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ORIGINAL PAPER

A surgical protocol for bicondylar four-quadrant tibial plateau fractures

Shi-Min Chang · Sun-Jun Hu · Ying-Qi Zhang · Meng-Wei Yao · Zuo Ma · Xin Wang · Jens Dargel · Peer Eysel

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Abstract
Purpose Bicondylar tibial plateau fractures involving four articular quadrants are severe and complex injuries, and they remain a challenging problem in orthopaedic trauma. The aim of this study was to introduce a new treatment protocol with dual-incision and multi-plate fixation in the floating supine patient position as well as to report the preliminary clinical results.
Methods From January 2006 to December 2011, 16 consecutive patients with closed bicondylar four-quadrant tibial plateau fractures (Schatzker type VI, OTA/AO 41C2/3) were treated with posteromedial inverted L-shaped and anterolateral incisions. With the posteromedial approach, three quadrants (posteromedial, anteromedial and posterolateral) can be exposed, reduced and fixed with multiple small antiglide plates and short screws in an enclosure pattern. With the anterolateral approach, after articular elevation and bone substitute grafting, a strong locking plate with long screws to the medial cortex is used to raft-buttress the reduced lateral plateau fracture, hold the entire reconstructed tibial condyles together, and contact the condyles with the tibial shaft. All patients were encouraged to exercise knee motion at an early stage. The outcome was evaluated clinically and radiologically after a minimum two-year follow-up.
Results The average operation time was 98±26 minutes (range 70–128) and the average duration of hospitalization was 29±8.6 days (range 20–41). Three cases used five plates, nine cases used four plates, and four cases used three plates. All patients were followed for a mean of 28.7±6.1 months (range 26–38). Fifteen incisions healed initially, while one patient developed a medial wound dehiscence and was successfully managed by debridement. All patients achieved radiological fracture union after an average of 20.2 weeks. At the two-year follow up, the average knee range of motion (ROM) was 98°±13.7 (range 88–125°), with a Hospital for Special Surgery (HSS) knee score of 87.7±10.3 (range 75–95), and SMFA score of 21.3±8.6 (range 12–33).
Conclusion For bicondylar four-quadrant tibial plateau fractures, the treatment protocol of multiple medial-posterior small plates combined with a lateral strong locking plate through dual incisions can provide stable fracture fixation to allow for early stage rehabilitation. Good clinical outcomes can be anticipated.

Keywords Tibial plateau fracture · Bicondylar fracture · Four-quadrant fracture · Enclosure fixation · Multi-plate fixation · Floating position · Dual incision

S.-M. Chang (✉) · S.-J. Hu · Y.-Q. Zhang · M.-W. Yao
The Department of Orthopaedic Surgery, Yangpu Hospital, Tongji University School of Medicine, 450 Tengyue Road, Shanghai 200090, People's Republic of China
e-mail: shiminchang11@aliyun.com

Z. Ma · X. Wang
The Department of Orthopaedic Surgery, Tongji Hospital, Tongji University School of Medicine, Shanghai 200090, People's Republic of China

J. Dargel · P. Eysel
Department of Orthopaedic and Trauma Surgery, Cologne University Hospital, Köln, Germany

Introduction

The tibial plateau anatomically consists of medial and lateral articular surfaces, and tibial plateau fractures are common injuries that include a large spectrum of fracture patterns. In clinical practice, the most common systems for classifying tibial plateau fractures are the Schatzker classification [1] and the AO/OTA classification [2]. With the use of computed tomography (CT) and three dimensional (3-D) image

reconstructions in the assessment of tibial plateau fractures, increasing attention has been paid to the fracture lines on the coronal plane [3]. Luo et al. [4, 5] proposed a CT-based, three-column classification for tibial plateau, and the fractures can be categorized with a single column fracture (anterior, medial, or posterior column) or different types of combined column fractures (2 and 3 columns). Chang et al. [6, 7] classified the tibial articular plateau into four-quadrants, and the fractures are categorized with an isolated single quadrant (anteromedial, anterolateral, posteromedial, and posterolateral) and different combinations of 2, 3 and 4 quadrants. The fracture on each quadrant may have unique characteristics [8–12] as well as require related incision or treatment protocols [13, 14].

