■ REVIEW ARTICLE

New trends and techniques in open reduction and internal fixation of fractures of the tibial plateau

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The operative treatment of displaced fractures of the tibial plateau is challenging. Recent developments in the techniques of internal fixation, including the development of locked plating and minimal invasive techniques have changed the treatment of these fractures. We review current surgical approaches and techniques, improved devices for internal fixation and the clinical outcome after utilisation of new methods for locked plating.

In the treatment of fractures of the tibial plateau emphasis has been placed on the strict adherence to the principles of anatomical reduction, rigid fixation and early movement.¹ At operation direct reduction requires periosteal stripping and stable internal fixation necessitates considerable dissection, thereby sacrificing the vascular supply. These techniques are associated with high rates of complication, with nonunion, the frequent requirement for secondary bone grafts and loss of reduction being of particular concern.²⁻⁴

The development of locking implants has allowed the use of minimally invasive approaches often allowing unilateral plating⁵⁻⁷ with improvement in the handling of soft tissue.⁸⁻¹¹ The success of spanning external fixation^{12,13} in pilon fractures¹⁴ has resulted in this method being used for fractures of the tibial plateau. This review discusses the surgical principles and approaches in the light of current techniques.

Radiological assessment of fractures

Standard pre-operative evaluation has included anteroposterior (AP) lateral and oblique radiographs. Additional traction views or tomograms may be obtained to facilitate the assessment of depression, true condylar widening and comminution. The use of three-dimensional (3D) reconstruction CT and intra-operative CT has been shown to be superior to fluoroscopy for assessing reduction of the fracture¹⁵⁻²⁰ (Fig. 1).

MRI in the pre-operative assessment is usually confined to the soft-tissue structures, and may be used to evaluate injury to the menisci and collateral ligaments. As a research tool MRI has advanced our knowledge of concomitant

injuries. Mui et al¹⁸ compared the use of CT and MRI and showed that although ligament injuries can be safely ruled out by CT, MRI is required to assess meniscal damage. Low-energy fractures of Schatzker type-II were identified as those most commonly associated with concomitant soft-tissue injuries. Gardner et al²¹ reviewed 103 patients with mainly low-energy fractures and found injuries to the lateral meniscus in 90%. However, this figure does not represent the incidence in high-energy fractures, and it should be remembered that all meniscal tears do not need surgical fixation. The value of MRI in diagnosing meniscal injuries has been shown to increase interobserver agreement on the classification and operative management of these fractures.²² The medial meniscus is most commonly injured in fractures of the medial plateau. Rupture of the cruciate ligaments occurs commonly as a concomitant injury in bicondylar fractures of the plateau. Overall, the anterior cruciate ligament (ACL) is injured in 57% and the posterior cruciate ligament (PCL) in 28% of these cases.^{21,22} Injuries to the collateral ligaments can occur with all types of plateau fractures. The lateral is most commonly injured in medial and bicondylar plateau fractures (57%) and the medial in lateral and bicondylar fractures (36%).^{21,22} Anteromedial compression fractures indicate injury to the posterolateral structures and the PCL. In a study by Chiba et al,²³ all 12 patients who presented with anteromedial compression fractures had associated lateral or posterolateral laxity.

Shortcomings of classification systems

All classification systems have shortcomings in terms of interobserver reliability and are not comprehensive.^{24,25} In particular, there is still a

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Fig. 1a

Fig. 1b

a) Anteroposterior radiograph of a high-energy bicondylar fracture of the tibial plateau after spanning external fixation, b) sagittal CT in traction.

lack of prediction of the outcome and in the need for a second approach or bone graft. The posterior shear fracture is not included in these classifications. Barei et al²⁶ proposed a rank-order system to classify fractures of the tibial plateau which allowed for planning of the surgical strategy. The fracture morphology as described by the AO/OTA classification,¹ appears to be a particularly useful tool for the purpose of research and communication.^{3,27}

