V/VI group showed a mean TPA of $84.91 \pm 3.51°$, a mean PA of $9.68 \pm 4.01°$, and a mean Rasmussen radiological score of $15.33 \pm 2.99$ points. During the 1-year follow-up, when the postoperative PA was re-measured, the TPA and Rasmussen score of the 2 groups did not change significantly ($P > .05$). At the last follow-up, the Schatzker type II group showed a knee flexion angle of 110° to 135° and a mean HHS score of $88.37 \pm 10.01$ points. The Schatzker type V/VI group revealed a knee flexion angle of 100° to 130° and a mean HHS score of $82.17 \pm 10.76$ points. Additionally, up to the last follow-up, the Lachman and knee Valgus (Varus) stress test results of the 2 groups were negative. No complications were found.

The extended anterolateral approach is a good choice to treat tibial plateau fractures involving the posterolateral column.

**Abbreviations:** CT = computed tomography, HSS score = Hospital for Special Knee Surgery score, PA = posterior angle, TPA = tibial plateau angle.

**Keywords:** extended anterolateral approach, fracture reduction and fixation, posterolateral tibial plateau fracture, surgical treatment

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*This study was retrospectively approved by the Ethics Committee of our institution, and patient consent was obtained. The approval date was December 26, 2014, and the approval number was YJRY2014K006.*

*Informed consent was obtained from all individual participants included in the study.*

*The participant has consented to the submission of the case report to the journal.*

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*The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.*

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## 1. Introduction

Tibial plateau fracture is an intra-articular fracture that is mainly caused by high-energy injuries such as traffic accidents and falls, accounting for approximately 1% of total body fractures.[1] Anatomically, the articular surface of the tibial plateau is concave, and the position of the lateral side of the plateau is higher and smaller than that of the medial side. Additionally, the bone of the proximal tibia in adults is mainly cancellous bone, and the cortex of the lateral side of the plateau is thinner than that of the medial side. These unique anatomical characteristics lead to lateral tibial plateau fractures more easily[2] and are always accompanied by varying degrees of depression, displacement, and surgical complications, which affect the stability and movement ability of the knee. In the later stage, degeneration of the knee joint and traumatic arthritis occurs. Posterolateral fracture of the tibial plateau fracture is defined as any single fracture segment based on the posterolateral quadrant or the fracture line extending to the posterolateral cortical bone.[3] With the development of computed tomography (CT) and image reconstruction technology, the Schatzker and Arbeitsgemeinschaftfür Osteosynthesefragen classification based on X-ray examination cannot meet practical needs. Luo et al[4] proposed 3-column classification of the tibial plateau using multidimensional reconstruction images to better evaluate tibial plateau fractures. Since then, understanding of tibial plateau fractures has gradually deepened, and a recent epidemiological study of tibial plateau fractures found that the classification of single lateral column fractures is relatively rare, with an incidence of only 12.54%, while the incidence of posterolateral column fractures is 62.69%.[3,5] Among all types of high-energy injuries, those caused by electric vehicle traffic accidents are as high as 32.42%, and electric bicycles are currently widely used to commute worldwide.[6] Traditionally, the anterolateral approach is used to solve these fractures by direct reduction and fixation. However, the traditional anterolateral approach has difficulty accessing the posterolateral angle (the posterolateral column of the tibial plateau) behind the fibular head. To increase the exposure and operation space of the posterolateral tibial plateau, we retrospectively analyzed the clinical efficacy of the extended anterolateral approach in treating posterolateral tibial plateau fractures at our hospital from 2015 to 2018.

## 2. Materials and methods

### 2.1. Inclusion and exclusion criteria

The inclusion criteria were as follows: A lateral tibial plateau fracture was diagnosed by pre-operative CT examination of the knee, with the fracture line involving the posterior column; an extended anterolateral approach was used in the operation; no vascular and nerve injury occurred; no osteofascial compartment syndrome was identified; and the patients were adults aged 18 years and older.

The exclusion criteria were as follows: Multiple fractures of the ipsilateral lower limb; primary disease of the ipsilateral hip and ankle joint and unable to walk normally before injury; severe degeneration of the knee joint with osteoarthritis and dysfunction; a history of rheumatoid arthritis or rheumatoid arthritis; a follow-up time less than 12 months; and an old fracture.

### 2.2. General information

Twenty-eight patients who met the above criteria from January 2015 to December 2018 were selected and divided into 2 groups according to Schatzker classification: Schatzker type II group and Schatzker type eV/VI group. The Schatzker type II group included 5 male and 11 female patients, with a mean age of 48.06 ± 12.58 years (range: 28–68 years). The causes of injury were 8 cases of traffic accidents, 6 cases of falls, and 2 cases of other injuries. In the Schatzker type V/VI group included 8 male and 4 female patients with a mean age of 49.75 ± 10.17 years (range: 29–67 years). The causes of injury were 7 cases of traffic accidents, 2 cases of falls, and 3 cases of other injuries. The demographic information is shown in Table 1.

