

ADVANCEMENTS IN MODERN SURGICAL MANAGEMENT OF TIBIAL PLATEAU FRACTURES: A COMPREHENSIVE REVIEW

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Abstract

This review aims to summarize the literature on classic and advanced surgical management strategies for tibial plateau fractures. The primary objective in treating these fractures is to restore joint functionality and ensure favorable short- and long-term outcomes. Effective surgical management minimizes the risk of joint instability, enhances long-term prognosis, and maintains the patient's quality of life. Most orthopedic surgeons adopt a staged treatment strategy, involving initial stabilization followed by definitive surgical fixation, respecting soft tissue conditions, achieving precise anatomical reduction, ensuring stable fixation, and promoting early rehabilitation. Surgical techniques include open approaches with arthrotomy for articular surface reconstruction and fixation using plates and screws, as well as minimally invasive approaches such as arthroscopy or percutaneous fixation with screws or external fixators. Modern osteosynthesis techniques—plates, screws, external fixators, and rotating hinges—have become the standard of care, except in cases of minimal displacement. These approaches collectively aim to optimize patient recovery and joint functionality.

Key words: tibial plateau, fractures, surgical management

INTRODUCTION

Tibial plateau fractures are intra-articular lesions of the knee joint, which bears significant axial loads and can be combined with a wide range of lesions of the soft tissues [1]. Tibial plateau fractures account for about 1% -2% of tibial fractures [2]. The severity of tibial plateau fractures ranges from minimal displacement fractures with favorable prognosis to comminuted fractures with high risk of post-operative complications and significant surgical challenges for orthopedic surgeon. These types of

fractures can alter the alignment of the limb and compromise both the stability and mobility of the knee joint [3]. Understanding the fracture trajectory is crucial for planning surgical intervention. Fracture line of the tibial plateau fractures depends on the direction of the force and the position of the limb at the time of injury. OTA (Orthopedic Trauma Association)/AO classification of the tibial plateau fractures is exposed in Table I [4-6]. Krause et al (2020) support a segment-based mapping ("ten segment classification") of the tibial plateau in order to improve a fracture-specific surgical approach. According to

this classification, in OTA/AO type B and C fractures, the posterior segments were most frequently involved, while limited visibility of these posterior segments, where accurate reduction and fixation are essential for long-term successful outcomes, requires considering posterior approaches in the management of tibial plateau fractures [7]. However, Dhillon & Patel (2017) recommend four column

classification in the treatment of the intra articular tibial plateau fractures, considering better results when compared to "ten segment classification"[8]. An epidemiological study reported AO type B3 as the most frequent fracture type (35% of all tibial plateau fractures), and C3 the second most common fracture type (17% of all tibial plateau fractures) [9].

Table I. OTA/AO classification in tibial plateau fractures [4-6]

OTA/AO class	Description
A	- extraarticular fractures - proximal tibial end segment fractures
A1	proximal tibial avulsion fractures
	A1.1. capsular attachment avulsion: lateral (Segond fracture)/medial
	A1.2. tibial tuberosity avulsion (patella tendon)
	A1.3. tibial spine fracture: anterior/posterior
A2	simple extraarticular proximal tibial fracture
	A2.1. spiral proximal tibial fracture
	A2.2. oblique proximal tibial fracture
	A2.3. transverse proximal tibial fracture
A3	extraarticular wedge or multifragmentary proximal tibial fracture
	A3.1. intact wedge fracture: lateral/medial
	A3.2. fragmentary wedge fracture: lateral/medial
	A3.3. multifragmentary fracture
B	- partial articular proximal end segment fractures - medial plateau split fractures - lateral plateau split fractures
B1	pure split fracture
	B1.1. lateral plateau split fracture
	B1.2. medial plateau split fracture
	B1.3. oblique fracture with involvement of the tibial spine: lateral/medial
B2	pure depression fracture
	B2.1. lateral plateau depression: anterolateral/posterolateral/central
	B2.2. medial plateau depression: anteromedial/posteromedial/central
B3	partial articular split depression fracture
	B3.1. lateral plateau split depression: anterolateral/posterolateral/central
	B3.2. medial plateau split depression: anteromedial/posteromedial/central
	B3.3. oblique fracture with involvement of the tibial spine: lateral/medial
C	- complete articular proximal tibial end segment fracture - complex articular fractures

