Fractures Associated with Knee Ligamentous Injury

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Ciaran Thrush, Timorthy S. Whitehead,
Jérôme Murgier, and Brian M. Devitt

13.1 Introduction

Injuries to the knee are often complex with significant involvement of both soft tissue and bony structures. Fractures are related to the position of the knee at the time of impact and the mechanism of injury involved. As such, a number of common fracture patterns have been described. In the treatment of these complex injuries, particular attention should be paid to the timing of operative intervention, surgical rationale, and order of treatment. Three broad categories of fractures are discussed in relation to these complex knee injuries: avulsion and impaction fractures commonly related to knee injury, articular or periarticular fractures with resultant soft tissue injuries, and fractures remote to knee injury.

13.2 Epidemiology

Becker et al. [1] published a report investigating multiligamentous knee injury patterns presenting to a level 1 trauma centre. Of the 106 knee ligament injuries examined over an 8-year period, 25% had associated ipsilateral tibial plateau fractures, and 19% had associated ipsilateral femoral fractures. A further study by Shepherd et al. [2], investigating the prevalence of soft tissue injuries in nonoperative tibial plateau fractures, determined that 40% had complete ligament disruption and 80% had meniscal tears. Considering tibial plateau fractures requiring operative intervention, Gardner et al. [3], in their study of 103 consecutive patients, revealed that 77% sustained a complete tear or avulsion of one or more cruciate or collateral ligaments and 68% had tears of one or more of the posterolateral corner structures of the knee; the most frequent fracture pattern was a lateral plateau split-depression (Schatzker II), sustained in 60% of patients. Stannard et al. [4], in a similar study, determined that 71% of patients with tibial plateau fractures tore at least one major ligament, while 55% of patients tore multiple ligaments. Therefore combinations of soft tissue injury and bony injury are common and should be considered in conjunction with one another.

13.3 Soft Tissue Knee Injury and Associated Fractures

In general, multiligamentous knee injuries, rather than isolated soft tissue knee injuries, are often associated with avulsion or impaction fractures [5]. Many of these fractures are visible on plain radiographs and are indicative of ligamentous disruption and possible reduced knee dislocation. Schenck described the anatomical classification

C. Thrush · T. S. Whitehead · J. Murgier
B. M. Devitt (✉)
OrthoSport Victoria, Epworth Healthcare, Richmond, VIC, Australia
e-mail: tswhitehead@osv.com.au; bdevitt@osv.com.au

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of knee dislocation based on the ligaments and structures that were injured [6], including four combinations of ligament injury (KD I to KD IV). An additional category, KD V, was added by Wascher et al. [7] to encompass fracture dislocations. KD V is specific to periarticular fractures and does not include avulsion fractures or fractures remote to the knee. The other fracture patterns encountered include Segond fractures, 'reverse-Segond' fractures, tibial spine avulsions, tibial plateau compression fractures, fractures of the fibular head, avulsions of the popliteus, osteochondral fractures, and marginal tibial plateau fractures. It is imperative to identify these fractures, as they should raise suspicion for associated neurovascular pathology that should not be overlooked when assessing a multiligamentous injured knee. It is the experience of the authors that isolated repair of avulsion injuries may give rise to residual laxity due to the plastic deformity to the ligament or capsular structure prior to the bony avulsion and that reconstruction may be more appropriate.

13.3.1 Segond Fracture

Segond fractures, first described in 1879, occur as a result of excessive varus and internal rotation and involve a bony avulsion from the tibia just distal to the lateral tibial plateau [8] (Fig. 13.1). The Segond fracture is caused by an avulsion of the anterolateral complex [9]. In a recent study, a magnetic ressonance imaging (MRI) analysis revealed that soft tissue attachments to the Segond fracture are the posterior fibres of the iliotibial band (ITB) and the lateral capsule in most of the cases [10]. These structures are involved in the control of the rotational stability of the knee. A Segond fracture, therefore, can be associated with significant knee damages, including anterior cruciate ligament (ACL) tears, meniscal tears, and injury to the posterolateral corner in addition to other ligamentous injuries [5, 11, 12]. Traditionally they are regarded as pathognomonic for ACL rupture, but any patient with a Segond fracture in the trauma setting should be evaluated for a concomitant multiligamentous injury, including a detailed vascular examination. It is possible to sustain a Segond fracture without ACL injury [13]; therefore a high index of suspicion should be maintained for other injuries.

