EOR | volume 5 | march 2020
DOI: 10.1302/2058-5241.5.190012
www.efortopenreviews.org

EFORT open reviews

Management of multiligament knee injuries

Jimmy Wui Guan Ng
Yulanda Myint
Fazal M. Ali

- Up to 18% of multiligament knee injuries (MLKI) have an associated vascular injury.
- All MLKI should be assessed using the ankle brachial pressure index (ABPI) with selective arteriography if ABPI is < 0.9.
- An ischaemic limb following knee dislocation must be taken to the operating theatre immediately for stabilization and re-vascularization.
- Partial common peroneal nerve (CPN) injury following MLKI has better recovery than complete palsy.
- Posterior tibial tendon transfer is offered to patients with complete CPN palsy if there is no recovery at six months.
- Operative treatment with acute or staged reconstructions provides the best outcome in MLKI.
- Effective repair can only be performed within three weeks of injury.
- There is no difference between repair and reconstruction of medial collateral ligament and posteromedial corner.
- Posterolateral corner reconstruction has a lower failure rate than repair.
- Early mobilization following MLKI surgery results in fewer range-of-motion deficits.

Keywords: knee dislocation; multiligament knee injuries

Cite this article: *EFORT Open Rev* 2020;5:145-155. DOI: 10.1302/2058-5241.5.190012

Introduction

Multiligament knee injuries (MLKI) are devastating injuries. They are defined as injuries to at least two of the four major ligaments in the knee: anterior cruciate ligament, posterior cruciate ligament, lateral collateral ligament (and posterolateral corner) and medial collateral ligament (and posteromedial corner) (Fig. 1).[1] These injuries are commonly classified using the Schenck classification system (Table 1).[2] The incidence of these injuries has been reported to be around 0.02–0.20% of all orthopaedic injuries.[3] However, this is likely to be an underestimation due to spontaneous knee reduction and missed injuries.

The immediate management of these injuries is crucial in identifying and treating any vascular and nerve injury. The literature has shown poor outcome and residual instability in those who were treated non-operatively.[4,5] However, the optimal surgical treatment for these injuries is not known, with differences in opinion amongst treating clinicians. There are controversies in the timing of surgery (early versus delayed), single-staged or two-staged procedures and whether the damaged ligaments should be repaired or reconstructed. This article aims to summarize the key points in the management of these injuries based on the best available evidence.

Initial assessment

Knee dislocation or multiligament knee injuries can present following low or high-energy trauma. High-energy injuries are usually associated with other injuries and low-energy knee dislocations typically occur in obese patients following a simple mechanical fall (Fig. 2).[6]

All suspected knee dislocations and multiligament knee injuries should be assessed thoroughly using the Adult Trauma Life Support (ATLS) principles. Subsequently, a detailed neurovascular examination with clear documentation of capillary refill time, distal pulses, function of all lower limb compartments and common peroneal and tibial nerve function should be carried out. Clinical examination of the vascular status for the limb alone is not sufficient or reliable to identify subtle vascular injury such as intimal tear. Further examination such as using the ankle brachial pressure index (ABPI) or vascular studies are required. This is discussed further in the 'vascular injuries' section.

A grossly dislocated knee must be reduced immediately with clear documentation of neurovascular status pre and post reduction. The knee should then be immobilized with plaster of Paris or extension splint to maintain reduction, preserve neurovascular function and allow swelling to improve.

