TRAUMA

Current management of high-energy tibial plateau fractures

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Tibial plateau fractures; External fixation; Internal fixation; Biologic osteosynthesis; High energy; Damage control

Summary
High-energy tibial plateau fractures present a therapeutic challenge to the orthopaedic trauma surgeon, both in terms of the osseous injury as well as the concomitant soft-tissue insult. Surgical treatment has evolved to address these fractures in a more biologically favourable manner without further compromising the soft tissues. We present a summary of these injuries and outline the contemporary approaches to treatment. Potential complications and their avoidance are also discussed. Outcomes following these injuries are reviewed to assist with determination of treatment goals.

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Introduction
Tibial plateau fractures associated with high-energy trauma are frequently complex injuries that portend a poor prognosis. The status of the soft-tissue envelope typically mirrors the amount of energy imparted to the bone. High-energy fractures present a therapeutic challenge to the orthopaedic trauma surgeon due to the high incidence of open fractures, comminution, soft-tissue injury, and neurovascular compromise. Traditionally, internal fixation of these injuries has been fraught with complications, including infections and wound breakdown. Contemporary or biologic surgical treatment emphasises preservation of vascularity and soft-tissue integrity by minimising further insult to the soft tissues. We present a summary of these injuries and the currently acceptable approaches to treatment as well as potential complications. We also briefly discuss the determinants of successful outcomes following internal fixation.

Classification
Adopted by the Orthopaedic Trauma Association, the AO/ASIF classification provides a thorough and descriptive catalogue of tibial plateau fracture morphology. This system defines fractures as extraarticular, partial articular, and complete articular, with further subdivision based upon increasing fracture severity and comminution. Its length and organisation makes it useful for research purposes.

For ease of communication, many North American surgeons use the Schatzker classification (Table 1).\textsuperscript{1} Tibial plateau fractures are classified by the presence or absence of a sagittal split, a depressed articular segment, the presence or absence of a medial condylar fragment, and

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attachment to the tibial shaft. Six fracture patterns are defined and correlate with the energy of injury.

For the purposes of this text, we will limit the discussion to Schatzker fracture types IV, V, and VI. A type IV injury involves a medial plateau split from the articular surface that exits out the medial metaphysis. Given the relative bony strength and mechanical axis, medial plateau fractures represent a much higher-energy mechanism of injury than their counterparts in the lateral plateau. In this type of fracture, the medial plateau piece remains in its anatomic position while the lateral fragment and entire lower leg displaces. Some authors describe this type as a “fracture dislocation” of the knee. These fractures have a higher incidence of lateral collateral ligament, anterior cruciate ligament, popliteal artery, and peroneal nerve injury than other subtypes. Type V fractures are bicondylar with varying degrees of comminution. Type VI fractures are bicondylar as well with meta-diaphyseal extension resulting in dissociation of the metaphysis and diaphysis. This subtype also has varying degrees of comminution.

Clinical assessment

Patients who have sustained a high-energy injury require a thorough trauma evaluation, typically by a multi-disciplinary team in accordance with established trauma care protocols. Potentially life-threatening injuries are addressed initially and once stabilised, the orthopaedic injuries are evaluated.

The evaluation of the neurologic status, the vascular status and the soft tissues is the critical first step of fracture care. The skin is inspected circumferentially around the distal thigh, knee, and leg. Openings in the skin are inspected to rule out the presence of communication with the fracture. At our facility, any skin embarrassment is digitally photographed and recorded as part of the patient’s medical chart in our institution’s trauma registry database. The Gustilo and Anderson classification for open fractures, originally used for tibial shaft fractures, is applied to these injuries. The classification of the injury is based upon the amount of skin injury, soft-tissue damage, fracture severity, contamination, and vascular status. In simple terms, Grade I injuries have a laceration less than 1 cm; Grade II injuries have increased periosteal stripping and typically a larger laceration (1–10 cm); Grade III injuries are more severe and are further subclassified (III A injuries have a laceration >10 cm, and/or increased comminution, contamination, or stripping, III B injuries require a soft-tissue coverage procedure to cover bone, and III C injuries require vascular repair to achieve salvage). This classification is formally done in the operating room, but an initial assessment using Gustilo’s system is performed in the emergency department to guide early care of open fractures.