The Schatzker classification³ distinguishes between fractures of the lateral and medial plateau and separates simple from complex patterns of injury. Isolated depression fractures (type III) are exceedingly rare.²¹ A type-V fracture is a bicondylar injury with the interspinous region remaining in continuity with the diaphysis of the tibia. Routine use of CT has improved the accuracy of describing patterns of fracture and has shown that in most cases there are visible fracture lines which separate the interspinous region from the diaphysis. The posterior shear fracture is extremely unstable, associated with severe concomitant injuries, and requires specific approaches.^{28,29}

Oblique posteromedial fractures, classified as AO/OTA B1.3 and B3.3, were reviewed by Wahlquist et al.²⁴ They proposed a simple classification into type-A, -B, and -C fractures. Type-A fractures are medial to, type-B fractures are through, and type-C fractures lateral to the intercondylar spines. A high incidence of associated injuries was found with type-C fractures including compartment syndrome and neurological and vascular complications. These unstable fractures must be evaluated carefully since they can be associated with complications similar to those seen in

dislocations of the knee. With displaced oblique posteromedial fractures, careful assessment of the vascular status and angiography may be required to rule out neurovascular compromise.

The value of the single-incision and minimally invasive percutaneous plate osteosynthesis (MIPPO) techniques

The single-incision anterolateral approach is commonly used for simple split and split-depression fractures confined to the lateral plateau. In preparation for surgery, the leg is best placed in 30° of flexion to release the collateral ligamentous structures. A straight incision is performed from the anterolateral joint line to 6 cm to 8 cm distally to allow a later approach for possible arthroplasty. In bicondylar injuries, the value of an additional medial buttress plate may be considered. Although type-C1 and type-C2 fractures are usually stable, in the case of displacement or severe comminution a medial plate may be helpful to maintain reduction. MIPPO has been advocated for both low-energy and high-energy fractures.^{7,8,13,30,31}

In a study of 69 high-energy fractures of the tibial plateau treated by unilateral locked plating by Gosling et al⁷ only one deep infection was observed, which the authors considered to be a result of sparing the patient a second incision. However, despite the use of a locking technique, loss of reduction was seen in 13% of the fractures. When dual-incision approaches are used a significantly higher rate of complications such as deep infection, arthrofibrosis and post-traumatic arthritis has been observed.^{2,26,32,33}

Fig. 2a

Fig. 2b

Anteroposterior radiographs of the same patient as in Figure 1 a) immediately after operation and b) at follow-up at four months.

The anterolateral approach is usually performed first to expose and reduce the proximal aspect of the lateral condyle and secure intercondylar reduction. For fixation of the condyles to the shaft, lateral locking plates can then be slid submuscularly and extraperiosteally, bridging the metaphysis (Figs 2 and 3). If the condylar fragments are not comminuted and are well reduced the medial condyle can be controlled by a laterally-based locking plate alone.^{7,13,34} This is only possible if anatomical cortical contact between the fragments is present. It is therefore important for the surgeon to recognise intra-operatively whether cortical contact will be sufficient to spare a second approach. The additional small medial approach involves application of a medial antiglide plate or a small locking plate. The anterolateral incision is the standard approach for fractures of the tibial plateau but is very close to subsequent incisions which may be required for future arthroplasty procedures. In order to allow for this a midline incision may be used which also allows good access to the medial and lateral compartments. For certain fractures, especially those with posterior displacement, dual or posterior incisions may be required.

Special situations requiring complex approaches

Fibular osteotomy may be required in the presence of depression of the posterolateral plateau and posterolateral fracture dislocations. Despite the extensive dissection required, good clinical outcomes have been documented.^{28,35}

Fig. 3

Clinical photograph showing intra-operative application of a lateral locking plate using the minimally invasive percutaneous plate osteosynthesis.

