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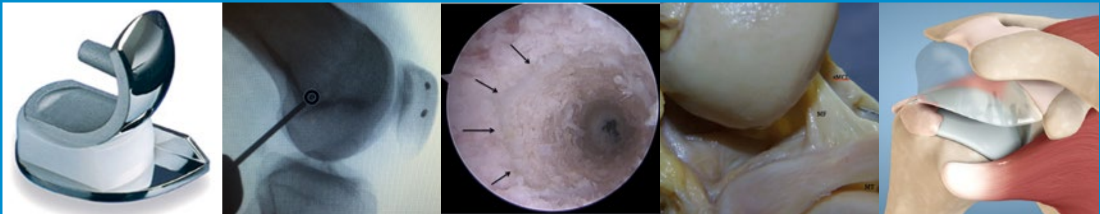

ESSKA Instructional Course Lecture Book

Glasgow 2018

ESSKA Instructional Course Lecture Book

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Preface

Dear ESSKA members,

It is our great pleasure to offer you this instructional course lecture (ICL) book. It includes the contents of all the ICLs that will be given at the 2018 ESSKA Congress in Glasgow.

The book encapsulates the latest updates on surgical knowledge in the field of knee surgery, sports traumatology and arthroscopy.

A mixture of eminence and evidence-based material on the indications for surgical interventions, surgical tips and tricks, and management protocols should empower practitioners at every stage in their career.

In the light of the educational mission of ESSKA, we are excited to share this tome with you.

We hope that you will enjoy every aspect of it.

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Bruderholz, Switzerland	Michael T. Hirschmann
Mölndal, Sweden	Jón Karlsson
Luxembourg, Luxembourg	Romain Seil

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The book represents the contents of all the instructional course lectures. We acknowledge the great contribution of the authors who allowed us to collate this book and present it at the 2018 ESSKA Congress. We would also like to acknowledge all those who have assisted us in the preparation and editing of the various chapters. A special word of thanks to Anne van der Made who did a great job in helping to motivate the authors to prepare their text and in keeping up the rhythm of the writing and editing.

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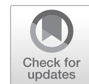

1 Advances in Treatment of Complex Knee Injuries

Gilbert Moatshe, Jorge Chahla, Marc J. Strauss, Robert F. LaPrade, and Lars Engebretsen

1.1 Introduction

Multi-ligament knee injuries are commonly defined as a tear of at least two of the four major knee ligament structures: the anterior cruciate ligament (ACL), the posterior cruciate ligament (PCL), the posteromedial corner (PMC), and the posterolateral corner (PLC) in the same incident [1, 2]. Knee dislocations often result in multi-ligament knee injuries, but some multi-ligament knee injuries are not knee dislocations. A knee dislocation is typically characterized by rupture of both cruciate ligaments, with or without an associated grade III medial- or lateral-sided injury [2, 3]. Knee dislocations with one of the cruciate ligaments intact have been reported, but these are less common [4, 5]. Multi-ligament injuries are heterogeneous and are often associated with other injuries in the ipsilateral limb and injuries to other organs. Therefore, a thorough diagnostic workup and treatment plan are mandatory when dealing with these injuries. The purpose of this chapter is to describe the principles of multi-ligament injuries including patient demographics and associated injuries, diagnosis and treatment approaches, surgical pearls for avoiding tunnel convergence, and grafts tensioning sequence, outcomes, and prevalence of osteoarthritis after knee dislocation surgery and future perspectives.

1.1.1 Classification

The most widely used classification system for the dislocated knee is based on the anatomical patterns of the ligaments torn and was described by Schenck et al. (Table 1.1) [3, 6]. The advantage of this classification is that it allows for identification of the torn ligaments

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Table 1.1 Table with Schenck's knee dislocation classification [6]

KD I	Injury to single cruciate + collaterals
KD II	Injury to ACL and PCL with intact collaterals
KD III M	Injury to ACL, PCL, and MCL
KD III L	Injury to ACL, PCL, and LCL
KD IV	Injury to ACL, PCL, MCL, and LCL
KD V	Dislocation + fracture

Additional caps of "C" and "N" are utilized for associated injuries. "C" indicates an arterial injury. "N" indicates a neural injury, such as the tibial or, more commonly, the peroneal nerve

ACL anterior cruciate ligament, *PCL* posterior cruciate ligament, *MCL* medial collateral ligament, *LCL* lateral collateral ligament

and associated vascular, neurologic injuries, and fractures and also for planning of treatment.

1.2 State-of-the Art Treatment

1.2.1 Patient Demographics and Associated Injuries

Multi-ligament knee injuries were historically believed to be uncommon; however, Arom et al. recently reported an incidence of 0.072 per 100 patient-years based on a database with 11 million patients [7]. These injuries are often caused by both high-energy trauma [8], such as motor vehicle accidents and falls from heights, and low-energy trauma [9] including sporting activities. Engebretsen et al. reported that high-energy and sports-related injuries accounted for 51% and 47% of knee dislocations, respectively, based on a cohort of 85 patients with knee dislocations [10]. In a recent review of a large cohort of 303 patients with bicruciate knee dislocations, Moatshe et al. [11] reported equivalent rates of high- and low-energy trauma, with 50.3% and 49.7%, respectively. Miller et al. reported on multi-ligament knee injuries in obese individuals as a result of ultralow-velocity trauma [12]. These patients are reported to have a high prevalence of associated vascular and nerve injuries [12]. With obesity becoming a global problem, the incidence of these injuries will potentially increase.

Knees with both cruciate ligaments torn should be treated as knee dislocations, and the risk of vascular and neurologic injuries is high [13]. Furthermore, Geeslin and LaPrade reported that only 28% of posterolateral knee complex (PLC) injuries occur in isolation; hence patients presenting with PLC injuries should be evaluated for concomitant injuries [14]. Moatshe et al. [11] reported common peroneal nerve injuries and vascular injuries in 19% and 5%, respectively, in an evaluation of 303 patients with knee dislocations. Based on their cohort, the odds of having a peroneal nerve injury were 42 times higher among patients with posterolateral corner injury than those without, while the odds of having a popliteal artery injury were 9.2 times higher in patients with a posterolateral corner injury. Additionally, a peroneal nerve injury was significantly associated with a vascular injury with an odds ratio of 20.6. Thus, patients with peroneal nerve injuries should be examined thoroughly for an associated vascular injury, and the surgeon should have a low threshold for obtaining a CT angiogram. In a systematic review by Medina et al. [15], the frequencies of nerve and vascular injuries in knee dislocations were 25% and 18%, respectively. Becker et al. reported a comparable prevalence of peroneal nerve injuries (25%) but a higher prevalence of arterial injuries (21%) in a series of 106 patients [13].

A high prevalence of meniscal and focal cartilage injuries is reported in multi-ligament knee injuries. In a review of 121 patients (122 knees), Krych et al. reported that 76% of overall patients had a meniscal or chondral injury; 55% presented with meniscal tears, while 48% presented with a chondral injury in a follow-up of 121 patients (122 knees) [16]. However, Richter et al. reported a lower incidence (15%) of meniscal injuries in association with knee dislocations [17]. In a recent review of 303 patients with knee dislocations from a single center, Moatshe et al. [11] reported meniscal injuries in 37.3% of the patients and cartilage injuries in 28.3%. Patients treated for multi-ligament injuries in the chronic phase had higher prevalence of chondral lesions.

Medial-sided injuries are usually the most common injuries in multi-ligament knee injury patterns. Moatshe et al. [11] reported that medial-sided injuries constituted 52% of the injuries in 303 patients with knee dislocations. In their series, lateral-sided injuries constituted 28%, and bicruciate injuries with no other ligament involvement constituted only 5%. In a review by Robertson et al. [18], medial-sided and lateral-sided injuries were reported in 41% and 28%, respectively. In contrast, Becker et al. reported that lateral-sided injuries were the most common (43%) in a series of 106 patients [13]. What is common for these studies is that KD III injuries are the most common ligament injury pattern in knee dislocations.

1.2.2 Acute Treatment and Diagnostics

1.2.2.1 Acute Multiple-Ligament Knee Injuries Diagnostics

It is important to estimate the amount of energy involved in the injury. High-energy trauma can cause injuries distant to the knee, which can take the attention from the injured knee, leading to a missed or late diagnosis. Furthermore, associated limb or organ injuries can affect the treatment plan. It is recommended to apply the Advanced Trauma Life Support (ATLS) principles when treating high-energy injuries. Concomitant injuries to the popliteal artery (23–32%) [8, 19] and the common peroneal nerve (14–40%) [15, 20] are commonly observed in high-velocity knee dislocations.