Fig. 13.1 Anteroposterior radiograph of the left knee depicting a Segond fracture (white arrow). This fracture is an avulsion of the anterolateral aspect of the tibial plateau and is associated with rupture of the anterior cruciate ligament. (Image courtesy of Dr. Ryan Martin, Calgary, Canada)

Typically the Segond fracture is not treated directly, but as it indicates a high likelihood of other significant knee pathologies, investigation and treatment are directed at that underlying pathology.

13.3.2 Reverse Segond Fracture

'Reverse Segond' fracture is the term attributed to avulsion fractures from the medial tibial

Fig. 13.2 Anteroposterior radiograph of the right knee demonstrating a 'reverse Segond' fracture. This is an avulsion fracture of the anteromedial aspect of the tibial plateau which is associated with medial collateral ligament and posterior cruciate ligament injuries

plateau (Fig. 13.2). This fracture is brought about by the opposite mechanism to that which creates a Segond fracture, valgus, and internal rotation of a flexed knee and typically requires a higher energy mechanism than a Segond fracture [14]. It has been associated with combined posterior cruciate ligament (PCL) and medial collateral ligament (MCL) injuries [14, 15]. Merrit et al. [16] have described a spectrum of pathology associated with the 'reverse-Segond' fracture, including intra-substance tears of the superficial, deep, and/or posterior oblique fibres of the MCL, in addition to extensive stripping of the soft tissue attachments off the proximal tibia on the medial side.

Treatment of these fractures is best performed in the acute setting. The avulsed bony fragment is identified and repaired with the adjacent soft tissue. A variety of techniques, including bone anchors and AO fracture reduction principles, can be employed. After 6 weeks, capsular structures, left unrepaired, tend to shorten, and anatomic reduction is difficult to achieve.

13.3.3 Anterior Cruciate Ligament Avulsion

Avulsion fractures of the tibial insertion of the ACL (Fig. 13.3) are common and are also frequently associated with a multiligamentous knee injury pattern [17]. Tibial eminence fractures are normally indicative of injury to the ACL and/or PCL as well as almost certain disruption to some or all of the meniscal root [16]. Traditionally, avulsion fractures of the tibial eminence have been described in the paediatric population using the Meyers and McKeever classification [18]. However, this classification can be applied to the adult population and may help to guide treatment.

Fixation of ACL avulsions allows early range of motion to avoid undue arthrofibrosis and assurance that the tibial footprint of the ACL is

Fig. 13.3 Anteroposterior radiograph depicting (white arrow) an avulsion of the tibial spine in a paediatric patient

restored. Arthroscopic repair of tibial eminence fractures is possible and allows concurrent assessment and treatment of any meniscal pathology. An arthrotomy may be required to assist reduction, and fixation may take the form of screws or trans-osseous sutures or a button device [19]. Krakow sutures through the ligament are often necessary to supplement screw fixation.

13.3.4 Posterior Cruciate Ligament Avulsion

Much like a tibial avulsion of the ACL, the PCL may be avulsed, typically in combination with injury to the posterolateral corner (PLC) (Fig. 13.4). Unlike midsubstance tears of the PCL, bony avulsions should be primarily repaired to restore function to the PCL. Fixation of a bony avulsion of the PCL can be achieved using an open approach, either directly posteriorly or posteromedially, which avoids direct dissection of the popliteal neurovascular structures [20]. Similar to an ACL avulsion, fixation may be achieved with screws or suture and button devices. Arthroscopic or arthroscopic-assisted techniques may also be used [21], which avoid the morbidity associated with open approaches.

