Diagnosis and treatment of multiligament knee injury: state of the art

Gilbert Moatshe,1,2,3 Jorge Chahla,2,4 Robert F LaPrade,2,5 Lars Engebretsen1,3

ABSTRACT
Multiligament knee injuries constitute a complex and challenging entity, not only because of the diagnosis and reconstruction procedure itself, but also because of the rehabilitation programme after the index procedure. A high level of suspicion and a comprehensive clinical and radiographic examination are required to identify all injured structures. Concomitant meniscal, chondral and nerve injuries are common in multiligament injuries necessitating a detailed evaluation. Stress radiographs are valuable in evaluating patients preoperatively and postoperatively. The current literature supports surgical management of multiligament injuries, and reconstructions are recommended because repair of ligaments has higher failure rates. Reconstruction of all injured ligaments in one stage is advocated (if possible) in order to achieve early mobilisation and to avoid joint stiffness. Using biomechanically and clinically validated anatomic ligament reconstructions improves outcomes. In the setting of multiligament knee reconstructions, several technical aspects that require consideration are vital, such as the graft choice, the sequence of ligaments reconstruction, tunnel position and orientation to avoid tunnel interference and graft tensioning order. This review article discusses the use of stress radiographs in diagnosing ligament injuries and evaluating postoperative stability. Tunnel convergence and tensioning sequence are potential problems, and guidelines to address these are also discussed. Recovery after a multiligament reconstruction surgery typically requires 9 to 12 months of rehabilitation prior to returning to full activities. The purpose of this article is to review the specific principles of multiligament injuries, classification, diagnosis, treatment options and rehabilitation guidelines for addressing these complex injuries.

INTRODUCTION
The definition of a multiligament knee injury is commonly recognised 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).1–3 The terms knee dislocation and multiligament knee injuries are often used interchangeably. Knee dislocations often result in multiligament knee injuries, but some multiligament knee injuries are not knee dislocations. A knee dislocation is typically characterised by rupture of both cruciate ligaments, with or without an associated grade III medial or lateral-sided injury.2,3 However, knee dislocations with one of the cruciate ligaments intact have been reported.4–6 Multiligament injuries are heterogeneous, and a thorough diagnostic workup and treatment plan is mandatory when dealing with these injuries. The purpose of this article is to review specific focused principles of multiligament knee injuries, classification, diagnosis, treatment options and rehabilitation guidelines for addressing these complex injuries. Key information and articles on these injuries can be found in box 1 and box 2 respectively.

Classification
Schenck described the most widely used classification system for the dislocated knee in 1994, which is based on the anatomical patterns of the torn ligaments (table 1).3,4 The advantage of this classification is that it allows for identification of the torn ligaments and planning of treatment. In addition, it makes it possible to compare the different studies in the literature using the same classification system of knee dislocations.

Aetiology
Multiligament knee injuries can be caused by both high-energy trauma,7 such as motor vehicle accidents and fall from heights, and low-energy trauma,8 including sporting activities. In a cohort of 85 patients with knee dislocations, Engebretsen et al reported that 51% were high-energy injuries, and 47% were sports-related injuries.9 In a review of 303 patients with knee dislocations, Moatshe et al10 reported equivalent rates of high- and low-energy trauma, with 50.3% and 49.7%, respectively. Miller et al reported on multiligament knee injuries in obese individuals as a result of ultra-low velocity trauma.11

Evaluation
Multiligament knee injuries are not uncommon. Only 28% of PLC injuries occur in isolation.12 The clinician should have a high level of suspicion, and a detailed knee examination should be performed including assessment of the limb’s neurovascular status. PLC injuries are associated with both common peroneal nerve injuries and vascular injuries (Moatshe et al).13–15 When both cruciate ligaments are torn, the risk of vascular and neurological injuries is very high and vascular assessment is often needed.2 Magnetic resonance imaging (MRI) is performed to evaluate all the injured structures (figure 1). For both acute and chronic injuries, stress radiographs are essential, but can be difficult to carry out in the acute phase (tables 2 and 3, figures 2 and 3).13–15

Acute multiligament knee injuries
For high-energy injuries, Advanced Trauma Life Support principles apply. Foot pulses and skin

