19 Fracture Dislocations About the Knee

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19.1 Intra-articular Proximal Tibia and Distal Femur Fracture/Dislocations

19.1.1 Background and Mechanism of Injury

While the relationship between ligamentous injuries and knee instability is well described, there is no comprehensive classification system to describe the range of bony injuries that may occur with high-energy injuries and fracture dislocation. A high index of suspicion for ligamentous instability must be maintained when approaching periarticular fracturs around this complex joint. Periarticular fracture dislocations about the tibiofemoral joint include both distal femur fractures and proximal tibial fractures.

For tibial plateau fractures, the Hohl and Moore classification (Table 19.1) fills the void in describing true tibial fracture dislocations about the tibiofemoral joint, and draws attention to patterns with associated joint instability, which often

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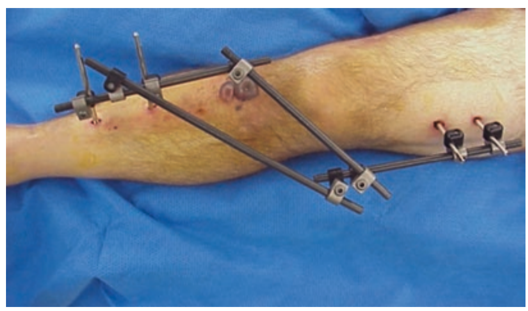

Fig. 19.1 Temporary knee-spanning external fixator. (Pelser, PC. (2010). Controversies in the management of tibial plateau fractures. SA Orthopaedic Journal, 9(3), 75–82)

Table 19.1 Hohl and Moore classification of proximal tibia fracture dislocations

Type I	Coronal split fracture
Type II	Entire condylar fracture
Type III	Rim avulsion fracture of the lateral plateau
Type IV	Rim compression fracture
Type V	Four-part fracture

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goes underrecognized when using systems such as the Schatzker classification [1, 2]. Tibial plateau fractures account for 1.7–2.0% of all fractures in adults and about 8% of fractures in the elderly [3]. These complex fractures represent a wide clinical spectrum that can be accompanied by skin and muscle compromise, neurovascular injury, compartment syndrome, ligament and meniscal tears, posterolateral corner (PLC) disruption and associated dislocation [4–8]. However, few of these fractures require separate soft tissue stabilization procedures. In a prospective cohort of 82 tibial plateau fractures, 73% had associated soft tissue injuries but only 2% required secondary soft tissue repair or reconstructive procedures [9]. Conversely, in a series of 90 consecutive multiligament knee injuries, Porrino et al. found 19 (21%) to have associated tibial plateau fracture (47% lateral plateau fractures, 37% medial plateau,16% bicondylar fractures) [4].

For distal femur fractures, there has been no definitive classification developed to describe true fracture dislocations; however, the OTA/AO classification system can be used to accurately describe the fracture pattern in terms of articular involvement and comminution. The eponymous Hoffa's fracture is a coronal plane fracture of one of the posterior femoral condyles. In the context of femoral shaft fractures, up to 30% of femoral shaft fractures have concomitant significant ligament injury [10]. In a series of 26 femoral shaft fractures, the ACL (50%) was found to be most commonly injured, followed by the MCL (31%), LCL (13%), and PCL (6%) [11]. In another series of 27 consecutive diaphyseal femur fractures who underwent MRI scans of the knee, 19% were found to have ACL injuries, 19% had grade 3 MCL injuries, 15% had grade 3 LCL injuries and 7% PCL injuries [12]. Similarly, in a series of ipsilateral femoral shaft and tibial shaft fractures (i.e. floating knees), 30% of patients had evidence of ligamentous injuries [13].

19.1.2 Clinical Presentation and Diagnostics

The first line of imaging investigations are standard orthogonal radiographs. These are typically followed by dedicated computed tomography (CT) scans to delineate fracture configuration, particularly the orientation, location and degree of displacement of depressed intra-articular fragments. Three-dimensional CT reconstruction offers a useful adjunct to the intra-articular sagittal, coronal and axial cuts to plan surgical approaches, reduction and fixation. Magnetic resonance (MR) imaging, even in the acute period, is a valuable tool to assess ligamentous, capsular, meniscal and chondral injury. MR imaging can be done following the initial injury, or, more typically, following provisional stabilization with an MRI-compatible external fixation.

19.1.3 Management Options and Evidence-Based Outcomes

Given the articular nature of these injuries, operative management is routinely necessary to restore joint stability, and limit functional impairment. In polytrauma patients, the timing of surgery is often dictated by the severity of the accompanying injuries and overall physiologic stability of the patient. General determinants such as cardiovascular, pulmonary, and neurologic function, as well as markers of response to resuscitation (i.e. lactate) play a major role in the timing and nature of acute and definitive surgical management; however, surrounding soft tissue envelope of the knee is often the definitive factor.

The high-energy nature of these injuries often precludes the use of internal fixation in the early post-injury period, given there may be surrounding soft tissue loss or rapid onset of swelling. This is illustrated as early definitive stabilization of high-energy tibial plateau fracture dislocations has been associated with a higher risk of wound breakdown and infection [14]. Alternatively, temporary external fixation, wherein a knee spanning external fixator is fixed to the femur and the tibia while the fracture zone is bridged and provisional reduction is achieved with distraction (Fig. 19.1). This technique is then followed by delayed definitive internal fixation once soft tissue swelling settles (e.g. resolution of fracture blisters, return of skin wrinkles) and has been shown to result in decreased rate of soft tissue complications [15]. This approach also facilitates the management of open wounds or vascular injuries and collection of advanced imaging (CT, MRI) with the knee in a provisionally reduced position.

For optimal external fixation, place pins on both the lateral (proximal femoral fragment) and anteriomedial (proximal tibial fragment) such that the connecting rod(s) are angled over the tibia in an oblique fashion. This provides area under the frame for swelling around the plateaus and allowing varying degrees of flexion through the knee joint should the reduction require it. Place pins at a minimum of 2 cm away from the joint line on the tibia (although farther is better in this context), and well proximal of the suprapatellar pouch on the femoral side to avoid intra-articular infection. For provisional reduction, use the half frames of the distal (tibial) and proximal (femoral) fragment as handles, and manually reduce the fracture in length with slight knee flexion (aided by a bolster), alignment and rotation.

Irrespective of the classification system used for the planning of definitive surgical treatment in tibial plateau fractures, it is important to determine the stability of the medial, lateral and posterior columns and the degree of any associated articular comminution or depression [16]. In the setting of distal femur fractures, it is equally important to determine the stability and integrity of the femoral condyles, the notch and trochlea, and whether there is a coronal plane fracture. With a 38.1% incidence of a coronal plane fracture (i.e. Hoffa fracture) in distal femur fractures with intracondylar extension, and nearly 30% of coronal plane fractures missed with plain radiographs, it is recommended to obtain CT imaging for all supracondylar-intercondylar distal femur fractures [17, 18]. This aids in determining the nature of the forces acting at the knee joint at the time of injury, and ultimately those that will need to be countered and resisted to provide a stable environment for fracture healing following fixation.

Once soft tissues allow, choice of surgical approach is paramount. Efforts must be made to utilize extensile exposures to provide adequate access to the compromised tibial column, or femoral condyle, while maximizing skin bridges and respecting the traumatized soft tissue envelope. There is insufficient evidence to broadly recommend an optimal fixation option among open reduction internal fixation (ORIF), hybrid/circular external fixation, and unilateral locked plating in proximal tibia fractures [19, 20]. For open reduction and internal fixation, anterolateral and posteromedial approaches in the supine position offer the safest and best exposure to the lateral and medial tibial columns, respectively, while prone positioning and posterior approaches may occasionally be required for select posterior column patterns. Midline anterior exposure should be avoided as a surgical approach option for proximal tibial fractures, particularly when access to more than one column is required to avoid soft tissue stripping and soft tissue complications [21]. Similarly, there is insufficient evidence to broadly recommend an optimal fixation option in the setting of intra-articular distal femur fractures between: locked plating options, dynamic condylar screws, and intramedullary fixation [22–24]. The surgical incision and approach used in the treatment of distal femur fractures will be dictated mostly by the fixation method used.

The overall goals in management are to restore articular congruity, bony alignment and stability at the knee to provide a normal mechanical axis during weight bearing in efforts to prolong lifespan of the native knee joint. Despite this, post-traumatic arthritis occurs after intra-articular fractures about the knee and causes disability in young active patients [25]. Moatshe et al. found that 42% of surgically treated knee dislocations developed OA at a minimum of 10-year follow-up [26]. Additionally, a large cohort study by Wasserstein et al. showed that 7.3% of patients treated with ORIF for a tibial plateau fracture underwent total knee arthroplasty (TKA) at 10 years [27]. This was compared with 1.8% in the matched control group. After adjustment for comorbidity in the statistical model, the risk of TKA was more than five times as likely in the tibial plateau ORIF group as in the control group, with older patients and those with bicondylar fractures having increased risk. However, the authors did not determine the role of mechanism of injury or associated knee stability, as there may have been unaddressed associated soft tissue compromise leading to advanced joint degeneration.