Fig. 13.4 Lateral radiograph of the left knee depicting a displaced avulsion fracture of the tibial attachment of the posterior cruciate ligament (white arrow) (Image courtesy of Dr. Ryan Martin, Calgary, Canada)

13.3.5 Impaction Fractures

The force imparted on the knee during injury may also give rise to impaction fractures (Fig. 13.5a, b). The mechanism of injury is typically a compression force with hyperextension and differs to that of avulsion fractures, which commonly involve a tensile force with or without a rotational element [5, 22, 23]. These fractures are often seen on the anteromedial aspect of the tibia and anterior medial femoral condyle and are associated with PCL and PLC/lateral collateral ligament (LCL) injuries [24].

Bony compression fractures may also occur on the distal femoral articular surface as a result of its impact on the tibial plateau [25]. This force is most commonly found with an ACL tear and joint subluxation in the classic pivot shift pattern.

The treatment of impaction fractures can be difficult. If dealt with acutely, anatomical reduction of the depressed subchondral fragment may be possible and held with a small buttress or 'washer' plate. 'Retrograde disimpaction' has been described to elevate the subchondral depression on the femoral side [26].

13.3.6 Fibular Head Avulsions

An avulsion fracture of the fibular head has been referred to as the 'arcuate sign' and represents a sleeve of bone pulled away from the proximal fibula [27, 28] with the corresponding soft tissue attachments (Fig. 13.6). The size and location of the avulsed fragment is helpful to

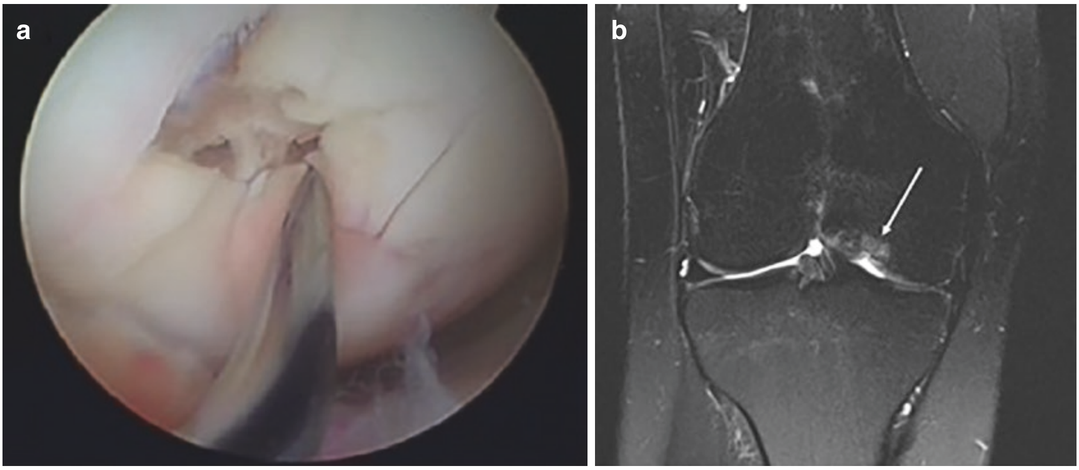

Fig. 13.5 (**a**) An arthroscopic view of the medial femoral condyle with an extensive impaction fracture of the chondral surface, which is highlighted by the arthroscopic probe; (**b**) A coronal T2 magnetic resonance image of the same knee depicting a depressed impaction fracture of the medial femoral condyle

Fig. 13.6 Anteroposterior radiograph depicting an avulsion fracture of the fibular head (white arrow). This is also called an 'arcuate sign.' This fracture typically represents injury to the structures of the posterolateral corner. (Image courtesy of Dr. Ryan Martin, Calgary, Canada)

identify which of the PLC structures have been injured. The LCL, popliteofibular ligament, biceps femoris, fabellofibular, and arcuate ligaments all insert on the fibular head at different locations. Larger avulsions or a comminuted fibular head fracture may indicate a more extensive injury, whereas smaller avulsion may suggest that a solitary structure has been avulsed [29]. These fractures make reconstruction considerably more challenging. The fixation method depends on the size and extent of comminution of the fragment. Where possible, direct screw fixation of the fracture is best; however, a variety of techniques may need to be employed including Krakow sutures with bone anchors and tension band wiring.

