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1 Introduction

Management and imaging of fractures of the proximal tibia have advanced significantly over the last decade and the operative treatment of tibial plateau fractures is now chosen more frequently.

The management of intra- and extraarticular tibial plateau fractures will depend upon the “personality” of the injury: patient factors, soft-tissue factors, and the fracture pattern must all be considered together with the available facilities and surgical expertise. In general, indications for surgery include:

- open fractures;
- fractures with vascular/neurological lesions or compartment syndrome;
- displaced fractures and fractures with articular impaction;
- fracture dislocations.

2 Surgical anatomy

The medial plateau is the larger of the two articular surfaces and is concave in both transverse planes. The lateral plateau is smaller and convex and lies slightly higher than the medial joint surface, which helps in identifying it on the lateral x-ray (Fig 6.8.1-1). When inserting screws from lateral to medial this fact must be taken into consideration in order to avoid penetrating the concave medial joint surface. The intermediate, nonarticular intercondylar eminence serves as the tibial attachment for the anterior cruciate ligament. Isolated avulsion fractures of the anterior cruciate ligament are not considered fractures of the tibial plateau. The tibial tuberosity and Gerdy’s tubercle are bony prominences located in the subcondylar region for insertion of the patellar tendon and iliotibial tract respectively. These landmarks are important when planning surgical incisions. The medial condyle, including its articular surface, is stronger than the lateral. As a result, fractures of the lateral plateau are more common and may have articular impaction and fragmentation [1]. Medial plateau fractures occur more often “en bloc” and are invariably associated with more severe injuries as well as with fracture dislocations (Fig 6.8.1-2). They have a higher degree of soft-tissue injury, such as disruption of the lateral collateral ligament complex and neurovascular structures. The proximal tibiofibular joint is located posterolaterally on the lateral tibial condyle. The fibular head provides attachment for the fibular collateral ligament and the biceps femoris tendon, and acts as a buttress for the proximal lateral portion of the tibial plateau. The stability of the tibial plateau depends upon three different osseous structures: the central portion, consisting of the insertion of the cruciate ligaments, the medial, and the lateral plateau.
3 Clinical examination

The clinical examination is pivotal for decision making.

Inspection of the soft tissues must assess any impending perforation by fracture fragments, the presence of fracture blisters, and the risk of compartment syndrome (Fig 6.8.1-3).

- The stability of the knee joint is very important and must be tested under anesthesia before and after reconstruction of the fracture.

The latter is to be suspected if there is severe, unremitting pain, or pain on passive stretching of the tendons. The neurovascular status should carefully be evaluated in every patient [2, 3].

Fig 6.8.1-2a–b 41-C3.1 fracture in a 44-year-old female after a skiing accident. In bicondylar fractures, the medial plateau is usually sheared off "en bloc" without major damage to the articular surface.

Fig 6.8.1-3a–b
a Severe soft-tissue swelling and blisters.
b Soft tissue after swelling has subsided.
4 Evaluation of soft tissues

Open and closed fractures have to be evaluated for soft-tissue injury. Physical examination should focus upon the integrity of the soft-tissue envelope, especially the presence of blisters, superficial abrasions, and degloving injuries. These indicate areas to be avoided until soft tissues have healed sufficiently. In case of severe contusion or soft-tissue loss, photodocumentation is recommended. The plastic surgeon should be informed as early as possible to include them in the decision making process.

The menisci and ligaments play a very important role in the stability and function of the knee joint. The menisci function as shock absorbers and increase femorotibial stability. Only a few studies have examined the incidence of these associated injuries. Bennett and Browner described a 56% incidence of soft-tissue injuries in nondisplaced as well as displaced tibial plateau fractures [2]. Shepard et al described a 90% incidence of ligamentous injuries in nondisplaced tibial plateau fractures. Among these 80% were meniscal tears and 40% ligamentous disruptions detected by MRI [4].

The degree of soft-tissue injury is an important factor for surgical decision making and intraoperative tactics. With extensive contusion or soft-tissue injury, a joint-bridging external fixator is recommended in order to provide sufficient stability for the recovery of the soft tissues. Internal fixation can be performed as a secondary procedure (Fig 6.8.1-3).

5 Diagnostic procedures

Conventional x-rays in four planes (AP, lateral, 2 × 45° oblique views) should be performed.

However, plain x-rays are not considered sufficient to adequately assess the fracture type. Although some studies showed superiority of MRI in the detection of fractures, preoperative CT scans with 3-D reconstructions have become the standard tool in the analysis of tibial plateau fractures in many parts of the world [4–7]. They demonstrate fracture displacement, impaction of the articular surface, and other associated injuries [5]. CT scans with multiplanar reconstruction are most useful for the planning of minimally invasive procedures (Fig 6.8.1-4). Traction x-rays after placement of a joint-spanning external fixator are also quite useful.