Although delayed, post-ORIF TKA does offer a definitive reconstructive option for those with ongoing functional compromise. It is well established that TKA for posttraumatic osteoarthritis secondary to malunion is associated with a higher rate of complications and poorer functional results than TKA for primary osteoarthritis of the knee [28]. This has led to increased interest in acute TKA for complex periarticular knee fractures, particularly as an option for elderly patients with poor bone stock and for whom prolonged non-weight-bearing status can be associated with considerable problems [29]. Interest has focused primarily on fractures of the distal femur, with some recent articles showing that TKA bypasses fracture healing issues and facilitates early mobilization and immediate weight bearing for tibial plateau fractures as well [30].

19.1.4 Case Presentation

A 59-year-old male presents to the emergency department after being struck by a car while riding his motorcycle. He had sustained an isolated right knee injury that was closed and had an intact peripheral neurovascular status. There were no clinical signs of compartment syndrome. The patient noted that he had to 'realign' his leg after the accident. The patient also had preexisting right knee pain and was scheduled to see an Orthopaedic Surgeon for 'osteoarthritis' (OA). Preoperative radiographs and CT scan images are shown in Figs. 19.2 and 19.3, respectively.

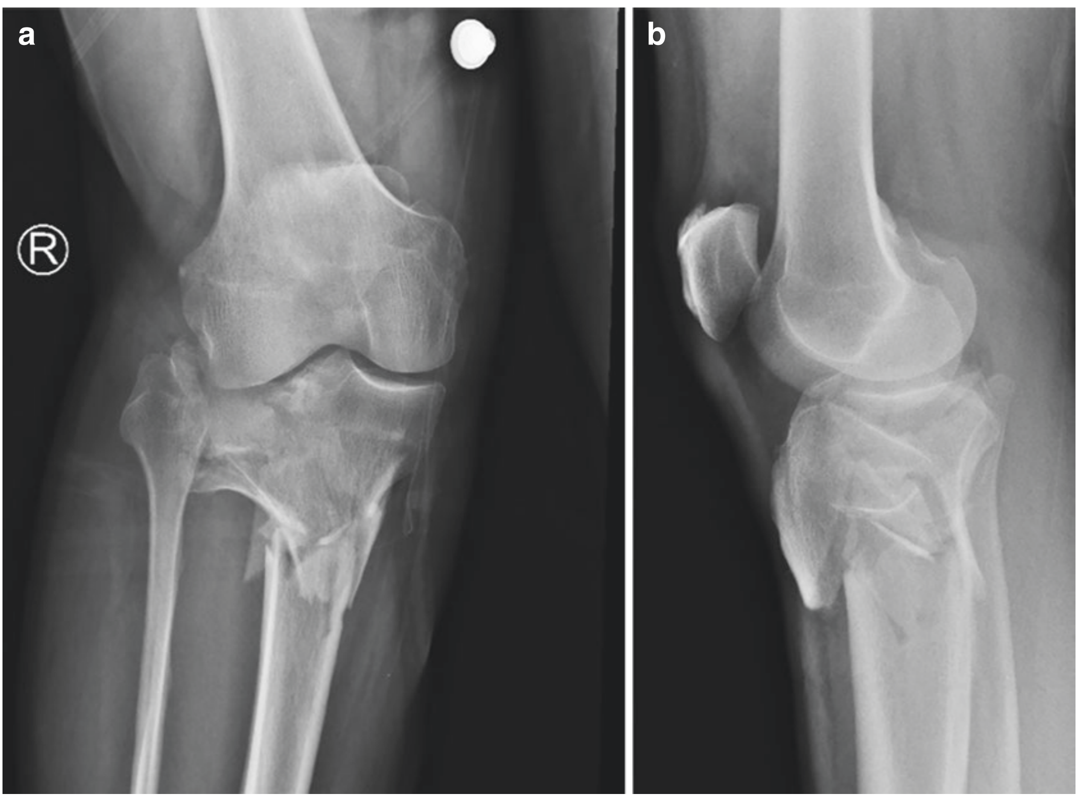

Fig. 19.2 Anteroposterior (**a**) and lateral (**b**) radiographs demonstrating preoperative right knee injury consistent with a Type V Hohl and Moore proximal tibial fracture dislocation

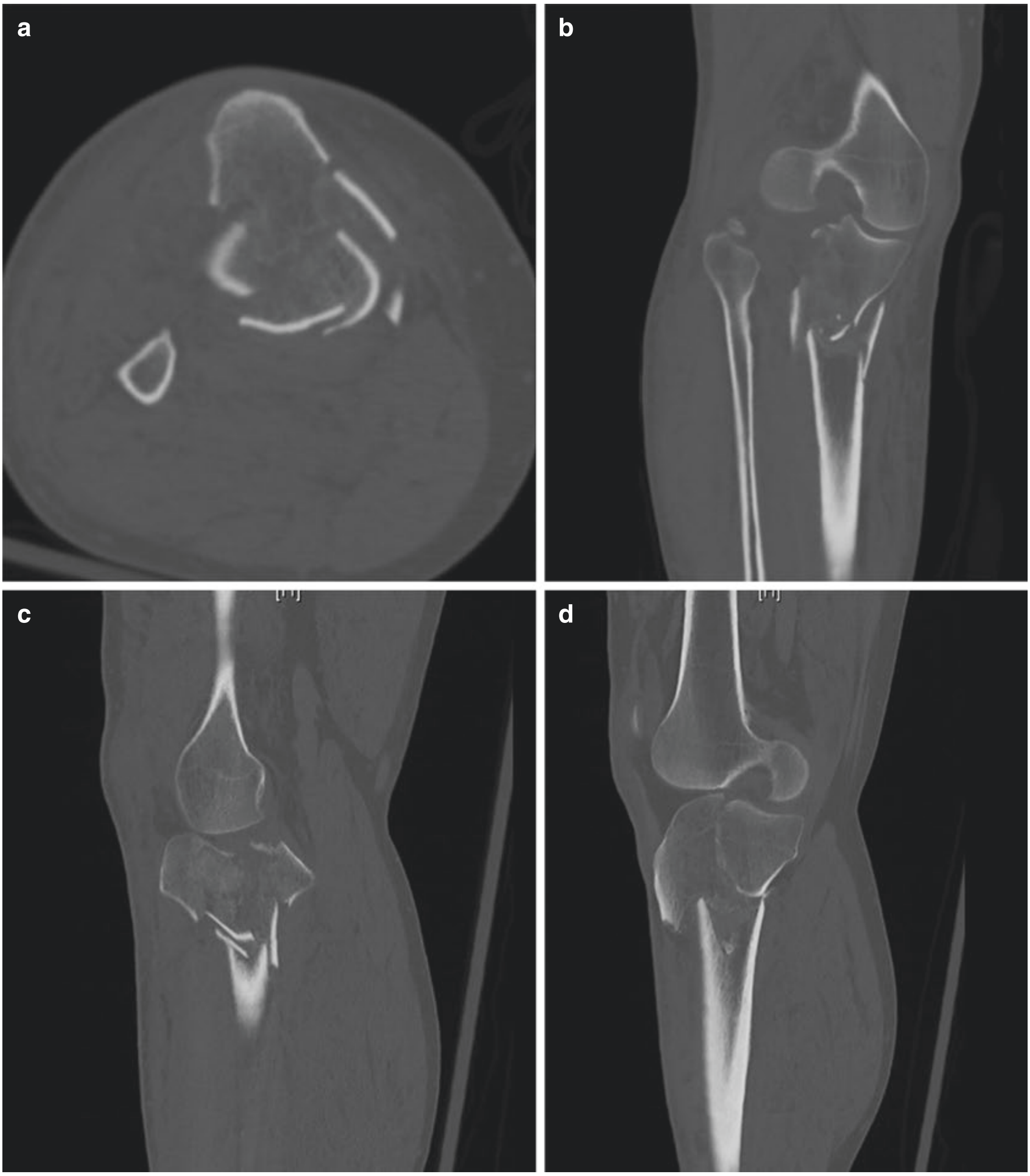

Fig. 19.3 Preoperative CT scan images of injured right knee. (**a**) Distal axial image showing comminuted diaphyseal dissociation. (**b**) Posterior-coronal image showing meta-diaphyseal dissociation and marked articular surface impaction. (**c** and **d**) Sagittal images showing marked articular surface comminution, a large tibial tubercle fragment and a large posterolateral tibial plateau fragment

The patient's history, physical examination and radiographs were consistent with a high-energy bicondylar tibial plateau fracture, with complete dissociation between the metaphyseal articular condyles and the tibial diaphysis. The tibia was shortened and in valgus alignment. In addition to condylar widening, the lateral and central joint surfaces were depressed. Further, there was significant comminution at the metaphyseal/diaphyseal junction with a large anterior tibial tubercle fragment. Given the history and the fracture pattern (Type V Hohl and Moore proximal tibial fracture-dislocation), care was taken in assessing for associated vascular injuries with serial ankle-brachial index measurements, and a full trauma team assessment was carried out to rule out non-orthopaedic injury.