13.3.7 Fractures Associated with Patella Dislocation

Patella dislocation may occur in conjunction with tibiofemoral dislocation or, more commonly, in isolation. Fracture associated with patella dislocation can range from osteochondral injury to avulsion fractures of the medial patellofemoral ligament [30] (MPFL) (Fig. 13.7). Osteochondral

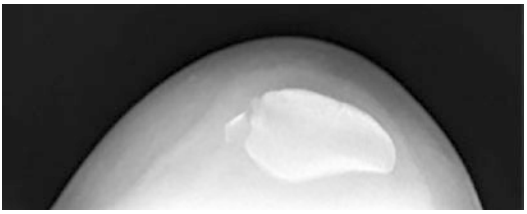

Fig. 13.7 Avulsion fracture of the medial patello femoral ligament

injury is said to be very common during patella dislocation, occurring in up to 95% of acute patella dislocations [30], and can range in severity from chondral impaction to displaced osteochondral fragments. They may be difficult to appreciate on plain radiography, requiring MRI for diagnosis. In general, impaction injuries are treated nonoperatively, and displaced osteochondral fragments should be considered for removal if small, or repair if large.

During acute patella dislocation, the MPFL is frequently injured and can range from intrasubstance ligament injury to avulsion of the attachment on the patella or femur. Avulsions may involve a large segment of patella chondral surface, which may benefit from fixation. However, the results of fixation of avulsions without chondral involvement may not indicate any benefit over nonsurgical management [31].

13.3.8 Osteochondral Fractures

Traumatic osteochondral fractures of the knee commonly occur in conjunction with soft tissue injuries such as ACL rupture or patella dislocation [32] (Fig. 13.8). The most common sites of injury are the patella or femoral condyles, and despite it being a common concurrent injury, there is little consensus as to an appropriate treatment algorithm [33]. There is much heterogeneity regarding different treatment options and indications, and therefore it is difficult to recommend one treatment over another. Options include excision or fixation with k-wires, bioabsorbable pins, and fibrin glue and range from arthroscopic to open surgery [33].

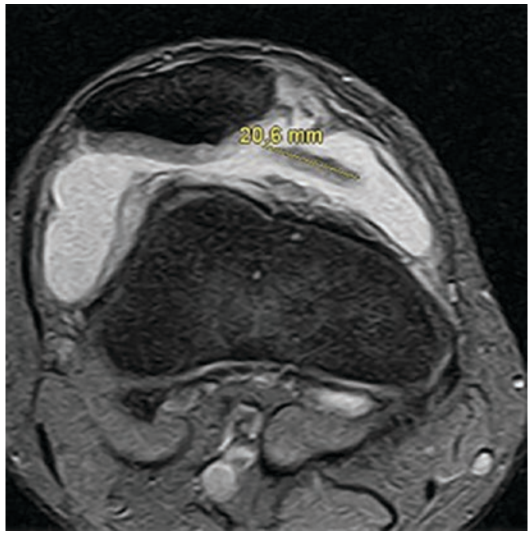

Fig. 13.8 An axial MRI which demonstrates a displaced osteochondral fragment (yellow line) from the medial patellar facet

13.4 Fractures and Associated Soft Tissue Injury

Severe fractures of the distal femur or proximal tibia represent a distinctly different problem compared to avulsion and marginal impaction fractures. The energy involved in these injuries is very high, and management of the fracture is normally independent of procedures required to confer ligamentous joint stability. The functional outcome of these injuries is worse than isolated ligamentous injuries, despite appropriate management of both the fracture and the soft tissue component.

13.4.1 Femoral Fractures

Periarticular and articular fractures of the femur include supracondylar fractures and femoral condyle fractures. Siliski et al. [34] reported supracondylar fractures with associated ligamentous injury; ACL injuries were found to be commonly associated with this fracture configuration. Interestingly, there were no reports of complete knee dislocation or multiple ligament injuries with supracondylar fractures.

Femoral condyle fractures have been associated with knee dislocation. In general the ligaments are preserved and attached to the fragment. However, despite fixation, these patients have only fair to good results with limited range of motion following fixation [35]. The 'Hoffa' fracture (Fig. 13.9) has been associated with disruption to the extensor mechanism, which typically occurs as a result of a shearing force when a load is transmitted to a flexed knee. Most references to these injuries in the literature are case reports; the consensus on treatment is that stiffness is a greater problem than instability. The recommendation is appropriate treatment of the fracture, typically via open reduction and internal fixation with compression screws and buttress plating, followed by nonoperative management of any ligamentous injury or delayed reconstruction once the fracture has healed, and range of motion has been re-established [35, 36].