### 2.3. Pre-operative planning

Before the operation, all the patients had undergone knee X-ray, CT 3-dimensional reconstruction, magnetic resonance imaging and low limb high resolution ultrasound to assess the fracture type, fracture displacement and articular surface depression degree, whether the fracture was combined with knee ligament injury and whether the fracture was combined with lower extremity venous thrombosis; The imaging examinations were also performed to exclude pre-operative contraindications and formulated individualized operation plans according to the results.

On the first day of hospitalization, all the patients were treated with limb elevation, detumescence and pain relief. Sixteen patients with severe swelling of the soft tissue around the knee joint or obvious displacement of the fracture end were treated with calcaneal bone traction. The traction weight was one twelfth of their body weight.

### 2.4. Surgical method

i. Position: The patient was placed in the supine position. After general or epidural anesthesia, the calcaneal traction device was removed, and a sterile sheet was placed under the injured shank to make the knee joint slightly bent at approximately 30°.
ii. Incision: The incision started from the anterior edge of the biceps femoris (approximately 5 cm above the crease of the knee joint) and extended down to the level of the fibular head. Next, arc cuts forward and through the Gerdy tubercle or the front edge of the fibular head, approximately 3 cm outside the tibial tubercle, were used as the marker point. The incision was parallel to the anterior edge of the fibula, passing through the marked point and extending to the distal tibia. Eventually, the whole incision showed an “s” shape and a length of 10 to 15 cm.

**Table 1**

**General information.**

| | Schatzker II group | Schatzker V/VI group |
|---|---|---|
| Age (years) | 48.06 ± 12.58 | 49.75 ± 10.17 |
| Sex (men/women) | 5/11 | 8/4 |
| Side (left/right) | 9/7 | 7/5 |
| BMI (kg/m$^2$) | 23.62 ± 3.96 | 22.41 ± 3.87 |
| Time from injury to operation (day) | 6.187 ± 2.663 | 9.666 ± 3.498 |
| Fibular head fractures | 4 (25%) | 8 (66%) |
| Pre-operative TPA (°) | 86.68 ± 5.43 | 88.45 ± 3.62 |
| Pre-operative PA (°) | 10.60 ± 3.24 | 10.01 ± 4.23 |
| Mechanism of injury (traffic/falls/other) | 8(50%)/6 (37.5%)/2 (12.5%) | 7 (58.3%)/2 (16.7%)/3 (25%) |

BMI = Body mass index, PA = posterior angle, TPA = tibial plateau angle.

iii. Exposure: After incision of the skin and subcutaneous tissue, an incision was made along the space between the iliotibial tract and biceps femoris tendon, and then the iliotibial tract and lateral collateral ligament were separated from the anterolateral proximal tibia. After that, the coronal ligament and lateral joint capsule were cut to release the blood in the joint cavity, the varus knee joint to expose the lateral tibial plateau, the edge of lateral meniscus was sutured and suspended with a surgical suture, and the lateral collateral ligament was pulled back. Finally, the depressed posterolateral articular surface of the tibial plateau was visualized directly.
iv. Reduction: According to the compression range and depth of the tibial plateau, the circular saw opened the bone cortex under the anterolateral tibial plateau, and then the bone marrow canal was established. The collapsed articular surface was restored with the "reduction rod", after which autologous bone or allogeneic bone was implanted to support the tibial plateau and bone marrow canal. Using the reduction forceps and Kirschner wire, the fracture was temporarily fixed. Additionally, the C-arm X-ray checked the reduction.
v. Fixation: After fracture reduction, a lateral tibial plateau locking plate was inserted. Technique: The locking plate was placed as far back as possible, and the height was approximately above the fibular head. Four transverse 3.5 mm locking screws on the plate head were used to further strengthen and support the articular surface of the tibial plateau. For some partial comminuted posterolateral splitting fractures, 1 or 2 additional screws were added from the lateral position of the tibial plateau to the direction of the posterior wall bone block to assist compression fixation (Fig. 1).

For cases involving 3 lateral column fractures (Schatzker type V/VI), an extended anterolateral combined with a medial approach was used. The arc-shaped incision was located at the medial side of the knee joint, approximately 15 cm long, and the skin and subcutaneous tissue were cut to expose pes anserinus tendon anterior segment of the gastrocnemius. A gap was formed between them; thus, the pes anserinus tendon was cut along the direction of the skin incision and marked with an operative suture. The gastrocnemius was separated from this gap, and the medial tibial plateau fracture line became visible. Under the same conditions, reduction, Kirschner wire temporary fixation, and C-arm X-ray confirmed the reduction, and the medial tibial plateau locking plate fixation fracture was used.