19.1.4.1 Clinical Decision-Making

Given the extensive soft tissue swelling around the proximal tibia, a spanning external fixator was applied to this patient's knee within 24 h of the initial injury. After 8 days, the soft tissues had settled enough clinically, with wrinkling present on the anteromedial skin of the proximal tibia, that the patient was taken to the operating room for definitive fixation.

Bicondylar fixation was performed using a combined anterolateral and posteromedial approach. This allowed direct visualization of the fracture fragments for anatomic reduction while respecting soft tissue bridges. Further, both medial and lateral approaches were positioned at minimum 7 cm away from midline to allow for adequate skin bridges should this patient go on to need a TKA in the future. Although this patient had a history and radiographic signs consistent with mild OA of the knee, his age, bone quality and marked meta-diaphyseal comminution precluded the use of acute TKA in the treatment of this fracture. With that said, this patient will be at risk for needing a TKA in the future, and this should be incorporated into the clinical decision-making process, including the placement of incisions and management strategies to restore alignment and promote adequate bone healing.

19.1.4.2 Intraoperative Findings

Intraoperatively, the fracture was extensively comminuted, especially at the lateral tibial plateau and the lateral metaphyseal-diaphyseal junction. This called for a lateral-sided sub-meniscal arthrotomy, which revealed a lateral meniscus that was avulsed from its capsular attachments and displaced along with the depressed articular segments. The meniscus was tagged for later repair once the bony stability was restored. It should be noted that arthroscopy can be used as an adjunct to assess meniscal pathology and entrapment in the tibial plateau fracture scenario. However, it is the authors' opinion that in the fracture dislocation population, formal arthrotomy with well-visualized fracture reduction, along with open meniscal surgical management leads to more optimal fracture reduction. The fracture pattern necessitated long, bridging fixation using a lateral locking plate extending from the articular block to the diaphysis, augmented with calcium phosphate bone substitute for a large bone void that remained once the articular surface was elevated and reduced, and a medial 1/3 tubular plate to provide stability while avoiding making the construct too rigid to promote healing. Stabilization of the tibial tubercle fragment to the reconstructed columns was achieved with lag-by-technique fixation, which allowed fragment specific fixation for this challenging fracture pattern. As a final step, the lateral meniscal avulsion was repaired to the lateral capsule, and the knee was examined through a full range of motion. The ligaments were deemed stable post-fracture fixation, precluding the need for any further soft tissue procedures.

19.1.4.3 Outcome

Post-operatively, this patient was initially made non-weight bearing with no range of motion for 2 weeks. Passive range of motion exercises in a hinged knee brace began thereafter. By the 6-week mark, this patient began weight bearing with knee range of motion from 0° to 90°. Post-operative and 6-month follow-up radiographs are shown in Figs. 19.4 and 19.5, respectively.

19.1.5 Case Presentation

A 39-year-old female who presents to the emergency department after falling off her bicycle at high speeds. She had sustained a left knee injury as well as a right wrist injury. The knee injury was open and had an intact peripheral neurovascular status. On examination of the left knee, there was a large 7 cm laceration with protruding bone from both the patella and distal femur. On irrigation in the trauma bay, a complete rupture of

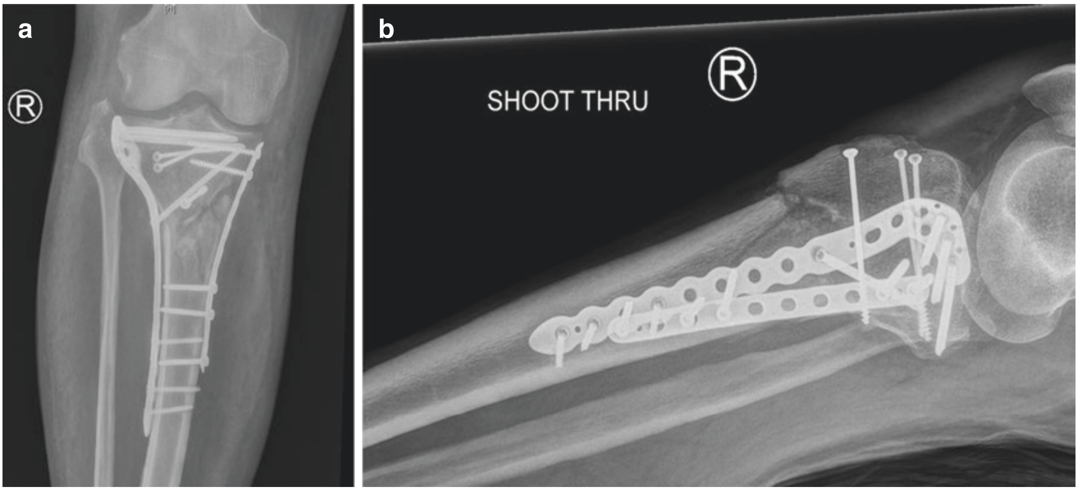

Fig. 19.4 Anteroposterior (**a**) and lateral (**b**) radiographs demonstrating immediate post-operative right knee fixation with a locked lateral plating along the diaphysis, augmented with calcium phosphate bone substitute, a medial 1/3 tubular plate and custom, lag by technique fixation of the tibial tubercle fragment

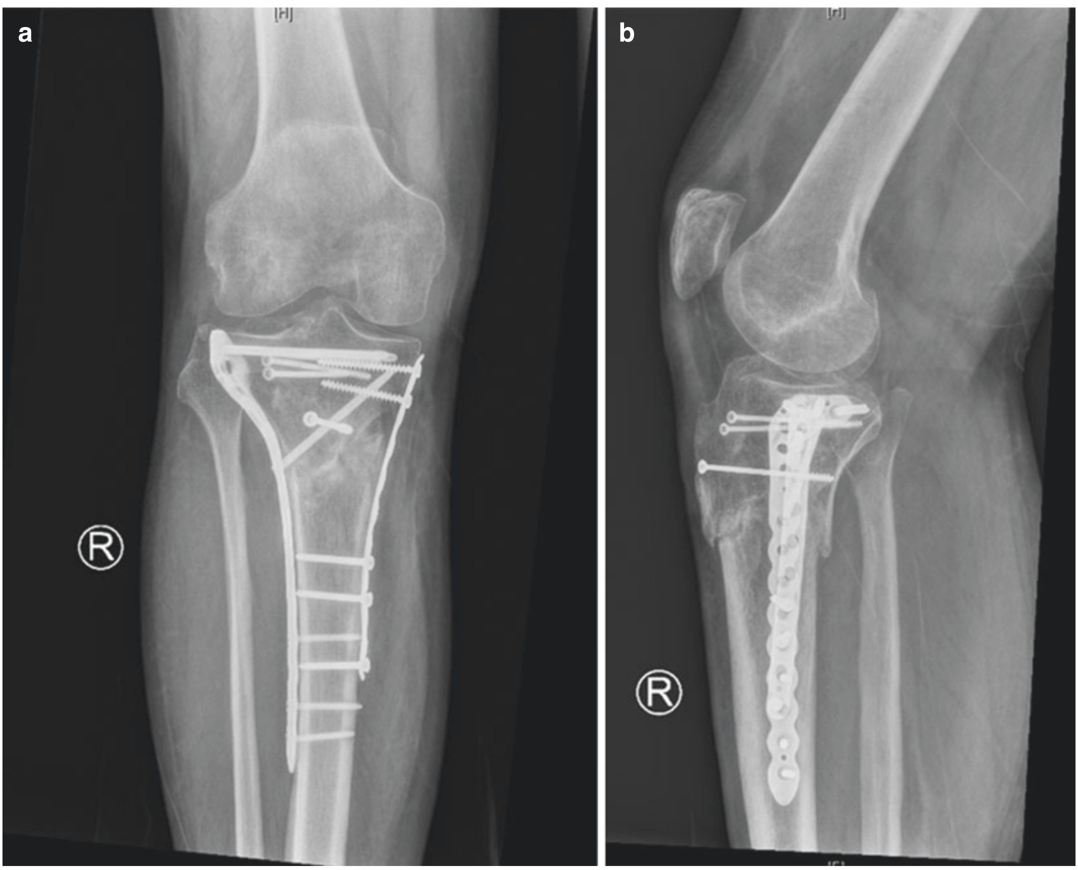

Fig. 19.5 Anteroposterior (**a**) and lateral (**b**) radiographs demonstrating immediate post-operative right knee fixation with adequate ossification and blurring of the fracture lines

the quadriceps could be palpated. Preoperative radiographs and CT scan images are shown in Figs. 19.6 and 19.7, respectively.

The patient's history, physical examination and radiographs were consistent with a high-energy open bicondylar intra-articular comminuted distal femur fracture, with associated ipsilateral patellar fracture and extensor mechanism disruption. The patient received the appropriate antibiotics, and a provisional irrigation and debridement in the trauma bay. The femur was shortened with a flexion deformity and condylar widening. Further, there was significant comminution at the metaphyseal/diaphyseal junction with bone loss. Given the history and the fracture pattern, care again was taken in assessing for associated vascular injuries with serial ankle-brachial index measurements, and a full trauma team assessment was carried out to rule out non-orthopaedic injury.