For vascular assessment, foot pulses and skin color should be examined and compared with the uninjured side and monitored after admission for early detection of change in circulation. Physical examination with the presence of a normal vascular examination (normal and symmetrical pulses, capillary refill, normal neurological examination) is reported to be reliable to screen patients with knee dislocations for "selective" arteriography [21]. The ankle-brachial index (ABI) is useful as an adjunct to the physical examination to assess for vascular injuries, especially in patients where physical examination is not reliable such as those with neurological injuries and the obese. An angiography is recommended when the ankle-brachial index (ABI) is <0.9 (Fig. 1.1) [22, 23].

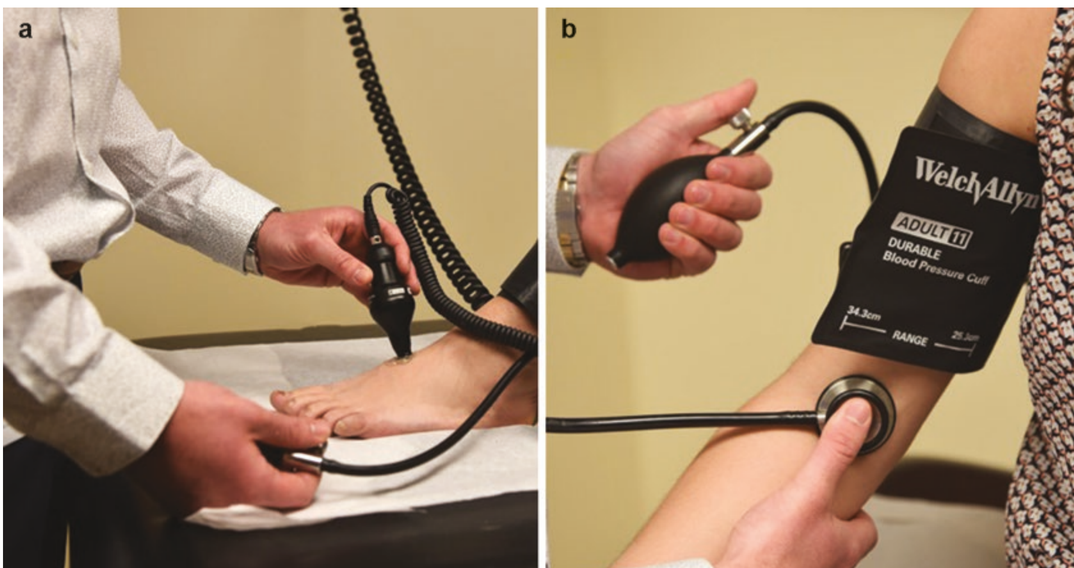

Fig. 1.1 Obtaining an (**a**) ankle- (**b**) brachial index (ABI) is important to have an objective evaluation of the vascular system. If the ABI is <0.9, angiography is recommended. Patients with peroneal nerve injuries have a higher odds of a concomitant vascular injury and should therefore be considered for CT angiography

In the obese patients with ultralow-velocity knee dislocations, one should have a low threshold for CT angiography examination because of the difficulty in physical examination and the previously reported high risk of vascular injuries [12, 24]. Some protocols recommend an ABI cutoff of <0.8 [25], while others recommend <0.9 to perform arteriography [21, 22]. The authors recommend a cutoff of <0.9 because ABI is easy and inexpensive to perform, while the consequences of not detecting vascular injury can be devastating. Patients with vascular injuries are initially treated with acute revascularization, and the knee is protected in an external fixator to protect the revascularization graft and to maintain knee reduction [25, 26]. The external fixator is usually removed at 2 weeks, and the knee is placed in a hinged brace to avoid pin infections and joint stiffness.

Magnetic resonance imaging (MRI) is performed to evaluate all the injured structures, including ligaments, menisci, and cartilage (Fig. 1.2). Stress radiographs are essential in the evaluation of the PCL, PLC, and the PMC but can be difficult to carry out in the acute phase due to patient guarding (Figs. 1.3 and 1.4) [27–29]. In cases where stress radiographs are difficult to perform, a mini C-arm can be utilized for the

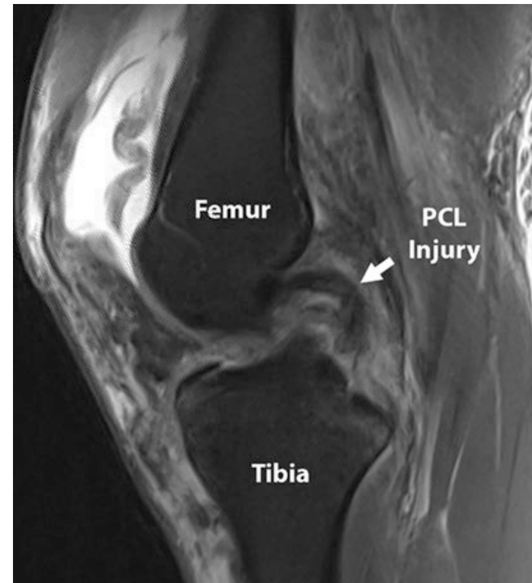

Fig. 1.2 Preoperative magnetic resonance image (MRI) showing a posterior cruciate ligament (PCL) tear in a patient with multi-ligament injury

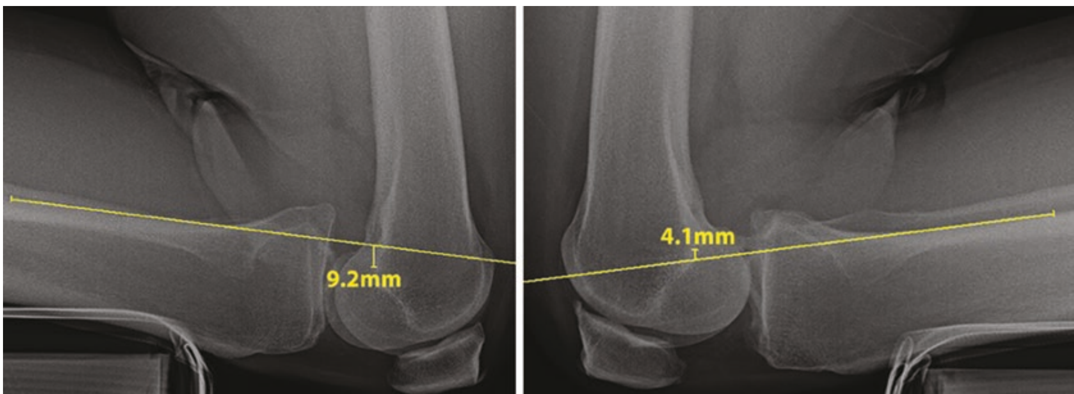

Fig. 1.3 Preoperative stress radiographs are important in evaluating patients with knee ligament injuries. In this patient, there was a 13.3 mm increase in posterior tibial translation on the left compared to the right knee, consistent with a combined PCL injury. To compare the posterior tibial translation, a point is identified along the posterior tibial cortex 15 cm distal to the joint line. A line is then drawn from this point parallel to the posterior cortex, through the femoral condyles. The most posterior point of Blumensaat's line is marked. A perpendicular line is drawn from the most posterior point of the Blumensaat's line to intersect the first line drawn parallel to the tibial cortex. This distance is compared to the contralateral side to give a side-to-side difference. A posterior translation side-to-side difference of 0–7 mm is usually due to partial PCL tear or in patients who are too sore to put sufficient weight on the knee; an 8–11 mm side-to-side difference is associated with a complete isolated PCL tear; and ≥12 mm is usually observed in patients with a complete PCL tear and additional ligament injury, usually the PLC or PMC but can also be seen in patients with decreased sagittal plane tibial slope

