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Chapter

Tibial Plateau Fracture

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Abstract

Tibial plateau fractures are a common orthopedic injury. These fractures involve the articular surface of the tibia that is part of the knee joint. Plateau fractures can range from low energy injuries with little or no displacement to complex fractures with significant associated injuries. Stability of these injuries depends on a combination of bony and associated ligamentous injuries. Treatment consists of a wide spectrum of therapies which have been discussed in this chapter. Complications such as compartment syndrome, post-traumatic arthritis, chronic pain, malunion, and wound problems (in addition to other complications) can develop.

Keywords: Tibial plateau, fracture, Schatzker, buttress plate, Bicondylar, calcium phosphate cement

1. Introduction

Fractures involving the tibial articular surface account for a little over 1% of all long bone fractures, 56.9% of all proximal tibia fractures/dislocations, and 8% of all fractures in the elderly [1–4]. They have an annual incidence of 10.3 per 100,000 [5]. The combined incidence of a patient having a tibial plateau fracture with associated polytrauma on admission has been estimated at 16–40% [6–8]. The age distribution is bimodal for both males and females which is similar to what is seen in other periarticular injuries [1]. The majority of fractures occur in males (70%) with men aged 40–44 years being the most affected patient population overall [4, 5]. Comminuted fractures are more common in males [3]. The highest incidence for tibial plateau fractures in females occurs between age 55 and 59 [4]. There is a shift of incidence between males and females that occurs after the age of 60 with females predominating (61%) [4, 9]. With an increase in life expectancy as well as a large aging population in many developed countries it is expected that the incidence of low-energy tibial plateau fractures will continue to increase.

2. Injury mechanism

The injury mechanism seen in tibial plateau fractures is largely age-dependent. The majority of tibial plateau fractures in the elderly are due to low energy falls. With an aging population and associated osteoporosis, the incidence of this injury is increasing. Osteopenia and osteoporosis play a large role in the fracture mechanisms and patterns observed. In the elderly, lateral fracture patterns are seen more commonly than medial. The forces acting on the bone in conjunction with the bone

quality determine the resulting fracture patterns [10]. Bone quality influences fracture patterns with low bone density decreasing the force necessary for injury. A higher incidence of compression fracture patterns tends to be seen in such cases despite lower energy injury mechanisms. In the younger population, high energy mechanisms predominate. Male gender is more common. The injury mechanism can involve motor vehicles, sports, and falls from height. The most common mechanism of injury overall is pedestrian struck by motorized vehicles (30%) and the second most common is low energy falls (22%) [11].

The magnitude and direction of the force of injury many times will influence the fracture pattern. Angular, axial, and compression forces can all lead to failure of the condyles. Axial load is usually a predominant component of the injury mechanism and produces higher energy at failure than angular forces. In general, greater axial load results in more severe fractures with increased comminution, fragment displacement, and associated soft tissue injury. In a cadaver study [12] that looked at mechanisms of injury it was found that pure valgus forces resulted in the typical lateral split fractures, axial forces resulted in joint compression fractures, and a combination of axial and valgus forces resulted in split depression fractures. The same study also concluded that an intact MCL is required for an isolated lateral plateau fracture to occur because the MCL acts as the pivot point causing the lateral femoral condyle to impact the lateral tibial plateau. The proximal tibia is more readily subject to valgus force because of an anatomic predisposition with 5–7° of knee valgus in normal anatomic alignment and due to lateral side impacts being a more common injury mechanism.

3. Anatomy

The superior tibia widens from the diaphysis proximally (**Figure 1**). The proximal anterior tibia forms the tibial tubercle and provides the attachment of the patellar tendon. Lateral to the tibial tubercle is Gerdy's tubercle which serves as the insertion site of the distal iliotibial band. The lateral proximal tibia forms the lateral tibial condyle and the inferior aspect of this serves as the attachment site of the anterior compartment muscles of the leg. The origin of the anterior muscles must be elevated in order to place an anterolateral plate. Medially and proximal to the tibial tubercle is the medial condyle. The medial condyle is less often involved in failure than the lateral condyle. The palpable fibular head (which is extra-articular to the knee joint) is found posterolateral and serves as the attachment site of the fibular collateral ligament and the biceps femoris tendon. The peroneal nerve wraps from posterior to anterior around the neck of the fibula. Even though the fibula does not participate in the knee joint articulation it does act as a buttress for the lateral tibial plateau. Because of this, associated proximal fibular fractures can result in greater valgus instability.

The medial and lateral tibial plateaus articulate directly with the medial and lateral condyles of the femur. The tibial articular width is slightly wider than the femoral articular width (tibia:femur articular width ratio was found to be 1.01 ± 0.04 in one study of healthy knees) [13]. With this in mind it might be useful to use the femur as a reference to judge pathologic tibial plateau widening and adequacy of intraoperative reductions [13, 14]. The lateral plateau is more proximal and slightly convex whereas the medial plateau is more concave and slightly distal to the lateral plateau. The medial plateau bears around 60% of the total load borne across the knee. Relative to the tibial diaphysis, the plateau is slightly varus due to the proximal nature of the lateral tibial condyle [15]. The concavity of the medial plateau allows for greater congruity of the medial tibia with the femoral condyle compared to the lateral. The tibial plateau slopes about 15° posteroinferiorly making

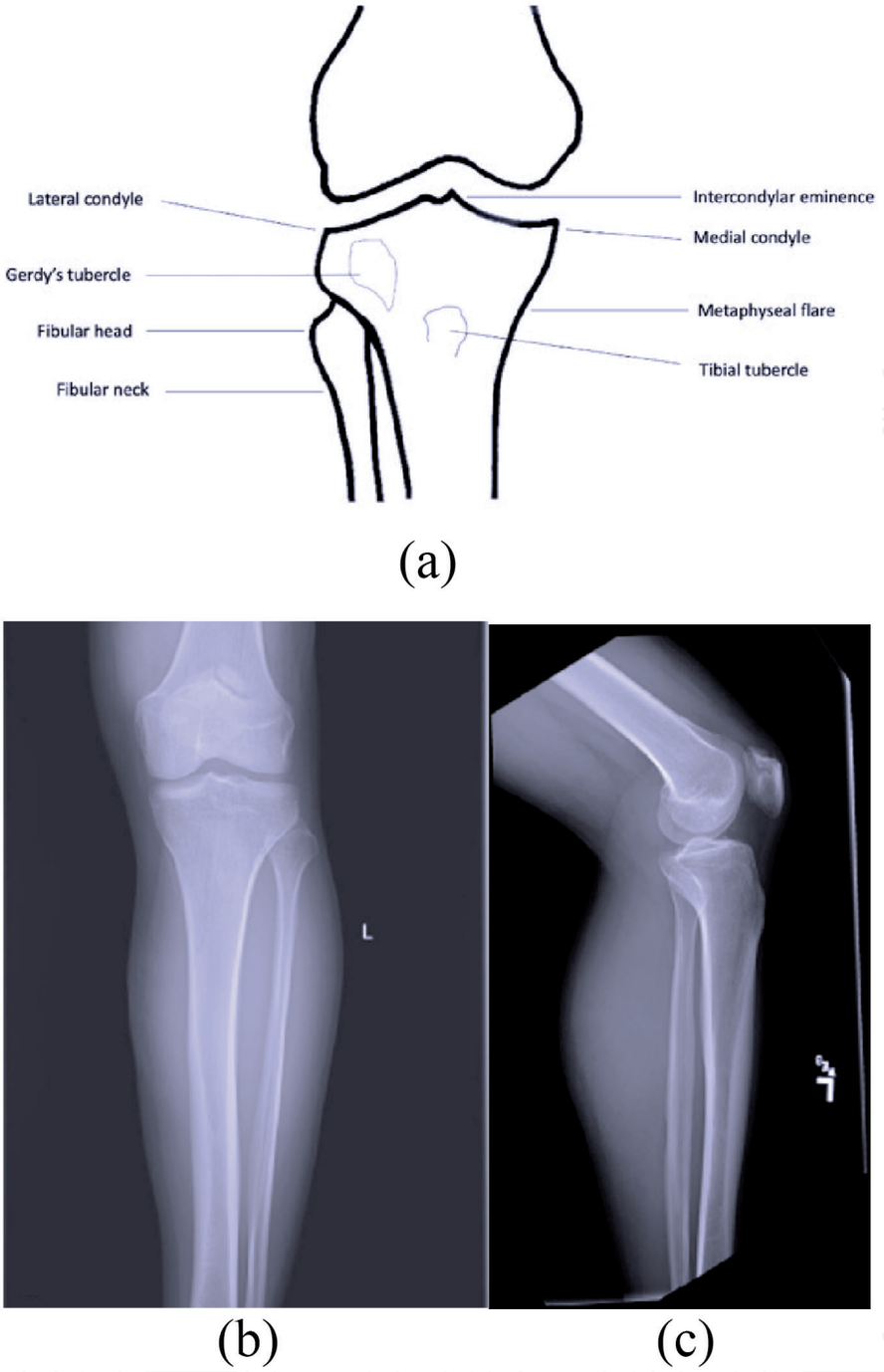


Figure 1.
Proximal tibia anatomy (A) and normal plain radiographs of the tibial plateau anterior-posterior (AP) view (B) and lateral view (C) (Drawing and radiographs: courtesy of John Riehl MD & www.johnriehl.com).

the anterior plateau proximal and posterior plateau more distal [16]. The medial plateau's posterior tibial slope is greater than the lateral plateau's posterior slope [17]. Variations to an individual's normal coronal and sagittal alignment can be crucial for surgical planning, so side by side knee radiographs can be useful in assessing each patient's anatomical variation [15]. The tibial plateau surfaces are covered by articular hyaline cartilage and partially by menisci composed of fibrocartilage. The lateral plateau is more covered by its meniscus than the medial plateau is. The intercondylar eminence consists of two spines, one medial and one lateral. The intercondylar eminence is non-articular and splits the proximal tibia into the lateral and medial plateaus. The medial spine serves as the attachment site of the anterior cruciate ligament and the posterior cruciate ligament attaches posteriorly on the proximal tibia.