To cite: Moatshe G, Chahla J, LaPrade RF, et al. JISAKOS 2017;0:1–10. doi:10.1136/jisakos-2016-000072. Copyright © 2017 ISAKOS

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Received 9 November 2016
Revised 8 January 2017
Accepted 15 January 2017

State of the Art
vascular injuries in knee dislocations. 25 Cautions.19 20 Ultra-low velocity knee dislocations in the obese common peroneal nerve occurs in 14%–40% of knee dislocations. 7 18 Injury to the popliteal artery (23%–32%). 7 18 Injury to the capillary refill, normal neurological examination) is reported to be reliable to screen patients with knee dislocations for ‘selective’ arteriography.22 Some protocols recommend an ABI cut-off of <0.8,23 and others recommend <0.9 to perform arteriography.22 24 Stannard et al developed a protocol for monitoring vascular injuries in knee dislocations.21 Patients with vascular injuries are treated with acute revascularisation, and the knee is protected in an external fixator to protect the revascularisation graft and to maintain knee reduction.21 22 The external fixator is usually removed at 2–6 weeks and the knee is placed in a hinged brace to avoid pin infections and joint stiffness.

ABI is useful as an adjunct to physical examination to assess for vascular injuries. 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.22 Some protocols recommend an ABI cut-off of <0.8,23 and others recommend <0.9 to perform arteriography.22 24 Stannard et al developed a protocol for monitoring vascular injuries in knee dislocations.21 Patients with vascular injuries are treated with acute revascularisation, and the knee is protected in an external fixator to protect the revascularisation graft and to maintain knee reduction.21 22 The external fixator is usually removed at 2–6 weeks and the knee is placed in a hinged brace to avoid pin infections and joint stiffness.

Some multiligament knee injuries are missed in the acute phase, or concurrent ligament injuries are not acknowledged, in a multi-trauma patient. A thorough patient history, clinical examination supplemented with stress radiography and MRI are mandatory to identify all injured structures. Concomitant cartilage and meniscal injuries should be diagnosed and treated concurrently. In addition, long axis radiographs of the lower extremity should be obtained to assess alignment, especially for chronic multiligament knee injuries. Varus malalignment is defined as being

<table>
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<tr>
<th>Table 1</th>
<th>Explaining Schenck’s knee dislocation classification</th>
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<tr>
<td>KD I</td>
<td>Injury to single cruciate + collaterals</td>
</tr>
<tr>
<td>KD II</td>
<td>Injury to ACL and PCL with intact collaterals</td>
</tr>
<tr>
<td>KD III M</td>
<td>Injury to ACL, PCL, MCL</td>
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<tr>
<td>KD III L</td>
<td>Injury to ACL, PCL, FCL</td>
</tr>
<tr>
<td>KD IV</td>
<td>Injury to ACL, PCL, MCL, FCL</td>
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<tr>
<td>KD V</td>
<td>Dislocation + fracture</td>
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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; FCL, fibular collateral ligament; KD, Knee Dislocation Classification I–V; MCL, media collateral ligament.

Figure 1 MRI showing a PCL tear on the sagittal plane (A) and a sMCL injury seen in the coronal plane (B). A detailed evaluation of the patient; and the images are mandatory to diagnose all the injured structures. PCL, posterior cruciate ligament; sMCL, superficial medial collateral ligament.

Chronic multiligament knee injuries

Some multiligament knee injuries are missed in the acute phase, or concurrent ligament injuries are not acknowledged, in a multi-trauma patient. A thorough patient history, clinical examination supplemented with stress radiography and MRI are mandatory to identify all injured structures. Concomitant cartilage and meniscal injuries should be diagnosed and treated concurrently. In addition, long axis radiographs of the lower extremity should be obtained to assess alignment, especially for chronic multiligament knee injuries. Varus malalignment is defined as being

Box 1 Key information

- Multiligament injuries are complex and challenging.
- Detailed evaluation with physical examination, MRI, stress radiographs and angiography if ankle–brachial index <0.9
- Concomitant injuries including meniscal, chondral, nerve and vascular injuries are common.
- Surgical treatment of all injured structures in the same setting is recommended.
- A well-crafted rehabilitation protocol is important to ensure good functional outcomes.
- Good functional outcomes can be achieved with surgical treatment.