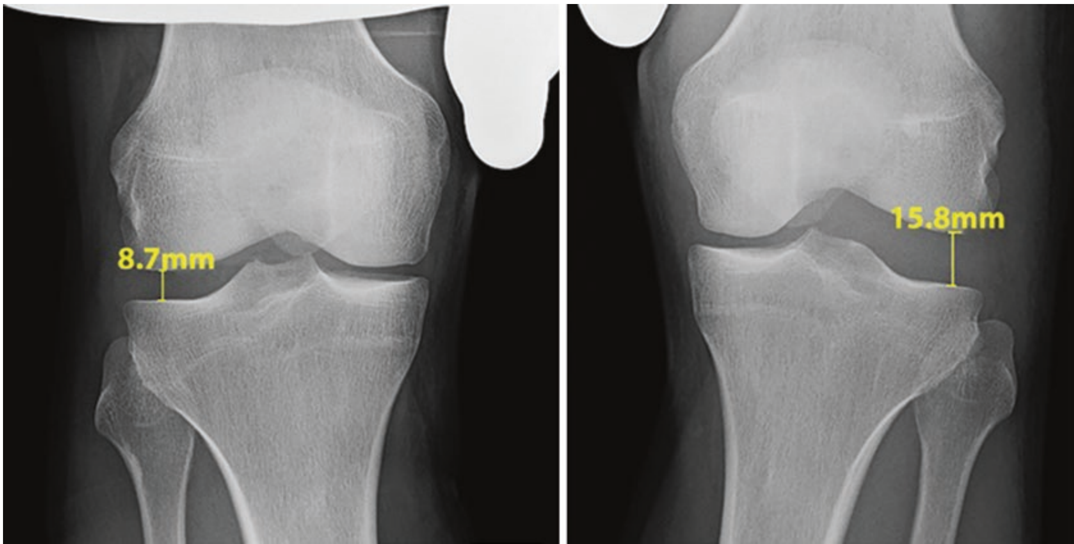

Fig. 1.4 Varus stress radiographs to evaluate the integrity of the posterolateral corner preoperatively. In this picture there is a 7.1 mm side-to-side difference consistent with a complete posterolateral corner (PLC) injury

examination under anesthesia at the time of surgery to objectively determine the amount of knee gapping. It is important to diagnose and treat collateral ligament injuries concurrently with cruciate ligament reconstructions because untreated collateral ligament injuries will lead to increased forces on the cruciate ligament reconstruction grafts, increasing the risk of graft failure [30, 31].

1.2.2.2 Treatment

It is commonly accepted that multi-ligament injuries should be treated with reconstruction of the torn ligaments. Non-operative treatment can be considered for the elderly, sedentary, and high surgical risk patients. Surgical treatment of the torn ligaments in multi-ligament injured knees improves patient-reported outcomes [17, 32, 33]. In a meta-analysis including 132 knees treated surgically and 74 treated nonsurgically, Dedmond and Almekinders reported better outcomes in the surgically treated group than the nonsurgical group, range of motion (123° in the surgical group vs. 108° in the nonsurgical group) and Lysholm scores (85.2 in the surgical group vs. 66.5 in the nonsurgical group) [32]. Richter et al. [17] reported significantly improved outcomes in the surgical group compared to the nonsurgical group in an evaluation of 89 patients with traumatic knee dislocations (63 patients treated with surgical repair or reconstruction, 26 patients treated nonsurgically) with a mean follow-up of 8.2 years. In a literature review by Peskun and Whelan [33] evaluating outcomes in 855 patients from 31 studies treated surgically, and 61 patients from 4 studies treated nonsurgically, functional outcomes, stability, and return to activity favored surgical treatment. In summary, the literature supports surgical treatment and postoperative functional rehabilitation of multi-ligament knee injuries.

1.2.2.3 Repair Versus Reconstruction

Several studies have demonstrated that reconstruction of the torn ligaments is superior to repair. Mariani et al. evaluated outcomes in a cohort of patients with multi-ligament injuries, 52 patients treated with repair of the ligaments versus 28 treated with reconstructions [34]. Patients with repair of cruciate ligaments had higher rates of flexion deficit, higher rates of posterior instability, and lower rates of return to preinjury activity levels. Studies by Stannard et al. and Levy et al. demonstrated high reoperation and failure rates in patients with posterolateral injuries treated with repair, further strengthening the argument for reconstruction of the collateral

ligaments [35, 36]. Anatomic reconstruction of the injured structures using biomechanically validated techniques restores knee kinematics to near normal and yields improved patient outcomes [37–39]. Therefore, in the setting of multi-ligament injuries, reconstruction of all the torn ligaments is recommended. Repair of the collaterals is usually reserved for bony avulsions that are large enough to be fixed with hardware or suture anchors [40].

1.2.2.4 Timing of Surgery

Timing of surgery during multi-ligament injuries is a topic of debate, and there is still no consensus on the point of demarcation between acute and chronic. Some authors have used 3 weeks as the critical time to better identify and treat the structures before scar tissue forms, making dissection and identification of the structures difficult, and tissue necrosis affects outcomes [10, 34, 41, 42]. However, some authors have used a 6-week timeline to demarcate between acute and chronic injuries [37]. Studies have reported superior outcomes in acutely treated patients compared to chronic treated patients [1, 43]. Even though some surgeons are concerned about the risk of joint stiffness in acutely treated injuries, Levy et al. reported no difference in range of motion after acute and chronic surgery in a systematic review of literature that included five studies [1]. The authors preferred acute treatment of the injured structures to facilitate early rehabilitation [37]. In addition, staging the reconstruction can potentially alter joint kinematics and increase the risk of graft failure [30, 31, 44]. In high-energy trauma, surgery may be delayed because of injuries to the soft tissue about the knee and concomitant injuries to other vital organs. However, stiffness in these patients may be easier to treat than recurrent instability.

1.2.3 Surgical Treatment Pearls

1.2.3.1 Avoiding Tunnel Convergence

Reconstructing several reconstruction tunnels in the distal femur and proximal tibia poses a risk of tunnel convergence because of limited bone mass

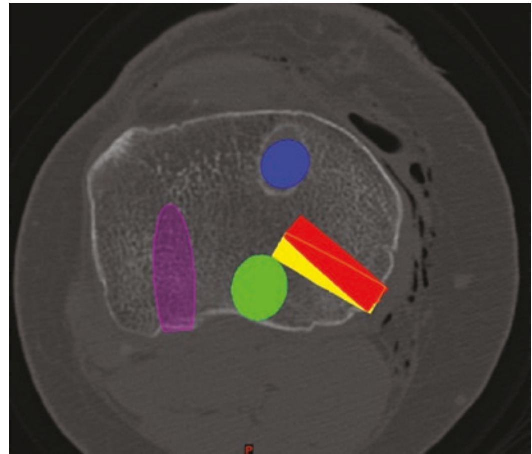

Fig. 1.5 There is a high risk of tunnel interference between the PCL (green) and POL (yellow) tunnels during multi-ligament knee reconstructions. Aiming the POL tunnel 15 mm anterior to Gerdy's tubercle (red) minimizes the convergence with the PCL tunnel (green). The anterior cruciate ligament (ACL) tunnel (blue) and the tunnel for the popliteus tendon and the popliteofibular ligament grafts (purple) are also shown. *PCL* posterior cruciate ligament, *POL* posterior oblique ligament, *ACL* anterior cruciate ligament

in these areas. Tunnel convergence increases the risk of reconstruction graft failure because of the potential damage to reconstruction grafts, fixation devices, and not having sufficient bone stock between the grafts for fixation and graft incorporation. Moatshe et al. reported a 66.7% tunnel convergence rate between the posterior oblique ligament (POL) tunnel and the PCL tunnel in the tibia when the POL tunnel was aimed at Gerdy's tubercle when evaluating the risk of tunnel convergence using biomechanically validated anatomic reconstruction techniques (Fig. 1.5). They recommended that the POL tunnels be aimed to a point 15 mm medial to Gerdy's tubercle to reduce risk of convergence with the PCL and that the superficial medial collateral ligament (sMCL) tunnel be aimed 30° distally to avoid convergence with the PCL tunnel [45].

On the lateral femoral side, Moatshe et al. [46] performed a 3D imaging study varying the angles of the FCL and popliteus tunnels. A 35–40° angulation in the axial plane and 0° in the coronal plane was safe and avoided tunnel convergence (Fig. 1.6). On the medial side, aiming the sMCL

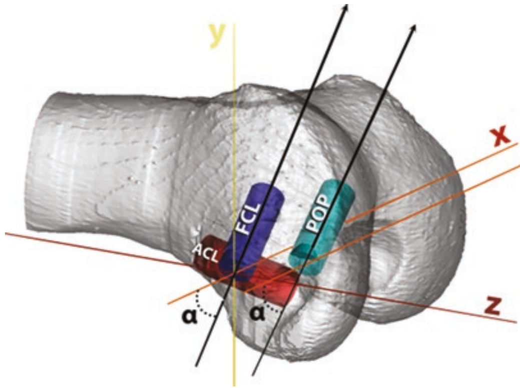

Fig. 1.6 Illustration demonstrating tunnels on the lateral femur condyle during multi-ligament knee reconstructions. Aiming the FCL (purple) and the popliteus (turquoise) 35–40° anteriorly minimizes the risk of tunnel convergence with the ACL (red) tunnel. *ACL* anterior cruciate ligament, *FCL* fibular collateral ligament, *POP* popliteus tendon tunnel (With permission from Moatshe G, Brady AW, Slette EL, Chahla J, Turnbull TL, Engebretsen L, LaPrade RF. Multiple Ligament Reconstruction Femoral Tunnels: Intertunnel Relationships and Guidelines to Avoid Convergence. Am J Sports Med. 2017 Mar;45(3):563–569.