Resulting from high-energy violence such as motor vehicle accidents or falling from a tall height, bi-condylar four-quadrant tibial plateau fractures are often combined with marked trauma to the surrounding soft tissue envelope. The management of these fractures is challenging, requiring reconstruction of the articular congruity and restoration of the anatomic alignment, rigid fixation of the fragments for early joint motion and weight bearing, and minimal soft-tissue invasion, providing a proper local environment for fracture healing [15–17]. The ideal treatment of these fractures is controversial, which depends on the level of fracture comminution, severity of soft tissue injury and bone quality. The current treatment choices for bi-condylar four-quadrant tibial plateau fractures can be classified into three categories, including (1) open reduction and internal plate fixation, such as dual-incision with two-plate and single lateral fixed-angle plate; (2) limited open reduction with percutaneous screw fixation and hybrid fixator stabilization; and (3) indirect reduction and application of a fine-wire circular external fixator. Each method has its own advantages and disadvantages [18–23].

Instead of conventional dual plates, we fix the four-quadrant tibial plateau fractures by a combination of medial-posterior multiple small antiglide-enclosure plates with a lateral raft-buttress locking plate. The outcome of these cases was satisfactory after short- to medium-term follow up. In this paper, we present our treatment protocol and experience with dual-incision and multi-plate fixation in a floating supine patient position with a single prep and drape.

Patients and methods

From January 2006 to December 2011, we prospectively enrolled 16 patients with bicondylar four-quadrant tibial plateau fractures (Fig. 1). All patients were managed according to our treatment protocol. There were 11 men (69 %) and five women (31 %), with an average age of 51 years (range, 28–67). The left knee was involved in ten cases and the right in six. They were all classified as Schatzker type VI or AO/OTA 41C2 and C3 fractures, including ten C2 cases (62.5 %) and six C3 cases (37.5 %).

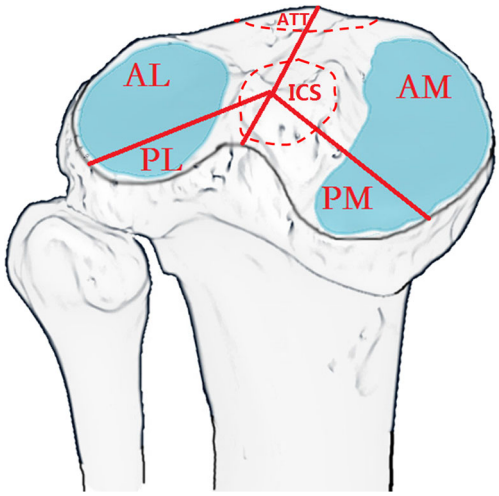

Fig. 1 Schematic drawing showing the four-quadrant classification of the tibial articular plateau. *AM* anteromedial, *PM* posteromedial, *AL* anterolateral, *PL* posterolateral, *ICS* intercondylar spine, *ATT* anterior tibial tuberosity

They were all closed fractures, and no associated neurovascular injuries were found at the time of admission. The soft-tissue integument injury grade, according to Tscherne-Oestern closed fracture classification [24], was grade I in three cases, grade II in 11 cases and grade III in two cases.

The fractures are initially stabilized with a spanning external fixator (seven cases) or calcaneal traction (nine cases) in a Brown brace for one to three weeks to allow for soft-tissue injury and subsiding of swelling. If a spanning fixator is used, care with pin placement should be taken to avoid pin-site insertion into the area of the planned incisions for future surgery. The interval period between primary injury and definite internal fixation was 11 days (range seven to 21 days).

Preoperatively, radiographs, including anteroposterior and lateral views of the knee joint as well as CT scans and 3D reconstructions, were taken to evaluate the severity of articular depression and cortical split, which were very useful for recognizing fragment features and pre-operative planning.

Surgical protocol

Under intra-tracheal general anaesthesia, the patient is placed in the supine position. A high thigh pneumatic tourniquet is applied to the injured extremity. We prepare and drape both legs. The contralateral hip is flexed, adducted, with the pelvis rotated towards the injured side. This manoeuver places the patient's pelvis and lower trunk in a semi-lateral position, and the injured leg is rotated laterally, allowing access to the posterior aspect of the knee [7]. A scrubbed assistant holds

the leg in position. General anaesthesia and sufficient padding and support from the back keep the position easily.