4. Classification

Fracture classifications are widely used in clinical practice in order to help communicate and plan treatment as well as to aid in prognosis and to provide standards for clinical research. Commonly used classifications include the Schatzker, Hohl-Moore, Luo, and Orthopedic Trauma Association classifications.

4.1 Schatzker classification

The Schatzker Classification (**Figure 2**) was first published in 1979 and is one of the most commonly used tibial plateau fracture classifications still today [18]. The system divides tibial plateau fractures into six types designated from I to VI. The main limitation of this classification system is its failure to account for many important tibial plateau fracture patterns [19–23]. The Schatzker classification was based on the use of AP plain radiographs of the knee and because of this it is primarily beneficial in analysis of sagittal fracture lines on the medial and lateral plateaus leaving out fractures in the coronal plane.

Type I fractures are pure split fractures. The lateral femoral condyle is driven into the lateral tibial plateau resulting in a sagittal fracture line that splits the lateral tibial plateau with a fracture line running laterally and inferiorly creating a wedge-shaped fragment. There is no associated articular depression or crush. These fractures are most commonly seen in young patients with healthy bone. Percutaneous screw fixation and lateral buttress plate fixation are two surgical treatments commonly employed for these fractures.

Type II fractures are split fractures combined with articular depression. These are similar to type I fractures with a lateral split except there is also lateral articular surface depression. The injury mechanism in type II fractures is typically either high energy, low energy with poor bone quality, or both high energy and poor bone quality.

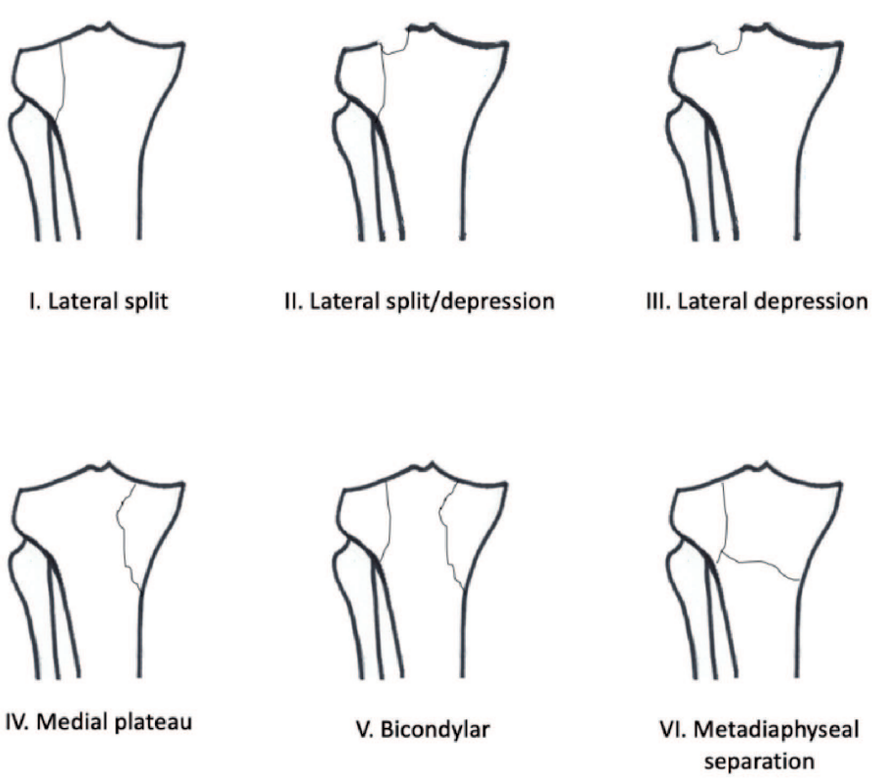


Figure 2.
Schatzker classification of tibial plateau fractures (Drawings created by www.johnriehl.com).

Treatment is dictated by the degree of joint depression, width of condylar split, and knee stability. Many Schatzker type II fractures are treated surgically with the elevation of the articular depression with some sort of bone grafting or graft substitute. The fracture is then often stabilized with articular surface compression and lateral buttress plating. Newer locking plates have shown promise in maintaining articular reduction following compression, especially in patients with poor bone quality.

Type III fractures are pure depression fractures. They do not have a lateral split as seen in type I and II. This is most commonly seen in elderly patients with poor subchondral bone quality from osteopenia or osteoporosis. The femoral condyle presses into the lateral tibial plateau resulting in depression of the articular surface rather than a split because of the underlying poor bone quality. The surgical treatment of these fractures involves elevating and supporting the articular surface.

Type IV fractures are medial condylar fractures (**Figure 3**). Schatzker describes these with two subtypes. In these subtypes, the medial plateau is either split off as a wedge fragment or depressed and comminuted. Either of these subtypes can also include fractures of the tibial spine. Pure medial tibial plateau fractures are rare. Fracture lines usually include the tibial spine and on occasion the lateral plateau. This fracture is more commonly associated with a higher energy mechanism of injury and results in a loss of medial buttressing. Non-operative management will often result in varus deformity. Medial tibial plateau fracture types are considered to be variants of knee dislocations. The ACL and MCL are intact but the lateral plateau and tibial shaft shift laterally away from the medial fragment. This puts patients at higher risk for neurovascular injury and compartment syndrome [24, 25]. The incidence of compartment syndrome may be as high as 53% in this fracture pattern [25].

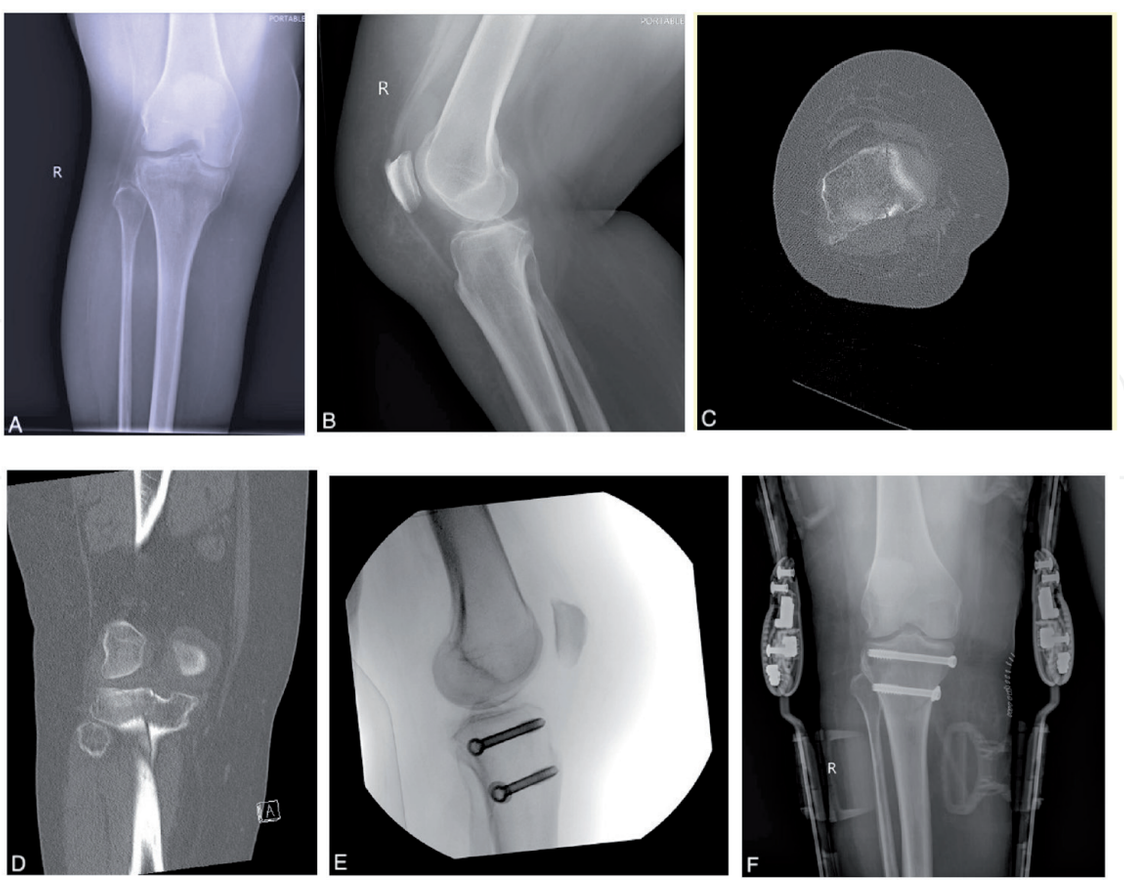


Figure 3.
Patient with multitrauma and a Schatzker IV fracture seen on plain radiographs (A and B) and CT scan (C and D) fixed with compression screws (E and F) (Radiographs and intraoperative imaging courtesy of John Riehl MD).