Box 2 Key articles

injury, usually the PLC or PMC. A posterior translation side-to-side difference of ≤11 mm is associated with a complete isolated PCL tear; ≥12 mm difference is associated with a complete isolated PLC tear; ≥15 mm difference represents an injury to all medial structures. A perpendicular line is drawn from the most posterior point of the right knee, et al. JISAKOS 2017;0:1–10. doi:10.1136/jisakos-2016-000072

Table 2 Evaluation of posterior knee instability

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<tr>
<th>Grade</th>
<th>Clinical finding with posterior drawer test</th>
<th>Kneeling stress radiographs</th>
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<tr>
<td>I</td>
<td>0–5 mm PTT</td>
<td>0–7 mm PTT → normal or partial tear</td>
</tr>
<tr>
<td>II</td>
<td>5–10 mm PTT</td>
<td>8–11 mm PTT → Complete PCL tear</td>
</tr>
<tr>
<td>III</td>
<td>&gt;10 mm PTT → posterior sag</td>
<td>≥12 mm PTT → Combined ligament injury</td>
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Clinical test findings and the corresponding stress radiograph values in evaluating posterior knee instability. PLC, posterior cruciate ligament; PTT, posterior tibial translation.

Table 3 Evaluation of varus and valgus instability using stress radiographs

<table>
<thead>
<tr>
<th>Varus stress test</th>
<th>Valgus stress test</th>
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<tr>
<td>&lt;2.7 mm</td>
<td>&lt;3.2 mm</td>
</tr>
<tr>
<td>2.7 mm → Isolated FCL tear</td>
<td>3.2 mm → Complete sMCL tear</td>
</tr>
<tr>
<td>≥4.0 mm → Complete PLC injury</td>
<td>≥9.8 mm → Complete tear of all medial structures</td>
</tr>
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Side-to-side differences between the injured and the noninjured knee using stress radiograph to evaluate varus and valgus knee instability. FCL, fibular collateral ligament; PLC, posterolateral corner; sMCL, superficial medial collateral ligament.

Figure 2 Kneeling stress radiographs for evaluation posterior laxity are an important part of the evaluation. In this patient, there was a 10 mm increase in posterior tibial translation on the left compared with the right knee. 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 with the contralateral side to give a side-to-side difference. A posterior translation side-to-side difference of 0 to 6 mm are usually due to partial PCL tear or in patients who are too sore to put sufficient weight on the knee; 8 mm to 11 mm side-to-side difference is associated with a complete isolated PCL tear; ≥12 mm is usually observed in patients with complete PCL tear with another ligament injury, usually the PLC or PMC, but can also be seen in patients with decreased sagittal plane tibial slope. PLC, posterior cruciate ligament; PLC, posterolateral corner; PMC, posteromedial corner.

Present when a line from the centre of the femoral head to the centre of the ankle joint (the mechanical axis) falls medial to the apex of the medial tibial eminence on a long-leg alignment radiograph (figure 3). When varus mal-alignment is present in a patient with a chronic PLC injury, a corrective osteotomy should be considered prior to reconstruction. Reconstruction grafts in the PLC do not tolerate varus mal-alignment, and this will potentially lead to graft stretching and reconstruction failure. Arthur et al reported on 21 patients with chronic combined PLC injuries, 38% had sufficient improvement after proximal tibia osteotomy that subsequent PLC reconstruction was not necessary.27

Concomitant injuries
High incidences of meniscal and focal cartilage injuries are reported in multiligament knee injuries. In a review of 303 patients at a level I trauma centre (Moatshe et al,10), reported meniscal injuries were found in 37.3% of the patients and cartilage injuries in 28.3%. Richter et al reported lower incidence (15%) of meniscal injuries in association with knee dislocations;28 however, Krych et al reported higher incidence (15%) of meniscal injuries associated with knee dislocation in 121 patients (122 knees) with 76% of overall patients having a meniscal or chondral injury; 53% presented with meniscal tears while 48% presented with a chondral injury.29 Common peroneal nerve injuries are frequently associated with lateral-sided injuries. Moatshe et al reported common peroneal nerve injuries and vascular injuries in 19% and 5% of the 303 patients with knee dislocations, respectively. Medina et al reported a frequency of 25% and 18% for nerve and vascular injuries in knee dislocations, respectively, in a recent systematic review.
Becker et al reported peroneal nerve injury in 25% of knees and arterial injury in 21% in a series of 106 patients. Moatshe et al reported that the odds of having a peroneal nerve injury were 42 times higher among patients with 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 (figure 6).