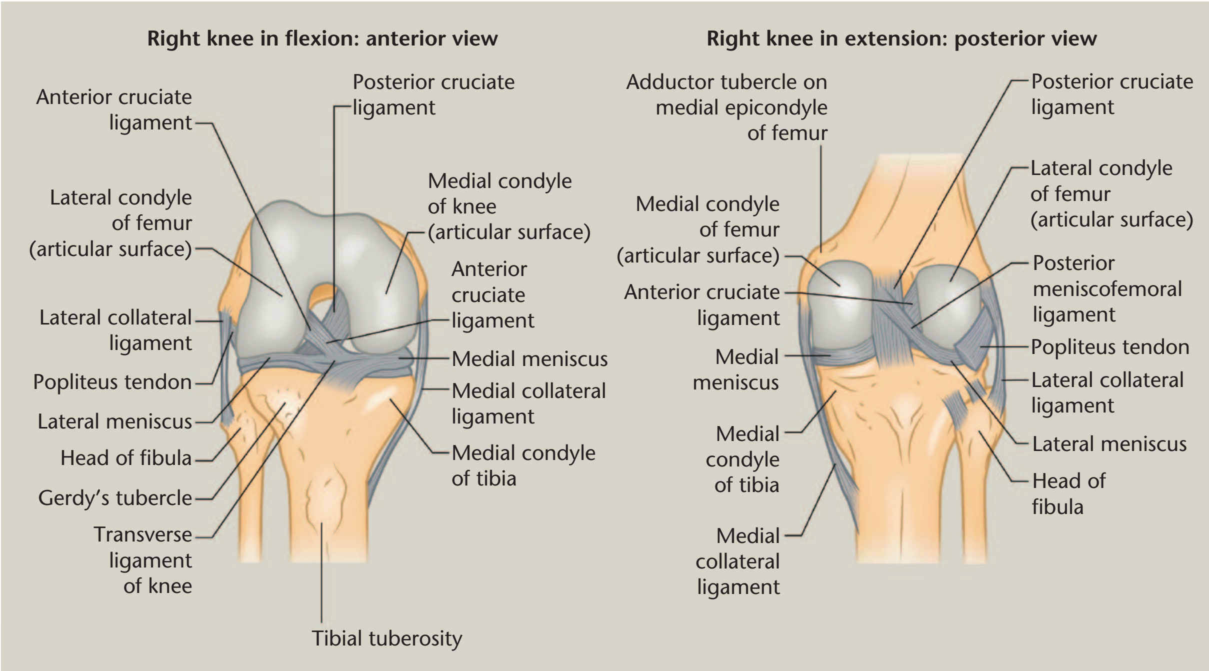

Fig. 1 Anatomy of the knee.

Source. With permission from Ng JWG, Price K, Deepak S. Knee pain in children. *Paediatrics and Child Health* 2019;29:521–527.[1]

Table 1. Schenck classification of knee dislocation[2]

Type 1	Description
KDI	Multiligament knee injury with ACL or PCL rupture
KDII	Multiligament knee injury with ACL and PCL rupture only
KDIIIM	Multiligament knee injury with ACL, PCL and MCL rupture
KDIIIL	Multiligament knee injury with ACL, PCL and LCL + PLC rupture
KDIV	Multiligament injury with rupture of all ligaments (ACL, PCL, MCL, LCL + PLC)
KDV	Knee dislocation with an associated fracture

Note. ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; MCL, medical collateral ligament; LCL, lateral collateral ligament; PLC, posterolateral corner.

Immediate stabilization (external fixator vs. cast immobilization)

There is a paucity of evidence in the literature comparing the use of an external fixator, plaster of Paris or an extension splint to stabilize the knee after reduction. However, the use of an external fixator is required when: (1) reduction is not achievable using a splint or plaster, (2) vascular injury is present and vascular repair is required, (3) it is an open injury and (4) there is an associated fracture (KDV), making the knee very unstable (Table 1). The external fixator applied should be away from the zone of injury and not interfere with any soft tissue or fracture fixation at a later stage. This is typically 10 cm away from the joint

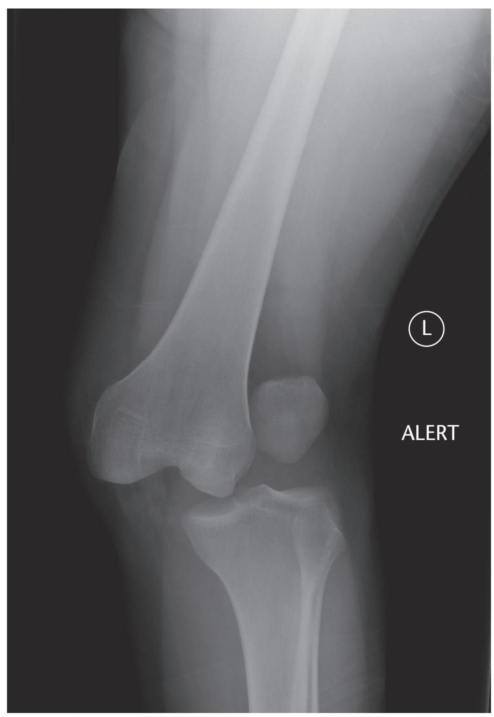

Fig. 2 Radiograph of knee dislocation.