Type V fractures are bicondylar fractures. In this fracture pattern, both medial and lateral tibial plateaus are fractured. A portion of the metaphysis and diaphysis remain continuous, however, differentiating it from a type VI pattern. Schatzker IV-VI fractures are most often the result of a high energy mechanism of injury. Surgical treatment (when indicated) for type V fractures includes reduction and fixation of both condyles in order to reestablish stability, which is often done with dual approaches and dual plating, but may be done occasionally through a single approach with locked plating depending on the fracture pattern and displacement.

Type VI fractures are tibial plateau fractures with dissociation of the metaphysis and diaphysis. The hallmark of these fractures is either a horizontal or oblique fracture line that separates the diaphysis from the joint segment. These fractures are very unstable. Reduction and fixation of both plateaus is often necessary. These patients are at increased risk for neurovascular and soft tissue compromise [26–28]. The literature reports an incidence of 17–34% of compartment syndrome in this fracture pattern [25, 26, 29].

4.2 Hohl-Moore classification

The Hohl-Moore classification (**Figure 4**) was developed in 1981 and reevaluated in 1987 based on 988 tibial plateau fractures seen at University of Southern California from 1970 to 1979 [2, 30]. It has been used to classify fracture-dislocations not described completely by the Schatzker classification which accounts for around 10% of all tibial plateau fractures. These fracture patterns more commonly involve the lateral plateau (79%) and are more associated with instability, soft tissue injury, vascular compromise, and compartment syndrome [2].

Type I fractures are coronal split fractures. These are found in 37% of tibial plateau fracture-dislocation [30]. These injuries are more clearly seen on lateral radiographs. They usually involve the medial plateau and the oblique fracture runs in a coronal-transverse plane. Common associations include avulsion fractures of the fibula or Gerdy's tubercle and capsular disruptions. Treatment of this fracture ranges from nonoperative casting to percutaneous screw fixation or ORIF with plate fixation. Treatment depends on the stability of the knee and the extent of the tibial plateau the fracture involves.

Type II fractures are entire condylar fractures. Either the entire medial or more commonly the lateral condyle is fractured. The fracture line extends beyond the tibial spine into the opposite plateau differentiating it from a traditional Schatzker I or IV. Soft tissue injury occurs in many of these patients. Opposite compartment collateral ligament injury occurs in up to 50% of patients and neurovascular injury in 12% [30]. Treatments range again depending on stability and extent of articular involvement.

Type III are rim avulsion fractures. The lateral plateau is involved 93% of the time but the medial plateau can be involved as well [2]. Tearing of the ACL or PCL or both is commonly seen. Neurovascular injury is common in this fracture pattern occurring up to 30% of the time [30]. Instability is generally present and usually requires fixation. Soft tissue repair or reconstruction is considered.



Figure 4.
Hohl-Moore classification of tibial plateau fractures (Drawings created by www.johnriehl.com).

Type IV are rim compression fractures. This fracture accounts for 12% of all tibial plateau fracture-dislocations [30]. The lateral plateau is much more commonly involved [2]. Collateral ligament injury of the unfractured condyle commonly occurs and cruciate ligament injury occurs in more than 75% of cases [30].

Type V are four-part fractures. These account for 10% of all fracture dislocations [30]. The medial and lateral condyles of the tibia are fractured as well as the intercondylar eminence. These fractures are highly unstable due to loss of the stabilizing effects of the collateral and cruciate ligaments. Neurovascular injury occurs as high as 50% of the time [30]. With their severe instability, these fractures will usually require surgical management.

4.3 AO/OTA

The AO/OTA classification system is a more comprehensive classification system that was first published in 1996 with the intent of bringing uniformity to all fracture classification [31]. This fracture classification uses two main components, fracture location and morphology. Localization defines the specific bone and the segment of bone involved (proximal, distal, shaft). Morphology classifies the fracture type, group, and subgroup delineating articular involvement and simple vs. multifragmentary patterns. With tibial plateau fractures the localization number is 41 (4 is for the tibia and 1 is for the proximal segment). Morphology types include extra-articular, partial articular and complete articular fractures which are labeled A, B, and C respectively and then fractures are further grouped and subgrouped using numbers 1–3 and 0.1–0.3 further specifying the fractures specific morphology. The AO/OTA system subcategories by degree of comminution of the metaphysis and articular surface making it more comprehensive than the Schatzker Classification and able to distinguish ranges of severity of high-energy patterns.

4.4 Luo three-column classification

The Luo Three-Column Classification (**Figure 5**) was published in 2010 based on 3D conceptualization of the tibial plateau and is useful in describing multiplanar complex tibial plateau fractures [19–21]. Traditionally the treatment

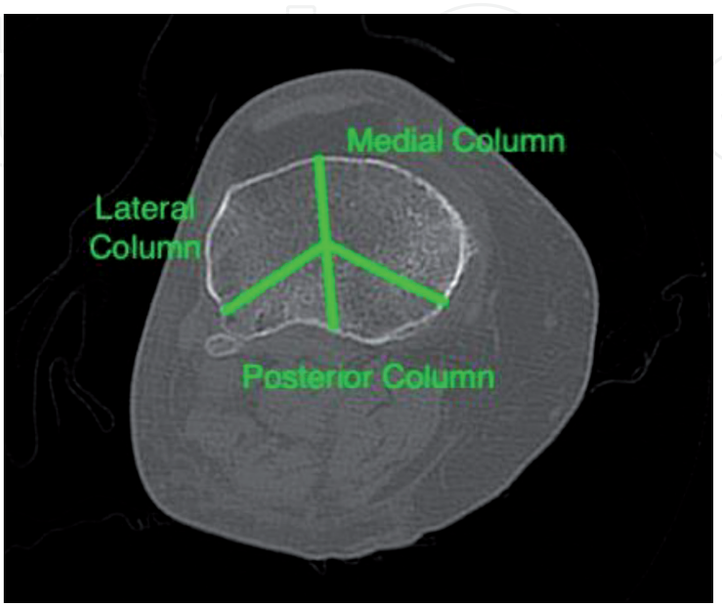


Figure 5.
Luo Three Column Classification (Radiograph courtesy of John Riehl MD).

and classification of tibial plateau fractures was based on two-dimensional classification systems like Moore and Schatzker that used plain radiographs whereas Luo uses axial CT scan images. Luo divides the tibial plateau using three intersecting lines dividing the plateau into three columns (medial, lateral, and posterior). The meeting point is the middle of the two tibial spines. The anterior line connects the midpoint of the plateau to the tibial tuberosity. The medial line travels from the midpoint to the posteromedial ridge and the lateral line is drawn from the midpoint to just anterior to the fibular head. Fractures can be defined as zero, one, two, or three column fractures. With this classification a column is considered fractured only if a cortical split is present in the column, thus a pure depression fracture (Schatzker III) is considered a zero column fracture. This classification system is useful in preoperative planning especially when there is posterior involvement. The posterior segment has been shown to be more prevalent than previously recognized and failure to identify and manage it has been associated with misalignment and functional instability [22, 32, 33].

5. Clinical evaluation

5.1 History

It is important to obtain a thorough history in all tibial plateau fractures. The mechanism of injury should be assessed to give an idea of the severity of the injury and the need for urgent or emergent management. Low energy falls or twisting injuries are more likely to have a lower risk of neurovascular injury or compartment syndrome whereas falls from a height, motor vehicle accidents, and pedestrians struck by a vehicle are more likely to be higher risk and may necessitate more urgent or emergent management. Although knowing the mechanism of injury can be helpful, the fracture pattern is also extremely important in determining the treatment approach and risk for complications. Location and severity of pain, the timing of the injury, associated injuries, and any treatments administered are helpful pieces of information. Past medical history should be assessed for tobacco use, prior knee problems, ambulatory status prior to injury, and medical comorbidities (such as pulmonary disease, diabetes, vascular disease, cancers, renal disease, nutritional deficiencies, previous poor DEXA scan results, as well as use of immunosuppressive medicines). Medical comorbidities and certain medications can affect bone quality, increase risk for postoperative infection, and inhibit wound healing. The patient's activity level, social support, mental condition, and employment status should be known in order to make an appropriate surgical and rehabilitation plan.

5.2 Physical exam

As a part of the initial assessment of tibial plateau fractures, the physical exam should attempt to rule out soft tissue compromise, open fractures, compartment syndrome, and neurovascular injury. A circumferential assessment of the overlying skin and a neurovascular baseline status should be conducted. Circumferential skin and soft tissue inspection and palpation should be done to assess for open injury and severity of soft tissue injury. The severity of soft tissue injury may be further defined based on size, character, and location of swelling, contusions, and fracture blisters. Soft tissue assessment is key to determining surgical approaches and timing.