Medial-sided injuries are usually the most common injuries in multiligament knee injury patterns. Moatshe et al reported that medial-sided injuries constituted 52% of the injuries in 303 patients with multiligament knee injuries. In their series, lateral-sided injuries constituted 28% and bicruciate injuries constituted only 5%. In a review by Robertson et al, 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.

**Surgical versus nonsurgical management**

Surgical treatment of the torn ligaments in multiligament injured knees improves patient-reported outcomes. In a meta-analysis including 132 knees treated surgically and 74 treated nonsurgically, Dedmond et al reported improved motion and Lysholm scores in the surgical treatment group. The surgical group had significantly better 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). Richter et al reported on 89 patients with traumatic knee dislocations with a mean follow-up of 8.2 years. Sixty-three patients were treated with surgical repair or reconstruction, while 26 patients were treated nonsurgically. The authors reported significantly improved outcomes in the surgical group compared with the nonsurgical group. Functional rehabilitation after surgery was reported to be the most important positive prognostic factor. In addition, patients who were 40 years of age or younger and who had low velocity sports injuries had better scores. In a literature review by Peskun and Whelan, evaluating outcomes in 855 patients from 31 studies treated surgically, and 61 patients from four studies treated nonsurgically, functional outcomes, contracture, instability, and return to activity favoured surgical treatment. In summary, the literature supports surgical treatment, and postoperative functional rehabilitation of multiligament knee injuries. It is in rare occasions such as advanced age, immobility and comorbidities that nonsurgical treatment can be considered.

**Repair versus reconstruction**

Earlier studies have reported poor outcomes after repair of isolated ACL injuries. Mariani et al evaluated outcomes in a cohort of patients with multiligament injuries; 52 patients treated with repair of the ligaments versus 28 treated with reconstructions. All patients had bicruciate ligament injuries, and they were divided into three groups; direct ACL/PCL repair (group 1), ACL reconstruction and PCL repair (group 2) and ACL and PCL reconstruction (group 3). Patients with repair of cruciate ligaments had higher rates of flexion deficit >6°, higher rates of posterior instability and lower rates of return to preinjury activity levels. High reoperation rates have been reported in patients with posterolateral injuries treated with repair. Anatomic reconstruction of the injured structures using biomechanically validated techniques has been reported to yield improved outcomes (figure 7). In the setting of multiligament injuries, reconstruction of the torn ligaments is recommended.
Repair of the collaterals is usually reserved for bony avulsion injuries.48

Timing of surgery
Timing of surgery during multiligament injuries is a topic of debate. In addition, 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 scarring and tissue necrosis affect outcomes.9 37 44 45 This is also particularly important in the case of bony avulsion injuries. However, some authors have used 6 weeks to demarcate between acute and chronic.46 Better outcomes are reported in acute compared with chronic treatment in studies that directly compared timing of treatment. Levy et al reported no difference in range of motion after acute and chronic surgery in a systematic review of literature that included five studies46 Moatshe et al. (unpublished data, 2016) reported on 303 patients with knee dislocations, and the percentage of patients developing arthrofibrosis was 15.2% and 3.8% in the acutely treated and the chronic injuries, respectively. The authors preferred acute treatment of the injured structures to facilitate early rehabilitation.49 In addition, staging the reconstruction can potentially alter joint kinematics, and increase the risk of graft failure.47–49 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.