Posteromedial plateau fractures, medial fracture dislocations and wedge-like posterior metaphyseal fractures are best managed from a posteromedial approach.³⁶⁻³⁸

The straight posterior approach is rarely indicated, but works well for isolated posterior shear fractures, injuries with avulsion of the PCL and posterior fracture dislocations. Bhattacharyya et al²⁹ used this approach to treat

31 posterior shear fractures. The use of buttress plates has been shown to give a good clinical outcome when accurate reduction has been achieved.^{29,39} The use of subchondral lag screws and buttress plates may be necessary to maintain anatomical reduction and T-plates or distal radial locking plates may be used.

High-energy bicondylar fractures, coronal split fractures of the posteromedial plateau, fractures with considerable medial comminution, posterior subluxation or fracture dislocation of the medial condyle and combined posteromedial and posterolateral fractures often require combined approaches. In these cases, the fractures are insufficiently stabilised by a laterally-based plate alone and usually require additional fixation to prevent varus malunion, despite the use of locking techniques.

When are locking plates unnecessary?

Conventional, non-locking plates which exert direct compression at the site of the fracture, are suitable for simple fracture patterns with minimal comminution. The development of atraumatic techniques of open reduction and stable internal fixation (ORIF) using slim, anatomically-configured implants has facilitated care of the soft tissues and allows early movement after fixation of the fracture.^{3,40-42} Fixation of non-comminuted single-split lateral plateau injuries may be accomplished by two or three 6.5 or 7.0 mm cannulated lag screws over guide-wires through small stab incisions. Biomechanical studies⁴³⁻⁴⁵ have shown the superiority of two lag screws over three or over a solitary antiglide plate. However, if the lateral fragment is exceptionally large or comminuted at its metaphyseal base, or if there is considerable osteoporosis, a laterally-based buttress plate or antiglide plate should be used.⁴³⁻⁴⁵

For split-depressed lateral plateau fractures, the depressed articular segment is elevated and fixation of the condyle is achieved by the use of a buttress plate or peri-articular raft plate. If there is little comminution and good bone stock in selected cases it may be possible to use solitary lag screws without a plate. However, it is usually safer to apply an additional buttress plate through a small incision. Fractures of the medial plateau which present with little or no comminution are best treated by reduction through a small incision which may be sufficient to allow for screw fixation and additional buttress plating. Reduction can be achieved by a valgus stress because of the intact capsular attachments and maintained by percutaneously applied reduction forceps and multiple cannulated screws. In order to avoid shear forces, a buttress plate is recommended in addition to the compression achieved by lag screws. For high-energy fractures of the medial plateau with gross instability, comminution extending into the intercondylar eminence and injury to the lateral ligaments, open reduction and buttress plating are always required.

When are locking plates indicated?

Locked plates are indicated for high-energy fractures, those with severe comminution and in osteoporotic injuries.

Historically, fractures of the tibial plateau involving both condyles have required extensile exposures, dual plating and large-fragment implants, which have led to wound dehiscence, infection, articular collapse, nonunion and malalignment. In order to minimise soft-tissue injury, percutaneous techniques such as the use of femoral distractors, Kirschner (K-)wire joysticks and percutaneously applied reduction forceps is indicated to manipulate the major condylar fragments.

Laterally-based locking plates provide increased stability in the presence of metaphyseal or metadiaphyseal comminution, and may offer an alternative to an additional medial plate or external fixator for added support of the medial column when a non-locking plate is used for bicondylar fractures.^{8,46} This allows fixation through a single lateral incision, potentially avoiding wound dehiscence and infection associated with combined or extended approaches in which a medial buttress plate is used.^{2,47-49} Because interfragmentary compression cannot be achieved by locked plates, the supplementary use of interfragmentary screws may be required to prevent loss of reduction and to ensure adequate compression of the fragments. Biomechanical studies have shown the superiority of locked plates in these high-energy and osteoporotic fractures and have also compared locked plates with bicolumnar plating.⁵⁰⁻⁵²