6 Fracture classification

The Müller AO Classification (Fig 6.8.1-5) adopted by the OTA is recommended as is the classification by Schatzker (Fig 6.8.1-6). Proximal tibial injuries tend to cause ligamentous lesions and vascular injuries, especially if combined with knee subluxation.

- Close monitoring of peripheral perfusion and pulses (Doppler) must be performed on these patients, with urgent vascular surgery consultation and/or arteriography if any abnormality of the distal circulation is suspected [8].
Specific fractures

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Fig 6.8.1-4a–d The rare case of an isolated fracture of the medial plateau, 41-B3.2 (or Schatzker IV) fracture, which may be associated with an injury to the popliteal vessels.

a Standard AP view.
b 3-D reconstruction as seen from behind.
c Lateral view.
d Lateral 3-D reconstruction.

7 Treatment

7.1 Nonoperative treatment

In nondisplaced fractures, nonoperative treatment may be a safe alternative. This principle may also be of value for aged and bedridden patients. Varus/valgus stability on physical examination indicates that limb alignment will be assured upon fracture healing [9]. Patients with a low risk of developing arthritis may also be good candidates for nonoperative treatment.

7.2 Operative treatment

7.2.1 Aims of surgery

Surgery aims to

- restore articular congruity, joint stability, and the original knee axis;
- provide fracture stability allowing for early pain-free movement of the knee and mobilization of the patient;
- obtain full functional recovery as a long-term goal;
- avoid posttraumatic arthritis.
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Fig 6.8.1-5a–i  Müller AO Classification.
In some special cases, primary joint replacement may be an option. The indication for this is severe intraarticular impact or crushing of the joint surface in elderly and osteoporotic patients, provided the metaphyseal region ensures adequate stability. However, we recommend that reconstruction be attempted in most cases with anatomical reduction and complete restoration of the height of both tibial plateaus. This may be difficult in severely displaced type C fractures with bone loss, or when delayed reconstruction is necessary [10].

7.2.2 Choice of implants

Preoperative planning is essential. Generally, a balance between the size of an implant, its function, and its effect on the soft tissues is advised. Intramedullary or extramedullary fixation techniques can be used.

In partial articular fractures (type B), the intact side of the tibial plateau may act as a stabilizer allowing the use of a conventional buttress plate. For bicondylar fractures, implants providing angular stability should be considered.

7.2.3 Timing of surgery

- Emergency surgery with closed reduction and temporary, joint-spanning stabilization is indicated for
  - open fractures;
  - acute vascular injury;
  - gross instability;
  - severe, closed soft-tissue injury;
  - damage-control in polytrauma.

Under stable conditions, the diagnostic work up can be completed to allow a thorough assessment and understanding of the fracture type and the soft-tissue condition. Once soft-tissue swelling has fully developed, it can take 7–10 days or more until surgery can be performed safely. We do not recom-
mend waiting for more than 3–4 weeks, since the fragments become “sticky” by rapid callus formation, which makes anatomical reconstruction difficult or impossible. In patients with compartment syndrome or open fractures, where primary skin closure is not possible, a temporary soft-tissue cover may be achieved by using artificial skin (Epigard) or a vacuum sealing system (chapter 4.2; 4.3).

- A good clinical indicator that the time for performing ORIF is safe is soft-tissue wrinkling that indicates the regression of edema (Fig 6.8.1-3b).

7.2.4 Surgical approaches

Patient positioning
In most cases, the supine position is used. This allows good access for all standard approaches. A bolster under the ipsilateral buttock may be used in order to improve internal rotation. A bolster under the contralateral buttock may improve access to the medial side of the leg. If a combined approach (anterior and posterior) is planned, the lateral position may be advisable.

Approaches
There are two standard approaches, the anterolateral and additionally the posteromedial approach. Both allow direct access to the fracture without raising a soft-tissue flap.

The anterolateral, parapatellar approach is used most frequently because of the frequency of lateral plateau fractures. It may include a lateral arthrotomy with transverse incision of the meniscotibial attachment and lifting of the meniscus to allow inspection of the lateral joint surface. Furthermore, this approach may also be used for any secondary intervention such as placement of prostheses.