Closed injuries are also closely assessed. The presence of contusions, blisters, and swelling is noted. Tscherne and Goetzen have described a classification system for the soft tissues associated with closed fractures. Grade 0 represents minimal soft-tissue damage done with an indirect force. Grade 1 represents superficial abrasion or contusion via pressure from within. Grade 2 represents deep, contaminated abrasion(s) with localised skin/muscle contusion and impending compartment syndrome. Grade 3 represents extensive skin contusion/crush, subcutaneous avulsion, underlying muscle damage, or compartment syndrome. This classification can help with both written and verbal communication.

High-energy injuries are commonly associated with neurovascular injury. Neurologic examination focuses on function of the peroneal nerve, which is most vulnerable in these fractures. The tibial nerve is in close proximity to the zone of injury and must also be evaluated. Vascular examination focuses on the popliteal artery. This examination is especially important in medial plateau injuries, which have a higher risk of arterial embarrassment. It is important to remember that posteriorly displaced fracture fragments can directly impinge on the neurovascular bundle. Ankle-brachial indices are obtained if there is any question of vascular injury. If these are less than 0.9 and other hard physical examination findings point to an arterial injury, an arteriogram and vascular surgical consultation is considered. Thorough and accurate documentation of the examination is crucial.

Although often difficult to assess acutely, knee stability should be evaluated. It is important to remember that a knee dislocation can pose as a fracture, heightening the importance of a thorough neurovascular examination in all cases. Stability to varus and valgus stress is tested in full extension. In the conscious patient, this often will require sedation. The knee effusion and haemarthrosis is aspirated and replaced with local anaesthetic under strict aseptic conditions. To minimise the patient’s discomfort, this assessment can be delayed until the operating room in fractures that have an operative indication beyond knee instability.

The timely diagnosis and management of compartment syndrome is critical. A high index of suspicion for compartment syndrome should be maintained when dealing with high-energy plateau fractures, and it must be ruled out in every patient with these injuries. Tense, firm compartments are early signs and may be sufficient for diagnosis. Severe pain and pain with passive stretch of muscle groups in the leg are diagnostic of compartment syndrome. Compartment pressures should be measured if the clinical examination is inconclusive or if the patient is obtunded or intubated and sedated. Compartment pressures within 30 mmHg of the diastolic blood pressure are diagnostic. The threshold for compartment measurement and fasciotomy should be low, given the disastrous consequences of a missed or delayed diagnosis. Schatzker V and VI fractures have an especially high incidence of compartment syndrome. Serial examinations

Table 1 Schatzker classification of tibial plateau fractures.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>I</td>
<td>Pure split fracture of lateral tibial plateau</td>
</tr>
<tr>
<td>II</td>
<td>Split-depression fracture of lateral tibial plateau</td>
</tr>
<tr>
<td>III</td>
<td>Pure central depression fracture of lateral tibial plateau</td>
</tr>
<tr>
<td>IV</td>
<td>Medial tibial plateau fracture</td>
</tr>
<tr>
<td>V</td>
<td>Bicondylar tibial plateau fracture</td>
</tr>
<tr>
<td>VI</td>
<td>Bicondylar tibial plateau fracture with metaphyseal–diaphyseal dissociation</td>
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are critical as compartment syndrome may develop several hours or more after the initial injury and post-operatively. Pallor, pulselessness, paresthesiae, and poikliothermia are late signs of compartment syndrome, and ideally patients are treated with fasciotomy prior to developing these ominous signs.