### 2.5. Surgical technique and experience

i. A locking plate should be placed as far back as possible, even above the fibular head, covering the posterolateral articular surface; otherwise, the edge of the plate may protrude from the skin overlap, leading to skin necrosis or postoperative pain.
ii. If the reduction forceps holder cannot restore the width of the tibial plateau, it should be considered that the meniscus may be embedded in the fracture line near the intercondylar spine. During the operation, we found that the lateral meniscus of Schatzker type V/VI fractures was often embedded in the fracture end, hindering reduction. Exposure to the extended anterolateral approach allows the detection of lateral meniscus injuries (which are also helpful for the reduction and fixation of avulsion fractures of the anterior cruciate ligament).
iii. When using the "reduction rod" to restore and gently knock down the depressed articular bone block, a slight excessive reduction can be used to compensate for the loss of articular surface height during the subsequent operation.
iv. The reduction sequence usually starts from the medial side. Because the medial bone block is generally large and the overall split, the degree of comminution is low, and it is easy to find the reduction mark.

### 2.6. Postoperative treatment

Postoperative routine drainage lasted for 48 hours, and antibiotics were used for 24 hours to prevent infection. Active knee flexion and extension were performed on the second day after the

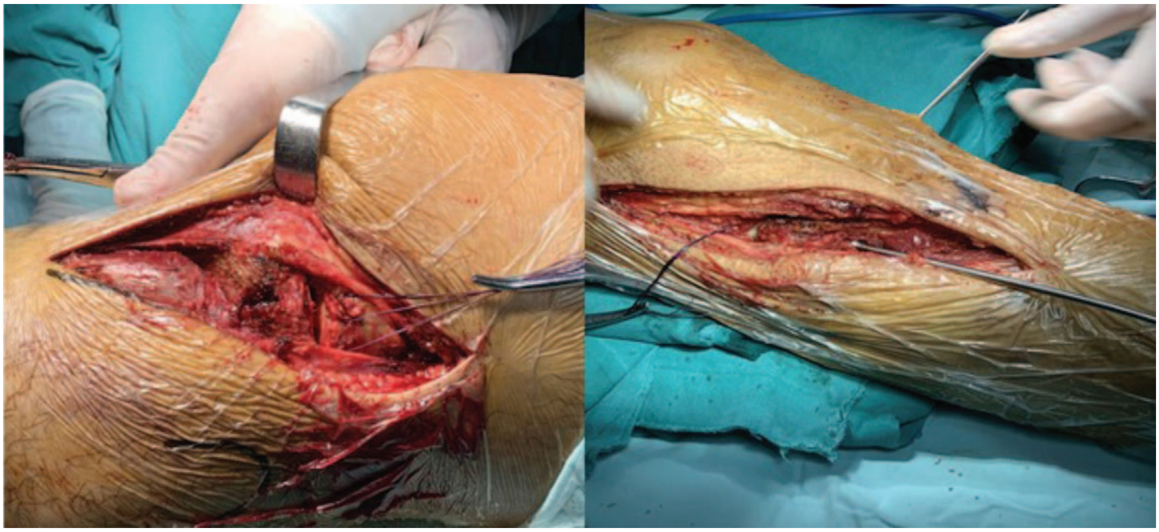

**Figure 1.** The extended anterolateral approach and "reduction rod". The extended anterolateral approach exposed the articular surface and used the "reduction rod" to restore the depressed area. The established tibial bone tunnel was then filled with autogenous or allogeneic bone.

operation. A continuous passive motion machine was used twice a day for 2 hours until the knee joint reached 0° to 95° flexion because some patients had poor knee function. The range of knee motion of all the patients gradually increased at least 5° each day until the range reached more than 120°. Twelve weeks after the operation, the patients began to load gradually.

### 2.7. Follow-up and evaluation indicators

The operation time, blood loss, fracture healing time, hospital stay, and postoperative complications of each patient were recorded. All the patients were followed up every 3 months using physical examination, and standard X-ray radiographs were obtained at each follow-up visit to evaluate the recovery of knee joint function and range of motion. Additionally, anteroposterior and lateral stability of the knee joint was measured using Lachman and knee Valgus (Varus) stress tests. The Rasmussen radiological score system[7] was used to evaluate fracture reduction and fixation. The maximum total Rasmussen radiological score was 18 points, including the degree of articular surface collapse (6 points), width of tibial plateau (6 points), and angular deformity (6 points): 18 points were excellent, 12 to 17 points were good, 6 to 11 points were fair, and 0 to 5 points were poor. The knee joint function was evaluated using the Hospital for Special Surgery score system[8] and includes pain (30 points), function (22 points), range of motion (18 points), muscle strength (10 points), knee deformity (10 points), and knee stability (10 points): 85 to 100 points were excellent, 70 to 84 points were good, 60 to 69 points were fair, and less than 60 points were poor.

