REVIEW ARTICLE

Arthroscopic management of tibial plateau fractures: Surgical technique

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Accepted: 27 November 2012

KEYWORDS
Fracture; Tibial plateau; Arthroscopy; Technique

Summary Tibial plateau fractures are serious articular fractures that are challenging to treat. Arthroscopy-assisted percutaneous fixation is the treatment of choice in Schatzker types 1, 2, 3, and 4 fractures, as it ensures optimal reduction and stable fixation consistent with early mobilisation. The most reliable fixation method seems to be percutaneous cannulated screw fixation, which is less invasive than open plate fixation. In complex proximal tibial fractures, arthroscopy may allow an evaluation of articular fracture reduction, thereby obviating the need for extensive arthrotomy. Complementary stable fixation is crucial and should allow early mobilisation to reap the benefits of the arthroscopic assistance. This article aims to review the technical points that are useful to the successful video-assisted management of tibial plateau fractures.
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Introduction

Tibial plateau fractures are articular lesions that threaten short- and long-term knee function. Their surgical management is often challenging. As with all articular fractures, the treatment goals consist of anatomic reduction, stable fixation consistent with early mobilisation, and minimisation of surgical trauma. Arthroscopy-assisted percutaneous fixation was first described in the 1980s by Caspari and Jennings [1,2] and was subsequently proven effective in Schatzker type 1, 2, and 3 fractures. Compared to open reduction and internal fixation, the decreased invasiveness of arthroscopy-assisted percutaneous fixation translates into decreased morbidity rates. Combining arthroscopy and percutaneous fixation improves the diagnosis, evaluation of the reduction, and management of accompanying lesions.

Although a consensus exists regarding the general surgical technique, a number of points remain controversial. Orthopaedic surgeons who want to use arthroscopy-assisted percutaneous fixation to treat tibial plateau fractures must be aware of the various technical options and stratagems described below. The use of arthroscopy in complex proximal tibial fractures (Schatzker types 5 and 6) has been suggested, to improve the quality of the reduction and to obviate the need for an extensive arthrotomy. In these fractures, arthroscopy must be combined with rigid fixation via a plate or external device.

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1877-0568/$ - see front matter © 2013 Published by Elsevier Masson SAS.
http://dx.doi.org/10.1016/j.otsr.2012.11.011
Background

Epidemiology

Tibial plateau fractures account for 1% of all fractures in adults. They may be related to high-energy trauma or, in elderly individuals with osteoporosis, to milder traumatic injury. Unicondylar fractures contribute 60% of cases and usually involve the lateral plateau (90%). The intercondylar eminence is fractured in 10% of cases. Tibial plateau fractures are bicondylar in 30% to 35% of cases.

Bone lesions and classification systems

Many classification systems have been developed for proximal tibial fractures. In 1934, Cubin and Conley distinguished five radiographic types. In 1939, Marchant [4] described a classification system that separated 23 fractures into nine types and established the basis for current classification systems by defining three elementary lesions: cleavage, depression, and the combination of both. The classification system developed by Duparc and Ficat in 1960 [3] distinguishes unicondylar and bicondylar tibial plateau fractures. Unicondylar fractures are classified according to whether they involve cleavage, depression, or both (mixed fractures). Bicondylar fractures are either simple or complex with, in this last situation, the addition of a mixed fracture of the lateral plateau (and, in the most serious forms, a coronal fracture of the medial plateau). The AO classification system for long-bone fractures [5] is too complex to be suitable for everyday practice.

The classification system developed by Schatzker is the most widely used today [6]. There are six different types: type 1 or lateral split, consisting in pure cleavage of the lateral plateau; type 2, lateral split with depression; type 3, pure depression of the lateral plateau; type 4, medial plateau fracture with or without an intercondylar fracture; type 5, bicondylar fracture; and type 6, unicondylar or bicondylar tibial plateau fracture with an extension that separates the metaphysis from the diaphysis (Fig. 1). The simplicity of the Schatzker system has made it extremely popular, although it is less detailed that the system described by Duparc and Ficat. We refer to the Schatzker system in this review.

Soft-tissue lesions

The periosteum

The proximal tibia receives its blood supply from an intramedullary network and a periosteal network (Fig. 2). Tibial plateau fractures compromise the blood supply from the intramedullary network but leave the periosteal network intact [7]. Percutaneous fixation techniques preserve the periosteal network, whereas extensive open fixation damages the proximal tibial vessels, inducing a risk of severe complications such as infection, necrosis, and non-union.
Lesions to the menisci and ligaments
The frequency of meniscal lesions varies widely across studies, from 2% according to Holzach et al. to nearly 47% in a study by Vangsness et al. [8,9] (Fig. 3).