**Radiological assessment**

Plain orthogonal radiographs are obtained. A 10° craniocaudal angle on the anteroposterior (AP) view of the knee allows assessment of the joint surface, given the posterior slope of the proximal tibia. This view is improved with traction in displaced fractures. The majority of fractures can be classified from the AP film. The lateral films afford a better assessment of coronal fracture lines and subtle joint depressions. The plateaux can be distinguished on the lateral view, as the medial plateau is lower and concave, whilst the lateral is convex.

Fine (2–2.5 mm) cut computed tomography (CT) images further delineate fracture morphology and are important in operative planning. It is usually more useful to obtain the CT after applying traction via an external fixator (see treatment section). With traction CT images, the degree of comminution and joint depression are more thoroughly defined. These images, in addition to plain radiographs, have been shown to change fracture classification, and subsequently the operative plan.5

The role of magnetic resonance imaging (MRI) in acute fracture management is controversial. High-energy tibial plateau fractures are associated with a high incidence of ligamentous and meniscal injuries. Although MRI allows for the assessment and diagnosis of intraarticular soft-tissue pathology, there is scant evidence that its routine use impacts on outcomes. Furthermore, incompatible external fixators often preclude the use of MRI with these injuries. The formal role of MRI in these fractures has yet to be defined.

**Treatment**

**Temporising treatment**

All high-energy tibial plateau fractures have a concomitant soft-tissue injury. It is not unusual for these patients to have massive swelling and fracture blisters encompassing the entire proximal leg. The severity of the initial injury and rate of recovery of the soft tissues drives the timing of definitive fixation. Early stabilisation of the fractured extremity is requisite for timely soft-tissue healing.

Temporary spanning external fixation is the initial treatment modality of choice, as it stabilises the soft tissues, provides pain relief, assists with fracture reduction via ligamentotaxis, allows visualisation of the soft-tissues, and permits mobilization. Not all, but most high-energy tibial plateau fractures require temporary external fixation to stabilise the soft tissues, the fracture fragments or both. CT imaging after application of the external fixator is ideal. Casts, splints, traction, and braces are other options for initial treatment, but none of these modalities offers the same broad range of benefits provided by external fixation. Definitive surgical treatment should be delayed until the soft tissues appear healthy enough to withstand incisional trauma. Time to definitive fixation will vary from a few days to 3 weeks or more.

This treatment algorithm has evolved from the use of temporary external fixation in the treatment of pilon and femoral shaft fractures.5-8 Catastrophic wound consequences following early surgery through compromised soft tissues have been well described. Delayed internal fixation after initial external fixation has enjoyed good outcomes with low complication rates in the treatment of high-energy proximal tibial fractures.9,10 Egol reports 5% deep wound infections in 53 patients with 57 high-energy tibial plateau fractures treated with temporary spanning, external fixation.8

Typically the external fixator spans the knee joint. A common construct is two pins in the femur (above the suprapatellar pouch) and two pins in the tibia (Fig. 1). If possible, the pins in the tibia should be distal to the zone of injury and away from the anticipated internal fixation. The femoral pins can be anterior, lateral, or antero-lateral. Anterior pins may provide a more rigid frame construct, but some have concerns for loss of knee motion due to scarring.

**Figure 1** A typical temporary spanning external fixator (a). Note the ligamentotaxis and ability to obtain adequate radiographs of the fracture site with appropriate fixator placement (b).
of the quadriceps. Lateral pins avoid these complications, but are often problematic for patients when they lay in bed. Antero–lateral pins avoid the issues of anterior and lateral pins, but the frame construct may not be as biomechanically strong as frames with anterior pins. Connector clamps between external fixator bars are ideally placed outside of the fracture zone to allow fluoroscopic and radiographic images of the reduced fracture without metallic artifact or interference. Consideration should be given to foot pins, a foot plate connected to the fixator, or an ankle foot orthosis (AFO). This is particularly important in patients with multiple injuries, severe soft-tissue injuries with an anticipated long delay prior to definitive fixation and obtunded patients.