The Picture Archiving and Communication System was used to measure 2 parameters on X-rays of the knee joint: tibial plateau angle (TPA): medial angle formed by the tibial anatomical axis and tibial plateau tangent on anteroposterior X-ray of the knee joint; lateral posterior angle (PA): angle formed by the intersection of the lateral line of the tibial plateau at the vertical line of the anterior tibial cortex on lateral X-ray of the knee joint. Loss of reduction was defined as a tibial plateau depression >2 mm, TPA ≥95°, and PA ≥15°. Further displacement of the fracture was defined as the articular surface of the tibial plateau showing a depression >2 mm and a TPA or PA difference >5° compared with immediate postoperative X-ray radiographs.[9]

### 2.8. Statistical analysis

The statistical analyses of the data were performed using Statistical Product and Service Solutions 24.0 software (SPSS Inc., Chicago, Illinois). The data were expressed as means ± SD. Repeated measurement data, such as the TPA, PA, and Rasmussen scores, were compared using one-way analysis of variance, and the difference was statistically significant at $P < .05$.

## 3. Results

### 3.1. Perioperative statistics

The mean operation time was 81.68 ± 18.59 minutes, and the mean blood loss volume was 79.37 ± 23.79 mL. In the Schatzker type II group, the mean operation time was 141.25 ± 30.46 minutes, and the mean blood loss volume was 114.16 ± 50.89 million in the Schatzker type V/VI group. The surgical details are presented in Table 2. In the Schatzker type II group, the patients were treated with lateral tibial locking compression plate fixation (Fig. 2). In the Schatzker type V/VI group, the patients were treated with lateral tibial locking compression plate fixation (Fig. 3).

### 3.2. Fracture healing

All 28 patients in this review were followed up for 15 to 31 months, with an average of 22.51 ± 3.76 months. Bone healing was achieved in all patients. The fracture healing time for the Schatzker type II group receiving the extended anterolateral approach was 12 to 17 weeks, with an average of 15.81 ± 2.73 weeks. The fracture healing time for the Schatzker type V/VI group receiving the extended anterolateral and medial approach was 13 to 19 weeks, with an average of 16.83 ± 3.53 weeks.

### 3.3. Radiological follow-up evaluation

Until the last follow-up, no reduction loss occurred, and the width of the platform and lower limb force line were normal in the Schatzker type II group. However, in the Schatzker type V/VI group, 2 patients with tibial plateau depression greater than 2 mm showed further displacement criteria. According to the Rasmussen radiological system, the scores at 12-month follow-up after the operation were calculated. The Schatzker type II group score was 12 to 18 points, with an average of 16.00 ± 2.06 points; the scores were excellent in 6 cases and good in 10 cases; thus, the excellent and good rate was 100%. The Schatzker type V/VI group score was 10 to 18 points, with an average of 15.33 ± 2.99 points; the scores were excellent in 4 cases and good in 6 cases; thus, the excellent and good rate was 83.33%. During the 1-year follow-up, after re-measuring the postoperative PA and TPA, the Rasmussen score of the 2 groups did not change significantly ($P > .05$) (Table 3).

### 3.4. Function follow-up evaluation

Until the 12-month operation follow-up, no patient manifested adverse effects on daily life and exhibited knee instability. Additionally, both the Lachman and knee Valgus (Varus) stress test results were negative. The knee joint of all the patients had reached the full extension position. Regarding the Schatzker type II group, the knee flexion angle was 110° to 135°, with an average of 125 ± 8.56°, and the Hospital for Special Knee Surgery score (HSS score) at the last follow-up was 69 to 98 points, with an average of 88.37 ± 10.01 points. The scores were excellent in 9 cases and good in 5 cases; therefore, the excellent and good rate was 100%. Concerning the Schatzker type V/VI group, the knee flexion angle was 100° to 130°, with an average of 120.83 ± 11.25°, and the HSS score at the last follow-up was 63 to 95 points, with an average of 82.17 ± 10.76 points; the scores were