Surgical principles
Avoiding tunnel convergence
Reconstructing several reconstruction tunnels in the distal femur and proximal tibia pose a risk of tunnel convergence because of limited bone mass 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. Few studies have evaluated the risk of tunnel convergence and optimal angulation of the tunnels. 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. 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.50

On the lateral femoral side, Moatshe et al. (in press, 2016) 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 were safe and avoided tunnel convergence. On the medial side, aiming the sMCL 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 (figure 8). In a laboratory study, Carmada 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.51 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.52 However, the diameter of their PCL tunnels were smaller than those used by Moatshe et al.

Tensioning sequence
The tensioning sequence in multiligament injuries is a topic of debate. Different tensioning sequences have been reported in the literature. Some authors advocate for starting with the PCL to restore the central pivot and tibial step-off, followed by the ACL in extension to ensure the knee can be fully extended, posterolateral corner and the posteromedial corner last.53 54 A biomechanical study by Wentorf et al reported that in a posterolateral corner deficient knee, tension during fixation of the ACL graft increased external tibial rotation of the tibia.49 Therefore, there

Figure 7 An intraoperative arthroscopy image showing double-bundle PCL reconstruction. Anatomic reconstruction of all the torn ligaments using biomechanically and clinically validated techniques is recommended. ALB, anterolateral bundle; PMB, posteromedial bundle; MFC, medial femoral condyle.

Figure 8 Reconstruction of the sMCL on a right knee. The AT is an important landmark to locate the adductor tubercle which is just distal to the adductor tendon insertion. The attachment site of the MCL is 12 mm distal and 8 mm anterior to the adductor tubercle. To avoid convergence with the PCL tunnels, the sMCL and popliteus tunnels should be aimed anteriorly and proximally. AT, adductor tendon; PCL, posterior cruciate ligament; sMCL, superficial medial collateral ligament.
are authors that advocate for fixing the posterolateral corner prior to the ACL to avoid external tibial rotation. Markolf et al reported in a biomechanical study that the PCL should be fixed prior to the ACL to best restore graft forces. Kim et al retrospectively reviewed 25 patients with multiligament injuries, 14 with the PCL tensioned first and 11 with simultaneous tension and fixing the ACL first. Posterior stress radiographs, Lysholm score, International Knee Documentation Committee (IKDC) scores favoured fixing the ACL first. "The optimal tensioning sequence can be best evaluated with well-designed biomechanical studies." The authors preferred tensioning sequence which fixes 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 at 20°–30° of knee flexion 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.

Surgical technique
A thorough preoperative assessment to aid patient selection and planning of treatment is important (box 3). The surgical technique uses both allografts and autografts depending on the ligaments injured. Anatomic ligament reconstructions that are biomechanically and clinically validated are performed. An open surgical approach is performed prior to arthroscopy to allow for improved soft tissue visualisation and to limit fluid extravasation into the surgical site. On the medial side, a skin incision is performed proximally between the adductor tubercle and the patella and extended 8 cm distally from the joint line to the medial part of the tibia. The semitendinosus and gracilis tendons are harvested and fixed at the superficial MCL attachment site, 6 cm distal to the joint line with two suture anchors. A femoral reconstruction tunnel is reamed at the anatomic attachment of the MCL, and the grafts are passed under the sartorius fascia and the graft ends are whipstitched so that 30 mm will fit into the femoral tunnel (figure 9). On the posterolateral side, a technique described by LaPrade et al is performed using a split Achilles graft (figure 10). The fibular, tibial and femoral tunnels are reamed and passing sutures are placed. After drilling the tunnels for the collateral ligament reconstruction grafts, attention is turned to the intra-articular injuries. An anatomic double-bundle PCL and single-bundle ACL reconstructions are performed. The concomitant meniscal and chondral lesions are addressed prior to graft fixation and tensioning. Graft tensioning is performed as described above. Tips and tricks, and some potential pitfalls when performing this type of surgery can be found in box 4 and box 5 respectively.