Open fractures are urgently irrigated and debrided in the operating room. Repeat debridements are performed as necessary. Antibiotics should be administered intravenously for a minimum of 24 h after each debridement. Typically, a first generation cephalosporin is given and Gram-negative coverage is added for Grade III injuries. Clostridial coverage should be initiated in fractures with soil or faecal contamination. Arterial lesions are evaluated with an arteriogram, but should be done, when feasible, in the operating room to avoid delay.

Open fractures and high-energy tibial plateau fractures with associated compartment syndrome represent unique and challenging subsets of these fractures. In both instances, urgent operative intervention is required, which violates the soft tissues at or near the fracture. Thus, delayed treatment until the soft tissues recover is not possible in its truest form. This does, however, present an opportunity to perform early internal fixation. At the time of debridement or fasciotomy, internal fixation could be undertaken with limited additional dissection. Stabilisation of fractures is believed to protect the soft tissues from further damage and decrease sepsis. In fact, Benirschke et al. report no deep infections in 14 open plateau fractures treated with immediate internal fixation and delayed closure. Early open reduction and internal fixation may facilitate articular reduction and provide rigid fixation that allows earlier knee range of motion and possible improved outcomes. In fact, the primary caveat of Egl’s protocol was knee stiffness. Additionally, spanning external fixation and early joint reduction with limited internal fixation could be undertaken, with further definitive internal fixation delayed until the soft tissues heal.

**Definitive treatment**

Non-operative treatment for these high-energy injuries has a role in the medically decompensated patient only. These injuries have poor outcomes with non-operative treatment. In extreme circumstances, an external fixator can be applied in the intensive care unit. This “traveling traction” allows for stability and reduced soft-tissue damage. It is used until either the patient and soft-tissue envelope can tolerate surgery or the extremity can be placed into a cast brace.

External fixation can be used effectively for definitive fixation. Frames usually do not span the knee joint for a prolonged period, so knee motion can be initiated to minimise stiffness. Hybrid, Ilizarov, and monolateral half-pin frames have all been used with success. Olive wires can be used to compress the joint surface. Typically, however, limited incisions are made to facilitate reduction and internal fixation is achieved with lag screws, the frame being used to support the metaphyseal portion of the fracture. External fixators must be maintained until sufficient healing has occurred, which can be problematic when pin or wire site complications occur.

Definitive internal fixation of closed, high-energy tibial plateau fractures should be undertaken only after the soft-tissue envelope has healed enough to allow incision. Often the return of the ability of the skin to wrinkle heralds the recovery of the soft tissues. Conventional techniques of high-energy bicondylar tibial plateau fractures often employed a single midline incision with medial and lateral plates. Absolute anatomic reduction and rigid fixation was performed at the expense of vascularity. Historically, soft-tissue complication and infection rates were as high as 50–80%. However, contemporary approaches to these fractures have significantly lowered the rate of adverse outcomes. Modern techniques of dual plating through two separate incisions preserves blood flow and soft-tissue integrity, which has lead to a decreased rate of infection. Advances in plate design have also afforded more biological approaches to these fractures. The use of fixed-angle locking plates avoids the diminished periosteal blood flow and bone necrosis seen with conventional plates under compression. Furthermore, minimally invasive submuscular, extraperiosteal techniques can be employed with these plates and the screws inserted percutaneously.

Lateral plateau fractures, if treated with internal fixation, can be fixed with a variety of techniques. Typically, a lateral approach is made. A direct approach is preferable to avoid excessive dissection and devascularisation of the bone fragments and soft tissues. The joint is visualised through a submeniscal arthrotomy and the joint is reduced under direct vision. Meniscal repair is performed if necessary. The joint surface is supported with either allograft or autograft. It is the authors’ opinion that synthetic graft is superior. Fixation is undertaken after reduction. Locking plates are commonly used for periarticular fractures, but their primary indication is for fixation in osteoporotic bone.