Lesions of the collateral ligaments should be sought routinely, as they may jeopardise knee stability and sometimes require surgical repair during the fracture fixation procedure.

Damage to the anterior cruciate ligament (ACL) is common. Rupture of this ligament was reported in 4% of cases by Cassard et al. and 32% by Gill et al. [10,11].

Posterior cruciate ligament (PCL) lesions are less common and usually well tolerated.

The popliteal vessels and nerves may be damaged in the event of a high-energy trauma, major fracture displacement, or severe ligament lesions. The blood vessels must therefore be explored in these situations [12].

Radiographic evaluation
The classification systems for tibial plateau fractures are all based on an analysis of anteroposterior, lateral, and oblique radiographs, which often underestimate the severity of depression [13]. It has been established that computed tomography (CT) with 2- and 3-dimensional reconstructions is valuable for understanding tibial plateau fractures and planning the surgical procedure [14]. Magnetic resonance imaging (MRI) can help to evaluate the overall lesions by detecting damage to the menisci and ligaments that can be repaired during arthroscopy-assisted percutaneous fixation. MRI can document bone and cartilage lesions of considerable prognostic significance. CT-angiography is the investigation of choice when the blood vessels must be evaluated; CT is performed almost routinely as part of the preoperative workup.

Surgical technique
Basic equipment
No specific equipment is needed for the fixation of a tibial plateau fracture. The instruments used for conventional knee arthroscopy should be available, as well as a ligamentoplasty aiming system, a set of trephines similar to those used for arthroscopic ACL reconstruction, and an image amplifier.

A few instruments are more specific and may be useful, depending on the fracture type and technical option chosen, as detailed below.

Schatzker types 1, 2, and 3 fractures (lateral tibial plateau)
Installation, clinical examination, and evaluation of the lesions
The patient is in the supine position with a support or stirrup at the root of the limb so that limb mobility is unrestricted and the knee can be positioned in varus or valgus during the procedure (Fig. 4). The leg can be placed on the operating table in flexion or allowed to drop according to the surgeon’s preference. A tourniquet is placed at the root of the limb. A sterile tourniquet and U-shaped sterile drapes are often chosen to facilitate access to the iliac crest for bone graft collection if required (Fig. 5). An image amplifier is placed on the side of the operated knee to allow anteroposterior and lateral imaging. The optimal position of the image amplifier is determined before draping.

The knee ligaments are tested cautiously to look for laxity in the coronal plane. Gentleness is crucial, to avoid increasing the displacement of the bone fragments. Ligament testing is performed under fluoroscopic guidance.

An anterolateral port is created for the arthroscope, which is gently introduced into the joint. A conventional antero-medial port is used for the instruments. Irrigation of the knee with saline is achieved with gravity or a pump. The use of a pump is not indispensable and has been criticised...
as possibly increasing the risk of compartment syndrome. Nevertheless, pump irrigation may facilitate joint lavage, provided the pressure is no higher than 50 mmHg.

The surgical procedure starts with evacuation of the hematoma, which is a lengthy and tedious step. A third port in a supero-lateral position can be useful for introducing a cannula that helps to evacuate the hematoma and decreases the risk of excessive joint pressure. When intra-articular visibility becomes sufficient, a shaver can be introduced to assist in removing the clots and small bone fragments within the joint cavity. The position of the instruments in the ports can be switched as needed.

Once joint lavage is complete, a comprehensive evaluation is performed to identify the bone and cartilage lesions, as well as any damage to other structures such as the menisci and ligaments. All findings must be scrupulously recorded in the operative report, as the extent of the lesions is of major prognostic significance and can require additional surgical procedures later on. Fractures that are very near the periphery of the plateau and partly located under the meniscus may be difficult to visualise. In this case, a loop can be introduced from lateral to medial to retract the meniscus, as suggested by Carro [15] (Fig. 6). Meniscal retraction hooks, which are designed for this purpose, can be used also, but their size is often problematic.