Clinical outcome studies have reviewed the results of lateral locked plating for bicondylar fractures of the tibial plateau.^{7,8,30} Cole et al⁸ described a prospective, clinical trial utilising the Less Invasive Stabilization System (LISS) in 54 proximal tibial fractures, of which 13% were associated with an ipsilateral fracture of the shaft, 13% were classified as AO/OTA type 41-C3 with extensive articular comminution and 31% were open. They observed malreduction in two patients with articular step-offs of 2 mm and 3 mm, an apex anterior deformity of between 5° and 10° in four and a varus malreduction in another. There were no additional varus or valgus malreductions of more than 5° and there was no late varus collapse or cut-out at the final follow-up. Union was achieved in 96% of patients with a rate of infection of 3.7%.

Higher rates of malalignment of the proximal tibia have been reported when using the LISS system.³⁰ A recent biomechanical study showed that dual-plate fixation allowed significantly less subsidence than isolated lateral locked plates after cyclical loading in a cadaver model.⁵³ These studies suggest that while isolated lateral locked plating may offer a more biological approach to bicondylar fractures, and may provide a viable alternative for open fractures with a medial wound or fractures with tenuous soft tissues, classical dual plating remains the most rigid construct. The surgeon must assess which fixation is best suited for the pattern of bony and soft-tissue injury and the overall medical condition of the patient.

Arthroscopy and fluoroscopy

Arthroscopic-assisted reduction and internal fixation is recommended for certain types of plateau fractures. Pure

depression fractures seem to be the most suitable, although they are rare. Extravasation of irrigation fluid, especially in extracapsular fractures, carries the risk of a compartment syndrome and must be used with extreme caution.⁵⁴⁻⁵⁶ Lobenhoffer et al⁵⁷ have shown in a series of 168 patients that adequate reduction could be achieved by the use of either arthroscopy or fluoroscopy.

Indirect fixation: the Ilizarov technique

The Ilizarov circular ring fixator can be a valuable option for high-energy fractures with gross intra-articular comminution (AO/OTA type C3), especially when associated with severe soft-tissue compromise. Indirect reduction is achieved through ligamentotaxis by spanning the knee with a ring and two K-wires each in the distal femur and distal tibia. In order to avoid the occurrence of septic arthritis, the most proximal pins in the tibia must remain at least 14 mm distal to the joint line to prevent violation of the capsule of the knee.⁵⁸ After anatomical alignment of the leg has been achieved, the articular surface can be reconstructed using indirect reduction and percutaneous fixation, either by K-wires, olive wires which allow compression or lag screws. The comminuted metaphyseal region is thereby bridged and remains *in situ*. Clinical studies⁵⁹⁻⁶³ have shown similar outcomes for ORIF and indirect reduction by wire fixation. The advantages of thin wire fixators are lower rates of re-operation, a shorter hospital stay and fewer complications both in number and severity. The rates of union are comparable, but loss of movement is common and must be carefully monitored post-operatively. There is a low threshold for manipulation under anaesthesia.⁶⁴⁻⁶⁶

Clinical outcome

It is difficult to determine the clinical outcome in these diverse injuries. Clinical studies must be defined by the pattern of fracture, the number and localisation of incisions performed, and the duration of follow-up, as summarised in Table I.^{7,13,16,26,28,29,43,67}

The quality of articular reduction, the time to follow-up and the pattern of fracture play a major role in determining the outcome.

Articular reduction. Historically, the quality of articular congruency achieved after operation did not appear to be a paramount goal. In 1971, Lucht and Pilgaard⁶⁸ stated that a good outcome occurred in 78% of their patients even if articular depression was up to 10 mm. Later, Rasmussen⁶⁹ noted a worse outcome when residual articular depression of > 5 mm was present. However, these studies had limited access to assessment of the fracture by CT. Subsequently, it became very evident that an anatomical reduction of the articular surface was mandatory to give a good outcome.^{67,70} In 41 patients with OTA type-C3 bicondylar fractures of the tibial plateau assessed five years after bicolumnar fixation, only 55% had been reduced to less than 2 mm of articular step-off.²⁶ Considerable residual dysfunction was found in those patients with an anatomical reduction with more deformity than this.²⁶