A non-compressible, firm extremity and pain with passive stretching are suggestive of compartment syndrome. Compartment syndrome should be monitored for throughout the patient's stay since this can develop days after injury or surgery. Measurement of

compartment pressures in high energy fracture patterns or unresponsive patients may be beneficial on presentation and may need to be repeated based on clinical assessment. If the diagnosis is made in conjunction with elevated compartment pressures or if the diagnosis is clear on the physical exam, a fasciotomy will need to be performed.

For high-energy injuries especially (such as fracture-dislocations and metaphyseal-diaphyseal dissociation patterns) it is imperative to obtain a thorough neurovascular assessment. Vascular injury is rare overall but delays >8 h in diagnosis and surgical intervention can result in lower extremity amputation rates as high as 86% [34–36]. Neurovascular assessment should include testing for sensation patterns in the distribution of tibial, superficial peroneal, saphenous, and sural nerves as well as extremity color and temperature, capillary refill, and distal pulses including the posterior tibial and dorsalis pedis. Results should be compared with the contralateral side. Any differences in pulses or sensation can be further investigated with an ankle-brachial index (ABI) measurement. For some high-energy fractures, consideration may be given to obtain ABI regardless. An ABI > 0.8 has a remarkably high negative predictive value, approaching 100%. With ABI <0.9 further vascular assessment with a CT arteriogram and/or a vascular surgery consultation should be obtained [34].

Varus and valgus stress testing may be necessary to assess for instability if this is unclear based on radiographic assessment. Valgus instability is important in determining indications for surgical management, especially in lateral tibial plateau fractures. If instability is present it may not resolve without surgical fracture reduction and fixation [37, 38].

6. Radiology (plain radiographs, stress views, CT, MRI)

Imaging is a large part of the surgical planning process. The imaging modalities used range from plain radiographs to CT with 3D reconstruction and MRI.

6.1 Plain radiographs

The diagnosis of a tibial plateau fractures is usually made initially by plain radiographs. For some simple fractures, this may be the only imaging modality necessary. Typically anteroposterior (AP) and lateral views of the knee are obtained for plain radiograph assessment. An additional view, the caudal view (also known as the "tibial plateau view") is shot 10–15° caudally from a typical 90° AP view and is used to provide a view in line with the plane of the plateau. This is done to account for the 15° posteroinferior slope of the plateau surface. In this view, the proximal articular surface can be viewed as a single radiodense line which allows better assessment than lateral and AP views of articular depression [16]. Radiographs of the entire tibia should be obtained as well. Oblique views have also been used to assess the fracture lines and degree of displacement, however, they are not routine now that computed tomography (CT) scans have largely filled the need that was once provided by additional views. Of note, it has been shown that plain radiographs alone can miss insufficiency fractures in osteopenic patients [39].

Traction radiographs are helpful when there is substantial displacement to better assess the fracture anatomy in both plain radiographs and CT scans. This can be obtained by manual traction or spanning external fixators.

Contralateral radiographs may be helpful in severely comminuted fractures to serve as a template for reduction, condylar width, coronal alignment, and the posterior slope of the plateau in the sagittal plane.

6.2 Computed tomography (CT)

Computed tomography (CT) scans have become a routine part of the assessment of tibial plateau fractures (**Figure 6**). Axial CT cuts are especially helpful in visualizing posteromedial fracture lines (**Figure 7**). Axial CT and reconstructions provide important insight into fracture anatomy as well as serving as an aid in preoperative planning. It has been demonstrated in numerous studies that the use of CT scans allows surgeons to more reliably classify fractures which aids in providing the most appropriate treatment formulation [40–46]. CT allows accurate visualization of articular displacement and comminution more readily than what is observed with plain radiographs [46]. CT also allows for better assessment of location and orientation of fracture lines as well as the degree of depression and size of articular segments, which provides important information in preoperative planning.

6.3 Magnetic resonance imaging (MRI)

Magnetic resonance imaging (MRI) continues to gain wider acceptance in use for evaluation of tibial plateau fractures. Some argue it is indicated to adequately assess and treat soft tissue injuries especially in fractures due to high energy mechanisms which have a high percentage of ligamentous and meniscal pathology [47]. MRI is more sensitive than CT in detecting ligamentous and meniscal injuries which are both common occurrences in tibial plateau fractures [48]. MRI is the gold standard when it comes to detecting occult fractures not seen on plain radiograph.

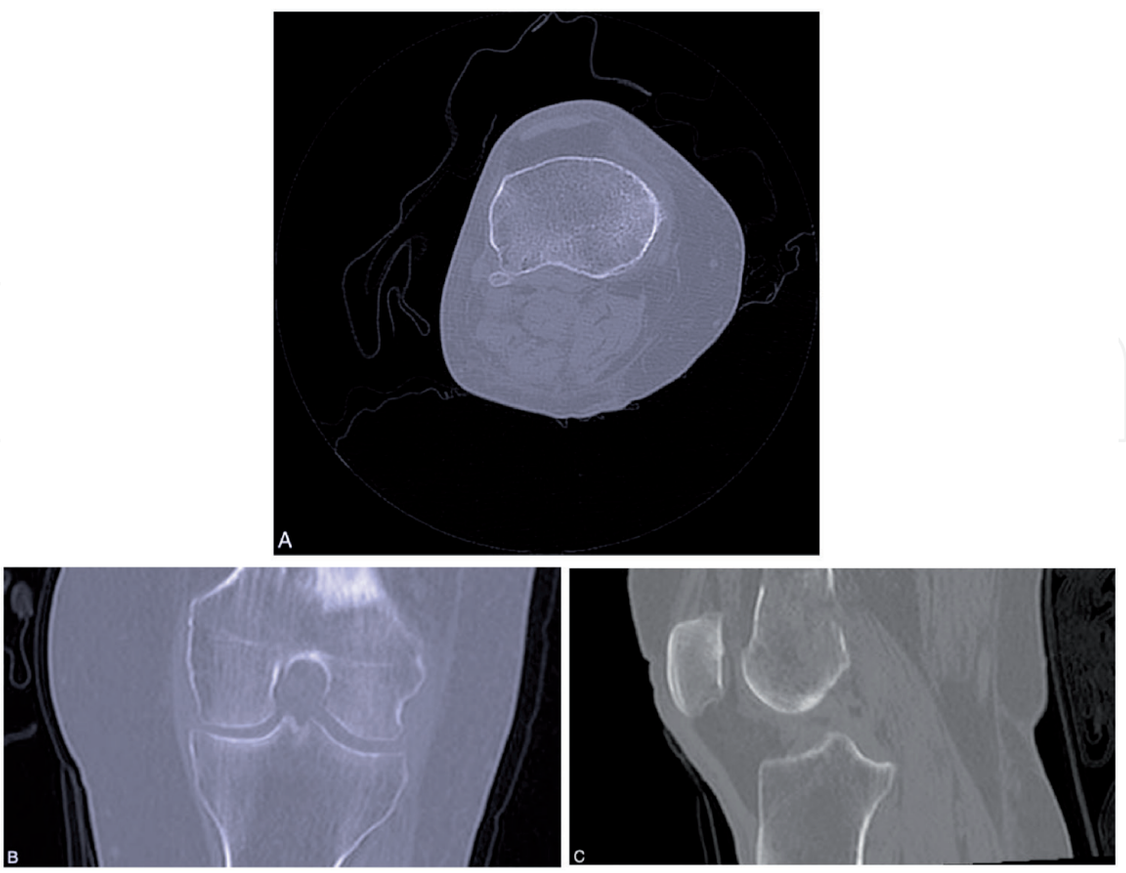


Figure 6.
CT of a normal tibial plateau axial view (A), coronal view (B), and Sagittal view (C) (Images courtesy of John Riehl MD).