19.1.5.1 Clinical Decision-Making

Given the open nature of the fractures and the extensive soft tissue damage around the knee, the patient was brought to the operating room urgently. A thorough irrigation and debridement was carried out with normal saline and gravity flow. Fixation with a lateral locking plate was used given the intra-articular nature of the fracture with associated comminution. Fixation was achieved through an anterior approach centred over the patella that was extended laterally to allow fixation of both the distal femur and patella while incorporating the open wound for debridement.

19.1.5.2 Intraoperative Findings

After appropriate irrigation and debridement, the traumatic arthrotomy, with extension superolaterally, allowed for adequate visualization of the distal femur. The trochlear groove fragment was provisionally stabilized to the lateral condyle fragment and the lateral Hoffa fragment in an anterior to posterior plane. Anatomic reduction at these osteochondral intra-articular fracture lines was obtained and stabilized with two fully threaded cancellous screws. K-wire joysticks were used to manipulate the medial osteochondral articular block to obtain a provisional reduction relative to the lateral side. Compression across the condyles was achieved with a periarticular reduction forceps. Once stabilized the entire articular block was then provisionally fixed to the femoral shaft. Even though there was bone loss at the meta-diaphyseal junction, cortical keys were used on both the lateral and medial

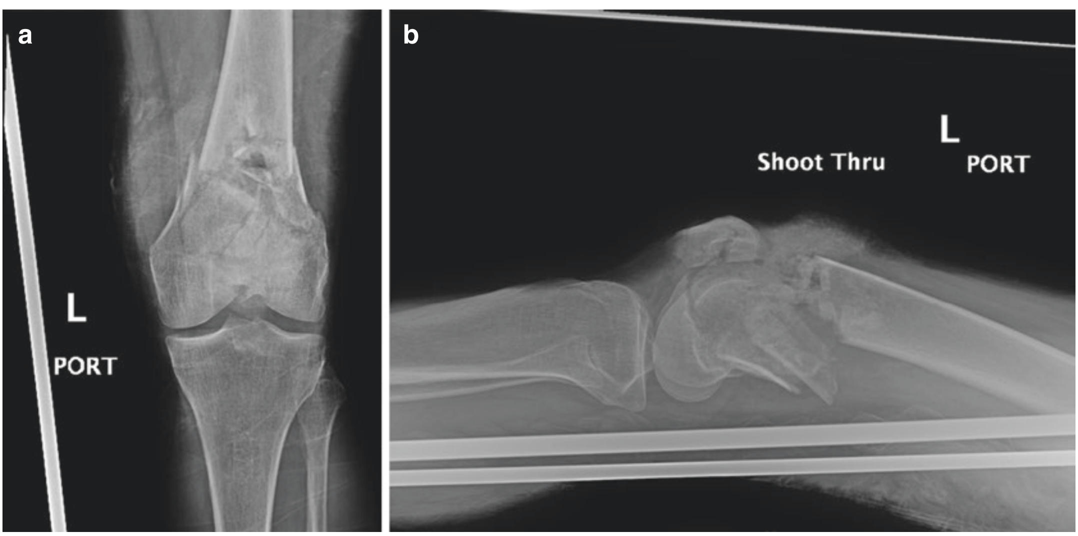

Fig. 19.6 Anteroposterior (**a**) and lateral (**b**) radiographs demonstrating preoperative left knee injury consistent with a Type 33C OTA/AO distal femoral intra-articular fracture

Fig. 19.7 Preoperative CT scan images of injured right knee. (**a** and **b**) Axial images showing intra-articular comminution with condylar widening/split with a large trochlear fragment. (**c** and **d**) Coronal images showing meta-diaphyseal dissociation and marked articular surface impaction, with meta-diaphyseal bone loss. (**e** and **f**) Sagittal images showing flexion deformity of the fracture pattern as well as a substantial lateral condyle Hoffa fragment

sides to achieve anatomic length and rotation. A long distal femoral locking plate was positioned appropriately on the distal segment. Care was taken not to position the plate too posterior, to ensure limited internal rotation of the articular block relative to the femoral shaft. As well, care was taken to limit medial displacement of the articular block, thus ensuring that no 'golf club deformity' was produced. After fixation of the distal femoral fracture the concomitant patellar fracture and extensor mechanism disruption was surgically addressed. As a final step, the bone void was filled with calcium sulphate resorbable beads (Osteoset®, Wright Medical) and vancomycin powder. The ligaments were deemed stable post fracture fixation, precluding the need for any further soft tissue procedures.

19.1.5.3 Outcome

Post-operatively, this patient continued on a 48-h course of IV antibiotics and the wound was monitored. She was initially made non-weight bearing with no range of motion for 2 weeks. Passive range of motion exercises in a hinged knee brace began thereafter. By the 6-week mark this patient began weight bearing with knee range of motion from 0° to 90°. Post-operative radiographs are shown in Fig. 19.8.

19.2 Acute Proximal Tibiofibular Injuries

19.2.1 Background and Mechanism of Injury

Acute proximal tibiofibular joint dislocations are rare injuries, accounting for less than 1% of all knee trauma [31]. Nonetheless, the majority of these injuries occur during sporting activities and may go unrecognized leading to prolonged pain and dysfunction [32].

The proximal tibiofibular joint is a synovial joint that has multiple normal anatomical variants in the population. In one of the earliest detailed descriptions of this joint, Ogden described two proximal tibiofibular joint anatomic variants: oblique and horizontal, with horizontal configuration being defined as <20° joint surface inclination relative to the horizontal plane [33]. In 10–12% of the population, the joint communicates directly with the knee joint [33–35]. The stabilizing structures around the joint include three broad ligamentous bands passing anteriorly, the posterior proximal tibiofibular ligament, and the structures of the posterolateral knee, including the popliteus and the lateral collateral ligament (LCL) [36].

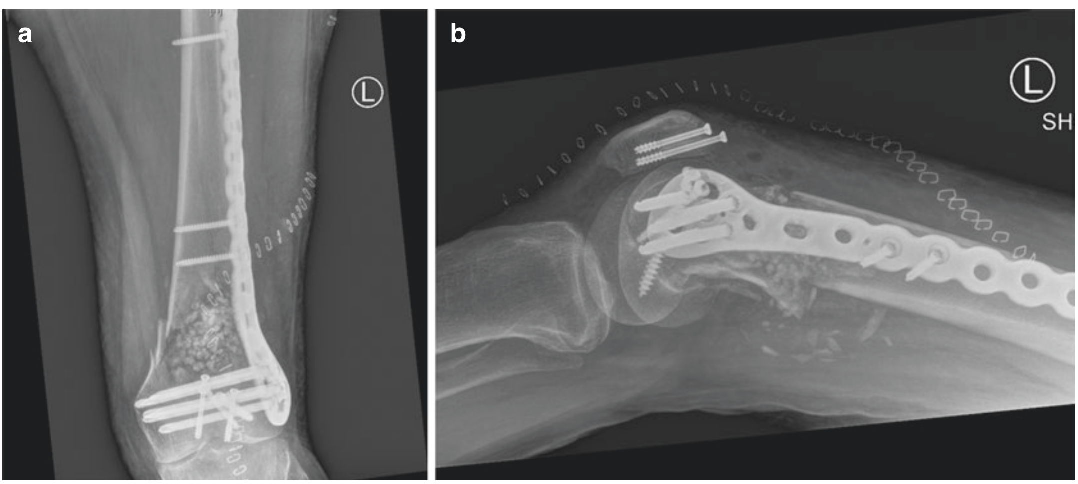

Fig. 19.8 Anteroposterior (**a**) and lateral (**b**) radiographs demonstrating immediate post-operative left knee fixation with a locked lateral plating along the diaphysis, augmented with calcium sulphate bone beads, with two cancellous screws providing fixation of the lateral Hoffa and intercondylar notch fragments

The most common mechanism of injury to the proximal tibiofibular joint is rotational, often through twisting of the knee in a flexed and externally rotated position, with concomitant inversion and plantar flexion of the foot [32, 37]. While sports injuries are the most common aetiology, high-energy polytraumatic injuries can also lead to proximal tibiofibular dislocations.

19.2.2 Clinical Presentation and Diagnostics

Diagnosis may be clinical or require imaging depending on the type and severity of the injury. In patients presenting with an isolated proximal tibiofibular joint disruption, localized pain and swelling over the fibular head is common. As well, prominence of the fibular head may be evident. Careful neurovascular examination should be undertaken as transient peroneal nerve palsy is common given its proximity to the proximal tibiofibular joint [36]. Plain radiographs may reveal the diagnosis, though not all cases are immediately evident. Contralateral radiographs can be helpful for direct comparison, with CT or MRI often being unnecessary for isolated injuries but may be indicated in polytrauma or cases with persistent posterolateral knee pain.

In his original case series, Ogden classified proximal tibiofibular joint dislocations into four types (Table 19.2). Type II injuries are the most common and usually sports-related, while Type III and IV injuries are more commonly related to high-energy mechanisms and direct trauma [38, 39].