Time to follow-up. Keating et al,⁷¹ evaluated 25 split depression fractures, 22 pure depression fractures and two bicondylar fractures, finding that 95% had good or excellent results at one year. Egol et al¹³ found a rate of arthritic changes of 5% at a follow-up of 16 months. The multicentre, prospective, randomised clinical trial by the Canadian Orthopaedic Trauma Society showed that in patients followed for more than two years, 37% developed signs of osteoarthritis.⁶⁰ In Marti et al's,⁶⁷ study, with a follow-up of 168 weeks, 10% of patients had evidence of osteoarthritic changes. Thus, it appears that cartilage damage in displaced fractures may not be evident in the first year, but clinical signs of arthritis develop thereafter. However, the pattern of the fracture plays a major role.

Some authors have suggested that filling of the osseous defects may be important. Keating et al⁷¹ demonstrated that calcium phosphate was appropriate for this purpose. Others have indicated that autologous bone may be used although donor-site morbidity may be of concern.^{72,73} The use of allograft, hydroxyapatite grafts, or calcium-phosphate cement may also produce comparable results, but a definitive answer to this question is not available at present.^{72,73}

Fracture pattern/approaches/clinical outcome measures. It would seem logical to expect a more limited outcome in very displaced and comminuted patterns of fracture. However, a study which compares the outcomes after different patterns is not yet available. The types of approach may also be an indicator of the severity of the fracture. Table I shows that assessment of follow-up and radiological and clinical outcome vary widely in the available literature and therefore comparisons of different studies are difficult.

The long-term outcome after fractures of the tibial plateau is limited. A favourable result seems to be achievable for low-energy injuries.^{57,74} Preservation of the meniscus and its ability to bear the load of the lateral compartment are important prognostic factors.^{75,76} In patients with high-energy fractures, the prognosis is best if mild-to-moderate articular displacement is present at the time of injury and articular reduction is achieved.^{7,13,26,64,66}

Complications

These are more likely to result from high-energy than from low-energy fractures. The outcome and complications are difficult to interpret since reports are often based on a heterogeneous group of fractures, from low-energy splits to highly comminuted open bicondylar injuries.⁴

Early complications include wound infection and deep-vein thrombosis, the rates of which are reported to be between 5% to 10%. Pulmonary embolism occurs in 1% to 2% of patients.^{70,77} The incidence of wound infections appears to correlate with soft-tissue compromise and the amount of metal implants used. Large open surgical approaches for internal fixation add to this risk, with rates of infection reaching 80%.⁷⁸ Heightened attention to the soft-tissue envelope and newer, minimally invasive techniques offer the possibility of

Table I. Clinical and radiological outcomes listed by surgical approach

Authors	Number of patients	Follow-up (mths)	Complications*	Radiological outcome†	Clinical outcome‡	Range of movement (°)
Single approach						
Gosling et al ⁷	69	12	Deep infection (1%), superficial infection (6%), NU (4%)	Anatomical reduction (78%), Loss of reduction (14%)		
Staged protocol						
Egol et al ¹³	53	16	Deep infection (5%), NU (4%), Revisions (16%)	100% within 5° of anatomical reduction, arthritis (5%)	WOMAC 91	1 to 106
Indirect reduction						
Canadian OTS ^{§60}	42	24¶	Deep infection (5%), 0% revisions	Arthritis (37%)	HHS 75	3 to 123
Chan et al ¹⁶	18	28	Superficial pin infection (67%)	Anatomical reduction (78%), DU (17%) requiring revision	KSS 66	103
Koval et al ⁴³	18	16	0	Anatomical reduction (72%)	89% good/excellent	
Dual approach						
Canadian OTS ⁶⁰	40	24¶	Deep infection (20%), ROH (20%), revision (10%)	Arthritis (29%)	HHS 68	4 to 113
Marti et al ⁶⁷	109	168	Deep infection (10%), MU (7%)	Anatomical reduction (93%), moderately severe arthritis (10%)	HHS 88.6	135
Bhattacharyya et al ²⁹	13	20	Superficial infection (8%) Flexion contracture (8%)	100% union	100% good	5 to 110
Posterior approach						
Barei et al ²⁶	41	59	Deep infection (5%), DVT (20%), ROH (25%)	Anatomical reduction (55%)	MFA 26.2	
Lobenhoffer et al ²⁸	29	48	MU (10%), TKR (7%)	80% good/excellent	95% good/excellent	
De Boeck and Opdecam ⁸⁴	7	80	Superficial infection (14%)	0 MU	100% good/excellent	7 to 122
Georgiadis ⁸⁵	4	18	0	100% good	100% good	2 to 125