Fig. 13.9 An anteroposterior radiograph of the left knee showing an intra-articular fracture (white arrow) of the medial femoral condyle, the so-called 'Hoffa' fracture. Typically the ligamentous attachments of the knee are maintained and fixation of the fracture will restore stability

13.4.2 Tibial Fractures

The association of ligamentous injuries with tibial fractures is well recognized [5] (Fig. 13.10). Standard et al. [4] have found that up to 71% of patients tore at least one major ligament with a tibial plateau fracture. Using the Schatzker classification, the prevalence of the ligamentous injuries associated with the fracture type has been subcategorized: Type I, 46%; Type II, 45%; Type IV, 69%; Type V, 85%; and Type VI, 79%.

Standard's study revealed that a significant difference exists between groups regarding the incidence of ligament injuries and also regarding high-energy (types IV, V, VI) versus low-energy (types I, II, III) fracture patterns. Knee dislocations (dislocated on presentation, bicruciate

Fig. 13.10 An anteroposterior radiograph of the right knee demonstrating a highly comminuted tibial plateau fracture. These injuries are commonly associated with injury to the soft tissue structures of the knee

injury, or at least three ligament groups torn with a dislocatable knee) were most common in Schatzker type IV fractures (46%). The study concluded that high-energy fracture patterns (Schatzker types IV, V, VI) clearly have a significantly higher incidence of ligament injury and these patients should be carefully evaluated to rule out a spontaneously reduced knee dislocation. The authors recommend that MRI should be performed for all tibial plateau fractures caused by a high-energy mechanism, allowing identification and treatment of associated soft tissue injuries.

Typically, treatment involves appropriate nonoperative or operative fixation of the tibial fracture, with either delayed reconstruction or nonoperative ligamentous management.

13.4.3 Patellar Fractures

The extensor mechanism can be injured in the setting of knee injury by rupture of the patellar ligament or fracture of the patella (Fig. 13.11). In a series of 112 patellar fractures, Kosanovic et al. [37] reported 5% had ligamentous injuries of the knee and 4% had knee dislocations. The fractures were all comminuted and underwent osteosynthesis at the time of ligament reconstruction. Postoperative knee motion is critical to prevent stiffness. However, it is of course possible to sustain a soft tissue disruption of the extensor mechanism, where early range of motion is contraindicated following repair and, therefore, increases the risk of the development of arthrofibrosis [38].

Fig. 13.11 A lateral radiograph of the left knee demonstrating a displaced transverse patellar fracture (white arrow)

13.4.4 Fractures Remote to the Knee

Bony injury may occur at an anatomical location separate to the concurrent knee injury and include fractures of the pelvis/acetabulum, hip, femoral and tibial shaft, distal tibia, plafond, foot, and upper extremity (Fig. 13.12). The very nature of multiple injuries indicates a high-energy injury with multisystem disruption. The presence of concomitant injury has a significant effect on clinical outcome and may affect surgical timing, rehabilitation, and the risk of the development of postoperative infection.

In general ipsilateral knee injuries are easier to rehabilitate, as the patient has a healthy contralateral limb. Surgery should proceed according to the standard principles for extremity injuries. Contralateral injuries present a bigger challenge. The surgeon must consider the benefits of early knee reconstruction against the risk of a bedridden patient. If reconstruction is to be performed, early range of motion should start as early as possible and weight bearing as best as possible.