For the anterolateral, parapatellar approach, the following landmarks are important: the joint line, Gerdy’s tubercle, the tip of the fibula, and the lateral femoral epicondyle. With the knee in 30° flexion, a slightly curved incision is performed, beginning in the area of the epicondyle and ending between the fibula and Gerdy’s tubercle (Fig 6.8.1-7). This incision can be extended proximally and distally if more exposure is needed. The deep dissection involves splitting the fibers of the iliotibial tract. Care should be taken not to dissect other structures that may be displaced, such as the meniscus, etc. The meniscus is then palpated and the knee joint may be opened below the meniscus.

For bicondylar type C fractures with displacement of the medial fragment, which can rarely be reduced anatomically through an anterolateral approach [11], an additional posteromedial approach is recommended. This should be a short approach (4–5 cm), with preservation of the head of the gastrocnemius muscle. It should be directed to the posteromedial edge of the medial tibial fragment. The pes anserinus (formed by the tendons of the sartorius, gracilis, and semitendinosus muscles) (Fig 6.8.1-8) may be retracted anteriorly or incised and repaired upon closure. The meniscus and joint are rarely visible although the exposure is extensile.

- For bicondylar fractures, two separate incisions (posteromedial and anterolateral) are recommended. It is much easier to reduce the medial fragment through the posteromedial incision first.

A midline anterior approach to the proximal tibia is rarely used now because it involves extensive soft-tissue stripping for exposure and this is often associated with significant complications.
Specific fractures

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Fig 6.8.1-7a–b  Anterolateral approach to the proximal tibia.

1  Patella.
2  Tibial tuberosity.
3  Fibular head.
4  Saphenous nerve.
5  Common fibular nerve.
6  Iliotibial tract.
7  Gerdy's tubercle.
8  Meniscus.
Fig 6.8.1-8a–b  Posteromedial approach to the proximal tibia.
1  Patellar tendon.
2  Pes anserinus.
3  Great saphenous vein and nerve.
4  Gastrocnemius muscle.
7.2.5 Reduction techniques and tools
Reduction of the intraarticular portion usually requires direct inspection of the joint. This can be done via arthrotomy or by using an arthroscope. The femoral distractor may be helpful to assist reduction by ligamentotaxis and to realign the correct axis in case of diaphyseal extension of the fracture (Fig 6.8.1-9). The image intensifier is very useful and many simple fractures may be reduced by minimally invasive means [12]. In cases of severe lateral displacement, a large pelvic reduction forceps may be used, especially if equipped with ballpoints. In lateral fractures, the lateral plateau can be rotated laterally with its soft-tissue attachments. This allows for direct inspection of the joint impaction. The depressed area and fragments can then be gently elevated and directly reduced (Fig 6.8.1-10). At this time, assessment of the intercondylar area should also be performed, with special attention paid to the cruciate ligaments.

Once reduction of the articular surface has been accomplished, decisions about maintaining the joint surface reduction must be made. A cancellous or corticocancellous autograft or a bone substitute may be required to support the articular surface and fill the bone defect. Recent evidence suggests that bone substitutes may be more efficacious than autogenous grafts because of their mechanical properties (Fig 6.8.1-11). The increased use of plates with locking head screws has shown that the need for a bone graft or bone substitute could be reduced considerably.

Most of these fractures benefit from operative stabilization, even if they are not greatly displaced or unstable. Different methods have been described, but due to the short proximal segment and the biomechanical problems described above, plates providing angular stability are preferred; they can usually be applied with minimal or no exposure of the fracture focus. Early reports on the clinical use of the LISS plate and LCP have shown promising results regarding fracture union, infection rate, and secondary loss of reduction [15–17]. The fracture must be reduced before fixation. This is achieved with the help of the large distractor and reduction clamps placed on the main fracture fragments through small incisions (Fig 6.8.1-12). Sometimes, additional lag screws or a medial plate are needed to stabilize isolated fragments.

- During percutaneous surgery, soft-tissue care is as important as in conventional plating.

In very unstable fractures and fractures with severe soft-tissue damage, there is a high risk that wound healing problems will arise. To avoid this, external fixation for temporary stabilization is performed. A fixation frame may bridge the knee joint. If the proximal pins are placed in the tibial plateau, knee motion will be possible. After soft-tissue healing, the external frame is replaced by internal fixation. As an alternative, the hybrid external fixator may be applied [18]. Safe proximal fracture fixation is accomplished with two or three transfixation wires, and distal fixation can be achieved with two well spread Schanz pins.

- It is essential that any external fixation pins are placed outside of the knee joint capsule or there will be a significant risk of septic arthritis.