C1	• simple articular and metaphyseal fractures
	C1.1. without intercondylar eminence fragment
	C1.2. with intercondylar eminence fragment
C2	• simple articular wedge or multifragmentary metaphyseal fracture
	C2.1. intact wedge fracture: lateral or medial
	C2.2. fragmentary wedge fracture: lateral or medial
	C2.3. multifragmentary fracture
C3	• with fragmentary or multifragmentary articular and metaphyseal fracture
	C3.1. fragmentary lateral plateau
	C3.2. fragmentary medial plateau
	C3.3. multifragmentary medial and lateral plateau fracture

AIM OF REVIEW

The search of recent literature on PubMed and Scopus databases was focused on classic surgical management strategies and recent advancements in the surgical treatment of tibial plateau fractures.

THERAPEUTIC PRINCIPLES

The tibial plateau fractures are complex injuries that can be challenging, even for experienced orthopedic surgeons, due to their variable geometry and morbidity [10]. The goal of treating tibial plateau fractures is to restore a functional joint for the patient, both in the short and long term. The treatment objectives are established for both immediate and extended outcomes. Short-term objectives include achieving stability, mobility, and pain relief. Long-term goals focus on preventing post-traumatic osteoarthritis by ensuring good articular congruence, knee stability, and proper alignment of the lower limb to allow even stress distribution between the two compartments [1].

The factors guiding the therapeutic approach are as follows [1,11]:

- Degree of fragment displacement;
- Extent of comminution;
- Severity of soft tissue damage;
- Associated neurovascular injuries;
- Patient's degree of osteopenia;

-Presence of other injuries in cases of polytrauma;

-Associated ipsilateral complex injuries.

Three factors influence the decision between non-operative and surgical intervention [1,11]:

-Presence of articular step-off;

-Instability;

-Axial deviation of the lower limb.

The presence of an articular step-off is associated with the development of post-traumatic osteoarthritis. When an articular step-off is present, anatomical reduction is recommended, aiming for a step-off of 2–3 mm. An articular step-off exceeding 3 mm increases intra-articular pressure (the ratio of force to the surface area it acts upon), leading to accelerated wear of the hyaline cartilage [12-14].

Deformities leading to instability require treatment. Patients with joint depression that cannot be reduced non-surgically should undergo surgical intervention. Axial deviation is caused by the depression of the articular surface, axial displacement of the condyles, or metaphyseal comminution, resulting in abnormal compartmental loading and dynamic changes to the axis of the lower limb [1].

An essential principle for the successful treatment of tibial plateau fractures is early mobilization. Articular congruence can only be restored through open reduction and internal fixation. For patients with preserved mobility, reconstructive interventions may be performed. Immobilization lasting longer than four weeks leads to joint stiffness, and osteosynthesis combined with prolonged immobilization exacerbates stiffness. In fractures with depression of the articular surface, surgical reduction is necessary to restore congruence, as impacted fragments cannot be reduced through traction or manipulation, and the depressed area cannot be filled with functional hyaline cartilage [1].

If there are general contraindications to open reduction and internal fixation, an alternative approach is traction combined with early mobilization [1].

SURGICAL MANAGEMENT

The short-term treatment goals for tibial plateau fractures include achieving stability, joint mobility, and pain relief, while the long-term objectives focus on preventing post-traumatic osteoarthritis by restoring proper joint congruence, knee stability, and a normal lower limb axis to ensure even tension distribution across both compartments [1].

Review of literature highlighted the lack of consensus regarding the actual approaches in orthopedic practice for managing tibial plateau fractures. Planning of the surgical management depends on the following factors: lesion mechanism, soft tissues status, open wounds presence, potential adverse effects and complications, limb neurovascular status [4]. Planning of

the surgical approach is based on imaging technique (radiographs, CT scans with 3D reconstructions, MRI). Diagnostic imaging of tibial plateau fractures on plain radiographs may reveal a fat-fluid level in the suprapatellar bursa, misalignment of the femoral condyles and tibial edges, and an increase in trabecular density in the lateral epicondyle. For patients where a tibial plateau fracture is suspected but radiographs are negative, a computed tomography (CT) scan should be conducted for further evaluation [15].

The American Orthopedic Association highlights reduction and stabilization to decrease the risk of secondary osteoarthritis. Achieving the best functional outcome requires a personalized approach for each patient, considering the specific injury pattern, patient characteristics, the surgeon's expertise, and the availability of suitable implant devices, combined with proper soft tissue management [16, 17].