Reduction of the fracture
Fractures characterised by pure cleavage (Schatzker type 1). Reduction is fairly easy to achieve. External reduction may be successful: the traction exerted by the capsule and ligaments when the knee is placed in varus elevates the lateral fragment. This manoeuvre is first performed under fluoroscopic guidance (Fig. 7). Temporary fixation is achieved using one or two K-wires, which should ideally be placed about 1 cm under the joint surface and can be used for subsequent fixation. A fragment that is not elevated to the level of the joint surface can be pushed gently using a square driver or a spatula resting on its cortex. Alternatively, a pin can be inserted percutaneously into the fracture site and used as a lever, similar to the Kapandji technique for reducing a Colles’ fracture. Fracture reduction can be facilitated and stabilised until pinning is completed by
using a ball-joint forceps (Fig. 8). When fracture reduction remains impossible, a slender spatula or palpation hook can be slipped into the fracture site within the joint cavity and used to disimpact the bone fragments [15]. This manoeuvre must be performed gently and under fluoroscopic guidance to avoid worsening the bone lesions (Fig. 9). Finally, reduction can be obtained by inserting one or two K-wires into the fractured plateau and using them as a joystick to elevate the fragment and to correct any rotational displacement. When the fragment is in the ideal position, pins are inserted parallel to the joint surface to ensure temporary fixation. Reduction quality is assessed by fluoroscopy and arthroscopy. In fractures with isolated depression (Schatzkertype 3). The subchondral bone (and therefore the joint surface) is elevated using a tool inserted through the metaphysis, under fluoroscopic and arthroscopic guidance. Direct elevation using a spatula or curved osteotome has been advocated. The instrument can be introduced through an anterolateral cortical window or even through the fracture site and is used to tamp the cancellous bone under the depressed fragment. Faultless technique is required to avoid worsening the displacement or penetrating into the joint cavity through the joint surface [1,2,15] (Fig. 10).

The key to good-quality reduction of the depressed joint surface is application of the elevating force at the centre of the depression. To this end, a guide-pin should be inserted in the middle of the depression using a ligamentoplasty aiming system [16,17] (Fig. 11). The pin can be made to penetrate the bone through the anterior cortex of the fractured condyle to avoid damaging the normal condyle and to apply a fragment-elevating force that is nearly perpendicular to the joint surface. Alternatively, the pin can be inserted through the other condyle to obtain a larger volume of cancellous bone for elevating the fragment. However, this
alternative technique causes damage to the intact condyle and elevates the joint surface in a more tangential direction, which may require a few manoeuvres to adjust the reduction. Using a cross-sighting technique, we have had no instances of fracture of the condyle penetrated by the pin.

To create the anterior cortical window for access to the cancellous bone, a ligamentoplasty auger guided over the pin previously inserted into the depression can be used. A trephine 10 mm in diameter is introduced, manually or using a power tool, to 2 cm below the depression (Fig. 12) to cut out a cancellous bone core, which is then gently packed subchondrally using a bone tamp 8 mm in diameter. If a cannulated bone tamp or impactor is available, the fragment can be elevated with the guide-pin in place. Otherwise, the guide-pin must be removed, which decreases the reliability of the manoeuvre (Fig. 13). Elevation should be performed very gently, under fluoroscopic and arthroscopic guidance. Manoeuvres to adjust the reduction of the rim of the depressed fragment may be needed and can be achieved using a spatula.

Rossi suggested the creation of a cortical flap using an ancillary to lift a cortical rectangle measuring 10 by 20 mm. A hollow trephine in which a bone tamp can be introduced is used [18]. Venkatesh advocated the use of cannulated impactors featuring an oblique impaction surface to allow elevation in a direction perpendicular to the joint surface [19].

Slight overcorrection of the joint surface depression followed by flexion of the knee is desirable to allow the femoral condyle to shape the joint surface. Temporary stabilisation is achieved using one or two pins introduced 1 cm below the joint surface. Pin position should be evaluated on anteroposterior and lateral fluoroscopy views (Fig. 14). Suganuma and Akutsu developed an automatic pinning system with
Figure 12  Creation of a bone core under the depression.

Figure 13  Elevation of the joint surface by packing of the graft under the depression.

Figure 14  Temporary fixation of the elevated fragment using pins positioned 1 cm under the joint surface through the bone core.

a targeting frame that slides over the pin implanted into the centre of the elevated fragment to guide the fixation wires just under the previously elevated joint surface [20] (Fig. 15).

In mixed fractures with both cleavage and depression (Schatzker type 2). The previously described technical stratagems should be used in combination. The depressed fragment is elevated first and the separation is then reduced using a large bone-grasping forceps. In some cases of major separation, a preliminary reduction step can be performed using the forceps to close the tibial epiphysis and restore relative cortical continuity, thereby facilitating elevation of the depressed fragment. When elevation is satisfactory, reduction of the separation is completed by increasing the pressure by the forceps.