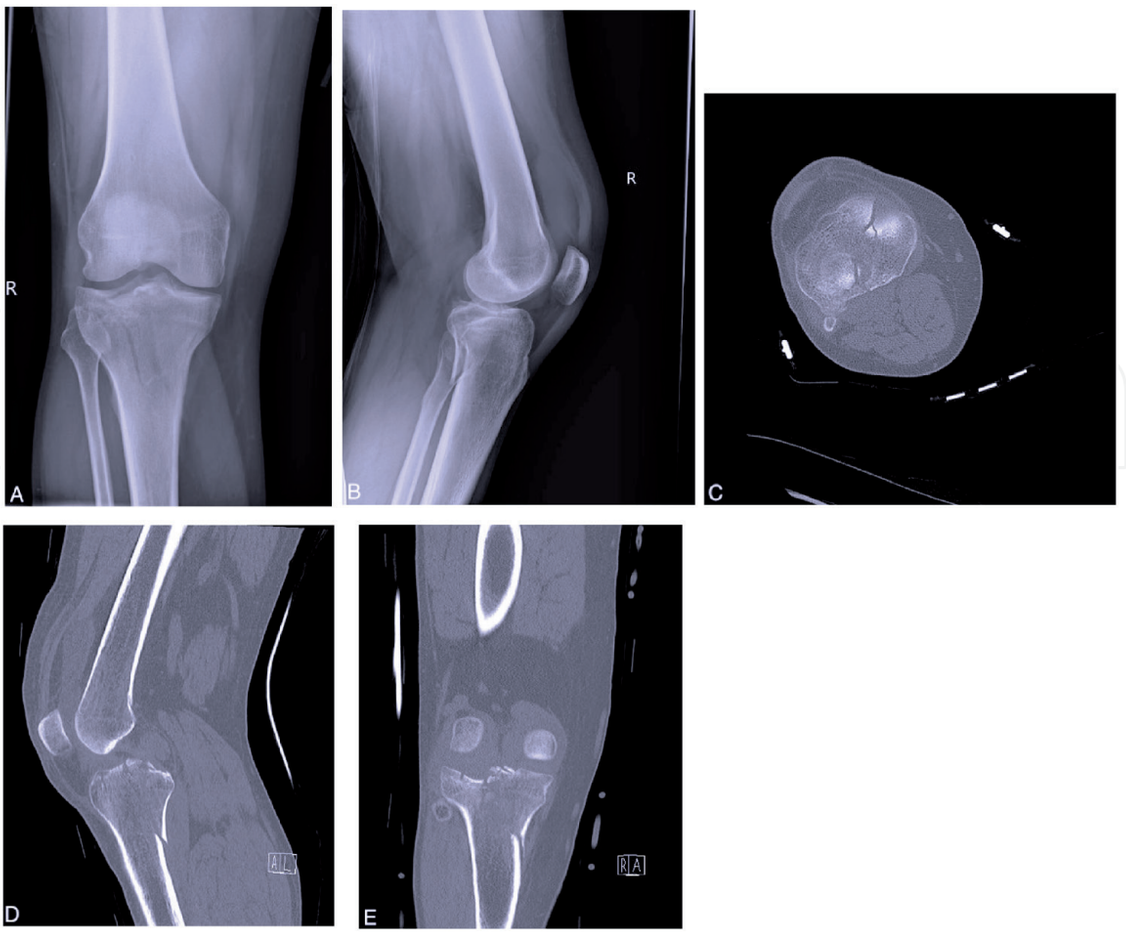


Figure 7.
CT allows for better visualization and more accurate classification compared with plain radiographs (A,B) of this bicondylar tibial plateau fracture more clearly seen in the axial view (C), sagittal view (D), and coronal view (E) (Images courtesy of John Riehl MD).

7. Compartment syndrome

Compartment syndrome (CS) is a serious complication of trauma and other conditions that cause bleeding, edema or vascular compromise. Progressive swelling of a limb increases mass within the myofascial compartment due to accumulation of blood or fluid as well as inflammation. The inelasticity of the muscle fascia and connective tissue results in increased pressure in the compartment compressing thin-walled veins leading to venous hypertension and tissue ischemia. Compartment pressure increases further once cellular death accelerates and lysis of cells releases osmotically active fluid into the interstitial space. Myonecrosis may occur within 2 h of injury [49] and after 6–8 h irreversible nerve damage occurs.

CS can be quite common in certain patterns of tibial plateau fractures, and has been found to be as high as 53% in Schatzker type IV fractures [25]. Overall the reported incidence of CS following tibial plateau fracture ranges from 0.7 to 12% [26, 29, 50–53]. Although a somewhat controversial topic with conflicting findings in the literature, acute compartment syndrome requiring fasciotomy has been reported in some studies to significantly increase the rate of non-unions [27] and infections [27, 54–56]. On the other hand, Ruffalo et al. [57] found no increase in the association of nonunion and infection. In medial plateau fractures, one study found a 67% CS rate when the fracture entered the joint line lateral to the tibial spine and exited through the medial metaphysis, 33% CS rate when the fracture is within the spine and 14% when the fracture is medial to the intercondylar spine [24]. CS was found to have a

higher incidence in Schatzker type IV (53%) compared with type VI (18%) fracture patterns [25]. However, this result was not consistent throughout the literature, and another group reported compartment syndrome to be relatively rare in type IV and only type VI patterns were significantly more likely to develop it [26]. CS was least common in Schatzker type I and II fractures [26]. The two biggest radiographic predictors of CS were fracture length and fibular head fracture [26, 28].

Early diagnosis of CS is crucial for avoiding the substantial morbidity caused by its late sequelae. A clinical diagnosis of CS can be difficult to make even when the generally accepted clinical signs of CS are present, which include worsening pain that is out of proportion to the clinical situation, pain with passive stretch, and paresthesia/hypoesthesia. These clinical signs and symptoms have been shown to have low sensitivity [58, 59]. Also, clinical findings can be difficult to obtain in polytrauma patients and impossible to assess in sedated patients. Late diagnosis can be diminished by frequent or continuous measurement of intramuscular pressure (IMP). When to initiate IMP monitoring is still controversial but whenever clinical examination is unreliable in an at-risk patient measurement of IMP could be considered. When using IMP, diastolic differential pressure (delta p) <30 mm Hg has been used as a threshold for compartment syndrome requiring fasciotomy. Prayson et al. [60] warn against using a single measurement <30 mm Hg alone as this may not be clinically significant. In their series they found that this can occur transiently in patients without evidence of compartment syndrome. About 84% of their lower extremity fracture patients had at least one delta p < 30 mm Hg and 58% had a delta p < 20 mm Hg. Instead, McQueen et al. [61] suggest a threshold for fasciotomy of an IMP<30 mm Hg for two consecutive hours or more, which had a sensitivity for diagnosis of CS of 94%.

One of the potential pitfalls of using pressure measurements is that intraoperative diastolic blood pressure measurements have been shown by Tornetta et al. [62] to give spuriously low delta p values and lead to unnecessary fasciotomies. The authors of this study recommend use of preoperative blood pressure values when calculating delta p in patients under general anesthesia unless the patient is to remain under anesthesia for numerous hours. IMP values also vary with proximity to the fracture site and muscular depth. Pressures are highest when measuring within 5 cm of the fracture [63] and centrally in the muscle [64]. Most recommend obtaining the measurement within 5 cm of the fracture site but the standarizability of this is still controversial.

8. Associated soft tissue injuries

Soft tissue injuries occur commonly in tibial plateau fractures. Overall soft tissue injury incidence has been estimated between 73 and 99% from MRI studies [65–67]. In an MRI analysis of 103 operative tibial plateau fracture patients, Gardner et al. [65] only found 1 patient who had complete absence of soft tissue injury. Collateral or cruciate injuries were sustained in 77% of patients and lateral and medial meniscus pathology was seen in 91% and 44%, respectively. Similar results were seen in a study on nonoperative tibial plateau fracture patients with 90% having significant soft tissue injuries, 80% with meniscal tears and 40% with ligament disruptions [66].

8.1 Ligament injury

Overall ligamentous injury incidence has been estimated by MRI studies to be between 40 and 77% [47, 65, 66]. MRI studies in the literature estimate that complete anterior cruciate ligament (ACL) tears have an incidence of 11–44%, posterior cruciate ligament (PCL) 8–40%, lateral collateral ligament (LCL) 29%, medial collateral ligament (MCL) 32%, and posterolateral corner (PLC) injuries 45–68% [47, 65]. Higher energy fracture (type IV–VI) patterns have higher incidences of ligamentous injuries.

8.2 Meniscal injury

The incidence of meniscal injury associated with tibial plateau fractures based on preoperative MRI has been reported from 49 to 91% [47, 65–68]. Degree of lateral articular depression and condylar widening has been shown to directly correlate with frequency of soft tissue injuries in many studies [69–71]. Gardner et al. [72] in their MRI study on lateral split depression fractures found that articular depression >6 mm and condylar widening >5 mm was associated with a lateral meniscal injury 83% of the time. Stahl et al. [73] in their 661 patient intraoperative visualization study found that the most common Schatzker pattern associated with a lateral meniscus tear was the split depression fracture (45%) and the most common associated meniscal tear for this fracture pattern is peripheral rim avulsions (83%). 86% of Schatzker IV fractures had an associated medial meniscus tear [65].

8.3 Soft tissue diagnosis and treatment

Diagnosis of soft tissue injury based on physical exam findings is difficult due to the pain, swelling, and instability that is frequently present with these fractures. Recent studies have utilized preoperative MRI or operative arthroscopy to evaluate the extent of soft tissue damage. Treatment and pre-operative imaging protocols of ligamentous and meniscal pathology are controversial. Some authors advocate for MRI screening and surgical repair [47, 74, 75] whereas others have shown good results with no surgical intervention and advocate against MRI screening [67, 76–78]. Others argue against the use of pre-operative MRI because it overstates the true incidence of meniscal tears that require operative management, and instead they recommend direct visualization for lateral split depression fractures because the incidence of meniscal injury is sufficiently high enough to warrant this [73]. The clinical impact of identification of ligament and meniscal injuries is not clear from the current studies in the literature. Determining the functional impact would require a study that randomizes ligament treatment into surgical and nonsurgical groups. The literature does provide us with a clearer indication for nonoperative management on specific ligamentous injuries like MCL tears which can heal with nonoperative care with excellent functional outcomes. It remains controversial whether ACL or PCL surgical reattachment is indicated in the setting of tibial plateau fractures.