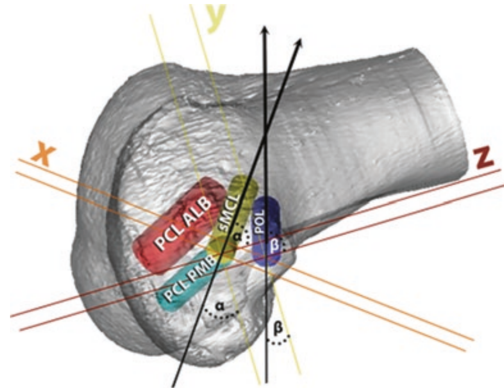

Fig. 1.7 Illustration demonstrating four tunnels in the medial femoral condyle. With four potential tunnels in the medial femoral condyle, the risk of tunnel convergence is high. Aiming the sMCL tunnel 40° anteriorly and 20–40° and the POL tunnel 20° anteriorly and proximally minimizes the risk of tunnel convergence (With permission from Moatshe G, Brady AW, Slette EL, Chahla J, Turnbull TL, Engebretsen L, LaPrade RF. Multiple Ligament Reconstruction Femoral Tunnels: Intertunnel Relationships and Guidelines to Avoid Convergence. Am J Sports Med. 2017 Mar;45(3):563-569.

tunnel 40° in the axial and coronal planes and the POL tunnel 20° in the axial and coronal planes was safe to avoid convergence with the double-bundle PCL tunnels (Figs. 1.7 and 1.8). In a laboratory study, Camarda et al. reported a high risk of tunnel convergence between the ACL and the FCL (69–75% depending on the length of the tunnel) and recommended aiming the FCL tunnel 0° in the coronal plane and 20–40° in the axial plane [47]. Gelber et al. evaluated tunnel convergence and optimal angulation of the tunnels on the medial femur condyle. They found that angulations of 30° in the axial plane and coronal plane reduced the risk of convergence with the PCL tunnels [48]. However, the diameter of their PCL tunnels was smaller than those used by Moatshe et al., and that can potentially explain the differences reported.

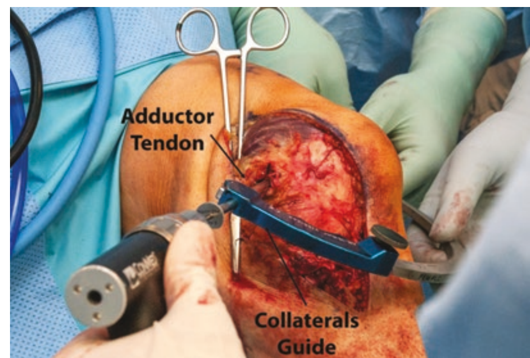

Fig. 1.8 An intraoperative picture demonstrating orientation of the sMCL tunnel on the femur to avoid convergence with the double-bundle PCL tunnels. The sMCL tunnel is aimed anteriorly and proximally to avoid convergence with the PCL tunnels. The adductors tendon is a "light house" on the medial side. The sMCL attaches 12 mm distal and 8 mm anterior to the adductor tubercle, which can be found just distal to the adductor tendon attachment. *sMCL* superficial medial collateral ligament, *PCL* posterior cruciate ligament

1.2.3.2 Tensioning Sequence

The tensioning sequence in multi-ligament injuries is a topic of debate, with different tensioning sequences having been reported in the literature. Some authors advocate for starting with the PCL to restore the central pivot and tibial step-off (Fig. 1.9), followed by the ACL in extension to ensure the knee can be fully extended, posterolateral corner, and the posteromedial corner last [49, 50].

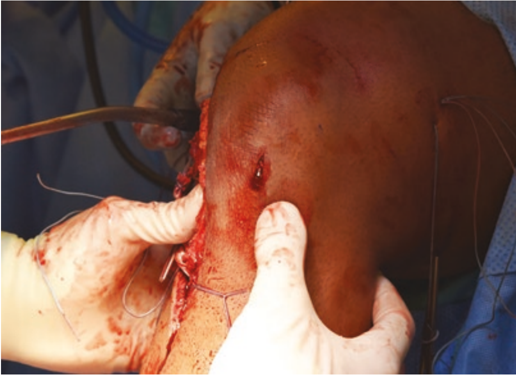

Fig. 1.9 An intraoperative picture showing reduction of a right knee to restore tibial step-off prior to tensioning and fixing the anterolateral bundle (ALB) of the PCL. The PCL is tensioned first to restore tibial step-off, followed by the posterolateral corner (PLC) tension and fixation. The ACL is fixed after the PLC and PCL, and the PMC is fixed last. *ALB* anterolateral bundle, *PCL* posterior cruciate ligament, *PLC* posterolateral corner, *ACL* anterior cruciate ligament

In a posterolateral corner-deficient knee, tension during fixation of the ACL graft increased external tibial rotation of the tibia [44]. This change in tibiofemoral orientation would change joint mechanics and loading. Therefore, some authors advocate for fixing the posterolateral corner prior to the ACL to avoid external tibial rotation. Markolf et al. reported that the PCL should be fixed prior to the ACL to best restore graft forces, based on a biomechanical study of cadaveric bicruciate-injured knees [51]. Kim et al. retrospectively reviewed 25 patients with multi-ligament injuries, 14 with the PCL tensioned first, and 11 with simultaneous tension and fixing the ACL first and reported that posterior stress radiographs, Lysholm score, and IKDC scores favored fixing the ACL first [52]. There is currently no consensus regarding the optimal tensioning sequence, and there is a need for well-designed biomechanical studies [53]. Such biomechanical studies will lay ground for multicenter clinical studies to evaluate the optimal tensioning sequence. The author's preferred tensioning sequence is fixing the anterolateral bundle of the PCL at 90° to restore the normal tibial step-off, the posteromedial bundle of the PCL in extension, the FCL (LCL) at 20–30° of knee flexion, neutral rotation, and a slight valgus force, followed by the rest of the PLC structures at 60° of flexion and neutral rotation, the ACL near full extension, and finally the posteromedial corner. The PLC is fixed prior to the ACL to avoid external rotation of the tibia during tensioning of the ACL. Prepping the contralateral knee and using an intraoperative C-arm may aid when reducing the injured knee during graft tensioning and fixation.

1.2.3.3 Rehabilitation

Another key step for a successful outcome is a comprehensive and staged rehabilitation program starting from day 1 postoperative. The main goals are to protect the surgical reconstructions and to restore range of motion (ROM). All patients are instructed to remain non-weight bearing for 6 weeks while wearing a brace (dynamic brace for PCL reconstruction patients), followed by a 2-week period of weaning off crutches before achieving full weight bearing at 8 weeks' postsurgery. ROM exercises are probably the most important part of the rehabilitation to avoid stiffness and include patellofemoral joint mobilization and tibiofemoral flexion and extension from 0–90°. Additionally, all patients began quadriceps-setting exercises day 1 postsurgery to achieve symmetrical active knee extension at 6 weeks to facilitate a normal gait pattern. A stationary bike was initiated at 6 weeks postsurgery, depending on the range of motion. Although every rehabilitation protocol is customized to the patient, the periodization concept was utilized and included the following phases: muscular endurance, strength, and power development. Each phase consists of at least 6 weeks to allow for physiological adaptation to the exercise stimulus. Rehabilitation progress is assessed throughout the recovery, with clearance to return to activities provided once patients had achieved a quadriceps index greater than 90% and a passing grade on the Vail Sport Test [54].

1.2.4 Outcomes and Prevalence of Osteoarthritis After Knee Dislocation Surgery

Surgical management is recommended for multi-ligament knee injuries; therefore, this section will focus on outcomes after surgical management.