An alternative is to use a complete circular frame system, which will allow early weight bearing. Split fractures of the tibial plateau may be fixed by one or two large, cannulated, cancellous bone screws [19] (Fig 6.8.1-13).
Fig 6.8.1-9a–b  Indirect reduction of a lateral 41-B3 fracture with the large distractor and the large pelvic reduction forceps. Preliminary fixation with K-wires.

Fig 6.8.1-10a–b  The impacted articular surface must be elevated gently with a pusher that can be introduced through the fracture or by creating a small cortical window. Most importantly, the resulting bone defect must be filled with a cancellous or corticocancellous autograft to prevent secondary collapse. Alternatively, bone substitute can be used.
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Fig 6.8.1-11a–c  The use of bone substitute.

a  41-B3 fracture in a 65-year-old female.
b  Sagittal CT scan showing joint depression.
c  After reduction of the joint surface, the bone defect was filled with bone substitute. A lateral buttress plate with locking head screws secures the fixation.
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**Fig 6.8.1-12a–h** 23-year-old male, snowboard injury.

- **a–b** Tibial head fracture (41-C3) extending into the diaphysis.
- **c–d** CTs (AP and lateral) show the extent of the articular comminution. Through a limited lateral approach the articular block is reconstructed with K-wires and 3.5 mm lag screws, including the tibial tuberosity.

- **e** The tibia LISS is inserted between periosteum and anterolateral muscles. The guiding handle facilitates this maneuver.
- **f–g** The 14-hole tibia LISS bridges the diaphyseal fracture zone.

- **h** Besides the proximal exposure for the articular reconstruction and insertion of the tibia LISS, only small stab incisions for the insertion of the distal locking head screws are necessary.

(With permission by Christoph Sommer.)
Conventional intramedullary nails are not really suitable for the stabilization of proximal tibial fractures. Unlike in the diaphysis, the proximal fracture must be reduced before nail insertion. A suboptimal entry point results in axial malalignment, while secondary malalignment with postoperative tilting of the proximal fragment may be the result of insufficient fixation (Fig 6.8.1-14a–b). Sometimes, additional forceps and implants are needed to secure stability [20, 21]. A correct entry point and the use of an additional Poller screw may provide alignment even with conventional nails. Some new nail designs, eg, the expert tibial nail, have up to five proximal locking options. Furthermore, the proximal interlocking screw can be fixed in position by the blocking end cap, thus providing angular stability. Biomechanical studies underline superior stability in unstable proximal fractures [14]. The insertion technique is slightly different from that of the unreamed tibial nail, and moderate reaming may be advisable to enable nail insertion without a hammer. Both cannulated and solid nails are available. Extended indications for the expert tibial nail are segmental fractures, comminuted fractures with a short proximal fragment, and distal metaphyseal tibial fractures (Fig 6.8.1-15).

7.2.7 Lateral plateau—pure split fractures (41-B1)
Pure split fractures (41-B1) may be treated by immediate lag screw fixation. In order to ascertain anatomical reduction, arthroscopic control may be useful [22]. Two large cancellous bone screws with washers are used for fixation. A third screw with a washer is recommended in an antiglide position (Fig 6.8.1-16). Care should be taken not to place the screws too proximally since they might interfere with ligamentous structures or compress the lateral joint compartment, which may cause pain. If there is fragmentation of the lateral fragment (41-B1.3), a lateral buttress plate should be used.
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Fig 6.8.1-14a–b A lateral entry point may induce primary varus deformity. An entry point situated too anteriorly leads to extension of the proximal fragment.

Fig 6.8.1-15a–b Patient with a segmental fracture. Due to the very proximal fracture extension (a) stabilization was done with the ETN (b). An additional Poller screw was used medially.

Fig 6.8.1-16a–b
a Pure lateral plateau split fracture (41-B1) may be fixed with lag screws only, provided there is good bone quality.
b Two 6.5 mm cancellous bone screws may be inserted percutaneously with or without arthroscopic control of the reduction. A third cortex lag screw may be applied in a buttress function at the tip of the fragment.
7.2.8 Lateral plateau—pure depression fractures (41-B2)

41-B2.1 and 41-B2.2 fractures have been classified as circumscribed impactions of the lateral plateau. In order to assess these fractures, a CT scan is required, since regular x-rays cannot show the true extent of the impaction. Complete restoration of the height of the affected joint compartment is essential as these fractures tend to undergo secondary collapse with loss of axial alignment and valgus deformity. These fractures are also indications for a generous cancellous bone graft or bone substitute (Fig 6.8.1-11). Intraoperative arthroscopy may be useful. If available, intraoperative CT scanning is to be preferred (Iso-C) to ascertain exact reduction and secure fixation with screws.