Surgical treatment is urgently indicated for open fractures, fractures associated with compartment syndrome, and fractures with accompanying vascular injuries. While open reduction and internal fixation are considered the gold standard treatment for tibial plateau fractures, most orthopedic surgeons prefer a staged treatment strategy that involves initial stabilization followed by surgical definitive fixation at a later stage respecting soft tissues, attaining precise anatomical reduction, ensuring secure fixation, and facilitating early rehabilitation [16, 17].

The surgical treatment options are as follows [5]:

- Extensive approach with arthrotomy, reconstruction of the articular

surface, and fixation with plates and screws;

-Arthroscopy or minimally invasive approach with percutaneous fixation using screws or an external fixator.

Internal fixation and reduction of the tibial plateau can be performed through an anterolateral approach, a posteromedial approach, or a combination of both. Only one of the two approaches is used for fractures located in the lateral area (anterolateral approach) or medial area (posterolateral approach) of the knee.

The Lobenhoffer approach is particularly valuable for managing complex tibial plateau fractures involving the medial and posterior columns, providing excellent access to the posteromedial and posterior regions of the proximal tibia, enabling effective reduction and stabilization of the isolated posteromedial tibial plateau fractures in this area using a posteromedial plate. The procedure is performed with the patient in the prone position. The surgical interval between the gastrocnemius and pes anserine is carefully developed to expose the fracture apex. Reduction is achieved through knee extension and valgus positioning, combined with direct manipulation of the fracture fragment. Stabilization is accomplished by applying a small fragment antiglide plate [18].

The anterolateral and posterolateral approaches are employed in bicondylar fractures conditions [5].

The anterolateral approach is considered the standard technique for addressing lateral tibial plateau, providing access to the lateral joint, metaphysis, while it can be extended if the fracture involves the shaft. In the case of Schatzker III tibial plateau fracture, emphasis is placed on performing a submeniscal arthrotomy to

inspect the joint surface and evaluate the reduction. A femoral distractor is used to assist in elevating the joint surface and enhancing visualization of the lateral plateau. A cortical window is created with a triple reamer from the sliding hip screw set. The joint surface is then reduced and supported with cancellous bone grafts. Finally, a lateral locking plate with rafting screws is applied to stabilize the fracture [19].

Steps in the Anterolateral Approach [5]:

-The incision starts anterior to the lateral femoral epicondyle, 3-5 cm proximal to the joint line, and extends distally in a straight or slightly curved line toward Gerdy's tubercle.

-The fascial incision is made in line with the skin incision;

-The iliotibial tract is reflected anteriorly and posteriorly from its insertion;

-Submeniscal arthrotomy;

-The meniscus is reflected superiorly;

-Meniscal tears are evacuated;

-The extensor musculature on the condyle is reflected extraperiosteally.

Recently, different posterior approaches, apart from the posteromedial approach, have been introduced for certain patterns of posterior fractures [20, 21]. The choice of surgical approach should be determined by the fracture pattern, the condition of the surrounding soft tissue, and the patient's overall health and clinical status, including any concomitant injuries. Certain surgical techniques enhance visualization and access to the posterolateral tibial plateau. These include three osteotomies performed via an anterolateral approach: lateral femoral

epicondyle osteotomy, fibular head resection osteotomy, and a new digastric fibular osteotomy [22]. The extended anterolateral approach is considered a good choice to approach tibial plateau fractures involving the posterolateral column [23]. The anterolateral combined with posterolateral approach and the transfibular neck osteotomy approach are both effective for surgically treating lateral tibial plateau fractures involving the posterolateral column. The transfibular neck osteotomy approach is particularly appropriate for cases with significant damage to the posterolateral plateau articular surface, including bone separation, displacement, and deep collapse. This approach is especially useful for fractures affecting a large portion of the posterolateral column, particularly those in the upper tibiofibular syndesmosis area, along the line connecting the anterior and posterior margins of the fibular head to the midpoint of the plateau [24].

Steps in the Posterolateral Approach [5]:

- The posterior skin incision is made parallel to the posterior-medial tibial border.

- The tendons from the pes anserinus are mobilized, and the interval between them and the medial head of the gastrocnemius is accessed.