We first start from the posteromedial approach. An inverted L-shaped incision is made, centring the horizontal limb at the popliteal crease [4, 7, 14]. The medial arm of the incision is made just posterior to the medial edge of the tibia. Sharp dissection is carried deep, and the posterior fascia is incised between the medial gastrocnemius (posterior border of the dissection) and the pes anserinus anteriorly. The medial collateral ligament remains intact anteriorly and deep to the pes anserinus. The pes tendons are mobilized anteriorly and proximally, keeping their insertion intact. A Penrose drain can be used to retract them.

The medial gastrocnemius muscle is then elevated and retracted posteriorly and laterally, exposing the posterior proximal tibia. No gastrocnemius tendon release is attempted. The soleus and popliteus muscles are then elevated from the posterior edge of the tibia by sharp dissection, exposing the fracture site. The joint is not entered posteriorly, carefully protecting the capsular and ligament insertions. The coronal split posteromedial quadrant fragment is initially reduced anatomically by exact reposition of its inferior V-shaped cortical spike under direct visualization, and a small undercontoured reconstructive plate (five holes) is placed onto the spike and fixed in an antiglide fashion, usually with four 3.5-mm cortical screws, two on each side of the spike. Then, by retracting the pes tendon posteriorly, the sagittal split anteromedial quadrant fragment is reduced and fixed with another small reconstructive plate, and the entire medial condyle is restored to the tibia shaft anatomically, providing a stable medial column to which the lateral plateau can be reduced and stabilized. Short screws that only grasp the proximal cortice are used to avoid later interfering with lateral plateau reduction. These two short plates should be placed in a lower position to leave a space in the proximal 1–2 cm beneath the articular surface for the later placement of long screws from the heavy lateral plate (Fig. 2).

Exposing the posterolateral quadrant through this indirect posteromedial approach, especially the articular surface, is somewhat difficult. The popliteal neurovascular structures are safely protected between the soleus and popliteus muscles, but overzealous retraction is avoided to prevent traction injury to the tibial nerve and vessels. However, for the posterolateral quadrant, we only perform a rough elevation of the depressed articular fragment through this posteromedial approach, and exact articular elevation and verification by vision is left until later, which is performed through the anterolateral approach. By referencing the reduced posteromedial fragment, the posteriorly displaced cortex of the posterolateral quadrant is elevated and returned to its normal position. A third reconstruction plate is placed in the oblique direction, from superolateral to inferomedial, to protect the ruptured posterior cortex from collapse. The distal part of the plate is fixed to the tibial shaft

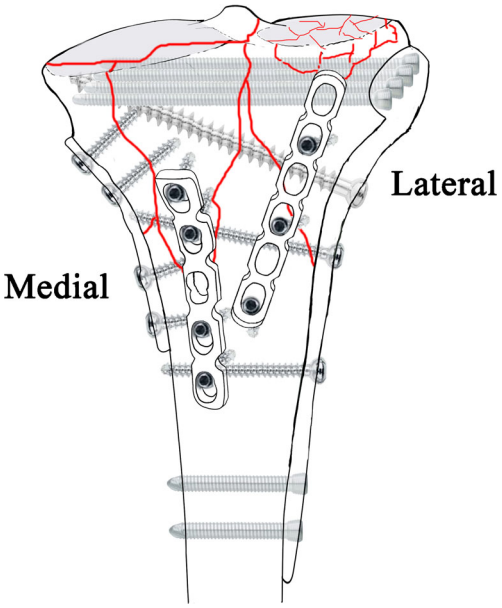

Fig. 2 Diagram of the fixation protocol. The posteromedial, anteromedial and posterolateral quadrants are supported by multiple small reconstructive plates with short screws in the antiglide mode. The lateral heavy locking plate with long screws works to raft-buttress the reduced lateral plateau, hold the entire reconstructed tibial condyles together, and contact the tibial condyles with the tibial shaft

with two to three screws, while its proximal part, worked as a metallic posterolateral wall, does not need any screws or needs only one to two short screws.