Table 19.2 Ogden classification of proximal tibiofibular joint dislocations

Type I	Atraumatic subluxation
Type II	Anterolateral dislocation
Type III	Posteromedial dislocation
Type IV	Superior dislocation

19.2.3 Management Options and Evidence-Based Outcomes

19.2.3.1 Non-operative Management

Closed reduction should ideally be attempted under general anaesthesia with full muscle relaxation, which also allows conversion to open reduction if necessary. To facilitate reduction, the knee should be flexed between 80° and 110° to relax the biceps femoris and LCL [32, 36]. The foot can also be externally rotated, everted, and dorsiflexed to also relax the peroneals, extensor hallucis longus, and extensor digitorum longus (EDL) [36, 37, 39], though some authors argue that this is not necessary [40]. Direct pressure is then applied to the fibular head, with orientation of force depending on the direction and type of dislocation. Successful reduction is often accompanied by an audible and palpable "pop" [36].

19.2.3.2 Operative Management

In cases where closed reduction is unsuccessful, or surgery is required to address other injuries about the knee, open reduction internal fixation may be undertaken. To approach the proximal tibiofibular joint in isolation, a lateral curvilinear incision is made centred over the joint and the peroneal nerve is identified and protected just distally as is wraps around the fibular neck from posterolateral to anteromedial. Open reduction can then be attempted under full general anaesthesia with muscle relaxation. If still unsuccessful, muscular attachments of the proximal fibula including EDL, biceps femoris, and peroneus longus may need to be released to allow for complete reduction [36, 41, 42]. Successful reduction should be confirmed both by direct visualization and fluoroscopic confirmation following which fixation of the fibula to the tibia is needed to maintain alignment as the surrounding soft tissues heal. At least three different fixation techniques have been described: K-wire fixation, screw fixation, and dynamic suspensory suture button fixation. Tricortical fixation with a screw or K-wire have been demonstrated to be adequate, and are performed in a similar fashion, with either a screw or k-wire being placed perpendicular to the joint in a posterolateral to anteromedial direction, while taking care to protect the posterolateral structures of the knee [36, 42]. Alternatively, Warner et al. (2016) describe the treatment of chronic proximal tibiofibular joint instability using an anatomic reconstruction of the posterior ligamentous structures of the PTFJ with a semitendinosus autograft [43].

The dynamic yet powerful suture button may offer an option that more closely recreates the proximal tibiofibular anatomy, and has been described by Main et al. who used the Tightrope™ (Arthrex, Naples, Florida) device [41]. In their case report, the patient already had a history of mild degenerative joint disease in both knees, and was presenting with a chronic and recurrent case of proximal tibiofibular dislocation. It was felt that allowing micro-motion at the proximal tibiofibular joint would have a protective effect against accelerated OA for the patient. Two divergent sets of suture buttons were placed, one from anterolateral to posteromedial and the other from posterolateral to anteromedial. This was augmented by a bio-absorbable screw placed just below the level of the proximal syndesmosis. At 1 year post-operatively, the patient was asymptomatic from the perspective of her proximal tibiofibular joint [41].

Given the rarity of proximal tibiofibular dislocations, the body of literature on the topic is almost entirely composed of case reports. Ogden's original case series, circa 1974, may in fact be the largest case series on this condition, consisting of 43 patients. In that series, Ogden described a number of complications, specific to the dislocation type. Type I was associated with chronic subluxation and peroneal nerve injury leading to foot drop. Patients with Type II dislocations were all treated non-operatively, which was associated with chronic instability in some patients eventually leading to surgical fixation [39]. More recent reports generally attempt closed reduction, followed by immediate open reduction in cases of failed closed attempts. Unsurprisingly, these case reports generally demonstrate no complications, and full return to activity, including competitive sports, with both operative and non-operative management, but higher quality evidence is needed to confirm [36, 42, 44–46].

19.2.4 Case Presentation

The patient had been involved in a head-on motor vehicle collision and presented as a trauma team activation. The patient was diagnosed with a left olecranon fracture, bilateral femur fractures, a left proximal tibiofibular dislocation, and a left tibial shaft fracture. An anterolateral dislocation was noted on plain radiographs and confirmed on CT scan (Fig. 19.9) [32, 39].

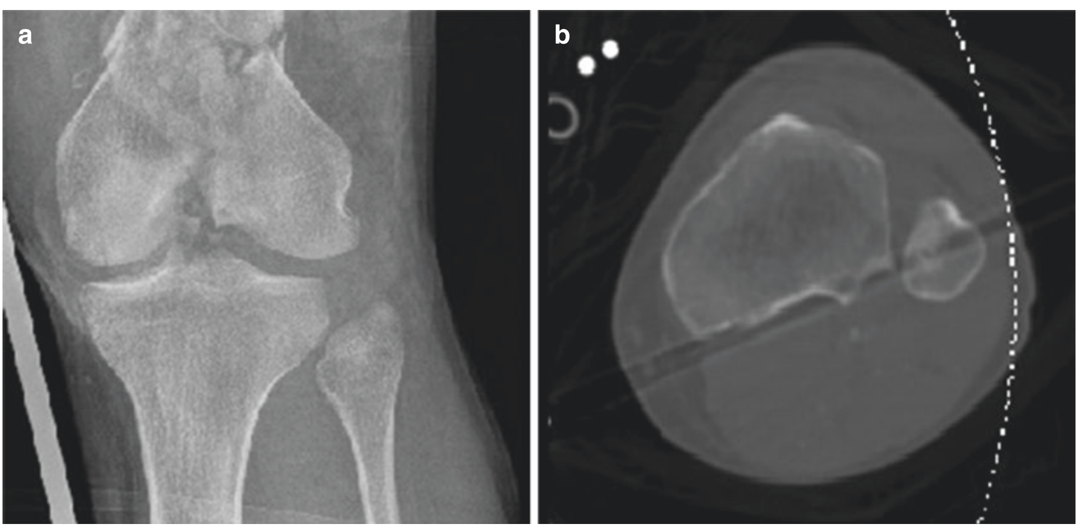

Fig. 19.9 (**a**) Anteroposterior radiograph demonstrating comminuted distal femur fracture and proximal tibiofibular dislocation; (**b**) Axial Computed Tomography scan confirming a Type II Anterolateral dislocation of the fibula

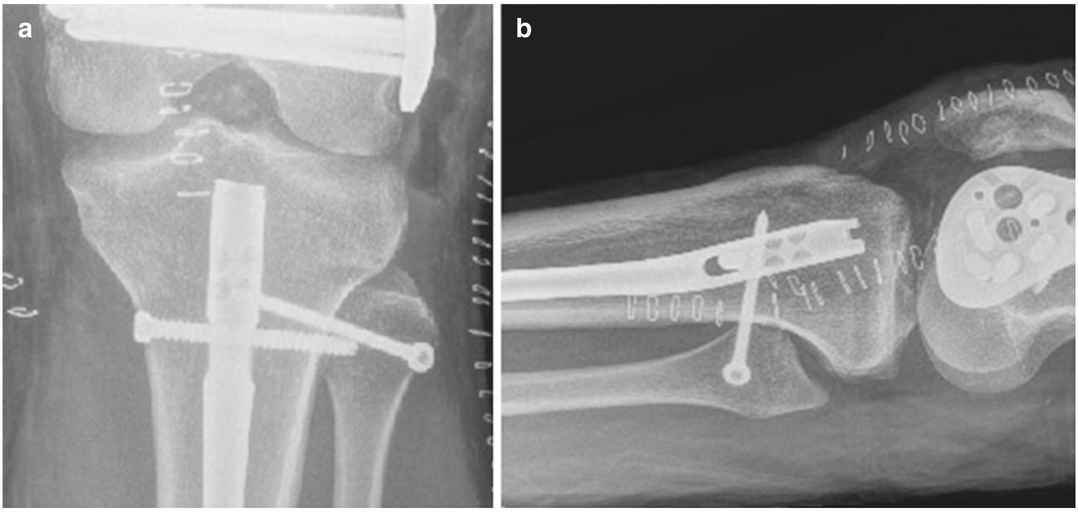

Fig. 19.10 Anteroposterior (**a**) and lateral (**b**) radiographs demonstrating fixation of the proximal tibiofibular joint with tricortical screw, intramedullary fixation of the tibia, and distal femoral locking plate

The patient was being taken to the operating room for their other injuries, and thus open reduction was performed. Minimally invasive-open reduction was achieved without any releases; however, a large enough incision was used to endure that the common peroneal nerve was intact and safe. A percutaneous tricortical screw was used to secure fixation of the proximal tibiofibular joint (Fig. 19.10). The patient was kept non-weight bearing in a long leg splint postoperatively. The patient will be monitored for symptomatology at the proximal tibiofibular joint at post-operative follow-ups to discern if hardware removal will be necessary.