Source. Case courtesy of Andrew Murphy, Radiopaedia.org, rID: 48228. Murphy A. Lateral knee dislocation. Radiology Case. https://radiopaedia.org/cases/lateral-knee-dislocation-1 line for soft tissue but varies depending on fracture pattern in KDV injuries.

Plaster of Paris and extension splints can be applied easily in the emergency department when an external fixator is not required. An extension splint also allows regular assessment of limb compartments and neurovascular status.

Vascular injuries

The incidence of vascular injury in knee dislocations and MLKI is reported to be around 18%.[7] As discussed above, further vascular assessment in addition to physical examination is required to identify any subtle vascular injury which can be catastrophic if missed. A meta-analysis by Barnes et al showed that absent pedal pulse only has a sensitivity of 0.79 and specificity of 0.91.[8] In a case series by McDonough Jr and Wojtys,[9] they reported 12 popliteal artery injuries in 72 knee dislocations. Only four popliteal artery injuries were identified by physical examination pre-operatively, five were identified using arteriography pre-operatively and a further three were not identified by physical examination or arteriography pre-operatively. The ABPI was not used in their study.[9]

Routine arteriography in all knee dislocations is not practicable, carries risks and is costly. Selective arteriography based on ABPI has been shown to be effective in identifying vascular injuries in knee dislocations. Mills et al reported in their study that an ABPI score of < 0.9 has a sensitivity, specificity and positive predictive value of 100% for identifying vascular injuries in knee dislocations.[10] All patients with ABPI < 0.9 must have further imaging studies such as computed tomography (CT) angiography if the limb is well perfused. Our algorithm for managing vascular injuries in knee dislocations is summarized in Fig. 3.

All patients with acutely ischaemic limbs must be taken to the operating theatre for stabilization using an external fixator, on-table angiography and vascular repair. The sequence of events in the operating theatre is summarized in Fig. 4.

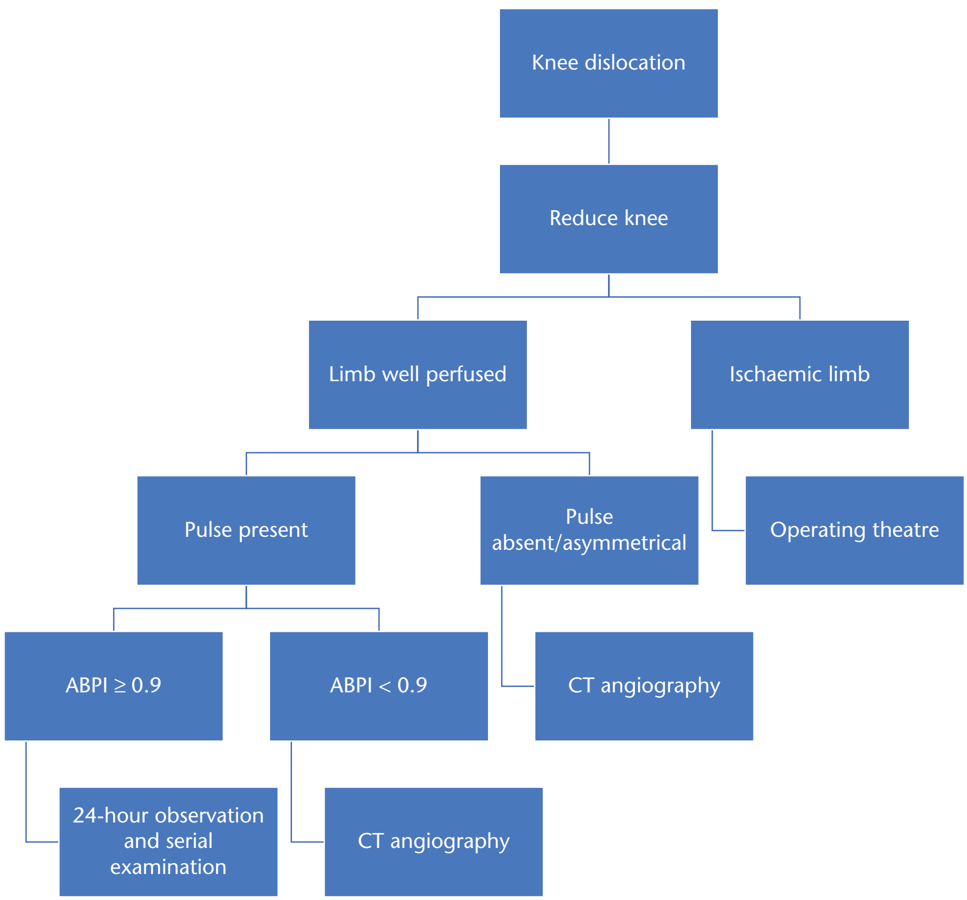

Fig. 3 Management flow chart for vascular injuries.