7.2.9 Lateral plateau—split-depression fractures (41-B3)

Split-depression fractures are defined as a combination of a lateral plateau fracture and impaction of the articular surface (41-B3.1). Thorough preoperative assessment is crucial to determine the exact damage to the articular surface. Provisional K-wire fixation is useful to stabilize the articular surface after elevation of the impacted fragment(s). Fixation is best achieved with a plate. Lag screws may be inserted independently and/or through the plate. These fractures are also good indications for the LISS plate or special plates that allow rafting of screws to support the impacted joint surface. In case of large defects, bone grafting with cancellous autografts or the use of bone substitutes may be used.

7.2.10 Medial plateau—isolated fractures (41-B2.3, 41-B3.2)

Isolated medial plateau injuries are mostly associated with a fracture dislocation of the knee joint and represent a rare but severe injury (Fig 6.8.1-4). They have to be assessed very carefully, since they are associated with a high incidence of vascular and neurological lesions, meniscal tears, ligament tears, and compartment syndrome.

7.2.11 Bicondylar fractures (41-C)

Fractures involving both the medial and lateral plateau (41-C1, 41-C2, and 41-C3) often result from high-energy trauma and are associated with a high risk of complications. In addition to the bicondylar fracture, fragmentation can extend into the shaft, which is associated with a considerable risk of compartment syndrome as well as severe soft-tissue damage. Many of these fractures will require an initial joint-spanning external fixator while the soft tissues settle.

Percutaneous reduction with a large “King Tong” forceps may be attempted in pure split fractures. To achieve anatomical reduction and stable fixation, ORIF should be performed. For fixation of the (usually large) medial fragment, we advocate a separate posteromedial incision, with a 3.5 mm plate applied as a buttress (Video 6.8.1-1). The lateral plateau is approached through an anterolateral, parapatellar incision. The reconstruction of the lateral plateau, including the impaction of the articular surface, follows the same principles as described for the 41-B3 fractures. Plates providing angular stability (eg, tibia LISS
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Plate or LCP proximal tibia plate 4.5) appear to be especially suited for these more complex 41-C2 and 41-C3 fractures. The precontoured proximal tibial LISS is used as a buttress, providing angular stability. Lag screw fixation of the anatomically reduced articular block prior to plate application is essential, while any metaphyseal or diaphyseal comminution may be bridged with a long LISS or locking plate (Fig 6.8.1-17).

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Video 6.8.1-1  Internal fixation of a bicondylar fracture of the tibial plateau with two conventional plates.

Fig 6.8.1-17a–c
a  A 38-year-old male who sustained a 41-C2.3 fracture. Initial stabilization was done with an external fixator.
b  The proximal block was stabilized with two 6.5 mm cancellous bone screws from medial. The lateral LISS inserted submuscularly, spans the long meta-/diaphyseal fracture zone.
c  X-ray after 15 months.
8 Postoperative management

After surgery, the limb is elevated and isometric quadriceps exercises are commenced as soon as possible. Alternatively, a CPM splint may be installed. Often a knee immobilizer is used until the patient gains quadriceps control. Resting knee flexion should be avoided as flexion contractures may occur. By 7–10 days, at least 90° of flexion is obtained. Patients are generally maintained on toe-touch weight bearing for 6–8 weeks. Exceptions are fractures caused by extremely high energy; these patients might need to adhere to toe-touch weight bearing for 10–12 weeks.

9 Pitfalls and complications

The major early problems associated with the treatment of high-energy tibial plateau fractures are wound complications [14].

- Wound problems can be minimized by careful evaluation of the soft-tissue envelope, precise timing of surgery, development of full-thickness flaps, extraperiosteal dissection of fracture fragments, and minimal soft-tissue stripping at the fracture site.

Malunion may occur with late joint collapse or deformity at the metaphysis-shaft junction. The mechanical axis should be corrected when appropriate [23].

- An essential goal of surgery is to provide stable fracture fixation that allows early joint mobilization. Failure to achieve this will often result in a worse outcome than nonoperative treatment.

10 Outcomes

For low-energy tibial plateau fractures (41-B1.1, 41-B2, 41-C1.1) treated surgically, results are good [24]. Studies with high-energy fractures requiring extensile approaches with double buttress plates have reported an increase in long-term problems. Patients treated with limited internal fixation and sound principles, including joint reduction using an image intensifier, have improved clinical outcomes. The importance of maintaining menisci, ligamentous stability, and bone alignment is emphasized in papers reporting outcomes [25]. Removal of menisci, articular incongruity, or varus malreduction increased the percentage of long-term degenerative arthritis (> 7-years follow-up).
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11 Bibliography


12 Acknowledgment

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