Good functional outcomes are reported in short to medium follow-up after surgical treatment of multi-ligament injuries [1, 10]. In a follow-up of 85 patients with knee dislocations at 2–9 years, Engebretsen et al. reported improved patient-reported outcomes with a mean Lysholm of 83, median Tegner activity score of 5, and mean IKDC 2000 subjective score of 64 [10]. Moatshe et al. [55] reported a mean Lysholm score of 84, Tegner score of 4, and subjective IKDC 73 in a follow-up of 65 patients with multi-ligament knee injuries at a minimum follow-up of 10 years demonstrating that good functional outcomes are possible at medium to long term. Geeslin and LaPrade [37] reported on 29 patients (30 knees), 8 knees had isolated posterolateral corner injuries, and 22 knees had combined ligament injuries involving the posterolateral corner. At a mean follow-up of 2.4 years, Cincinnati and IKDC subjective outcome scores improved from 21.9 to 81.4 and 29.1 to 81.5, respectively. Side-to-side varus gapping on stress radiographs improved from 6.2 mm preoperatively to 0.1 mm postoperatively [37]. Postoperative stress radiographs are an important objective method of evaluating stability (Fig. 1.10). Certain factors have been reported to correlate with poor outcomes including high-energy trauma [10], repair of medial-sided injury [56], age >30 years [55, 57], concomitant cartilage injury [58], and combined medial and lateral meniscal tears [58].

Despite good functional outcomes reported by these studies [37, 39, 43, 49, 59, 60], posttraumatic osteoarthritis (PTOA) is a common problem, reported to range from 23 to 87% [10, 43, 60] in the different studies (Fig. 1.11). Engebretsen et al. reported an 87% prevalence of PTOA, evaluated by the Kellgren-Lawrence (grade II or more) classification, after knee dislocation surgery of the patients in a cohort of 85 patients at 5–9 years' follow-up. In a follow-up of 68 patients at a median follow-up time of 12 years (range, 1–27 years), Hirschmann et al. reported a 31% prevalence of PTOA, and 16% had grade III and IV on Kellgren-Lawrence scale [43]. Fanelli et al. reported degenerative changes in 23% (10 of the 44) of the patients treated for knee dislocations at a mean follow-up of 10 years (range 5–22 years) [60].In a recent evaluation of knee dislocation patients treated surgically at a minimum follow-up time of 10 years, Moatshe et al. [55] reported that 42% of the cohort had radiologic osteoarthritis (KL $\geq$ 2) in the injured knee compared to only 6% in the uninjured knee.

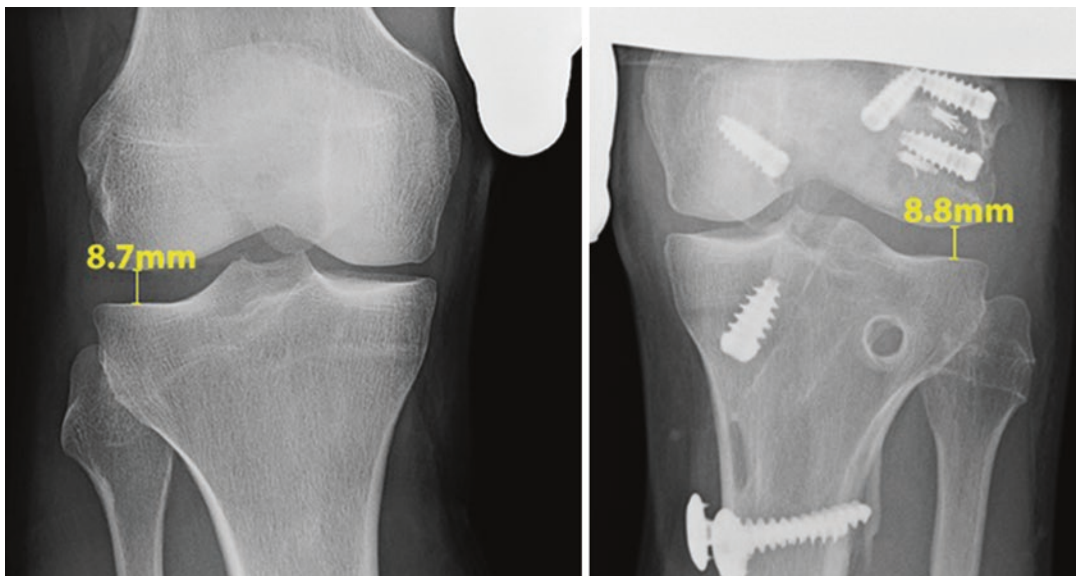

Fig. 1.10 Postoperative varus stress radiographs demonstrating a 0.1 mm side-to-side difference in the lateral compartment gapping compared to the normal contralateral knee Postoperative stress radiographs are valuable in evaluating knee stability.

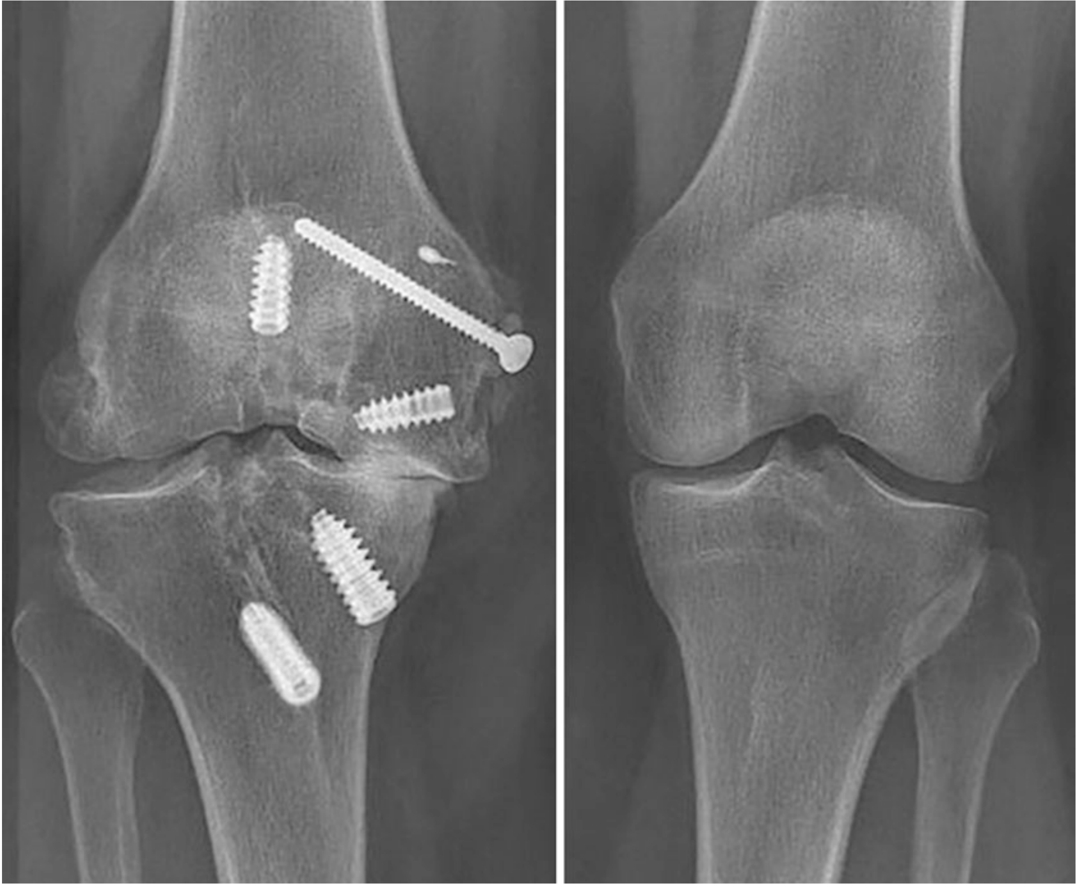

Fig. 1.11 A plain radiograph showing posttraumatic osteoarthritis on the right knee after knee dislocation surgery involving the ACL, PCL, and sMCL. The injured left knee has no sign of osteoarthritis. *ACL* anterior cruciate ligament, *PCL* posterior cruciate ligament, *sMCL* superficial medial collateral ligament

1.2.5 Future Treatment Options

Multi-ligament knee injuries are complex, and a high level of suspicion is required when evaluating these patients. Some of the concurrent ligament and meniscal injuries may be missed initially, and this requires a detailed history and clinical examination, supplemented with MRI and stress radiographs as part of the initial workup. Failure to treat all injured structures can lead to changes in knee kinematics and hence poorer outcomes and an increased risk of graft failure. Treating all the injured structures in the acute phase is recommended in order to facilitate early rehabilitation and better restoration of knee function. Biomechanical studies are necessary to evaluate the effects of the different tensioning orders to the knee kinematics. This will potentially pave the way for multicenter clinical studies to evaluate this in clinical settings. In addition, several reconstruction grafts are often needed during this type of surgery, posing a problem in areas where allografts are not available. Optimal reconstruction in the setting where allografts are not available is an area that needs further research. With the growing population and more grown-up people wanting to remain active, there is a need for research on enhancing healing of the reconstruction grafts because of poor healing potential that comes with age.