9. Nonsurgical treatment

Nonsurgical management is an option for certain fractures and specific clinical circumstances. Immediate passive range of motion with non-weight bearing for anywhere from 6 to 12 weeks in hinged bracing is currently preferred because it allows for mobility while maintaining coronal support. Indications for nonsurgical treatment include undisplaced or minimally displaced fractures, less than 5° of varus/valgus instability, delayed presentation, significant medical comorbidities precluding patients from operation, nonambulatory patients, and elderly patients with low functional status where deformities would be tolerated. Key to selecting patients for nonsurgical management is the ability to predict the post-treatment risk for deformity, malalignment, and instability. Angular malalignment is not well tolerated by patients and will cause cosmetic issues, articular cartilage overload, and increased likelihood of knee instability which can cause patients to be unbalanced and have an increased risk for falls. Risk for instability can be further assessed with a knowledge of the patient's demographics, activity level, comorbidities, and limb alignment. Imaging assessments that are helpful in assessing risk for instability include bone quality, fracture type, condylar width, degree of articular depression, and extent of fracture comminution.

Looking at the fracture pattern can further help your decision making. Larger lateral split depression fractures and all medial plateau fractures have a much higher propensity to collapse into valgus and varus deformity respectively whereas smaller fragment Schatzker II fractures can be amenable to nonsurgical management. Nearly all unicondylar medial tibial plateau fractures with displacement and displaced bicondylar fractures should be operated on [79].

Surgical treatment is commonly utilized in order to assure accurate limb alignment, gain early mobility, and achieve a better reduction. However, it behooves the clinician to remember that nonsurgical treatments can achieve excellent outcomes for patients unable or unwilling to undergo surgery despite articular incongruities and displacements [80].

10. Surgical treatment

Until the 1950s tibial plateau fractures were mostly treated nonoperatively with cast immobilization, however, operative treatment is currently the standard of care in the majority of tibial plateau fractures overall. The goals of surgical treatment of a tibial plateau fracture are to restore articular congruity, axial alignment, joint stability, and knee functionality. Fixation must be able to maintain stability postoperatively while allowing for early motion and minimizing complications.

10.1 Surgical indications

Operative management is indicated for tibial plateau fractures where near-anatomic alignment cannot predictably be achieved based on fracture pattern, physical exam findings, and radiographic measurements. In young active patients without comorbidities, fracture patterns that necessitate operative management include bicondylar plateau fractures and shaft dissociation patterns. Also, the majority of medial and lateral plateau fractures require surgical management unless they are minimally displaced and normal tibial/knee alignment can be achieved without fixation.

Another proposed indication for surgery is based on the amount of articular depression. This indication is more heavily debated and different cutoffs are found throughout the literature. Cutoffs for articular depression that result in poor outcomes if not operatively managed range from >2.5 to >10 mm [37, 38, 79, 81–85]. Unfortunately, the accuracy and reliability of measuring degree of articular depression is questionable. Martin et al. found that independent observers make articular depression measurements that differ by 12 mm or more 10% of the time [86]. Having a greater degree of articular depression than a predetermined cutoff should not be the sole basis for proceeding or not proceeding with surgery.

Poor functional outcomes and a high incidence of meniscal pathology have led many authors to suggest a condylar width increase of >5 mm and varus/valgus instability >5° as an indication for surgery [38, 72, 79]. However, Wang et al. [87] were unable to predict soft tissue injury based on tibial plateau widening. Johannsen et al. [14] suggest that discrepancies in the literature on condylar widening can be reconciled by instead using a ratio of the articular widths of the femur and tibia in order to minimize problems in measurement with magnification and calibration.

In the elderly, inactive or less active, or patients with comorbidities that place them at higher surgical risk, the decision whether to proceed with operative management needs to be more carefully assessed. A risk benefit analysis for each individual patient needs to be weighed in order to decide appropriate management. Elderly and the less active will be less affected by minor deformity if their functional demands are less.

10.2 Temporary external fixation

External fixation use has continued to evolve in the temporary and definitive management of these injuries. External fixation is commonly used as a temporary treatment by spanning the knee. This technique realigns and restores length allowing for soft tissue recovery prior to definitive treatment with internal fixation. Egol et al. [88] demonstrated the effectiveness of this technique with relatively low rates of complications in patients with high-energy tibial plateau fractures. With minimal soft tissue complications, the group recommended staged fixation for all high-energy fractures of the proximal tibia. Temporary external fixation not only provides skeletal stabilization to maintain length, alignment, and rotation, but also allows for easy access for wound and blister management. Studies have been performed, however, that show immediate fixation of most high energy tibial plateau fractures is safe and effective [89–91].

10.2.1 Definitive external fixation

Definitive external fixation typically uses a fine wire external fixator to compress against the fracture segments in conjunction with limited-access internal fixation which allows for minimal soft tissue disruption and permits early range of motion compared to ORIF with similar stabilization. Indications for definitive external fixation include severe open fractures and highly comminuted fractures where internal fixation is not possible. External fixation can also be used in conjunction with minimal internal fixation such as lag screws providing compression to the articular fragments. Multiple studies report equivocal rates of infections and complications when comparing ORIF and external fixation [76, 92, 93]. On the contrary, Krupp et al. [94] conducted a study comparing external fixation and open reduction of bicondylar tibial plateau fractures and they report significantly higher rates of malunion (7% vs. 40%), infections (7% vs. 13%), knee stiffness (4% vs. 13%) and overall complications (27% vs. 48%) of external fixation compared to ORIF. Shao et al. [56] also report significantly higher surgical site infection rates with external fixation.

10.2.2 Pin site placement for external fixation

Pin site placement and its importance varies between surgeons and in the literature. Classically, it is recommended that pins should be placed outside the zone of future plate placement and at least 14 mm distal to the joint line to avoid penetration into the joint [95]. However, there is new conflicting data on whether this has any effect at all on infection rate. Labile et al. [96] found no increased infection rate whereas Shah et al. [97] found the opposite. However, until we have a larger study to give us a definitive answer the recommendation is to place pin sites outside of the zone of injury in the case of temporary external fixation, and outside of the knee capsular reflection when placing wires for definitive treatment. With that being said, these recommendations should not outweigh the goal of achieving restoration of length, alignment, and stability of the fracture regardless of plans for future surgery.

10.3 Open reduction internal fixation (ORIF)

Open Reduction internal fixation (ORIF) is the most commonly used operative treatment for tibial plateau fractures. Multiple surgical approaches have been described in the surgical treatment of tibial plateau fractures. Anterolateral and posteromedial are the two surgical approaches that are most commonly used to reduce and internally fix tibial plateau fractures. They are used either together or in isolation depending on the fracture pattern. Dual incision approach is as effective in obtaining

reduction and much safer than extensile approaches with no significant increase in infection rates seen [54, 98]. There are also multiple other posterior approaches described in the literature that have become popular. The fracture pattern is the main determinant of the approach and fixation technique. Direct anterior approaches can be helpful in conjunction with parapatellar arthrotomy in order to gain direct visualization and access to a greater area of the articular surface, especially centrally. It is important to note that when a direct anterior approach is used, soft tissue dissection should only proceed in one direction, medial or lateral from the incision. Anterior midline approaches with large dissection medial and lateral on the plateau are not recommended due to the devascularization caused to the plateau itself.

Plates and screws are the most common implants used in the fixation of tibial plateau fractures. Manufacturers have available pre-contoured periarticular plates as well as locking plates that are designed to fit against the proximal tibial surface. The plates can serve different functions depending on the anatomic placement and fracture pattern. Anterolateral plate placement in split depression fractures allows the plate to act as a buttress of the lateral tibial condyle supporting the weakened lateral cortex. On the other hand posteromedial plate placement functions as an antiglide device that resists shearing forces. Precontoured medial plates are also available from some manufacturers. Recently, plates have become thinner and both lateral and medial plates are most commonly 3.5 mm instead of the previous 4.5 mm. This allows the plates to fit closer to the bone and the corresponding 3.5 mm screws can be placed closer to the articular surface to better support reduced fragments. The plates also allow for subchondral screws to be placed parallel to the articular surface through the head of the plate, termed "rafting" (**Figure 8**), to significantly minimize postoperative articular depression [99]. Medially, plate position is more important than screw placement. The plate position must be closely intimate to the apex of the fracture and a screw near the apex of the fracture will help to ensure close apposition of the plate in this critical area.

Lateral plates alone can occasionally be used for bicondylar and Schatzker type VI fractures (**Figure 9**). These plates must resist axial, rotational, and bending force. The addition of locking screws to the plate has been a major advance in moving away from dual plating in some instances. Bending forces tend to create a varus deformity, however, and this must be considered if planning on using a single lateral plate in a bicondylar fracture pattern. Decreasing this varus collapse with fixed angle devices has decreased the need for dual plating in some instances, but this alone may be insufficient for providing adequate support for an unstable medial column. Although locking technology is available for most tibial plateau specific implants, its use in unicondylar fractures for buttress or antiglide plates is of unknown significance.

A special consideration must be taken for posterior plateau fragments which may not be adequately buttressed by medial or lateral plating. Involvement of the posterior segment has been shown to be more prevalent than previously recognized and failure to identify and manage it has been associated with misalignment and functional instability [22, 32, 100]. This could also be one of the reasons for failure in some fractures that still collapse secondarily after fixation [98, 101]. The use of the three column concept [19–21] may help in adequately addressing these fractures.