19.3 Patellar Dislocation with Associated Osteochondral Fractures

19.3.1 Background and Mechanism of Injury

Lateral patellar dislocations are a common orthopaedic injury with a documented prevalence of 2.29–5.8 per 100,000 in the general population [47, 48]. The prevalence rises dramatically in adolescents to 11.9–29 per 100,000 and most commonly occurs during athletic endeavours [47, 48]. Several osseous and soft-tissue risk factors for dislocation have been identified including trochlear dysplasia, patella alta, tibial tubercle lateralization, generalized ligamentous laxity, and a history of previous dislocations [49–52].

Common associated injuries of patellar dislocations include chondral and osteochondral fractures. They are often found on the medial and central patellar facets and the lateral femoral condyle [53]. The prevalence of associated patellar chondral injuries is high, ranging from 38 to 95% [54–56]. Femoral-sided chondral injuries are less common and range from 5 to 32% [53, 54, 57, 58]. The high prevalence of osteochondral damage is thought to be due to the high prevalence in adolescents and differences in the properties of the chondral surface and subchondral bone [59]. Osteochondral lesions are more common in traumatic, high-energy dislocations when compared to low-energy recurrent dislocations in patients with underlying anatomic risk factors for dislocation [55]. Regardless of mechanism, however, the presence of osteochondral injuries in the setting of patellar dislocations significantly increases the rate of posttraumatic patellofemoral arthritis later in life [60, 61].

19.3.2 Clinical Presentation and Diagnostics

First-time patellar dislocations usually occur with a flexed knee and internal rotation of the tibia [62]. Acute patellar dislocations occur most commonly during athletics and tend to dislocate laterally [63]. Cartilage defects may present with ongoing pain and swelling, clicking and instability [64].

Plain radiographs of patellofemoral and tibiofemoral joints consisting of anteroposterior, lateral and skyline views should be obtained. Given that plain radiographs miss a large proportion of osteochondral injuries, they should primarily be utilized to assess for predisposing factors of patellar instability as well as concomitant injuries [49, 63]. Trochlear dysplasia can be assessed on plain radiographs utilizing the sulcus line, double contour sign and supratrochlear spurs [65, 66]. The Insall-Salvati, Caton-Deschamps and the Blackburn-Peel ratios are all measures of patellar height to assess for patella alta [67–69].

CT provides fine bony detail and three-dimensional reconstruction but comes with added radiation exposure. CT scans can be used to measure all of the same values as plain radiographs with the added benefit of accurately measuring the distance between the tibial tubercle and the trochlear groove (TT-TG) [70]. The TT-TG distance quantifies the lateralization of the tibial tubercle. Increased TT-TG distance increases the risk of recurrent patellar instability and is particularly important when tibial tubercle osteotomies are being considered in patients with predisposing malalignment [70].

MRI is considered the gold standard imaging modality for assessing both soft tissue, cartilaginous and bony injuries that occur with patellar dislocations [63, 71, 72]. Disruption of the medial ligamentous stabilizers, mainly the medial patellofemoral ligament (MPFL) and patellar retinaculum, are well visualized on MRI [57, 72–74]. Magnetic resonance imaging demonstrates a sensitivity of 81% when compared with arthroscopic evaluation of MPFL tears [72].

Bone oedema secondary to the contusion is seen on the medial patellar facet and the lateral femoral condyle after acute dislocations [71, 74]. Magnetic resonance imaging demonstrates a sensitivity of greater than 90% in assessing for chondral damage when compared to arthroscopy. Intra-articular loose bodies present as a separated fragment of chondral or osteochondral tissue and can be found in up to 33% of patients following patellar dislocations [57, 63, 75]. MRI should be obtained when there is clinical suspicion of an MPFL tear, osteochondral injury not elucidated on prior imaging, and recurrent patellar dislocations refractory to non-operative management.

19.3.3 Management Options and Evidence-Based Outcomes

The management of patellar dislocations with associated osteochondral lesions varies widely and is based largely on level IV evidence and expert opinion. Patients presenting with osteochondral lesions or loose intra-articular bodies are often excluded from clinical trials given the risk of further damage if left untreated [76–78]. Lesion size, location, chronicity, patient and surgeon preferences all play a role in the decision-making process. Given the lack of high-level evidence, there remains significant variation in the management of these injuries [79].

The presence of a loose intra-articular body following an episode of patellar instability is considered an indication for operative intervention in order to prevent symptoms and further chondral damage [76, 80–82]. Nikku et al. (2005) have performed the largest RCT to date examining the operative management of 127 primary patellar dislocations [76]. They did not find patellar realignment surgery to be beneficial, but they did find that the subset of patients presenting with loose bodies led to significantly poorer functional outcomes.

Surgical repair of unstable osteochondral fractures is the preferred method of management [83, 84]. Historically, these patients have had poor outcomes when treated non-operatively [85]. However, there is no consensus on the size, depth or location of a fragment that is considered amenable to fixation. Duthon et al. (2015) suggested that surgical fixation is favourable for fractures involving >10% of the articular surface [83]. Although limited to small case series and retrospective reviews, the outcomes of fixation after osteochondral fractures have been favourable for lesions of both the patella and femoral condyle [86–91]. Gesslin et al. (2019) retrospectively reviewed patients who underwent fixation compared to debridement for OCF lesions. Despite the fixation group presenting with larger fracture fragments, they had significantly better long-term clinical outcome scores and significantly fewer reoperations [86]. Kang et al. (2018) reviewed patients who underwent fixation compared to debridement for OCFs that did not involve the weight-bearing surface. They demonstrated that excision and debridement in this subgroup had improved clinical outcomes [92]. Should the fracture fragment be amenable to fixation, techniques for fixation vary widely and include bioabsorbable or nonabsorbable countersunk screw or pin fixation [86–91, 93]. The theoretical advantage of bioabsorbable implants is that they do not need to be removed if further revision surgery is required. Given the lack of comparative studies, method of fixation is left to the discretion of the treating surgeon.

Microfracture is a well-established technique aimed at marrow stimulation for chondral and osteochondral lesions [94]. Although short-term results have been favourable in younger patients, there is variable long-term efficacy particularly when examining older patients and microfractures of the patella and trochlea [95, 96]. Microfractures result in a fibrocartilaginous tissue that is biomechanically inferior when compared to the natural hyaline cartilage . Meta-analysis data has suggested that functional outcomes were improved if the lesions were <4 cm for all patients and <2 cm for the athletic subpopulation [97]. However, given the lack of literature that examines the efficacy of microfractures for the patellofemoral joint specifically, it is difficult to draw any conclusions about the size, depth and location that would benefit from microfracture [98]. It is the authors' experience that microfracture is rarely required or warranted by the time the patient seeks operative management following lateral patellar dislocations.

The MPFL is disrupted in the vast majority of acute patellar dislocations. However, the role of repair or reconstruction in the setting of an acute patellar dislocation remains controversial [79, 82]. Early randomized controlled trials focused on acute repair of the MPFL and demonstrated no differences in outcomes between surgical and conservative management [76, 99, 100]. The understanding of the anatomy and biomechanics of the MPFL has increased considerably in recent years, which has aided in the popularization of various reconstruction techniques [101, 102]. There is level I evidence that demonstrates lower dislocation rates and improved clinical outcomes in patients undergoing MPFL reconstruction compared to non-operative management in the setting of both acute and recurrent patellar dislocation [103–105]. However, these studies include both patients with normal anatomy and those who have anatomic risk factors for dislocation, making it challenging to apply these results to the individual patient. There remains a lack of data guiding the management of the MPFL in the setting of operative osteochondral lesions.

It is the senior author's recommendation that patients undergo a thorough preoperative assessment to assess for risk factors for patellar instability. In the absence of these risk factors, MPFL reconstruction is of questionable additional benefit in first time dislocators with osteochondral defects. However, if the patient presents with a history of recurrent instability and/or anatomic risk factors for instability, MPFL reconstruction is warranted. There are several proposed methods of MPFL reconstruction including single bundle vs. double bundle and various autografts or allografts [106].

19.3.4 Case Presentation

An otherwise healthy 13-year-old female presented to the orthopaedic outpatient clinic 4 days after a left knee injury. The patient reported that she was playing ball hockey in gym class and planted her foot when another player fell onto the outside of her knee. A "pop" was felt and the patient stated that she saw her knee cap dislocate laterally and reduce spontaneously. She had significant pain and swelling to the knee and was unable to ambulate. She presented to the Emergency Department where she was placed in a knee immobilizer. Initial plain radiographs demonstrated a fracture off the lateral femoral condyle with an intra-articular loose body (Fig. 19.11).