1.2.6 Take-Home Messages

- Multi-ligament injuries are challenging and require a detailed preoperative diagnosis, treatment plan, and a dedicated surgical and rehabilitation team to take care of the patients.
- Stress radiographs are valuable preoperatively to evaluate the torn ligaments and plan the surgery and postoperatively to evaluate the integrity of the ligament reconstructions.
- Posterolateral injuries are commonly associated with peroneal nerve and vascular injuries. Furthermore, the odds of vascular injuries are higher in the presence of a peroneal nerve injury. A high level of suspicion is advocated.
- Avoid tunnel convergence by detailed preoperative and intraoperative planning; the FCL tunnel should be aimed anteriorly or anteriorly and proximally to avoid convergence with the ACL tunnel. The sMCL tunnel and the POL tunnels should be aimed anteriorly and proximally to avoid convergence with the PCL tunnels.
- A well-designed, customized rehabilitation protocol is mandatory for good outcomes. The reconstruction grafts should be protected in a brace, while healing, and periodization of the rehabilitation is important.
- Treatment of these complex cases should be centralized and treated by dedicated teams with extensive surgical experience and volume.

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“Small” Fractures Below the Knee: Do Not Miss—Do Not Mistreat!

2

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2.1 Introduction

Many of the small fractures below the knee are known by eponyms. Although some are well known such as the Maisonneuve and Lisfranc fractures, several are less well known, such as the Cedell and Tillaux fractures. Unfamiliarity with these small fractures may result in failure of detection at initial emergency department surveys or treated suboptimally by lack of experience. This ICL chapter consists of an overview of several common “small” fractures of the foot and ankle, not to be missed, not to be mistreated.

2.1.1 Maisonneuve Fracture [1–15]

The Maisonneuve fracture is on this list because of its reputation to be overlooked, not because of its benign nature. On the contrary, it is an ankle fracture by definition; suboptimal treatment may predispose the ankle to the onset of posttraumatic osteoarthritis (Fig. 2.1). Pankovich appreciates five stages of the Maisonneuve fracture: rupture of the anterior talofibular ligament (ATFL), rupture of the interosseous membrane, fracture or rupture of the posterior talofibular ligament (PTFL), rupture of the anteromedial joint capsule, and fracture of the fibula and a rupture of the deltoid ligament or fracture of the medial malleolus. Since 7–15% of the body weight is transferred through the fibula, shortening will lead to lateral tibiotalar overload. Late repairs of syndesmotic injuries have less favorable outcome than primary stabilization.

2.1.2 Posterior Malleolus Fracture [16–21]

Approximately 7–44% of ankle fractures have involvement of a posterior tibial fragment. Patients with fractures that include a posterior tibial fragment tend to have a poorer prognosis than fractures

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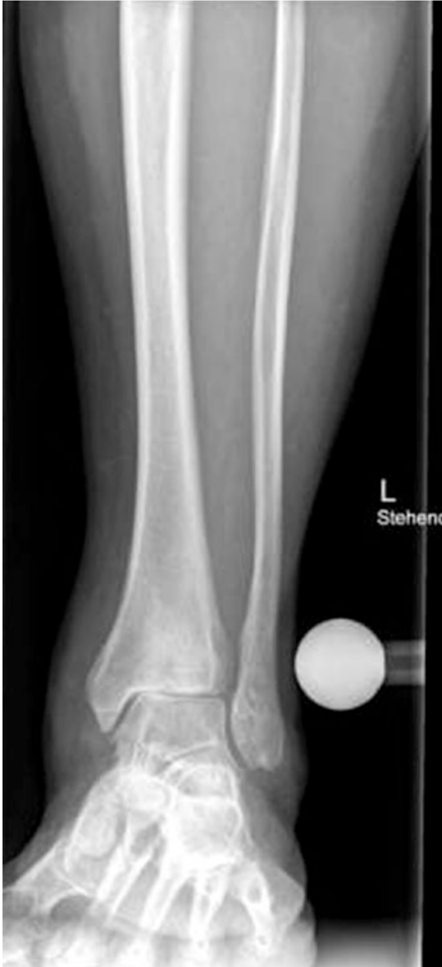

Fig. 2.1 Missed Maisonneuve fracture

without posterior involvement. Haraguchi and colleagues classified posterior malleolar fractures into three types, based on pathoanatomy of posterior malleolar fragments. The deep deltoid ligament can be attached to the posteromedial fragments, which has significant implications for stability. There seems a remarkable preference to fix Haraguchi type I fractures. These larger posterolateral fragments are best visible on plain lateral radiographs. Posteromedial fragments are at risk of being overlooked and undertreated and may lead to persisting medial instability in cases of malunion.

2.1.3 Tillaux Fracture [22–37]

Paul Jules Tillaux is credited to have discovered that an anterolateral distal tibial fracture was due to the pull of the anterior inferior tibiofibular ligament. In adolescents, physeal closure follows a predictable pattern from the anterolateral aspect of the medial malleolus to the posteromedial physis, then the posterolateral, and finally the anterolateral aspect. Because the distal lateral tibial growth plate is still open, adolescent Tillaux fracture is classified as a Salter-Harris type III epiphyseal fracture or, rarely, as a Salter-Harris IV fracture, of the distal tibia.

2.1.4 Osteochondral Talar Fracture [38–47]

Osteochondral talar fractures are rarely seen as a fresh injury. However, they are a commonly encountered foot and ankle disorder in an elective practice. In the majority of cases, patients with this pathology have a history of ankle sprains and/or fractures. Internal fixation of an osteochondral talar defect shows good results in the literature. However, in most studies, arthrotomies with or without a malleolar osteotomy were performed to fixate the osteochondral defects (OCDs).

2.1.5 Lateral Talar Process Fracture [48–59]

The lateral talar process provides stability to the ankle mortise and forms the talofibular and subtalar articulations. A lateral process fracture comprises 6% of all ankle fractures and 24% of fractures of the talar body. A lateral talar process fracture should be evaluated as an impact and crush injury instead of an avulsion injury. Because of the mechanism of injury, a lateral process fracture is often seen in snowboarders. Nonunion rates of 60% are found in missed or conservatively treated lateral talar process fractures. Nonunion rates of only 5% are found in lateral talar process fractures managed operatively.

2.1.6 Cedell Fracture [60–65]

Carl-Axel Cedell, a Swedish orthopedic surgeon, first described four cases of posteromedial talar tubercle fractures. This fracture is rare and often

missed in the initial diagnostic setup. The mechanism of injury can be due to direct or indirect trauma. Patients usually present with clinical pain over the posteromedial aspect of the ankle. The physical examination reveals ecchymosis and tenderness over the posteromedial aspect of the talocalcaneal joint and the posterior aspect of the medial malleolus.

2.1.7 Anterior Calcaneal Process Fracture [66–71]

Anterior calcaneal process fractures are among the most frequently overlooked and underestimated foot injuries. It is held that these are either missed completely or not adequately diagnosed in about 30–40% of cases. The central bifurcate ligament acts as a pivot of the Chopart joint as a whole. Avulsion fractures of the anterior process should be operatively fixated whenever possible.

2.1.8 Lisfranc Injury [72–82]

Compared to many other injuries involving the musculoskeletal system, the overall incidence of Lisfranc injuries is low, with published rates approximating 0.2–0.4% of all midfoot injuries. Lisfranc injuries are still frequently missed by the unsuspecting clinician because initial radiographic evidence can be occult, especially with lower energy injury. The patients often exhibit plantar ecchymosis on examination of the midfoot region, which, when present, should mandate a high index of suspicion for possible Lisfranc injury.

2.2 State-of-the-Art Treatment

2.2.1 Maisonneuve Fracture [1–15]

Late repairs give satisfactory but less favorable outcome compared to properly treated acute injuries. In the largest series reported of operatively treated Maisonneuve fractures, 92% of patients had good or excellent clinical outcomes. Radiographic evidence of osteoarthritis was observed in 49% of patients. According to systematic reviews, the medial malleolus should be fixed in case of a fracture. For the fibula, one or two 3-and 4-cortical screws can be used. There is no recommendation for proximal fibula fracture fixation. Neither is there a recommendation for direct repair of the deltoid ligament. Suture buttons have become a viable alternative to screw fixation. A recent randomized controlled trial shows that syndesmotic screw and TightRope fixation (Fig. 2.2) result in a low malreduction rate (5%), and both methods maintained reduction well (syndesmotic screw 84% and TightRope 95%). Intraoperative or immediate postoperative control of fibular reduction in the mortise is necessary, since there is malreduction in 6–52% of the cases. It is not possible to conclude from the type of injury, type of treatment, or experience of the surgeon whether an increased risk of persistent dislocation is present. A nonanatomical reduction outcome must therefore be expected in many cases. The currently available literature does not support routine elective removal of syndesmotic screws. Secondary procedures increase overall healthcare costs and expose the patient to additional risk of complications. Therefore, in the absence of high-quality evidence, there appears to be little justification for routine removal of syndesmotic screws.