The mechanical role of these medial-posterior reconstruction plates is to provide enclosure support to the anteromedial, posteromedial and posterolateral quadrants, keeping these fragments in anatomic reduction and preventing later collapse after bone grafting from the anterolateral approach. Usually, every fragment spike needs its own plate in the antiglide mode. They are supplementary plates in the entire fixation construct (Fig. 2).

After checking the fracture reduction by fluoroscopy, the support on the patient's back is removed, which returns the patient to lying on a true supine position for lateral plateau manipulation. A bump added under the ipsilateral hip further internally rotates the lower limb. The lateral tibial plateau is exposed through the conventional anterolateral approach. After submeniscus arthrotomy, the comminuted lateral plateau is visualized. The depressed articular fragments are elevated with substantial cancellous and subchondral bone together. The interspace is filled with a bone-grafting substitute to support the elevated fragments. An L-shaped heavy lateral locking plate with long screws to the medial cortex is used to raft and buttress the reduced lateral plateau fracture, hold the whole tibial condyles together, and contact them to the tibial shaft.

If the patient has an anterior tibial tubercle fracture, it is easily reduced and fixed with a small plate and short screws through the anterolateral approach (Fig. 3).

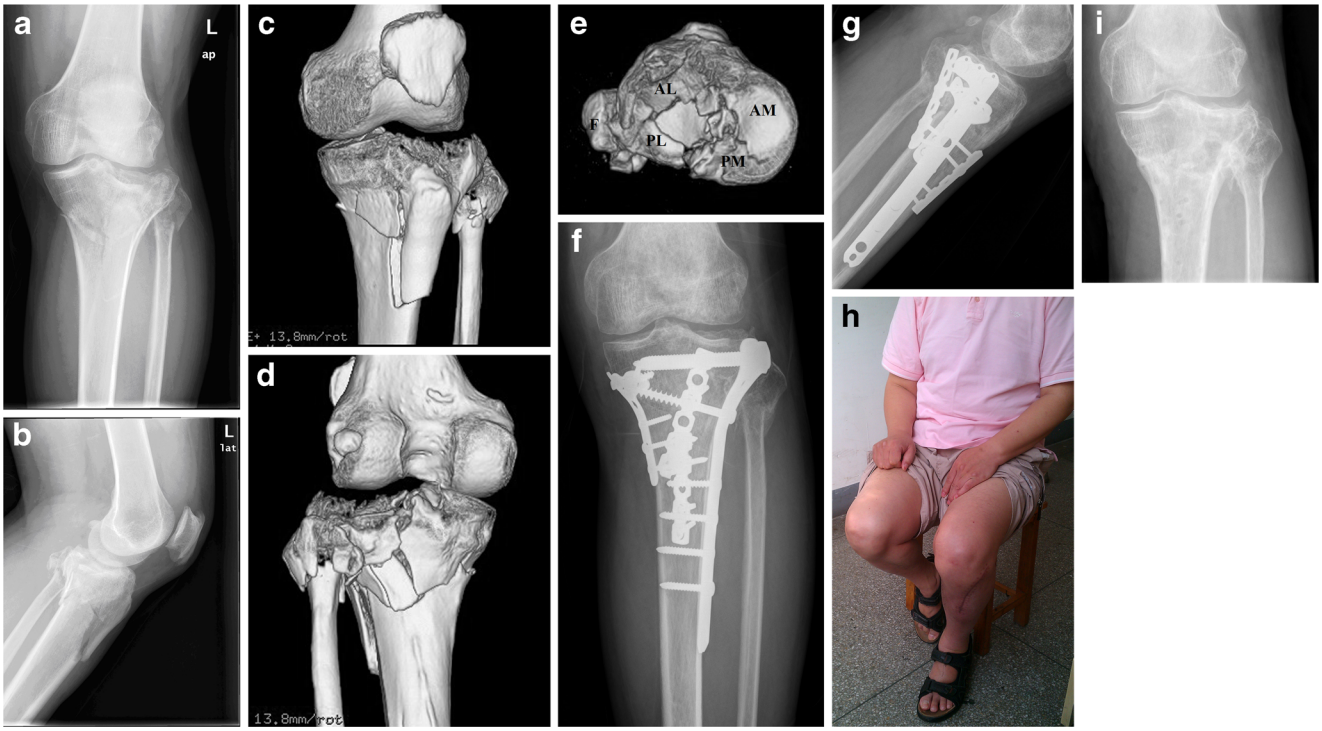

Fig. 3 A 49-year-old male with bicondylar four-quadrant tibial plateau fracture. **a**, **b** Preoperative AP and lateral radiographs of fracture. **c**, **d**, **e** Preoperative 3D reconstruction showing a severe complex bicondylar four-quadrant fracture. Anterior, posterior, and superior views. **f**, **g** Postoperative AP and lateral radiographs. Note a small plate was used to stabilize the anterior tubercle fragment. **h** Knee function at the 1-year follow-up. **i** Implant removal after two years