Fixation method

Although the best fixation method is controversial, there is a consensus that lateral tibial plateau fractures should be stabilised using two or three large-diameter (6.5 mm) cannulated screws inserted percutaneously, in combination with a washer (Fig. 16). The screws are tightened under arthroscopic guidance. Care should be taken to avoid excessive
tightening, which can adversely affect reduction quality. Screw length and position are checked fluoroscopically.

In clinical practice, this screw fixation method has been proven reliable in isolated split fractures by several authors including Schatzker et al., Denny et al., and Koval et al. [6,21,22]. However, biomechanical studies are scarce and their results conflicting. Denny et al. [21] found that plate fixation was superior over screw fixation in split fractures, but this result was contradicted by Koval et al. [22]. In split-depression fractures, a cadaver study by Boisrenoult et al. found no evidence that plate fixation was superior over screw fixation [23]. A biomechanical study by Patil et al. in a synthetic bone model supports the use of multiple 3.5-mm screws [24].

Specific features of medial tibial plateau fractures (Schatzker type 4)

Cift et al. showed in an experimental model that loads were greater through the medial than through the lateral knee compartment and that percutaneous screw fixation was less stable than plate-screw fixation [25]. Nevertheless, no reliable clinical studies have established the need for invasive fixation in these patients who will not bear weight on the affected limb for 2 months. Invasive internal fixation cancels out some of the benefits from arthroscopic treatment, making percutaneous fixation a reasonable choice in this type of fracture. However, extensive fixation may be warranted in the event of a comminuted fracture and in patients with osteoporosis.

Replacing lost bone

The main risk factor for secondary displacement is the existence of a large bony defect under the depression. Therefore, consideration must be given to filling this defect. The 1999 SOFCOT symposium found no significant difference between patients managed with and without bone grafting [26]. However, filling seems preferable when the depression is greater than 6 mm. Filling is undoubtedly in order in patients older than 55 years of age and in those with marked osteoporosis, who are at increased risk for secondary depression [12,27,28].

Several materials are available for filling the bone defect:

- autologous iliac crest bone grafting results in good osteointegration and is inexpensive. However, the graft is composed of cancellous bone, whose immediate mechanical strength is limited. In addition, graft collection results in non-negligible morbidity [29];
- frozen allogeneic bone grafts are not very convenient for traumatology, given their high cost and limited availability. In addition, their use is associated with a risk of infection [30];
- freeze-dried allogeneic bone or synthetic bone substitutes available as granules are safe but expensive and lack the bone-induction properties of autologous bone.

All these materials are implanted by impaction. Their limited initial mechanical strength has led to the suggestion that an interference screw be used to close the elevation orifice, thereby improving stability [31]. Tightening of the screw can serve to gradually elevate the depressed fragment (Fig. 17):

- the bone defect can be filled with orthopaedic cement (PMMA), which provides a useful degree of immediate mechanical strength. However, cement is an inert foreign body that can cause problems in the event of infection or revision surgery (Fig. 18). Thus, cement should be reserved for very elderly patients. An appealing alternative consists in the use of hydroxyapatite, which provides the same immediate mechanical strength as cement but
allows osteo-induction to occur, thus restoring bone stock. Disadvantages of hydroxyapatite are its high cost and risk of leakage into the joint cavity. The injection must be cautious, slow, and performed under arthroscopic guidance [32].

**Treatment of other lesions**

**Meniscal lesions**

Sound evidence indicates that meniscal preservation during the management of tibial plateau fractures governs the medium- and long-term outcomes [6,33,34]. Meniscal tears are sutured under arthroscopic guidance after fracture stabilisation whenever possible. Conventional methods for arthroscopic meniscal suturing are used. Meniscectomy is performed only when suturing is not feasible.

**Peripheral ligament lesions**

Severe damage to the collateral ligaments compromises knee stability in the coronal plane. The knee should be examined before and after fracture fixation and stress radiographs should be obtained at the slightest doubt. Most collateral ligament lesions are managed conservatively, particularly when the medial collateral ligament is involved. In some cases, lateral laxity may require immediate surgical treatment in patients with the genu varum morphotype [9,33].

**Lesions of the central pivot**

ACL lesions are particularly common and should be described in the operative report. Ligamentoplasty during the fracture fixation procedure has been advocated but considerably increases the complexity and length of the operation [2]. Many ACL tears are asymptomatic, and a frequently recommended approach therefore consists in performing ACL reconstruction secondarily in those patients who develop chronic knee instability [1,9,10,33,35].