Fig. 19.11 Anteroposterior (**a**) lateral (**b**) and skyline (**c**) radiographs demonstrating acute fracture of the lateral femoral condyle with intra-articular loose body, circled in white

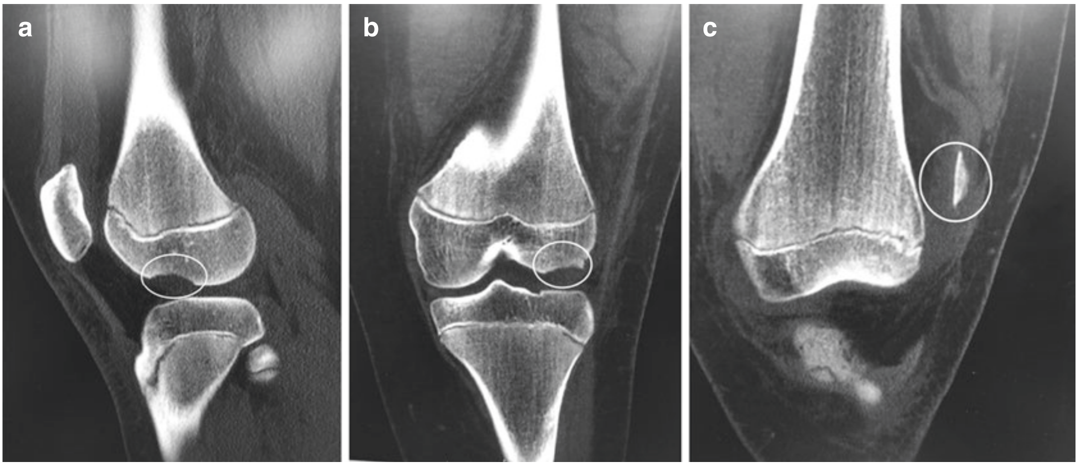

Fig. 19.12 Sagittal (**a**) and Coronal (**b**) cuts of the CT scan demonstrating osteochondral donor site on the lateral femoral condyle and associated cartilage fragment in the lateral joint recess on an anterior coronal slice (**c**)

The patient was seen in the orthopaedic clinic where a CT scan was triaged. The CT scan demonstrated an ossific fragment measuring 1.6 cm in its craniocaudal dimension × 0.5 cm in its transverse dimension × 1.5 cm in its AP dimension within the lateral aspect of the knee joint just superior to the lateral femoral condyle. The donor site involving the cortical and subcortical aspect of the inferior portion of the lateral femoral condyle measured 1.4 × 0.9 × 1.4 cm. The CT scan also demonstrated some lateral shift of the patella and subtle widening of the patellofemoral articulation in its medial aspect (Fig. 19.12).

Given the osteochondral fracture and associated loose bodies, we discussed the potential risks and benefits of undergoing operative intervention. The patient and his family consented to left knee arthroscopic loose body removal with possible open reduction and internal fixation of the osteochondral fracture. Given that the patient had no history of recurrent patellar instability and no risk factors on imaging, the decision was made to not perform an MPFL reconstruction at the index surgery.

19.3.4.1 Intraoperative Findings

Diagnostic arthroscopy identified a significant chondral defect at the lateral femoral condyle. This was subsequently debrided with the arthroscopic shaver. The loose osteochondral fragment was found in the lateral gutter and retrieved in one piece. It measured approximately 2.5 cm × 2 cm with a small piece of bone on the underside.

The operation was converted to an open procedure with the lateral vertical portal site extended proximally. A small lateral parapatellar approach was utilized to enter the knee joint. The defect was visualized and surrounding soft tissue and callous were removed. The osteochondral fragment was reduced and fixed with six 16 mm biodegradable SmartNail® implants (CONMED, Linvotec). Intraoperative images are shown in Fig. 19.13.

19.3.4.2 Outcome

The patient was placed in a hinged knee brace locked in full extension and instructed to be non-weight bearing for the first 6 weeks with progressive range of motion in the brace. At last follow-up this patient regained painless gait and range of motion of her knee with only 3° of terminal extension deficit and 90% quadriceps bulk compared to the contralateral knee. She continues with her athletic endeavours with a patellar brace. Post-operative radiographs have remained normal (Fig. 19.14).

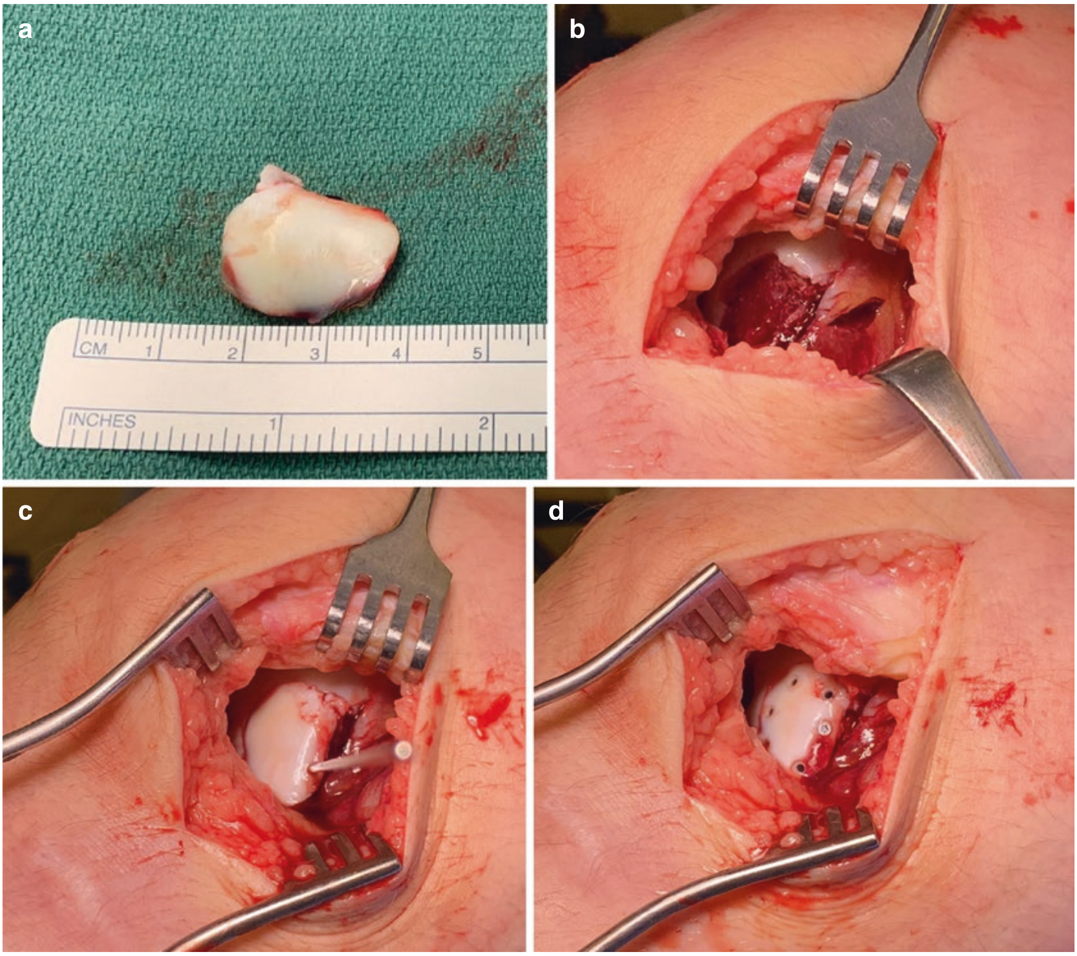

Fig. 19.13 Intraoperative images showing the 4 day-old lateral femoral condyle fracture fragment measuring approximately 2 cm in height (**a**) and the corresponding defect on the condyle (**b**). Provisional fixation (**c**) followed by definitive fixation with biodegradable SmartNail implants (**d**)

19.4 Tibia Physeal Fractures of the Knee in the Paediatric Population

19.4.1 Proximal Tibia Physeal Fractures

19.4.1.1 Background and Mechanism of Injury

Proximal tibia physeal fractures most commonly occur in adolescents 11–14 years of age. Given the stability of the proximal tibia via the medial collateral ligament (MCL), LCL, fibula, and tibial tubercle, displaced fractures of the proximal tibial physis requires a high-energy mechanism [107]. The mechanism of injury affects the degree and direction of the resulting displacement; hyperextension injuries result in anterior displacement of the epiphyseal fragment, and hyperflexion injuries result in anterior displacement of the metaphyseal fragment [108]. Given the location of the popliteal artery which runs along the posterior tibia and trifurcates just below the physis, these injuries present serious concern for laceration or thrombosis of the popliteal vessel in children [109].