Note. ABPI, ankle brachial pressure index; CT, computed tomography.

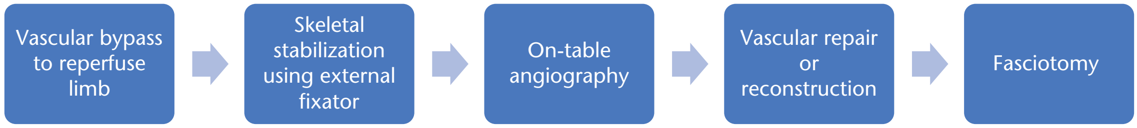

Fig. 4 Sequence of events for management of ischaemic limb following knee dislocation.

Nerve injuries

It is estimated that up to 40% of knee dislocations and MLKI have common peroneal nerve (CPN) palsy.[11–14] The rate of nerve injury is lower in KDI (see Table 1), but higher in lateral-sided injuries. The prognosis of complete CPN palsy is significantly worse than partial CPN palsy. The rate of functional recovery following complete CPN palsy was reported to be 38% and complete recovery following partial CPN palsy was 87%.[13] Treatment options for CPN palsy following knee dislocation include observation, neurolysis, nerve grafting, motor nerve transfer and posterior tibial tendon transfer. Exploration and neurolysis of the CPN is routinely performed as part of the approach during posterolateral corner repair/reconstruction and helps to avoid iatrogenic injury.[13] There is no evidence in the literature to support neurolysis over observation.[13] Kim et al[15] have reported good outcomes in nerve grafting for CPN lesion of < 6 cm with 75% functional recovery. However, their study included all causes of CPN palsy. Another study reported that the majority of CPN lesions following knee dislocations were > 6 cm with 40% of these injuries being 10 cm macroscopic contusions or complete ruptures.[16] None of them had functional recovery. A recent systematic review by Woodmass et al[13] showed that nerve grafting and motor nerve transfer have poor outcomes in CPN palsy following knee dislocations and were therefore not recommended. It was recommended that patients with complete CPN rupture and those who do not show recovery in their common peroneal function at three months, should be offered a posterior tibial tendon transfer to restore functional ankle dorsiflexion.[13] In this systematic review, 16/22 patients[13] had their outcomes reported and all of them regained ankle dorsiflexion against gravity with a posterior tibial tendon transfer.

Meniscal and chondral injuries

Meniscal and chondral injuries are very common in MLKI. Up to 55% of all patients with MLKI have meniscal injury and up to 48% have chondral injury.[17–19] Chondral injury and combined medical and lateral meniscal tears have been shown to be associated with inferior outcomes in MLKI.[20] These injuries must be identified and treated concurrently during surgical reconstruction/repair.

Operative vs. non-operative treatment

Current literature has shown significantly better functional outcomes with operative treatment of MLKI compared with non-operative treatment.[5,21–23] A recent systematic review by Levy et al demonstrated higher mean Lysholm scores, Tegner scores, better International Knee Documentation Committee (IKDC) scores and higher rates of return to work and pre-injury sports activities with no difference in mean knee range of motion.[21]

Non-operative treatment is only reserved for patients who are unfit for surgery, frail or sedentary. They are treated with a short period of immobilization and non-weight-bearing followed by mobilization in a hinged knee brace (Table 2).

Timing of surgery

Although there is general consensus on surgical treatment providing better outcomes, there is ongoing debate and controversy on the timing of surgery. There are three approaches to the timing of surgery for MLKI: acute, staged or delayed.[3,21,24]

Acute reconstruction/repair is defined as surgery performed within three weeks of injury. Although this time

Table 2. Studies comparing operative with non-operative treatment in multiligament knee injuries

Author	Study type	Level of evidence	Year of publication	No. of patients		Lysholm score		IKDC (% excellent/good)	
				Op	Non-op	Op	Non-op	Op	Non-op
Wong et al[23]	Retrospective	IV	2004	15	11	NA	NA	73	54
Rios et al[22]	Retrospective	IV	2003	21	5	77	40	76	0
Ritcher et al[19]	Retrospective	IV	2002	59	18	78	65	24	6
Dedmond et al[5]	Meta-analysis	IV	2001	132	73	85	67	NA	NA

Note. IKDC, International Knee Documentation Committee.