10.4 Void filling

Articular depression fractures (i.e., Schatzker II and III) result in a loss of cancellous bone volume due to the compression of cancellous trabeculae (**Figure 10A**). As a result of this, reduction of depressed tibial plateau articular fragments leads to an area void of bone underneath the reduced fragment (**Figure 10B** and **C**).These fragments in turn need to be adequately supported in order to reduce the risk of redisplacement. Metaphyseal void filling in these fracture patterns can be done to reduce this risk and to increase stability (**Figure 10D**).



Figure 8.
AP radiograph of a medial tibial plateau fracture treated by ORIF with a medial buttress plate (Radiograph courtesy of John Riehl MD).

A wide range of options for materials to fill these voids are available. Autograft bone can be used, but supply is limited, extra surgical time is required, and there is associated morbidity at donor sites. Complications range from temporary pain or numbness, superficial infections, seromas, and minor hematomas to chronic pain, herniation of abdominal contents through donor sites at the pelvis, vascular injuries, deep infections, neurologic injuries, deep hematomas and iliac wing fractures.

Allografts have the advantage of no donor site morbidity and increased quantity available from bone banks. Osteogenesis, osteoinduction and osteoconduction are benefits and properties of autografts whereas only osteoconduction and poorer osteoinduction are provided by most allografts. As a result, the healing of allografts is often slower than the healing that occurs with autograft. The possibility of donor disease transmission exists but this risk is significantly reduced with donor screening and tissue testing. Segur et al. [102] found no complication secondary to the allograft transplantation in their short term follow up study (non-union, infection, fracture, resorption and transmission of disease).

Several commercially available graft substitutes are now used in the treatment of tibial plateau fractures. Most recently, phase-changing cements have shown promising results with better mechanical properties to autologous and allogenic bone grafts. Calcium phosphate cement was significantly stiffer and displayed significantly less



Figure 9.
AP radiograph of a Schatzker VI tibial plateau fracture treated by ORIF with a lateral plate and three independent lag screws (Radiograph courtesy of John Riehl MD).

displacement at 1000 N when compared to cancellous bone in a split depression fracture cadaver model study [103]. Lobenhoffer et al. [104] noted improved radiographic outcomes and earlier weight bearing due to its high mechanical strength. Russell et al. [105] noted a significantly higher rate of articular subsidence during the 3- to 12-month follow-up period in the autogenous bone graft group compared with the calcium phosphate group in their 119-patient study that included all six Schatzker patterns. Welch et al. [106] found similar results in their study comparing autologous bone graft with calcium phosphate in lateral articular depression fractures in goats. They found the autograft did not maintain anatomic reductions and calcium phosphate had significantly reduced fracture subsidence compared to the autograft at all time points. Recently, the use of calcium phosphate has also shown improved results in complex tibial plateau fractures (**Figure 11**) with significantly lower rates of articular step-off [107].

Another option that has been recently studied is beta-tricalciumphosphate which is a synthetic bone substitute that is biocompatible, biomechanically stable, and osteoconductive. Rolvien et al. [33] studied the long term results in tibial plateau depression fractures that used beta-tricalciumphosphate. They found no

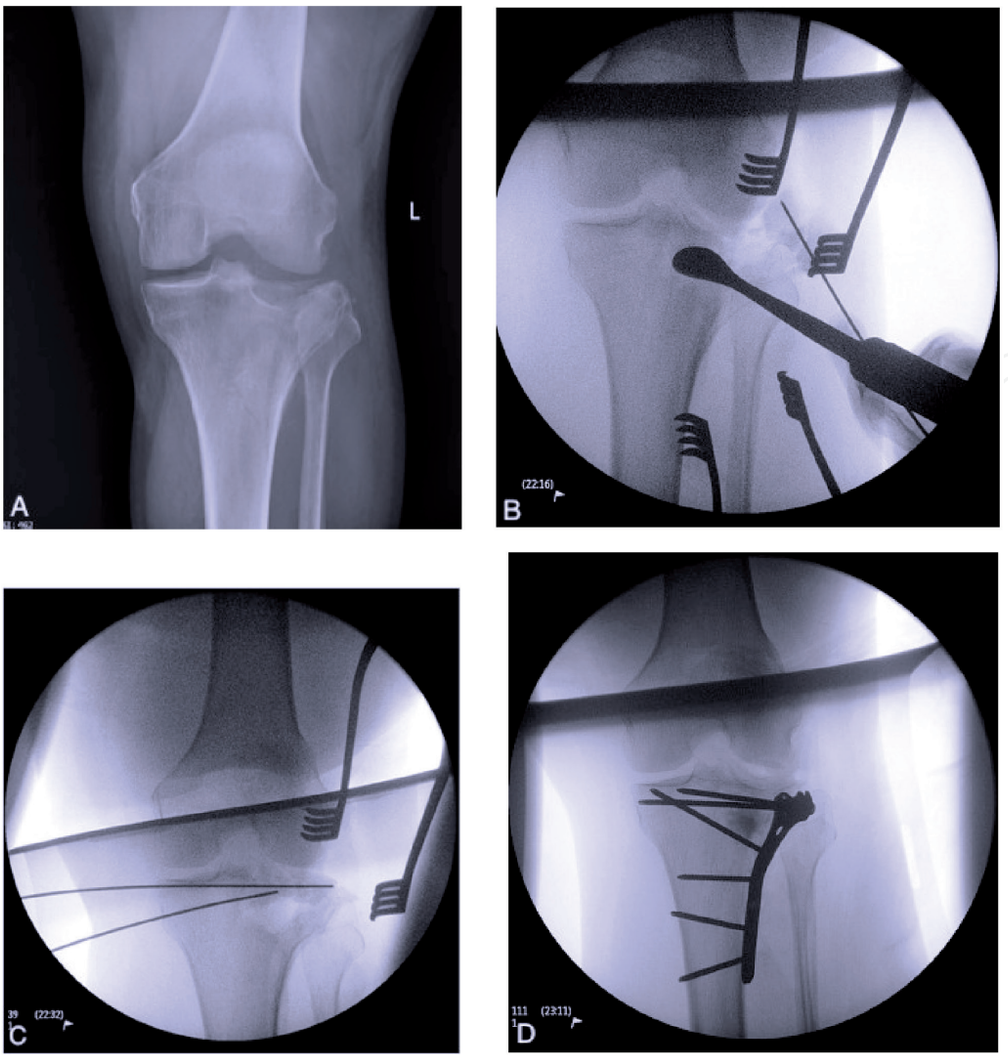


Figure 10.
Preoperative AP (A) X-ray of a Schatzker II split depression fracture. Intraoperative fluoroscopy shows elevation of the articular segment with a Cobb elevator (B), provisionally stabilized with K-wires creating a metaphyseal void (C). Final intraoperative imaging shows the reduced fracture with a lateral plate and calcium phosphate void filling cement (D) (Radiographs courtesy of John Riehl MD).

non-union or loss of reduction at a mean of 36 months of follow up. About 83% of patients achieved excellent reduction with <2 mm residual incongruity and 82% of patients achieved excellent functional outcomes. Histologic analysis of 7 of the patients demonstrated incorporation of bone around the graft but complete resorption was not observed. They concluded that beta-tricalciumphosphate represents an effective and safe treatment for these fractures, but its biological degradation and replacement is less pronounced in humans compared with previous animal studies.

Calcium sulfate has also been used as a void filler. Yu et al. [108] followed 28 patients for a mean of 14.6 months after using calcium sulfate as a void filler and found that 67% of the graft material was incorporated at 8 weeks and full incorporation was seen at 12 weeks. Fractures healed in all patients, and no nonunion or infection occurred. Wound exudations were observed in two cases, and the wound healed in 2–3 weeks with wound dressing. However, Goff et al. [109] showed possible reason for caution with the use of calcium sulfate in their more recent meta-analysis including 672 patients, comparing multiple void filling substitutes. They reported secondary collapse of the knee joint surface ≥2 mm in 8.6% in the biological substitutes (allograft, demineralized bone matrix, and xenograft), 5.4% in the hydroxyapatite, 3.7% in the calcium phosphate cement, and 11.1% in the calcium sulfate cases. It should be noted that the sample size of the calcium sulfate cases in this study was <40.