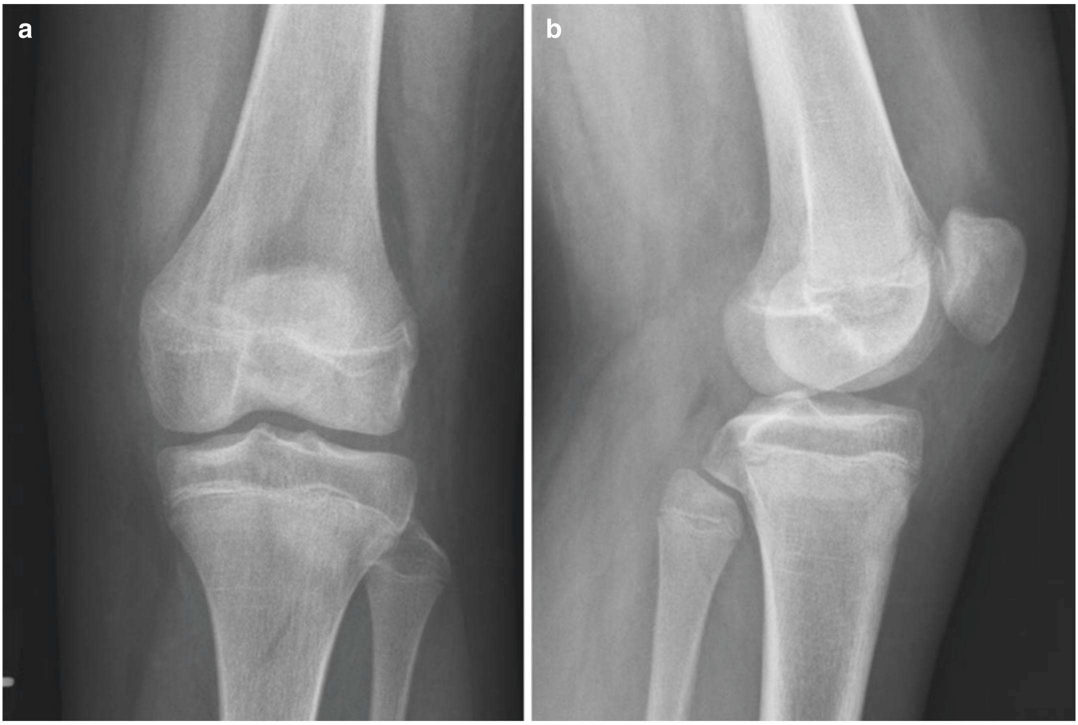

Fig. 19.14 Anteroposterior (**a**) and lateral (**b**) radiographs taken 6 weeks post-operatively demonstrating fracture healing and normal alignment

19.4.1.2 Clinical Presentation and Diagnostics

Patients with proximal tibial physeal fractures present with focal pain, soft tissue swelling and commonly a knee joint effusion. For all proximal tibial physeal fractures, a thorough neurological and particularly vascular examination of the leg is critical given that the incidence of vascular injuries are equivalent to that of multi-ligamentous knee dislocations [110]. Anteroposterior and lateral radiographs are required for initial diagnosis, with CT scans helpful as an adjunct to assess for the existence and degree of articular involvement. An MRI is another useful adjunct in displaced patterns to assess for ligamentous injuries that may be entrapped within the fracture gaps [110]. The widely used Salter-Harris classification for paediatric physeal fractures is the most commonly used system to classify proximal tibial physeal fractures [111].

19.4.1.3 Management Options and Evidence-Based Outcomes

For Salter-Harris types I and II fractures with displacement, an initial trial of closed reduction and long-leg casting may be acceptable if reduction achieves less than 2 mm of residual displacement [108, 110]. Residual displacement warrants open reduction to assess for soft tissue interposed between the fragments (MCL, LCL, pes anserinus, or periosteum), and pinning using transphyseal, smooth wires. Pins are typically placed in a crossed manner and can be inserted either anterograde or retrograde. Benefits of anterograde pinning include a less technically demanding procedure; however, the pins are often intra-articular leading to a higher risk of septic arthritis [110, 112].

Salter-Harris types III and IV fractures that are non- or minimally displaced can be managed with closed reduction and percutaneous screw fixation; however, any displacement warrants open reduction to achieve anatomic reduction of the articular surface under direct visualization [112]. The construct for fixation typically consists of screws or pins that are perpendicular to the physis within both the metaphysis and epiphysis.

The most commonly reported complications following physeal fractures of the proximal tibia are growth disturbances, vascular injury, neurological compromise, and less commonly nonunion. Growth disturbances have been reported to occur in up to 25% of proximal tibial physeal fractures, resulting in either unequal limb lengths or angular deformities [113]. Therefore, it is recommended that these patients be followed regularly until skeletal maturity with full leg-length films [113]. Vascular injuries of the limb occur in 10–15% of cases, and therefore, it is recommended that these patients be admitted for monitoring for at least 24 h post-operatively [109, 112].

19.4.2 Tibial Tubercle Fractures

19.4.2.1 Background and Mechanism of Injury

Fractures of the tibial tubercle most commonly occurs in adolescent males 12–17 years of age, comprising approximately 3% of all proximal tibia fractures [107, 114, 115]. The closure of the tubercle physis from proximal to distal during skeletal maturity leaves the distal aspect of the tubercle susceptible to injury [116]. The mechanism of injury is typically caused by jumping or forced flexion of the knee leading to a powerful contraction of the quadriceps muscle [107, 114, 117].

19.4.2.2 Clinical Presentation and Diagnostics

Patients with tibial tubercle fractures present with local soft tissue swelling and focal tenderness to palpation of the tubercle. When minimal swelling precludes an obvious diagnosis, pain with straight leg raise or resisted knee extension may provide a clue towards a possible diagnosis. Serial neurovascular examination is critical for any diagnosed or suspected tubercle fractures as damage to the anterior recurrent tibial artery may result in swelling and compression to the anterior compartment where the deep peroneal nerve and anterior tibial artery may be occluded [116].

Anteroposterior and lateral radiographs of the knee are required for initial diagnosis. In order to obtain a perfect lateral view of the tubercle, slight internal rotation of the leg provides a direct view of the apophysis, which is slightly lateral to the midline [116]. However, plain radiographs have been shown to underestimate the severity more than 50% of the time, and therefore, CT scans are useful to assess whether there is intra-articular or metaphyseal extension. The most commonly used classification is the Ogden modification of the Watson-Jones classification with grades I–III (relating to the location relative to the junction between the proximal tibia and the apophysis) each divided into subtypes A and B (for non-displaced or displaced/comminuted fractures, respectively) (Table 19.3) [118].

Table 19.3 Ogden modification of the Watson-Jones classification for tibial tubercle fractures

Type IA	Fracture line through ossification center of tibial tubercle with no displacement
Type IB	Anterior and proximal displacement of the fracture fragment
Type IIA	Fracture extends through the junction of proximal tibia and the tibial tubercle
Type IIB	Similar to IIA with comminuted tubercle fracture fragment and anterior displacement
Type IIIA	Fracture extends to the articular surface with associated discontinuity
Type IIIB	Intra-articular with comminution

19.4.2.3 Management Options and Evidence-Based Outcomes

Non-displaced fractures may be treated non-operatively with a long leg cast in extension [119]. Displaced fractures of the tubercle often require open reduction and internal fixation. A midline anterior approach is typically used, with intra-articular fractures commonly requiring arthroscopic assistance, or a parapatellar arthrotomy. The construct for fixation typically consists of two- to three cannulated, partially threaded screws perpendicular to the fracture, as screws have been shown to offer superior compression and fixation to percutaneous pins [120]. Washers may be used to prevent penetration into soft apophyseal bone [110, 117]. Given the anticipated significant anterior compartment swelling due to injury of the recurrent anterior tibial artery, intraoperative compartment pressure monitoring may be used if clinically indicated, necessitating possible decompression of the hematoma alone or in combination with a prophylactic anterior compartment fascia release distal to the surgical site [114]. Post-operative management includes admission to hospital for 24–48 h to monitor swelling of the anterior compartment, with the leg braced or splinted in extension for a minimum of 4 weeks [115].

The most common complications in order of acuity following tibial tubercle fractures are compartment syndrome, hardware prominence, bursitis, and growth disturbances. Compartment syndrome has been reported with incidence ranging from 2 to 20% [117, 118]. Hardware prominence resulting in bursitis is a problem primarily for thinner patients, and removal may be required in more than 50% of patients treated with open reduction and internal fixation [116, 120]. For patients younger than 13 years of age, long-term follow-up is suggested to monitor for growth arrest resulting in genu recurvatum [110, 114].

Fig. 19.15 Lateral sagittal CT image demonstrating a type IIA fracture of the tibial tubercle as well as a minimally displaced Salter-Harris type IV fracture of the proximal tibia physis

19.4.2.4 Case Presentation

A 12-year-old male presented to the Emergency Department with a left knee injury sustained during soccer, when early in the kick phase, the kicking leg was abruptly stopped and forced into eccentric contraction of the quadriceps, after hitting a section of raised playing surface. The patient was found to have no neurological compromise and compartments were monitored. Imaging, including plain radiographs and CT scan were performed, demonstrating a type IIA fracture of the tibial tubercle (Fig. 19.15) as well as a minimally displaced Salter-Harris type IV fracture of the proximal tibial physis.

Fig. 19.16 Post-operative lateral radiographs. Two cannulated, partially threaded screws placed parallel to both the physis and perpendicular to the fracture. A washer was also used to prevent penetration into the bone

19.4.2.5 Intraoperative Findings

Operative management was undertaken using a midline incision. Given the swelling of the anterior compartment, the hematoma was evacuated, and a small fascial opening over the anterior compartment was made and left open. Two cannulated, partially threaded screws were placed parallel to both the physis and perpendicular to the fracture were placed using a washer to prevent penetration into the bone (Fig. 19.16). A long leg cast was applied, and the patient was admitted to hospital for monitoring of his compartments for 72-h post-operatively.

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