* NU, nonunion; ROH, removal of hardware; MU, malunion; DVT, deep-vein thrombosis; TKR, total knee replacement

† DU, delayed union

‡ WOMAC, Western Ontario McMasters Index (functional knee score); HHS, Harris hip score; KSS, knee society score; MFA, musculoskeletal functional assessment

§ OTS, Orthopaedic Trauma Society

¶ prospective, randomised trial

minimising these risks, but infection still occurs in approximately 10% to 14% of high-energy injuries.^{2,79}

Late complications include loss of fixation, redisplacement, malunion, nonunion, and post-traumatic arthritis, which may result from the initial chondral damage or may be related to residual incongruity of the joint.^{3,44,66,75,80} Avascular necrosis has occurred after combined medial and lateral plating, especially when performed through an anterior midline approach.⁸¹ Considerable rates of arthrofibrosis are reported with the use of circular ring fixators, but also pose a risk for any method of fixation in high-energy fractures.^{2,4,65,78,82} Schatzker et al³ found an acceptable clinical outcome of 80% only if the period of

immobilisation was for less than four weeks and if the bone had no signs of osteoporosis.

A technique for the late improvement of joint congruency in malunited fractures was proposed by Marti et al.⁶⁷ In patients with valgus malalignment and residual intra-articular depression an oblique osteotomy of the middle third of the fibula and an open wedge osteotomy of the tibia, combined with arthrotomy and disimpaction of joint incongruity were performed. By this technique a mean correction in the coronal plane of 9° was achieved and 15 of 23 patients had no further radiological evidence of progression of osteoarthritis with a good clinical outcome at 14 years.

As demonstrated in several studies, the rate of post-traumatic arthritis is high. The Canadian Orthopaedic Trauma Society showed that 30% of patients had radiological signs of arthritis at two years regardless of treatment.⁶⁰ Vince and Abdeen⁸³ observed wound complications in total knee replacement (TKR) after fractures of the tibial plateau, relating them to soft-tissue compromise and multiple incisions during ORIF. They recommended the use of the most lateral incision, the most recently healed incision or soft-tissue reconstruction. Saleh et al⁸⁰ treated 15 patients after ORIF of fractures of the tibial plateau by TKR. They showed adequate functional outcome with the Hospital for Special Surgery outcome score increased from 51 to 80 points, but there was a high rate of complications with infection in 20% and rupture of the patellar tendon in 13%.

Summary

The operative treatment of fractures of the tibial plateau is challenging. It requires a detailed history and physical examination, imaging, availability of resources and skill and determination of the best timing. Treatment algorithms should involve the type of fracture, meticulous assessment of the soft tissues and other comorbidities. A good clinical outcome with regard to function and the prevention of osteoarthritis can be achieved when the initial fixation provides anatomical reduction and secondary loss of reduction can be avoided. Newer biological techniques and the development of locked-plate technology have improved outcomes, lowered the rates of revision and lessened the occurrence of deep soft-tissue infections. However, non-union, avascular necrosis, soft-tissue compromise and deep infection remain concerns.

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