Long bone injuries of the femur or tibia also pose a difficult problem. A number of studies have demonstrated the association with femoral and tibial shaft fractures and knee ligament injuries [5, 39]. The primary concern relates to the initial stabilization of the long bone injuries as part of the initial resuscitation effort and to establish limb alignment; this is often achieved with an intramedullary nail. It is very important that anatomic alignment and rotation are restored as this can compound an unstable knee leading to greater

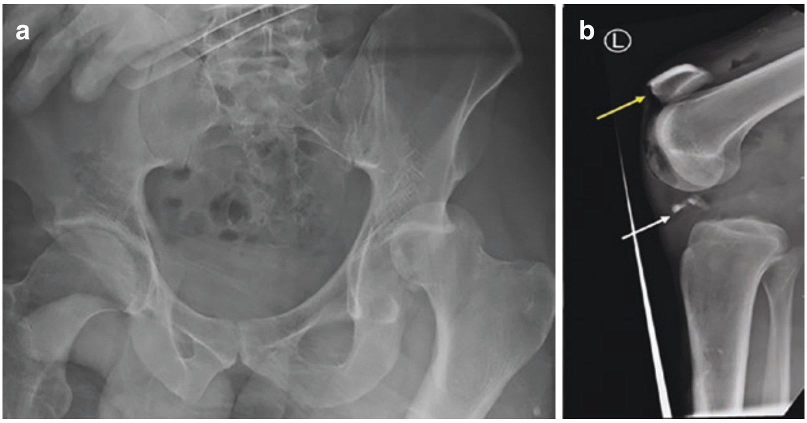

Fig. 13.12 (**a**) An anteroposterior pelvic radiograph taken in the trauma setting depicting a fracture-dislocation of the left hip that was sustained concurrently with a ipsilateral knee dislocation with disruption all major knee ligaments and the patella tendon (**b**). (**b**) A lateral radiograph of the left knee of the same patient depicted in (**a**) of the ipsilateral leg. The radiograph demonstrates a multiligamentous knee injury with avulsion of the patellar tendon (white arrow) and superior migration of the patella (yellow arrow). The tibia is also grossly subluxed

instability with an alteration in the mechanical axis. In addition, the surgeon should be cognizant of the need for further soft tissue reconstructive procedures in the future and leave sufficient room for tunnel placement in the proximal tibia and femur. Chahal et al. [40] have established an algorithm for the treatment of multiligamentous injuries in the setting of tibial fractures.

13.5 Surgical Timing, Rationale, and Order of Fixation

The timing and sequence of injury fixation in a multiple-injured patient can be difficult. The adage of life before limb is particularly appropriate in this setting, and the patient must be treated in concordance with advanced trauma principles. Equally, the fixation of life-threatening skeletal trauma must take precedence over knee bony and ligamentous injury. A clinical suspicion of associated knee ligamentous injury will allow the surgeon to make subtle adjustments in the fixation of long bones of the lower limb to accommodate delayed reconstructive procedures as necessary. Complex knee injuries may require temporary external fixation to stabilize the joint until it can be definitively treated or to allow urgent treatments such as wound management or vascular repair [41].

In general, in patients with bony avulsions [20, 21] or impaction fractures, the earlier the treatment is performed, the easier it is to achieve an anatomical repair or to correct the bony deformity. Ideally this should be performed in the first 2 weeks and incorporate reconstruction procedures, if necessary. This avoids the need for multiple procedures, allowing healing of the soft tissue injury, fracture, and reconstruction at the same time and reducing the potential rehabilitation time.

Soft tissue interventions can be considered after the patient has been stabilized, and life-threatening injuries are managed. Delaying these interventions also allows the use of arthroscopic techniques that may not be possible earlier due to capsular disruption and the risk of fluid extravasation. However, the surgeon must also consider the risk of waiting too long and encountering significant contracture and arthrofibrosis that will impair functional recovery.

Fractures involving the weight-bearing portion of the tibial plateau (Schatzker II–VI) should be fixed primarily with open reduction internal fixation, with reconstruction of the soft tissue being delayed. It may be possible to repair collateral ligament soft tissue avulsions at the initial surgery. It is important to achieve anatomical reduction as best as possible, to ensure future soft tissue reconstruction is not disadvantaged by subsequent angular deformity.

13.6 Conclusion

Fractures associated with knee injury are common. They may be broadly classified into soft tissue injuries with associated fractures, fractures with associated soft tissue injury, and fractures remote to knee injury. The treatment of each type of injury pattern must be considered in the broader context of the patient's overall condition, as many of these injuries are as a result of high-energy trauma.

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