Rehabilitation
Multiligament knee injuries are complex and challenging pathologies to rehabilitate due to the extensive soft tissue damage and the different injury patterns that can occur. An appropriate diagnosis and treatment of all the damaged structures is vital for a successful outcome. Reconstruction of all injured ligaments and repair of soft tissue structures such as the meniscus or cartilage are recommended to aid in early mobilisation and to avoid joint stiffness or graft failure. Postoperative recovery after a multiligament reconstruction procedure typically requires 9–12 months of rehabilitation prior to returning to full activities. This allows proper time for the grafts to incorporate and to heal in order to prevent reconstruction graft failure. A well-crafted rehabilitation plan after a multiligament reconstruction should focus on graft protection and functional outcomes including regaining motion, strength and function. A dynamic PCL brace

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**Box 3 Key issues of patient selection**

- Injury to >1 major knee ligament (ACL, PCL, MCL, FCL or PCL)
- Active patients without major comorbidities
- Detailed assessment of all injuries
- Aim for surgical treatment of all injured structures in the acute setting
- Obese patients have higher complication rates
- Delay ligament surgery in patients with vascular injuries

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Box 4  Tips and tricks

- **Patient positioning:** The patient should be positioned to allow full flexion and extension of the knee.
- **Graft preparation:** Ensure availability of grafts and correct graft length. Tightly spacing the whipstitch sutures protects the grafts from laceration when securing with an interference screw.
- **Steps during surgery:** Start with the collateral ligament injuries. Fluid extravasation from arthroscopy can impair visualisation and identification of structures.
- **Tunnel positioning:** All the tunnels should be placed at the anatomic footprint of the ligaments being reconstructed. All the tunnels’ positions and orientations should be planned in detail to avoid tunnel convergence. Aiming the femoral FCL and popliteus tunnels anteriorly reduces the risk of convergence with the ACL tunnel and the risk of violating the intercondylar notch. The centre of the popliteus tunnel is 18.5 mm anterior to the centre of the FCL tunnel, and there is an 8–9 mm bone bridge between the tunnels. The femoral tunnels for the posteromedial corner should be aimed anteriorly and proximally to avoid convergence with the PCL tunnels. The femoral PCL tunnels should be divergent.
- **Acorn reamers:** These reamers allow the surgeon to add fine adjustments to the tibial tunnel paths. The edges of the tunnels should be smooth to prevent the bone edges from damaging the grafts.
- **Fixation:** The sequence of graft fixation affects the tibiofemoral orientation and the graft forces. The PCL is tensioned first, followed by the PLC, then the ACL and finally the PMC.
- **Postoperative rehabilitation:** Early protected range of motion is important. Periodisation, progressive weight bearing, quadriceps activation and patella mobility. Rehabilitation takes 9–12 months. Use brace during activities the first year of returning to activities.

Box 5  Major pitfalls

- **Patient positioning:** Incorrect positioning of the patient may limit knee motion and the space available for the surgeon to work effectively.
- **Graft preparation:** Oversizing the grafts can complicate the passage of grafts in the tunnels. Care must be taken to ensure availability of graft for all torn ligaments.
- **Tunnel convergence:** With many tunnels being created in both the femur and tibia, the risk of tunnel convergence is high. Tunnel convergence will potentially damage the grafts, fixation devices, create too short tunnels or leave not enough bone stock for graft fixation and integration. The PCL femoral tunnels should be divergent.
- **Meniscal root injuries:** Malposition of the PCL tibial tunnel can potentially injure the posterior root of the medial meniscus. Malposition of the ACL tibial tunnels can potentially injure the anterior horn of the lateral meniscus.
- **Neurovascular complications:** There is increased risk of neurovascular injuries when creating tibial femoral tunnels. The guide pin should be visualised and advancement of the guide pin should be prevented during reaming.
- **Fixation:** The sequence of graft fixation can theoretically alter tibiofemoral orientation and thus knee kinematics, increasing the risk of graft failure and osteoarthritis.

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(Ossur PCL Rebound brace, Foothill Ranch, CA, USA) or a Jack PCL brace (Albrecht GmbH, DE, USA) is used in the rehabilitation period (9–12 months) to protect the reconstruction. It is also recommended to use a brace on the first year of returning to activities. Full range of motion is especially vital to long-term outcomes, and patients should aim to obtain 0–90° of knee flexion within the first 2 weeks after surgery. Once a muscular strength foundation with good dynamic neuromuscular control has been established, patients can progress to their functional sport specific exercises.