The medial plateau fragment is the key to fixation of medial and bicondylar tibial plateau fractures. There are biomechanical data to support the use of a single laterally based locking plate and these are commonly used and occasionally a good option (Fig. 2). It is crucial, however, for the surgeon to understand both the location and fracture line orientation of the medial fragment and the particular screw configuration of the implant being employed to achieve a successful outcome. While intraoperative traction may reduce the medial fragment and allow laterally based fixation, it may be preferable to approach the medial fragment through a separate incision. Persistently displaced medial fragments should be reduced through a medial incision. The medial incision should be along the posterior border of the tibia. The pes tendons can be cut and repaired at the end of the procedure or retracted. The fragment is reduced and the fragment is fixed, typically with a buttress plate. The medial side is commonly fixed first, so care should be taken to avoid
A 45-year-old male involved in a motor vehicle accident presented with pain and soft tissue swelling in the left knee. Anteroposterior (A) and lateral (B) radiographs revealed a Schatzker VI tibia plateau fracture. A CT scan revealed significant medial and lateral comminution with dissociation of the metaphysis and diaphysis (C,D). Following temporary spanning external fixation and improvement in the soft tissues, open reduction and internal fixation was performed with a Synthes LISS plate through a submuscular extraperiostal approach via a limited lateral incision (E,F).
screw placement that may hinder later reduction of the lateral plateau.\textsuperscript{10}

Postoperative protocols should emphasise early motion. Although controversial, it is our practice to begin physical therapy with continuous passive motion (CPM) on postoperative day number one to avoid stiffness. Bracing may be performed on an individual basis. Typically, these patients are kept non-weight bearing on the injured extremity for 10–12 weeks after surgery. Progressive weight-bearing and activities are then initiated.

We reviewed our experience with bicondylar tibial plateau fractures to illustrate our current approach to these injuries. Our study population was identified using a prospectively collected trauma registry and operative database. Between January 2002 and June 2004, 25 patients with 26 fractures were treated at our institution using the less invasive stabilisation system (LISS) plate and followed to union. There were 14 males and 11 females with an average age of 46 (range: 28–83). Five (19\%) of the fractures were open (1 Type II, 2 Type IIIA, 2 Type IIIB). Nine (34\%) of the fractures were complicated by compartment syndrome requiring fasciotomy. According to the OTA classification there were 6 (41C1), 8 (41C2), and 12 (41C3) fractures. A single surgeon performed all operations. CT scan and plain radiographs were used routinely for pre-operative planning for all cases. An anterolateral approach to the proximal tibia was used. The lateral meniscus was elevated to allow direct visualisation of the articular surface. Using fluoroscopy and direct visualisation any depressed articular segments were elevated through a cortical window using tamps. The metaphyseal defects were filled with allograft cancellous bone or Norian SRS (Synthes) material. Independent lag screws were used to obtain articular fixation. Fracture fixation was obtained with a tibial LISS plate (Synthes) inserted submuscularly along the anterolateral tibia. A minimum of 4 locked screws were used in the proximal and distal segments. Clinical follow-up was obtained consisting of physical examination and radiographs.

Twenty-five patients with twenty six fractures were followed until union, with total follow-up of an average of 8.5 months (range 6–13). Our complications included one varus malunion, one superficial infection, and three deep infections eventually requiring hardware removal. Interestingly, three of the infections occurred in patients requiring fasciotomies. Therefore, the overall infection rate was 15\% and in those patients requiring fasciotomies it was 33\%. Of note, only one of five open fractures became infected. The average articular step-off was 1.4 mm. Our average initial post-operative varus-valgus alignment was 1.9° of varus. The average change in tibial alignment at last follow-up was less than one degree. The patient with a varus malunion represented axial malalignment present at the index procedure. Union was defined by the presence of bridging callus seen on at least two cortices on AP and lateral radiographs and weight bearing as tolerated was allowed at that time. Time to union averaged 13.1 weeks (range 72–118 days). One patient required refixation and bone grafting to treat a non-union (63-year-old female with grade IIIA open fracture). On exam, patients had an average flexion to 110 degrees (range 85–130). Twenty-one patients (22 knees) had full extension. Four patients had flexion contractures at follow-up measuring 5°, 5°, 5°, and 20°. No hardware failure occurred.