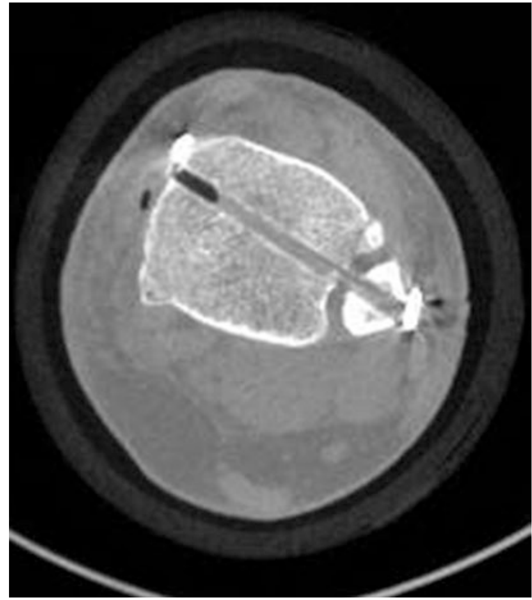

Fig. 2.2 Syndesmotic screw and TightRope fixation

2.2.2 Posterior Malleolus Fracture [16–21]

Diagnostic accuracy of measuring on plain lateral radiographs to assess articular involvement of posterior malleolar fractures is 22% (Fig. 2.3). Surgeons should no longer solely rely on plain lateral radiographs to judge the pathoanatomy of posterior fragments in ankle fractures. The size of the posterior malleolar fragment is long thought to be of relevance for decision-making. However, larger posterolateral fragments may be left unfixated, whereas smaller posteromedial fragments should be fixated since the deep deltoid ligament is attached to the posterior colliculus of the medial malleolus. Arthroscopically assisted percutaneous reduction and fixation of posterior malleolar fragments should be considered when the surgeon has the skills and ability. Fixation of a posterior malleolus provides 70% of stability whereas syndesmotic screws provide 40%.

2.2.3 Tillaux Fracture [22–37]

The correct diagnosis and appropriate treatment of the Tillaux fracture are of extreme importance because this fracture involves a major weight-bearing articular surface. However, treatment protocols in the literature are not uniform for this kind of fracture, and numerous case reports can be found describing various treatment methods. Anatomical reduction and internal fixation are required for every displaced epiphyseal fracture, especially in cases with more than 2 mm fragment displacement. This cutoff value is relevant because a gap of more than 2 mm on plain radiograph can lead to posttraumatic osteoarthritis.

Initial management with a closed reduction can be performed in the emergency room. To reduce a Tillaux fracture, the foot must be plantar flexed and then internally rotated; finally, the ankle must be maximally dorsiflexed. An assistant should stabilize the knee at 90° during this

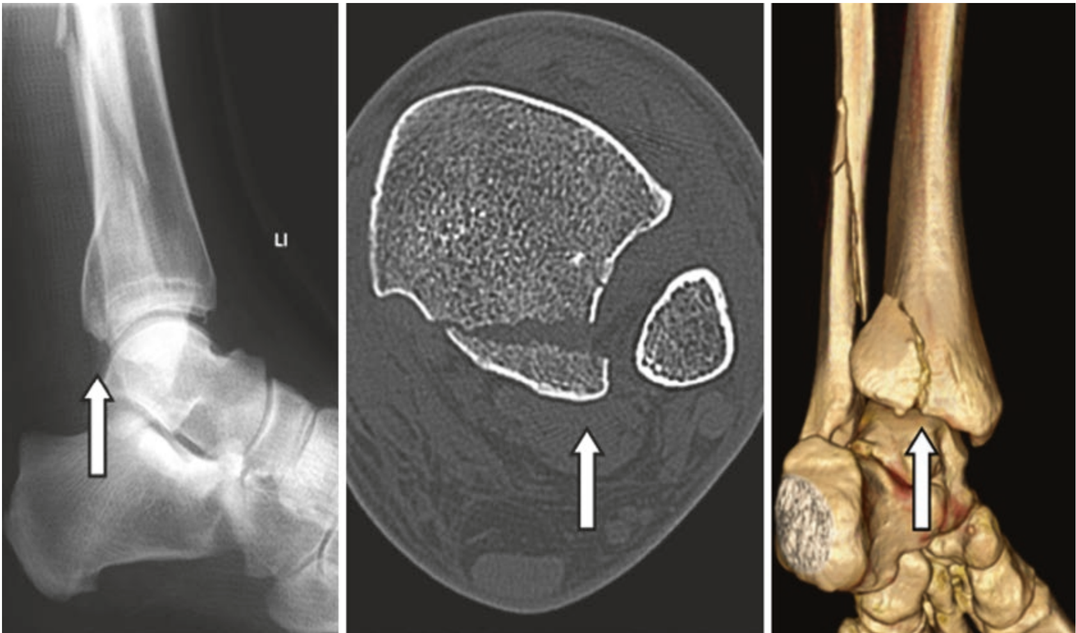

Fig. 2.3 Articular involvement of posterior malleolar fractures

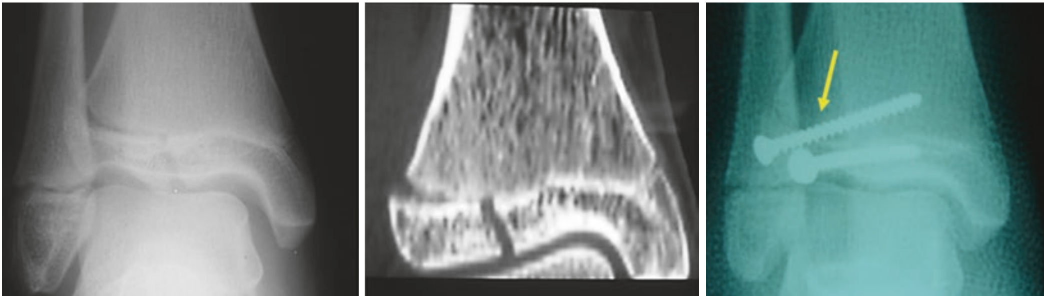

Fig. 2.4 Closed reduction and percutaneous fixation

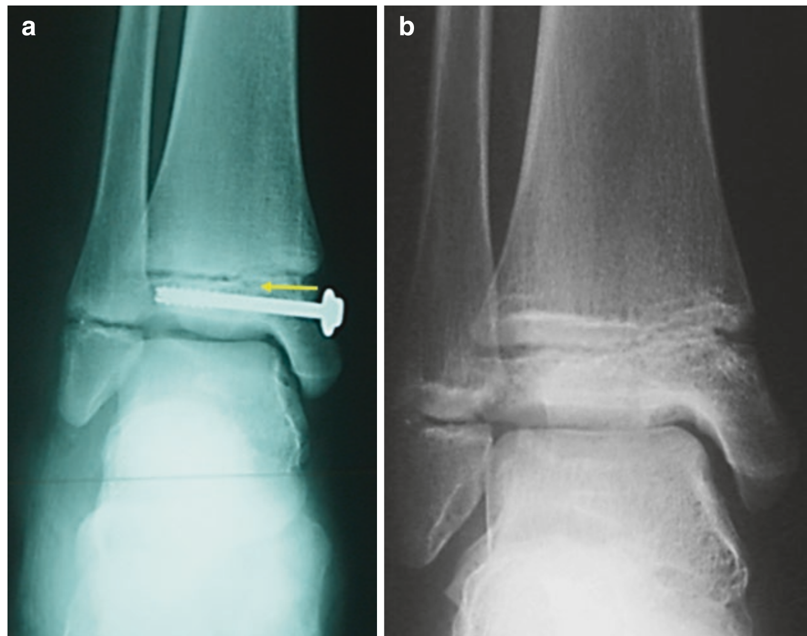

Fig. 2.5 (**a**) Percutaneous screw fixation of a Tillaux fracture (yellow arrow), respecting the epiphyseal plate. (**b**) 7 months postoperative radiographic control after screw removal

manipulation. The closed reduction is followed by casting or splinting; a CT scan is then mandatory to confirm the adequacy of reduction, with a residual gap or step-off of <2 mm being considered acceptable.