In the next clinical situations surgical interventions can only be performed after creating optimal conditions [1]:

- Unstable fractures of the lateral plateau,

- Most displaced fractures of the medial plateau,

- Most displaced bicondylar fractures.

In cases of polytrauma, surgical interventions may be delayed to stabilize the patient's general condition or when other interventions take precedence. In such situations, the fracture is temporarily stabilized with external fixation, allowing traction, preventing posterior displacement of the distal fragment, and facilitating compartment pressure monitoring [1]. Whenever feasible, reduction through ligamentotaxis is recommended, which can be achieved either through traction or with the use of a femoral distractor. Surgical approaches must be tailored to the fracture pattern as follows [1]:

- For coronal plane fractures or those with a posterolateral fragment: posterolateral or posterior incision;

- For unicondylar fractures: medial or lateral parapatellar approach, depending on the lesion's location;

- For bicondylar fractures:

- Fernandez's technique, involving osteotomy of the anterior tibial tuberosity;

- Schatzker's technique, which includes a Z-shaped tenotomy of the patellar tendon followed by its reconstruction.

Surgical treatment indications for young, healthy patients include unstable displaced tibial plateau fractures. The fracture categories that require surgical intervention are as follows [5]:

- Displaced, unstable tibial plateau fractures where the normal axis of the lower limb cannot be assessed;

- Displaced bicondylar fractures and diaphyseal fractures;

- Medial plateau fractures (except those with minimal displacement);

- Lateral plateau fractures with valgus displacement;

-Lateral plateau fractures with a large displaced fragment, depression of more than half of the lateral articular surface, or associated with a fibular head fracture;

- Instability;
- Ligamentous injuries;
- Significant displacement of the articular surface;
- Open fractures;
- Compartment syndrome.

Currently, surgical treatment of tibial plateau fractures, utilizing osteosynthesis techniques such as plates, screws, external fixators, and rotating hinges, has become the standard, except in cases of minimal displacement [25]. For fractures involving the condyles, locked screw plates are used to maintain fixed angles and support the stability of the osteosynthesis. In fractures with displacement and associated soft tissue injuries, external fixators are recommended to maintain limb length and reduce the fracture while soft tissue heals, thus lowering the risk of postoperative complications. For fractures involving the posterior condyle of the tibial plateau, posterior approach techniques are employed to effectively reduce fractures with a posterior trajectory and minimize the risk of fracture reduction loss after osteosynthesis. Plates and screws are the most commonly employed systems for stabilizing tibial plateau fractures [4]. Their function varies depending on the fracture classification and the implant's location. The most frequently used are 3.5 mm plates and screws, which are less cumbersome and easier to handle. Smaller screws, less than 3.5 mm in diameter, allow for multiple placements close to the joint surface, effectively supporting smaller bone

fragments. The "rafting screws" technique involves multi-hole plates designed for parallel screw placement near the joint surface, providing robust support for small joint areas and reducing the risk of postoperative failure [26-28]. Posteromedial plates serve as anti-slip devices, countering shear forces. In posterolateral approaches, 3.5 mm plates or pre-contoured plates are commonly used. The positioning of the plate relative to the fracture apex is critical, as screws placed near the apex enhance plate stability in this region [4]. For bicondylar and Schatzker VI fractures, side plates are employed to resist axial, rotational, and bending forces [4]. Plates combined with locking screws are frequently used in these cases to prevent varus deformity caused by bending forces. This approach reduces the need for external fixators or dual plates. Advanced techniques now favor polyaxial plates, which offer flexibility in screw placement while maintaining fixed-angle stability. Polyaxial locking plates allow for versatile mounting without significantly increasing mechanical complications or risking reduction loss [29-30]. Variable-axis locking plate systems provide stable fixation for both extraarticular and intraarticular proximal tibial fractures, delivering good functional outcomes with low complication rates and effective fragment binding [29-32]. For unicondylar fractures, the plate serves as a buttress (lateral tibial plateau) or anti-slip device (posteromedial plateau) [4]. The following fixation methods were used in the surgical treatment of tibial plateau fractures: plates (57.13%), screws (22.22%), a combination of plates, screws, and Kirschner wires (4.76%), and rotating hinges (15.9%) [33].