**Figure 17** Fixation of the graft using an absorbable interference screw. Tightening of the screw can serve to gradually elevate the joint surface.

**Figure 18** Use of cement to fill the bone defect followed by percutaneous screw fixation.

Intercondylar fractures should be treated during the same arthroscopic procedure. Fixation can be achieved using non-absorbable suture or a 0.5-mm steel wire. The sutures are threaded through the bone via a wire with an eye and are positioned on either side of the intercondylar eminence. Alternatively, a 15 wire can be placed in the centre of the lateral tibial spine and bent into the joint cavity. Traction on this wire with the knee in extension ensures reduction of the fracture. Definitive fixation is achieved by bending the distal tip of the wire on the anterior cortex.

PCL lesions are less common (0% to 15%) and are usually treated conservatively [2,33,35].

**Other bone lesions**

Bone and cartilage lesions of the femoral condyle are common. Fixation should be performed whenever possible, ideally by arthroscopy. Osteochondral fragments that are too small for fixation may have to be removed. Cartilage damage can cause persistent pain and early osteoarthritis and must therefore be described in the operative report (location, size, and treatment). In patients with a rapidly unfavourable course, the presence of cartilage lesions may warrant the prompt performance of a secondary intervention such as a realignment osteotomy.

**Postoperative care**

Drainage is unnecessary. Hospital stay length ranges from 4 to 7 days. Mobilisation is started on the day after surgery, but weight-bearing is resumed only 8 to 10 weeks later.
Arthroscopy for tibial plateau fractures

Thromboembolism prophylaxis is given until the resumption of weight-bearing.

Compartment syndrome is the most dreaded complication but is also exceedingly rare. We are aware of a single case, described in 1997 by Belanger and Fadale [36]. If an irrigation pump is used, the pressure should not exceed 50 mmHg [33] and the calf should be monitored during the procedure. Thromboembolism and infection are exceedingly rare [37].

Results

In most studies, the short- and medium-term outcomes were good. However, few studies had follow-ups longer than 3 years. Cassard et al. [10] reported knee and function scores above 90% and Scheerlinck et al. [33] obtained excellent HSS knee scores in 79% of patients after more than 5 years of follow-up. A return to the previous level of sporting activities was obtained in 63% of the patients studied by Scheerlinck et al. [33] and in 87% in a study by Holzach et al. [8]. It should be pointed out that significant joint space narrowing was found in 10% to 30% of patients followed-up for more than 3 years [8,10,33].

Complex fractures of the proximal tibia

The management of complex proximal tibial fractures (Schatzker 5 and 6) usually relies on reduction via an extensive arthrotomy followed by fixation with one or more plates. This procedure results in considerable trauma to the soft-tissues and compromises the blood supply to the bone (Fig. 19). Complications include stiffness, non-union, and deep infection and occur in up to 50% of cases. Consequently, the use of arthroscopy-assisted fixation has been suggested. The objective is the restoration of joint surface congruity to obviate the need for a large arthrotomy incision. Additional stable fixation appropriate for the extent of the fracture lines is crucial to allow early mobilisation.

It has been suggested that fixation requires the use of plates (and most notably of locking plates) [38,39]. Hybrid or ilizarov external fixation has also been advocated [40–43]. Arthroscopic fixation is complex in these rare fractures but relies on the same reduction modalities as in "simple" fractures. Installation on an orthopaedic table has been advocated as contributing to joint fracture reduction and facilitating restoration of the mechanical limb axis.

Conclusion

Arthroscopy now has a key role in the management of tibial plateau fractures. Extensive experience with arthroscopy is crucial. Arthroscopy allows an evaluation of fracture reduction without an extensive arthrotomy incision and also enables optimal treatment of concomitant lesions. However, arthroscopy is merely an evaluation tool that provides complementary information to that obtained by fluoroscopy. Consequently, "arthroscopic fixation" may be a less appropriate term than "arthroscopy-assisted management".

The benefits of arthroscopy are greatest when stable percutaneous fixation consistent with immediate mobilisation is performed. Therefore, the best indications are pure split, pure depression, and split-depression fractures of the lateral tibial plateau.

In patients with complex proximal tibial fractures, the use of arthroscopy by an experienced surgeon can minimise the surgical trauma, provided stable fixation consistent with early mobilisation is performed.

Disclosure of interest

The author declares that he has no conflicts of interest concerning this article.

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