If, after close reduction and casting, a residual step-off of >2 mm in any plane persists, operative treatment is indicated. Several surgical techniques have been described to treat displaced Tillaux fractures, which can be divided in closed reduction and percutaneous fixation (Figs. 2.4 and 2.5a, b), mini-open reduction and internal fixation, and open reduction and internal fixation.

A mini-open technique is defined as a small incision used to manipulate the fracture for reduction with an instrument under fluoroscopy but without formal articular visualization or exposure. More recently, arthroscopically assisted reduction and fixation has also been proposed. The treatment of choice of Tillaux fractures is dependent on the fracture displacement, stability of the fracture, articular congruity, and presence of associated injuries.

Early treatment is recommended, although acceptable results were also obtained with a 5-week delayed treatment. If screw fixation is performed, the screw should be removed within 1 year, since cannulated screw removal from the distal tibial epiphysis after more than 1 year postoperatively can be often complicated by screw breakage and screw head stripping.

2.2.4 Osteochondral Talar Fracture [38–47]

The distinction between fresh and chronic osteochondral lesions is difficult to make. There is a wide variety of treatment regimens for chronic lesions, whereas for fresh osteochondral fractures, fixation is to be preferred (Fig. 2.6a, b). There are several studies showing osteochondral lesions to occur as a result of ankle fractures. However, there is a paucity in the literature regarding the epidemiology of fresh osteochondral fractures. Probably, there is a role for conservative treatment, since 61.5% yields successful results in chronic lesions. For chronic lesions, none of the interventions for the treatment of primary osteochondral defects to the talus show clinical superiority over another or others. Internal fixation of a large enough fresh or chronic osteochondral talar defect is a good technique. The advantage is to restore the natural congruency of the subchondral bone and to preserve hyaline cartilage. However, often, a medial or lateral arthrotomy, often combined with a malleolar osteotomy, has to be performed to allow proper visibility and working access.

We advise an arthroscopic fixation technique for primary osteochondral talar defects: lift, drill, fill, and fix (LDFF). The contour of the anterior tibia can be identified and the distal tibia rim removed with a shaver to facilitate better access to the ankle joint. The arthroscopic portals should be interchangeably used to allow optimal vision. With a probe, the location of the OCD is identified, and a beaver knife is used to allow the making of a sharp osteochondral flap. The posterior side of the flap is left intact and can be used as a lever, allowing lifting from anteriorly with the use of a chisel (lift). The attached bone of the osteochondral flap and the osteosclerotic area of the bed can be debrided and drilled to promote revascularization (drill) in case of older lesions. After debridement and drilling, the defect can be filled with cancellous bone of the distal tibial metaphysis. Cancellous bone is harvested with a chisel by creating longitudinal particles that are transported into the defect with a grasp (fill). Finally, the osteochondral flap can be correctly aligned and fixed with a bio-screw (fix). Clinical success rates between 78% and 89% after fixation through an open procedure are reported.

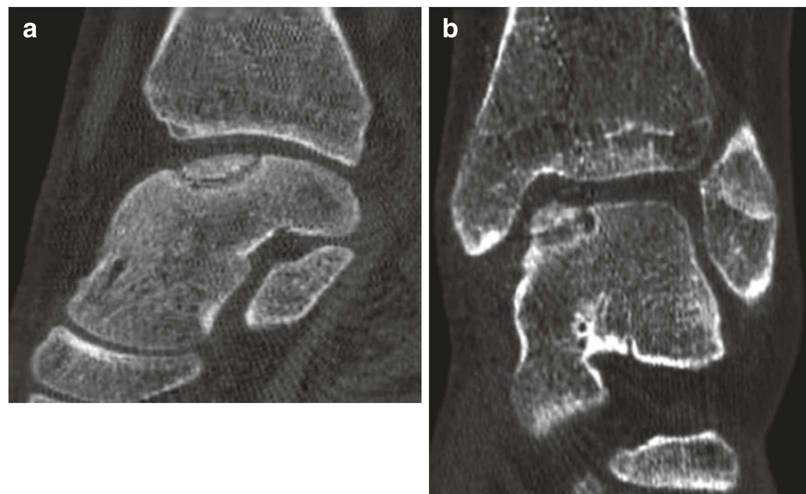

Fig. 2.6 (**a**) Large osteochondral fracture suitable for fixation. (**b**) Large osteochondral fracture suitable for fixation

Long-term outcomes after arthroscopic treatment are not yet available; however similar or higher values could be expected.

2.2.5 Lateral Talar Process Fracture [48–59]

A lateral talar process fracture is often misdiagnosed as an ankle sprain, assuming there is only soft tissue damage. Of all lateral talus fractures, 33–59% are missed on initial presentation. Misdiagnosis and undertreatment can lead to malunion or nonunion, eventually resulting in osteoarthritis. This can have severe consequences for the quality of life in the young and active patients suffering from this injury. Therefore, the diagnostic workup is essential.

The physician evaluating a patient with lateral ankle pain should suspect a lateral talar process fracture after a high-impact trauma or after snowboarding. Patients with a lateral talar process fracture present with pain, swelling, and hematoma. Palpation anteroinferior to the lateral malleolus is frequently painful. The lateral malleolus itself may also be painful. In most cases, the Ottawa ankle rules are positive in patients with a lateral talar fracture, leading to the first step in diagnostic imaging: radiography.

Standard radiography is false negative in 21–40% of the cases. The fracture is best established on a mortise view or Broden's view. Chip fractures might overproject on the fibula and calcaneus and are therefore better seen on the lateral view.

An intact lateral process of the talus has a symmetrical V-shaped contour. A crooked or asymmetrical V-shape can be seen in a displaced fracture. Von Knoch et al. described this as a positive V-sign. A posterior subtalar effusion on the lateral ankle radiograph raises suspicion of a lateral talar process fracture. Holding the ankle in dorsiflexion and inversion can contribute to a better view of the fracture.

After diagnosing a lateral talar process fracture on plain radiography, a computed tomography (CT) scan should be made to visualize the type of fracture, amount of displacement, comminution, and involvement of the subtalar joint (Fig. 2.7). A CT scan can also be diagnostic in patients with a

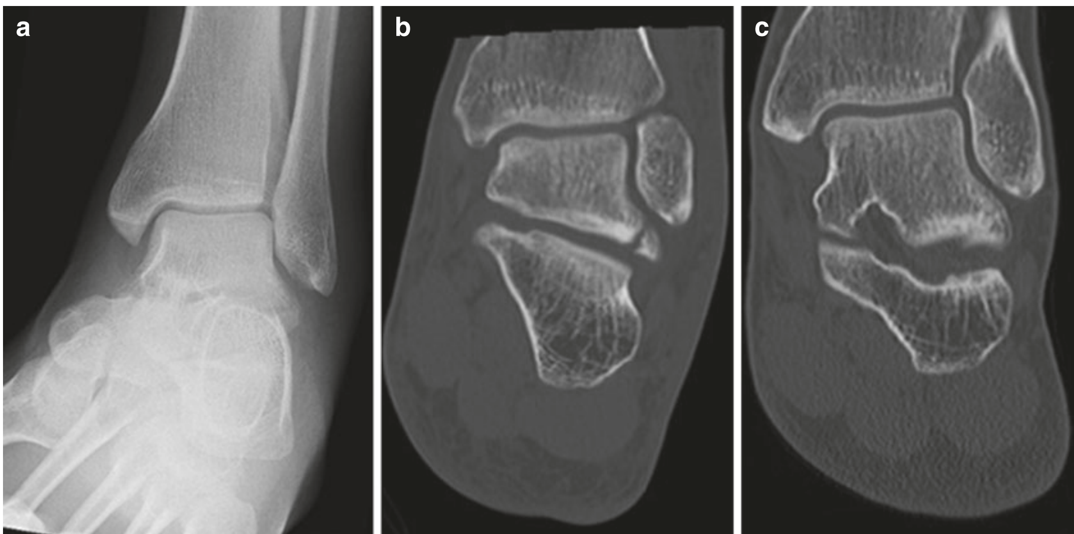

Fig. 2.7 A 30-year-old male with a lateral talar process fracture (**a**). The CT scan showed a Hawkins type I fracture with 3 mm dislocation (**b**). Despite the advice to perform open reduction and internal fixation, the patient chose a conservative treatment. Immobilization in a short-leg, non-weight-bearing cast for a period of 6 weeks was provided. The patient was seen 2 years after the initial treatment with persisting ankle pain. Physical examination revealed a limited ankle dorsiflexion. The CT scan showed a consolidated lateral talar process (**c**) and moderate subtalar arthrosis