POST-OPERATIVE CARE

The stage of postoperative care aims to minimize complications and the rate of fracture reduction loss, as well as to maximize knee mobility, accelerate recovery, and restore functionality [4]. The patient requires a period of avoiding weight-bearing or only bearing minimal weight to minimize the chances of displacement of the reduced fragments. The healing duration depends on the fracture pattern and the strength of fixation, ranging from 6 to 12 weeks. After this period, the resistance to displacement of the fractured fragments significantly increases. In certain clinical situations, early mobilization is recommended, as knees immobilized for more than 2 weeks tend to become stiff. In situations where it is allowed, early mobilization contributes to the patient's early clinical and functional recovery [4]. In the case of tibial plateau fractures with an intact fibula, the use of locking plates allows early mobilization without increasing the risk of interfragmentary movement [34-35].

MANAGEMENT OF POST-OPERATIVE COMPLICATIONS

Open reduction and internal fixation can be associated to post-operative complications as follows: knee stiffness, acute infection, chronic infection (osteomyelitis), malunion, non-union, or even post-traumatic osteoarthritis [36-37]. Independent long-term predictors of knee stiffness are increased patient's age, the time spent in external fixation, the presence of bilateral tibial plateau injuries as well as sustaining a postoperative complication of a deep infection [38-39]. Treatment of knee stiffness ranges from mobilization under anesthesia to arthroscopic release or even open release is for refractory cases or those exceeding six months in duration [37]. In

case of acute infections and healed fracture, the hardware will be removed, followed by lavage, debridement, and antibiotic therapy. In case of acute infections and unhealed fracture, the hardware will be retained, and multiple rounds of lavage, debridement, and antibiotics will be performed until healing occurs [37]. The post-operative evolution to osteomyelitis requires a staged treatment as follows: aggressive debridement of necrotic tissue and bone, placement of antibiotic spacers, and temporary external fixation to control the infection in the first stage; in the second stage, once infection was resolved, definitive surgery will be performed with grafting or soft tissue reconstruction, depending on the extent of the bone defect [37]. In case of malunion, intra-articular or extra-articular osteotomy will be performed for young, active patients without significant joint damage [37, 40]. Osteotomy correcting the three components of the traumatic deformity at the distal femoral metaphysis level will allow the correction of the mechanical axis and rotation anomalies, and at the proximal tibia level for realignment purposes [41]. An associated osteotomy can address rotational deformities that cannot be corrected through standard bone cuts. For deformities located near the joint, osteotomy enables the placement of a moderately constrained prosthesis. This approach is guided by rotational deformity measurements obtained through CT scans, as such deformities typically necessitate osteotomy. Additionally, osteotomy is indicated when extraligamentous deformities are present and cannot be corrected through surgical release of the collateral ligaments [42]. A recent technique of intra-articular osteotomy via

an extended anterolateral approach was proposed for posterolateral tibial plateau fracture malunions with no loss of reduction, nonunion, or wound infection [43]. A research group proposed a recent algorithm for malunited tibial plateau fractures following failed initial treatment. It was evaluated the presence of infection; need for total knee arthroplasty; depending on the specific characteristics of the malunited tibial plateau fracture, personalized surgical techniques were proposed to achieve optimal reduction. The research group recommended the adoption of a proper revision strategy according to the individual characteristics of the patient's tibial plateau fracture malunion [44]. If malunion was associated to severe joint involvement or when cartilage damage leads to knee osteoarthritis, total knee arthroplasty must be standard surgical intervention [36, 37]. When needed, tibial tuberosity osteotomy and realignment procedures should be performed without jeopardizing the overall outcome. In severe cases of limited flexion, releasing the

extensor mechanism can provide significant improvement, provided there are no skin scar contractures or recent infections present [45, 46].

CONCLUSIONS

Effective surgical management of tibial plateau fractures plays a critical role in reducing the risk of joint instability, improving long-term outcomes, and preserving the patient's functionality and quality of life. Surgical options include open approaches involving arthrotomy for articular surface reconstruction and fixation with plates and screws, as well as minimally invasive techniques such as arthroscopy or percutaneous fixation using screws or external fixators. Modern osteosynthesis methods—plates, screws, external fixators, and rotating hinges—have become the standard of care, except in cases with minimal displacement. Furthermore, proper postoperative care is essential to minimize complications, prevent fracture reduction loss, and optimize functional recovery. Early rehabilitation, tailored to the patient's needs, facilitates knee mobility restoration, accelerates recovery, and supports the return to daily activities and long-term joint functionality.

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