After finishing plate fixation of the entire tibial plateau, a draw test is performed to decide whether the ACL attached fragment needs to be fixed by a cortical screw.

After checking the fragments' position by fluoroscopy, both incisions are closed using absorbable sutures in a routine fashion over suction drains.

Postoperative management and follow up

The lower limbs were elevated, and no plaster cast was used to immobilize the knee. After the skin incision was stabilized, usually in three to four days, continuous passive motion with a machine was applied to allow for less than 45° of knee flexion in the first week which was increased gradually to 90° in the second week. Patients are encouraged to gain full range-of-motion (ROM) in four weeks. Weight bearing is restricted to toe-touch (5–10 kg) during the first two months and is increased progressively in the third month. Full weight bearing is not permitted before three months.

Patients were reviewed at six weeks, three months, six months, and one and two years after operation, with clinical and radiographic assessment of the progress of fracture healing and complications. The knee ROM was assessed by physical examination. The functional outcomes were assessed by the HSS knee score system (Hospital for Special Surgery, HSS) and SMFA score (Short Musculoskeletal Function Assessment, SMFA) at the final follow-up.

Results

The average operation time was 98±26 mins (range 70–128) and the average duration of hospitalization was 29±8.6 days (range 20–41). All incisions healed primarily. An obese female patient developed medial wound dehiscence due to subcutaneous fat necrosis, which was successfully managed by debridement, vacuum sealing drainage (VSD), and secondary suture. There were no cases of deep infection or osteomyelitis. None of the patients developed vascular injury, nerve injury or compartment syndrome.

Through the posteromedial inverted L-shaped approach, all 16 cases had PM fragment fixations, 12 cases had AM fragment fixations, and 11 cases had PL fragment fixations. Through the anterolateral approach, all 16 patients had lateral proximal locking plate fixations, five had anterior tibial tubercle fixations, and three had ACL-attachment screw fixations. Ultimately, four patients used three plates, nine patients used four plates, and three patients used five plates.

Follow-up assessment was carried out after a minimum of two-year follow-up. The average follow-up period was 28.7±

6.1 months (range 26–38). According to radiographs, all patients achieved solid union of the fracture after an average of 20.2 weeks. Three cases developed slight loss of articular reduction (step off <3 mm) without lower limb alignment changes. No cases of broken implants were seen on radiographs. Ten patients had the fixation devices removed after fracture healing.

At two-year follow-up, 11 (68.8 %) patients had no pain in the injured limb and five (31.2 %) patients had occasional, slight complaints after long-distance walking. The average knee ROM was 98±13.7° (range 88–125). Five (31.2 %) had knee flexion restrictions, and four believed that it did not interfere with their daily activities. Fourteen (87.5 %) patients were satisfied with the treatment results and returned to their pre-injury work and activities, one (6.25 %) patient changed his occupation and worked part-time, and one did not resume work. The average HSS knee score was 87.7±10.3 (range 75–95), and the average SMFA score was 21.3±8.6 (range 12–33).

Discussion

With the increased frequency of high-energy automobile accidents, complex bicondylar tibial plateau fractures involving the four articular quadrants are not uncommon. Surgical treatment is indicated for most of these fractures to obtain a stable and functional knee. The onset age of these fractures is relatively young (the average age in our case series was 51 years old), and the mainstream treatment for the bicondylar tibial plateau fractures is open reduction and internal plate fixation, while single external fixation or total knee arthroplasty could be supplementary choices [25].