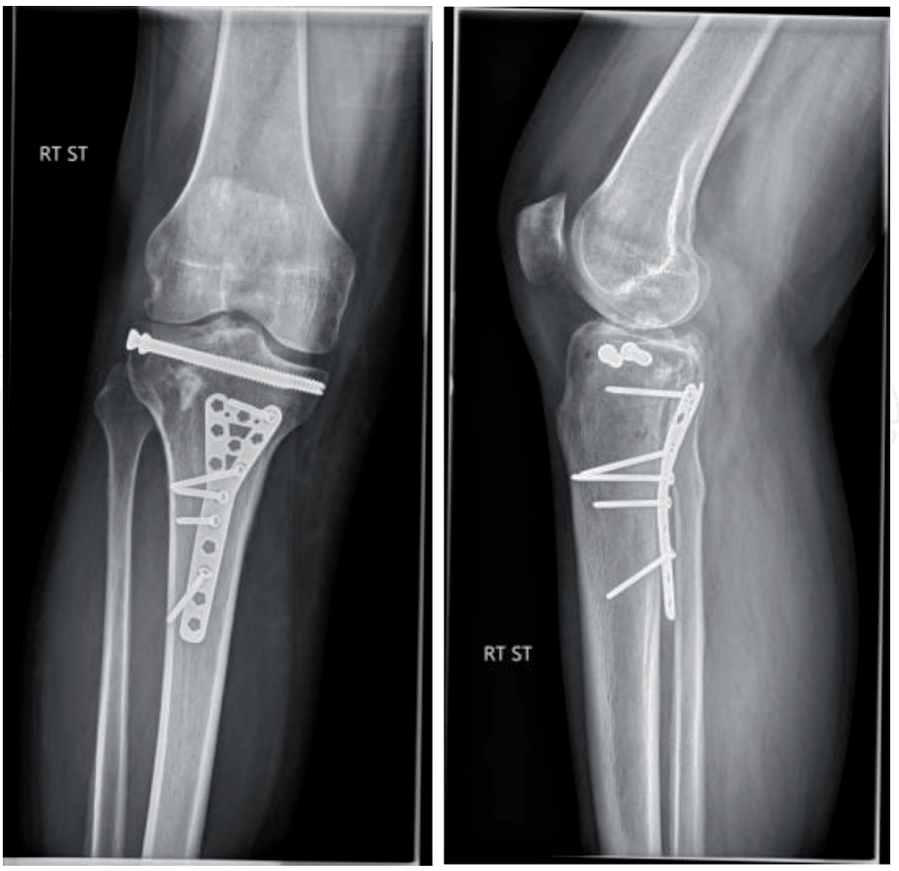


Figure 11.
AP and lateral X-ray showing reduction and fixation of a bicondylar tibial plateau fracture with posteromedial buttress plating, lateral lag screws, and quickset calcium phosphate (Radiographs courtesy of John Riehl MD).

Biphasic bone grafts that include calcium sulfate may give better results than calcium sulfate alone. A 2020 prospective, randomized control, multicenter study was conducted by Hofmann et al. [110] comparing autologous iliac bone graft to biphasic hydroxyapatite and calcium sulfate cement (60% calcium sulfate and 40% hydroxyapatite) in tibial plateau fractures. They concluded that the bioresorbable cement used was noninferior in both patient reported and radiographic outcomes to autologous bone graft in tibial plateau fractures.

10.5 Minimally invasive plate osteosynthesis (MIPO)

MIPO is a plating technique that enables indirect fracture reduction and percutaneous submuscular implant placement which improves healing rate due to its minimal disruption of soft tissues, including the periosteum and its vascularity [111–113]. Farouk et al. performed a cadaver study comparing post-procedure bone blood supplies in conventional plate osteosynthesis versus MIPO. Perforating and nutrient arteries remained intact and better periosteal and medullary perfusion was observed in the MIPO group compared to conventional plating [113]. ORIF allows for direct visualization, reduction, and fixation, but it is at the cost of substantial soft tissue dissection, increased risk of wound breakdown, stiffness, and deep infections [114]. Surgical techniques can provide benefits of both ORIF and MIPO techniques with the utilization of a small incision near the joint line with direct visualization and fixation of the joint while simultaneously performing percutaneous minimally invasive techniques in placement and securing the shaft portion of a plate. While some surgeons prefer to place percutaneous screws with use of fluoroscopy and feel, percutaneous guides can assist in efficient and accurate placement of shaft screws in these plates.

10.6 Intramedullary nailing

Intramedullary nailing (IMN) has many advantages for fracture fixation. These include minimally invasive exposure, biologically friendly implant insertion, longer implants to span more complex fractures, and load sharing fixation that allows for earlier weight bearing. With previous implants, concern for malreduction with intra-articular fractures was due to the nails inherent design flaws that failed to align properly with metaphyseal and epiphyseal segments. Recent advances in the implants have placed multiplanar interlocking screws clustered near the ends of nails to facilitate greater purchase in proximal segments and the ability to lock the interlocking screws to the nail creating a fixed angle construct which theoretically improves stability [115]. With these new improvements intramedullary nailing can be safely used to



Figure 12.
Tibial plateau fracture with diaphyseal extension treated with a combination of lateral buttress plating and a tibial nail (Radiograph courtesy of John Riehl MD).

stabilize proximal intra-articular tibial fractures in which a stable articular block can be created. Often, this is performed by placement of independent lag screws proximally and outside of the intended path for the nail, or with buttress plating used with techniques compatible with nailing (**Figure 12**). Intramedullary nailing can especially be considered in tibial fracture patterns with diaphyseal extension, segmental injuries, or patients with increased risk for wound complications [115, 116]. Patients at increased risk for wound complications include patients with morbid obesity, diabetes, peripheral vascular disease, thin skin and compromised soft tissues. Prior to nailing, fractures should be converted from C-type articular fractures to A-type fractures by obtaining anatomic reduction and stable fixation of the articular surface. Contraindications to nailing may include tibial tubercle involvement in the fracture pattern and inability to reconstruct the articular surface outside of the planned nail trajectory. Fractures with tibial tuberosity fragments are poor candidates because the nail can cause a substantial anteriorly directed deforming force [115].

Intramedullary nailing reliably leads to excellent outcomes when performed for appropriate indications. In a multi-center case series Yoon et al. [117] found excellent outcomes with the use of adjunct plate fixation prior to IMN for complex tibial plateau fractures with 93% (25/27) achieving bony union and no late fracture displacement reported. Jia et al. [118] had similar excellent outcomes in their cohort with no incidences of malunion, nonunion, or infection. Meena et al. [119] randomized proximal metaphyseal tibia fractures to lateral percutaneous locked plating versus IMN. The IMN group had significantly shorter average hospital stay, time to fracture union, and time to full weight bearing. No significant difference was found for infection rate, range of motion of the knee or degrees of malunion and nonunion.

11. Postoperative treatment

11.1 Bracing

Bracing postoperatively is common practice with rigid braces holding the knee in extension, or more commonly hinged braces used for 3–6 weeks [120]. However, a recent prospective trial conducted by Chauhan et al. [121] found no significant difference between 6 weeks of bracing and no bracing at all after ORIF of tibial plateau fractures for union rates, postoperative range of motion, and Medical Outcomes Study 36-Item Short Form scores.

11.2 Weight bearing

Full weight-bearing is commonly delayed for 9–12 weeks with 4–6 weeks of non-weight bearing followed by 4–6 weeks of partial weight-bearing [120]. Two recent retrospective articles with sample sizes of 17 and 90 have challenged this notion with excellent results with immediate full weight bearing as tolerated [122, 123]. Basic science evidence supports a period of protected weight bearing followed by progressive loading due to evidence that gentle compressive loading may positively impact articular cartilage healing by improving chondrocyte survival, but excessive shearing may be detrimental [124]. More robust research is likely needed before major changes in weight-bearing protocols are implemented.

11.3 Surgical site infection

A 2019 meta-analysis including 7925 patients found the incidence of superficial and deep surgical site infections after tibial plateau fracture repairs to be 4.2% and 5.9%,

respectively [55]. Risk factors that have been found to be associated with surgical site infections include open fractures [54–56, 125], compartment syndrome [27, 54–56], smoking [55, 56, 125], alcohol intake [126], definitive external fixation [56, 94] and intraoperative duration approaching 3 h [54, 56, 125]. A recent article found a strong correlation between a significantly higher peak of C-reactive protein (CRP) >100 μg/mL on postoperative day 3 and the development of surgical site infections in tibial plateau patients [127]. This finding might be an indication for more close surveillance in these patients regardless of CRP normalization over the following days, especially if the patient is at increased risk for noncompliance (e.g., Dementia).

11.4 Posttraumatic arthritis

The incidence of knee osteoarthritis following tibial plateau fractures reported in the literature has a wide range from 13 to 83% [6, 37, 38, 83, 84, 128–134]. Associated risk factors of early onset knee arthritis include degree of comminution, bicondylar fractures, meniscectomy, axial malalignment, joint instability, and older age [83, 85, 135, 136]. Wasserstein et al. [136], reporting on 8426 tibial plateau fractures, found that 7.3% of patients underwent total knee arthroplasty (TKA) 10 years after surgical management of tibial plateau fractures compared to only 1.8% in their control group. However, only adult patients treated by open reduction internal fixation (ORIF) were included and young patients and patients managed by conservative means or external fixation were excluded. Elsoe et al. [137] studied 7950 tibial plateau fracture patients in a matched cohort study and found the rate of TKA after tibial plateau fracture was 5.7% compared to 2% in their reference group.

12. Conclusion

Tibial plateau fractures comprise a wide range of fracture patterns, injury severity, and can exist with the presence or absence of significant associated injuries. History, physical exam, and imaging modalities can help to determine management of this complex category of injuries. Surgical and nonsurgical treatments can be employed to achieve healing and satisfactory long term results. Emerging technologies and implants continue to provide the promise of improved patient outcomes.

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