Outcomes

Several studies suggest articular incongruity after tibial plateau fractures, particularly lateral plateau injuries, is well tolerated and that the amount of articular displacement has little effect in determining management outcomes. The tibial plateau articular surface has a thicker articular cartilage layer than do many other joints, but it is not known whether this accounts for its high tolerance for articular malalignment.

Lucht and Pilgaard\textsuperscript{22} found that patients with persistent joint depression of 3–10 mm had an acceptable functional result a mean of 7 years after injury. In another study, the clinical outcome was similar in patients who had >5 mm of articular incongruity than in those who had ≤5 mm of incongruity (mean follow-up, 7.3 years).\textsuperscript{23} When those same patients were reevaluated a mean of 20 years after injury, there were no significant changes in clinical outcomes from the original study.\textsuperscript{24} All 20 patients with articular incongruity between 5 and 10 mm had good or excellent clinical results (including 9 patients with instability of the knee). In addition, all five patients with >10 mm of articular incongruity and stable knees had a good or excellent result. A poor functional and clinical result occurred only when a combination of factors was present: a central depressed lateral condylar fragment; articular incongruity >10 mm; and instability of the knee at the time of follow-up. Honkonen reported that the incidence of secondary OA was not significantly different in the patients with 0 to 3 mm and those with >3 mm of articular incongruity (99 and 25 patients, respectively).\textsuperscript{25} Koval et al. reported that clinical results were no different for patients with anatomic and non-anatomic reductions (13 and 5 patients, respectively).\textsuperscript{26} Weigel and Marsh\textsuperscript{13} found no correlation between articular surface reduction and knee score at an average of 8 years after injury in a group of 23 patients with 24 high-energy tibial plateau fractures treated with external fixation.

Some studies that have reported a strong effect of articular reduction on outcomes have methodological problems that make the significance of their conclusions uncertain. Blokker et al.\textsuperscript{27} reported that the adequacy of articular reduction was strongly associated with outcome in 60 patients treated for tibial plateau fractures. In this study, no patient with a step-off ≥5 mm had a satisfactory result. This study has been cited as evidence mandating anatomic reduction of the tibial articular surface; however, a final rating of satisfactory required a satisfactory clinical and radiographic result. An unsatisfactory rating in either area resulted in a final rating of unsatisfactory. The radiographic criteria for a satisfactory result required a residual articular depression ≤5 mm. Thus, a patient with an articular incongruity >5 mm was automatically assigned an unsatisfactory final result, regardless of the clinical rating, suggesting bias in the conclusions.

It is generally accepted that knee stability and restoration of mechanical axis are important determinants in patient outcome. As noted above, Lansinger found good to excellent results in 90\% of patients with stable knees, which appeared
more important in outcome than the quality of articular reduction. However, mild varus or valgus instability is often functionally well-tolerated and good results have been reported. Mechanical malalignment greater than 10° has been correlated with poor long-term functional results and may complicate future knee arthroplasty.

**Conclusion**

Historically, high-energy tibial plateau fractures have been associated with high complication rates. Although they remain a challenge for the orthopaedic trauma surgeon, contemporary treatment of high-energy tibial plateau fractures can have satisfactory outcomes. Important aspects of management include assessment of soft-tissue injury, management with temporary spanning fixation in select cases, appropriate imaging of articular injury, and timely, accurate reduction and fixation.

**Practice points**

- All high-energy tibial plateau fractures have a concomitant soft-tissue injury
- Temporary spanning external fixation is often the initial treatment of choice
- A biologic approach, mindful of the vascularity of soft tissue and bone, can prevent many adverse outcomes
- Definitive treatment is aimed at restoring mechanical alignment and joint congruity

**References**