**Table 2**

**Statistics of perioperative.**

| Parameter | Schatzker II | Schatzker V/VI |
|---|---|---|
| Surgical time (min) | 81.68 ± 18.59 | 141.25 ± 30.46 |
| Blood loss (mL) | 79.37 ± 23.79 | 114.16 ± 50.89 |
| hospital stay (day) | 17.93 ± 2.95 | 20.58 ± 4.94 |
| Bone graft (allograft/ autograft/both) | 8 (50%)/3 (18.7%)/4 (25%) | 4 (33.3%)/1 (8.3%)/7 (58.3%) |
| Fracture healing time (weeks) | 15.81 ± 2.73 | 16.83 ± 3.53 |
| Duration of follow-up (months) | 15.93 ± 23.69 | 16.50 ± 3.98 |

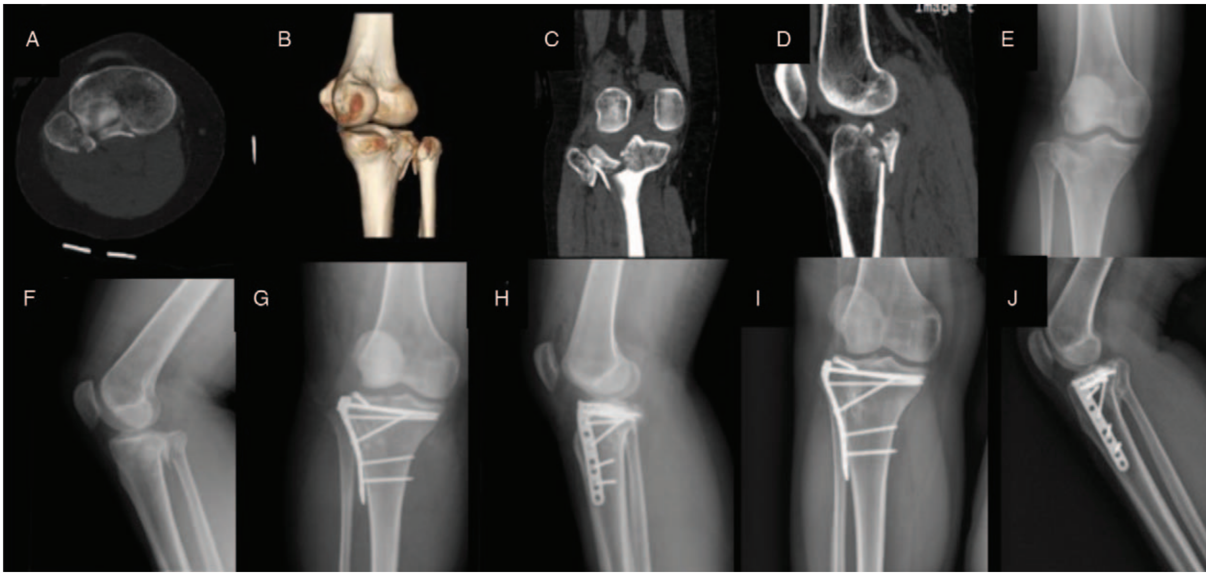


Figure 2. A female Schatzker type II patient, 28 years old, with a right tibial plateau fracture (Schatzker type II) and fibular head fracture due to a traffic accident injury. Pre-operative X-ray and CT cross-sectional, coronal, and sagittal reconstruction showed that the fracture line involved the posterior and lateral columns (A–F). The extended anterolateral approach involved L-shaped plate plus auxiliary screw fixation. Immediate postoperative X-ray (G, H) showed that anatomical reduction was achieved. Fifteen months after the operation, X-ray (I, J) showed an articular surface without depression and no increase in the width of the tibial plateau. CT = computed tomography.