However, there is much controversy over the incisions and implant choices. Traditional treatment for bicondylar fractures is reported by the use of dual-incision and bilateral buttress plates, which requires massive dissection of soft tissue envelope, or a lateral locking-buttress plate with a supplementary medial antiglide small plate [18, 19]. However, it is not enough for bilateral plates to stabilize a tibial plateau fracture with four quadrant involvement, which usually contains at least four main articular-fragments and cortical-column ruptures. Chang et al. [7] reported using additional reconstruction plates to stabilize the coronal posteromedial and posterolateral quadrant fragments. With the combination of a heavy lateral locking plate and multi medial-posterior small antiglide plates, good results were achieved in 12 patients in the preliminary report [7]. Zhai et al. [26] reported their experience with applying multi-plates (3–, 4–, and 5-plates) for severe and complicated bicondylar tibial plateau fractures in 26 young patients. They used 3.5-mm T-plates for the medial and posterolateral fragments, and a heavy locking plate for the split-depressed anterolateral fragment. The outcome was satisfactory according to the Rasmussen score at final follow-up.

We note that the morphological characteristics of the complex bicondylar four-quadrant tibial plateau fractures follow a regular pattern, which was also described by others [8–12]. The concave medial plateau is usually split into two large fragments (posteromedial and anteromedial) without articular depression, while the convex lateral plateau is split-depressed into various degrees of multi-fragments with broadening of the lateral compartment (anterolateral and posterolateral). The coronal posteromedial quadrant fragment usually has an inferior V-shaped cortical spike, which can intraoperatively be used as a landmark. Some cases have a separate anterior tubercle fragment. Additionally, the attachment of the ACL/PCL may be isolated from the intercondylar spine and form a solitary fragment. Clinically, because the posterolateral quadrant fragments are very difficult to approach and fix, involving the posterolateral quadrant is a marked feature of the term "severe and complex bicondylar tibial plateau fractures" [26].

The combined approaches used in our cases includes posteromedial inverted L-shaped and traditional anterolateral incisions. The distance between the two skin incisions is large, and the risk of wound complications is relatively low. In our case series, 94 % of the incisions (15/16) healed primarily. Through the posteromedial inverted L-shaped approach exposure of three quadrants, the PM, AM and PL, can be visualized and manipulated. The vertical arm of the incision can be placed slightly anteriorly (approximately 2 cm) to expose and manipulate the AM fragment. However, care should be paid to protecting the great saphenous vein and its accompanying saphenous nerve. The exposure of the PL quadrant is somewhat difficult because the gastrocnemius-soleus muscles are very strong in some cases and it is difficult to retract them laterally. Through the anterolateral approach, the articular surface can be visualized clearly, and the depressed articular fragments can be fully elevated, while the laterally displaced and widened plateau can be exactly reduced. Additionally, the anterior tubercle fragment and the ACL-fragment can be visualized and fixed through this incision.

Our fixation construct can be summarized as a medial-posterior enclosure and lateral raft-buttress. For those complex bicondylar fractures, anatomic reduction of the PM fragment is of paramount importance [4, 7, 26, 27]. By exact reposition of the distal V-shaped fracture spike, the fragment height and tilt angle can be anatomically restored. Small plates with short screws are used to stabilize the PM, AM and PL quadrant fragments, which would not interfere with the later placement of lateral long raft screws. The working mode of these medial-posterior small plates is likely to set up a fence that can keep the fragments from collapse, and the construct can be termed enclosure fixation (Fig. 2). The anterior tubercle fragment can also be fixed in this pattern. The lateral heavy locking compression plate with long rafting screws works as suspending

arms that hold the lifted articular surface, connecting the reconstructed tibial condyle to the shaft via bicortical long screws.

A prolonged operation time and repeated pneumatic usage are related to an increased overall risk for surgical site infection after open plating of the tibial plateau fractures [28]. In our case series, the average operation time was 98±26 minutes Most of the cases were finished within two hours, which may be one of the important reasons for the low wound complication rate. With early knee joint motion exercise, we achieved 56.3 % excellent and 31 % good results (overall 87.5 % acceptable results) with our treatment protocol.

In conclusion, for severe and complex bicondylar four-quadrant tibial plateau fractures, multiple medial-posterior small plates combined with a lateral strong locking plate through dual incisions can provide stable fixation to allow for early stage rehabilitation. The procedure is quick and the soft-tissue complication is low. Good clinical outcomes can be anticipated.

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