Initial management should focus on supportive measures such as pain control, inflammation/effusion control (cryotherapy, elevation and compression of the affected limb), range of motion re-establishment, patellar mobilisation, restoring appropriate muscle activation patterns and progressive gait training. Soft tissue healing involves a predictable series of phases (inflammation, proliferative and remodelling phases) that should be addressed at a proper time to promote physiological healing responses, minimise negative changes and facilitate the proliferation and alignment of collagen fibres. Patellar mobilisation should be a primary initial focus of the rehabilitation, as hypo-mobility of the proximal pole of the patella can interfere with the extensor mechanism leading to loss of range of motion and a quadriceps lag. Conversely, flexion can be affected by a diminished patellar inferior glide. With regards to weight bearing, to date there is no randomised clinical trial assessing the effectiveness of early weight bearing after a multiligament reconstruction, and therefore protected weight bearing is carried out for the first 6 weeks after which partial weight bearing is allowed.

Periodisation is the division of a training or rehabilitation programme into smaller phases (periods) as a means of creating more manageable segments. In a multiligament knee reconstruction rehabilitation programme, the phases are constituted by muscular endurance, strength and power and can be developed based on the patient’s expectations and return to activity timeline. The length of each phase depends on the time frame of the rehabilitation programme, but it should be no shorter than 6 weeks. With range of motion (ROM) restored, the treatment emphasis shifts to the development of a muscular endurance base. A transition in training emphasis to the development of muscular strength can then be made before muscular power is developed. Three to four sessions a week are appropriate while still providing adequate recovery between sessions.

Given the numerous variables (age, BMI, sport, concurrent injuries, etc) that can interact in the decision to allow a patient to return to sport, the rehabilitation process and return to sport timeline should be tailored to each patient. A systematic review of 264 studies by Barber-Westin and Noyes reported that the return to play decision was based on subjective nonspecific criteria such as ‘regained full functional stability’, ‘normal knee function on clinical examination’, ‘satisfactory stability’ or ‘nearly full ROM and muscle strength’. Few studies described objective criteria such as time from surgery, muscle strength, ROM and effusion, which were the most frequently used.

**Subjective and objective outcomes**

Poor outcomes are reported for nonsurgical management of multiligament knee injuries, therefore this section will focus on outcomes after surgical management. Preoperative and post-operative stability and functional scores are usually compared to evaluate patient outcomes (box 6). Unfortunately, most studies on multiligament knee injuries have small cohorts and the follow-up is generally short. Good functional outcomes are reported in short to medium follow-up after surgical treatment.
of multiligament injuries. 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. However, 87% of the patients in the cohort had radiological osteoarthritis in the injured knee based on Kellgren-Lawrence classification. Moatshe et al (unpublished data, 2016) reported a mean Lysholm score of 84, Tegner score of 4 and subjective IKDC 73 in a follow-up of 65 patients with multiligament knee injuries at a minimum follow-up of 10 years. Forty-two per cent of the cohort had radiological osteoarthritis in the injured knee compared with only 6% in the uninjured knee. Geeslin et al 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. Postoperative stress radiographs are an important objective method of evaluating stability (figure 11).

Good functional outcomes have also been reported by other authors. Despite good functional scores, several studies report relatively high prevalence of radiographic osteoarthritis ranging from 23% to 87%. Certain factors have been reported to correlate with poor outcomes including high-energy trauma, repair of medial side injury, age >30 years (Moatshe et al.,), concomitant cartilage injury, combined medial and lateral meniscal tears.

CONCLUSIONS AND FUTURE PERSPECTIVES

Multiligament knee injuries are complex and a high level of suspicion is required when treating these patients. Some of the concurrent ligament and meniscal injuries may be missed initially, and this necessitates a detailed history and clinical examination, supplemented with MRI and stress radiographs. 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. Good functional outcomes can be achieved after surgical treatment of these injuries, but post-traumatic osteoarthritis is common.

There is still no consensus on the optimal tensioning sequence of the grafts during multiligament knee injury surgery. Biomechanical studies are necessary to evaluate the effects of the different tensioning orders to the knee kinematics. This will potentially pave the way for multicentre 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 (box 7).

REFERENCES
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