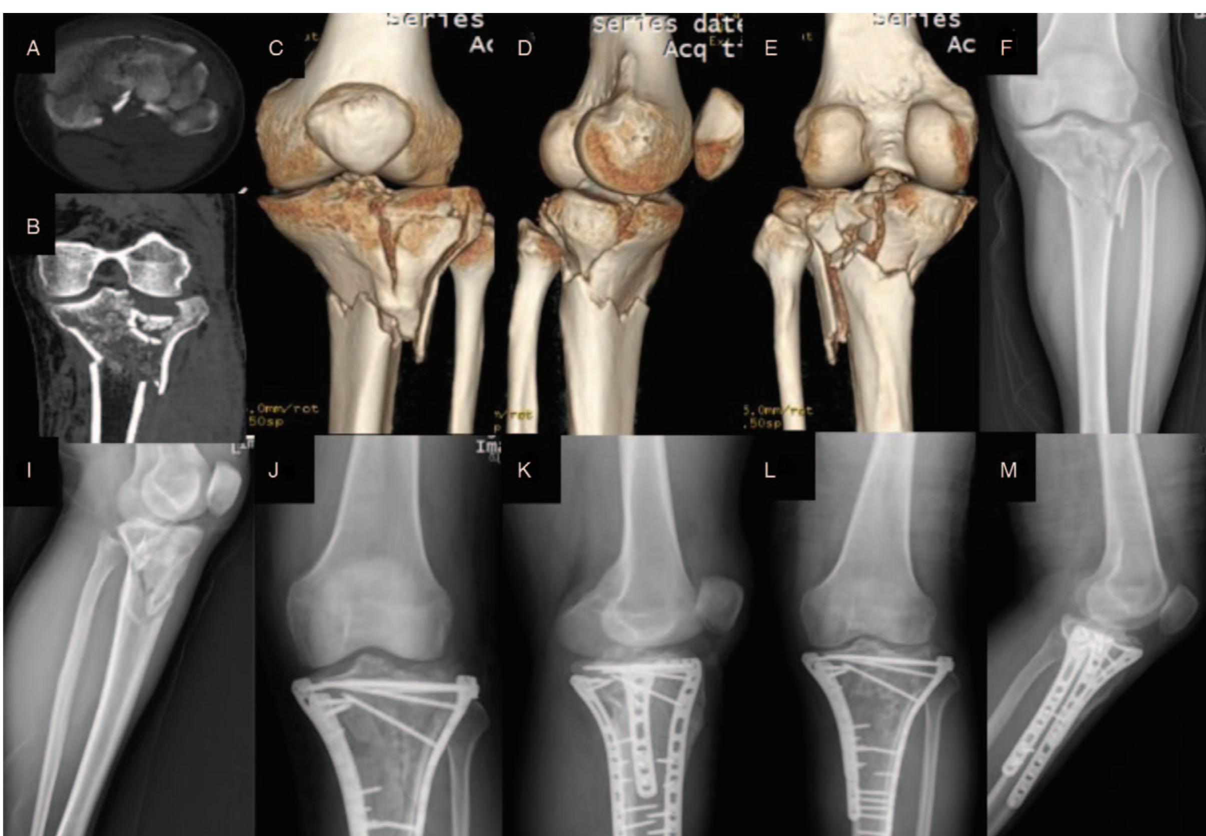


Figure 3. A male Schatzker type V/VI patient, 47 years old, with a left tibial plateau fracture (Schatzker type VI) due to a traffic accident injury. Pre-operative X-ray and CT reconstruction showed that the fracture line involved the medial, lateral, and posterior 3 columns (A–I). The extended anterolateral combined with a medial approach involved L-shaped locking compression plate plus medial locking compression plate fixation. Immediate postoperative X-ray (J, K) showed that anatomical reduction was achieved. Twelve months after the operation X-ray (L, M), the fracture healed well, the fracture line was blurred, and articular reduction was still maintained. CT = computed tomography.

**Table 3**

**Radiological follow-up evaluation.**

| Group | Parameter | Immediately postop | 3 month | 12 month | P |
|---|---|---|---|---|---|
| | PA (°) | 7.50 ± 3.19 | 7.65 ± 2.67 | 7.43 ± 2.68 | .274 |
| Schatzker II | TPA (°) | 86.65 ± 4.18 | 86.83 ± 3.73 | 86.38 ± 3.92 | .114 |
| | Rasmussen score | 16.62 ± 1.89 | 16.12 ± 1.85 | 16.00 ± 2.06 | .41 |
| | PA (°) | 8.74 ± 3.75 | 8.77 ± 3.90 | 9.68 ± 4.01 | .366 |
| Schatzker V/VI | TPA (°) | 86.91 ± 3.47 | 86.62 ± 2.36 | 84.91 ± 3.51 | .081* |
| | Rasmussen score | 15.83 ± 2.88 | 15.50 ± 2.84 | 15.33 ± 2.99 | .196 |

PA = posterior angle, TPA = tibial plateau angle.
* $P < .05$.

excellent in 5 cases and good in 3 cases; therefore, the excellent and good rate was 66.67%.

### 3.5. Complications

All the patients' incisions healed well, and no infection or skin necrosis occurred in the perioperative period. Up to the last follow-up, no patient had joint stiffness, knee instability, internal fixation loosening, fracture or rejection. However, 1 patient in the Schatzker type eV/VI group had deep venous thrombosis, and 3 patients in the Schatzker type II group had calf intra-muscular venous thrombosis, which improved after subcutaneous injection of low molecular weight heparin.

## 4. Discussion

Fractures of the posterolateral column of the tibial plateau are usually caused by axial and valgus forces when the knee joint is in a semiflexion position of 30° to 60°[10,11]; however, the knees are typically in this position when we ride. No official treatment guidelines exist for posterolateral column fractures of the tibial plateau requiring strict surgical intervention. Thus, regarding posterolateral split and collapse fractures of the platform caused by shear force, if effective steps for reduction and fixation are not followed, the posterolateral stability of the knee may be affected after weight-bearing of the knee joint, often leading to further displacement or collapse of the fracture, leading to instability of joint flexion and limited range of motion. When the joint surface collapses to 3 mm, the local stress will increase by 75%, further increasing the aggravation of the collapse degree. Next, the abrasion of articular cartilage will increase correspondingly, accelerating the degeneration of the joint and seriously affecting knee joint function. Presently, the generally accepted surgical indications for tibial plateau fractures are a plateau collapse greater than 2 mm, metaphysis displacement greater than 1 cm, and a coronal or sagittal angle greater than 10°, all of which should be treated with surgical reduction and internal fixation.[11–13]

For a single fracture of the lateral column of the tibial plateau, the standard anterolateral approach is usually sufficient. However, for posterolateral plateau fractures, the fracture line extends to the posterior tibial plane. Because of the fibular head, the standard anterolateral approach is not only relatively difficult to expose, hindering visualization of the fracture sites, but is also a narrow space between the lateral tibial plateau and fibular head, leading to the plate not being placed across the fibular head. Consequently, fracture of the posterior column of tibial plateau prevented reduction and fixation. Presently, the best surgical approach for posterolateral tibial plateau fractures remains uncertain, but it should have the greatest degree of visualization and easy reduction, and the damage to the surrounding structure is minimal to ensure the quality of reduction, stability of fixation, and enhanced recovery after surgery.[3,14] Currently, common surgical approaches for posterolateral tibial plateau fractures include the direct posterior approach, posterolateral approach with or without fibular osteotomy, posteromedial approach and modified or extended anterolateral approach. Because the posterior surface of the proximal tibia is inclined, the operation area is relatively deep, leading to difficulty restoring the depression area and plate fixation in various posterior approaches. In this regard, various improved posterior and combined approaches have also been proposed and promoted and have achieved good results.[4,9] Frosch et al[15] proposed an improved posterolateral approach without fibular osteotomy and directly exposed the posterolateral column, including the marginal area and posterior wall of the posterolateral platform. Although this approach has significant advantages regarding exposure of the posterolateral fracture block and reduction and fixation, exposure of the surface of the tibial plateau is poor, and the tibial plateau is mostly collapsed or shows depression fractures.[16] After recovering the depressed articular surface of the platform using this approach, whether the surface is smooth is unclear. Additionally, the fracture block in the front of the lateral platform still requires other approaches.[17] With better understanding of fracture of the posterior lateral column of the tibial plateau, Mancini et al[18] recently improved the Frosch approach based on previous methods. They not only further exposed the posterior tibial plateau fracture and increased the operation space but also used the same surgical incision to treat lateral tibial plateau fractures. In addition to improving various surgical procedures, the corresponding internal fixation plates for posterolateral column tibial plateau fractures are constantly being improved and innovated. Berg et al[19] invented a new WAVE posterior proximal tibia plate with a 12° diaphyseal axial twist and an additional 15° metaphyseal axial twist. This plate was more consistent with the anatomical structure of the posterior tibia, and the horizontal arm of the plate can provide both posteromedial and posterolateral support. At the same time, the proximal drift screw bifurcates posteromedially to anterolaterally to achieve medial and lateral platform support and intercondylar eminence fixation. This innovative improved plate not only reduces the stripping of posterior soft tissue but also can be operated in a narrow space and reduces the learning curve of the posterior surgical approach. Overall, the prone or lateral position should be used in posterior surgery because of the risk of injury to the lower lateral knee, anterior tibial artery, and common peroneal nerve during operation, all of which lead to higher requirements for body position and operation level of the surgeons. Thus, the posterior approach is usually used for rare isolated posterolateral coronary shear fractures. Generally, all types of posteromedial and posterolateral plateau fractures can be solved using a posterior approach. However, once the anterolateral tibial plateau is involved, regardless of the fracture type, other anterolateral methods are required to assist in solving the problem.

Traditionally, lateral tibial plateau fractures are mostly treated using the anterolateral approach. However, exposing and fixing the posterior tibial plateau is challenging using the traditional anterolateral approach. Through literature review, the advantages of the extended anterolateral approach are as follows: the patient can be in the supine position; exposure of the lateral, posterior, and platform surface of the tibia is relatively clear, and sufficient operation space exists; neurovascular injury and fibular head osteotomy are avoided, and damage to the original anatomical structure is small; in anterolateral column and posterolateral column fractures, this approach can be used alone for fracture reduction and plate fixation; the learning curve is relatively simple compared with that of the posterior approach.[20,21] Previous studies using the extended anterolateral approach to treat posterolateral tibial plateau column fractures have achieved good clinical results. Chen et al,[22] in the last follow-up of 10 patients, revealed an average HHS score of $95.3 \pm 6.5$ points (range: 80–100 points), an average knee flexion of $119.8 \pm 17.2°$ (range: 95°–140°) and an average knee extension of $2.1 \pm 2.1°$ (range: 0°–6°). Sun et al[23] extended the anterolateral approach. Based on lateral tibial plateau locking plate fixation, another screw was inserted from the position around the tibial tubercle to the posterior wall of the tibial plateau to assist fixation; according to the biomechanical experiment, that screw can provide similar biomechanical stability to the posterior support plate. During the 1-year follow-up, the average range of motion of the affected knee was 2.3° to 125°, and the average HSS score was 94.2 points.

In contrast to other retrospective studies, in this study, Schatzker type II and Schatzker type V/VI were investigated separately, and the 2 groups had their own before and after comparison. The main reason is that Schatzker type V/VI (involving 3 lateral columns of the tibial plateau), compared with Schatzker type II (involving bilateral columns of the tibial plateau), showed a more severe degree of force, fracture comminution, soft tissue swelling and injury than Schatzker type II. Additionally, in the perioperative period, Schatzker type V/VI has bilateral incisions, long operation times, increased blood loss, and late recovery of patients. Combined with previous data, the average anteroposterior distance of the lateral tibial plateau was 10.22 mm (11.18–31.17 mm), and the average posterior horizontal distance was 22.93 mm (4.1–49.95 mm).[16] By extending the anterolateral approach, 1 or 2 screws can be fixed to the posterior bone block, and biomechanical tests show that the mechanical strength obtained by this method is markedly improved.[24] In the present study, most patients obtained reliable internal fixation using the double "raft effect", which not only increases the fixation rate but also ensures support to the articular surface. Additionally, no significant difference was found in the tibial plateau PA, TPA, and Rasmussen score after the operation. However, for Schatzker type V/VI, when more comminuted small bone blocks were present on the posterior side, floating screw fixation may not meet the needs, the ratio of unfixed posterolateral fragments in this group was relatively high, and the posterior plate was sometimes needed for fixation of the central bone block.

Because of less coverage of soft tissue around the tibial plateau fracture, the implanted internal fixation plate further increases the burden of soft tissue around the joint, and postoperative pain can cause muscle reflex spasm and venous reflux disorder, which can aggravate limb swelling. If the recovery of soft tissue around the joint is not ideal, wound healing will be directly affected, and exposure of the plate may lead to operation failure. Compared with other imaging techniques, high-resolution ultrasound is easily accepted and repeated by patients because it is non-invasive. At the same time, ultrasound can clearly show the internal structure of the superficial soft tissue of the body and can conduct a detailed examination of muscle and tendon injury. High-resolution ultrasound is also helpful to evaluate the recovery of soft tissue around the joint.[25,26] However, in the present study, we did not specifically measure periarticular swelling and soft tissue recovery using high-resolution ultrasound. Because some patients had undergone calcaneal traction before the operation, the traction weight was set according to the weight of the patients. Thus, the postoperative measurement results may not be reliable. Future research can include periarticular high-resolution ultrasound, which will be conducive to early recovery and reduce the incidence of postoperative complications.

The current study has some limitations. First, the present study used a cross-sectional design, and the clinical efficacy of the extended anterolateral approach requires a prospective study for further evaluation. Second, posttraumatic osteoarthritis is a long-term chronic disease; thus, it cannot be fully evaluated in short-term follow-up. Third, this study had a single-center retrospective design, and the number of cases included was relatively small. More long-term follow-up verification in multiple centers and a large number of cases are required.

Although many approaches are available to treat posterolateral tibial plateau fractures, when choosing 1 or more combinations, the condition of soft tissue injury, shape of the whole platform fracture, including the posterolateral bone block, and the available fixation methods must be considered. The best approaches should provide maximum exposure of the platform, sufficient space for reduction and fixation, and minimum damage to the surrounding structures. For anterolateral platform fractures combined with isolated posterolateral fracture fragments, the extended anterolateral approach is more suitable as a single approach. For multiple column tibial plateau fractures, a dual approach (extended anterolateral combined with a medial approach) can be used to enter the whole plateau area.

## Author contributions

All the authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Min Zhang, Yousen Zhu, Jinguang Wang and Jiangying Ru.

Operation and patient management were performed by Li Li and Gang Chen.

The first draft of the manuscript was written by Wenwen Mao, and all the authors commented on previous versions of the manuscript.

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