Table 3. Studies comparing timing of surgery for MLKI

Author	Study type	Level of evidence	No. of patients			Subjective outcomes (% excellent/good)			Mean Lysholm score		
			Acute	Staged	Delayed	Acute	Staged	Delayed	Acute	Staged	Delayed
Jiang et al[25]	Systematic review	IV	77	43	33	58.4	79.1	45.5	NR	NR	NR
Mook et al[26]	Systematic review	III	244	106	46	51.5	78.7	37.3	83.1	85.0	85.4
Levy et al[21]	Systematic review	IV	80	NR	50	47.0	NR	31.0	90.0	NR	82.0
Hohmann et al[27]	Meta-analysis	IV	149	NR	111	31.0	NR	15.0	Pooled estimates showed significantly better scores in acute surgery (SMD –0.669, 95% CI: 0.379 to 0.959, p = 0.0001, I2 = 0%)		

Note. NR, not reported; SMD, standardised mean difference.

frame is arbitrary, this is considered to be the critical time frame within which soft tissue planes are still definable without significant scarring. The damaged ligaments can also be repaired as they are identifiable and not significantly retracted. Authors who advocate acute surgery argue that by repairing/reconstructing all the damaged ligaments acutely, normal knee kinematics are more likely to be restored. In addition, the risk of further meniscal or chondral damage is lower. However, acute surgery carries the risk of arthrofibrosis and knee stiffness.[3,21,24] If arthroscopic repair/reconstruction is undertaken acutely, a delay of 1–2 weeks to allow capsular healing is recommended to prevent fluid extravasation.

Staged repair/reconstruction involves acute repair/reconstruction of the extra-articular structures (medial and lateral structures) with a delayed reconstruction of the cruciate ligaments at a later date, once full range of movement is restored.[3,21,24]

Delayed reconstruction is undertaken more than three weeks after injury. Reconstruction is typically performed as scarring and retraction of damaged structures would prevent satisfactory repair. However, delayed reconstruction offers the advantage of better range of movement of the knee and avoiding unnecessary repair/reconstruction of structures which may heal with sufficient stability without surgery.[3,21,24]

Due to the complexity of the injury and patient characteristics, the literature on timing of surgery for multiligament knee injury is unclear and conflicting. Early literature suggested that delayed reconstruction yielded better outcomes. This was due to the post-operative rehabilitation and especially the length of time of immobilization of the knee post-operatively, which tends to cause arthrofibrosis in patients who undergo early surgery. However, more recent literature has favoured staged and acute surgery with improved surgical technique and aggressive rehabilitation.[3,21,24]

Systematic reviews by Jiang et al[25] and Mook et al[26] showed that staged reconstruction resulted in the best overall outcomes in patients with Schenck classification KD III multiligament knee injuries. However, Mook et al demonstrated a higher rate of anterior instability and further treatment for knee stiffness post-operatively in patients who underwent acute surgery. In other systematic reviews conducted by Levy et al[21] and Hohmann et al,[27] patients who underwent early surgery were found to have better clinical outcomes. However, both the studies included patients with Schenck KD II, III and IV injuries.

Our preferred strategy in managing these injuries is to undertake staged reconstruction: we repair/reconstruct extra-articular structures (i.e. medial and lateral structures first) and undertake cruciate reconstruction at a later stage, usually 6–8 weeks following the first procedure (Table 3).

Graft choice

Graft selection can be challenging in multiligament knee reconstruction. Surgeons have the option of using autograft, allograft or synthetic graft. Each of these options has its advantages and disadvantages (Table 4).[28] The decision on graft choice usually depends on the number of ligaments requiring reconstruction/augmentation, graft availability, surgeon preference and the chosen surgical technique for reconstruction (certain techniques require longer grafts).[28]

Autograft options include hamstring (gracilis and semitendinosus) tendon, BPTB (bone-patella tendon-bone) and quadriceps tendon (with or without a distal bone block).[28] These grafts can be harvested from the injured knee or from the contralateral knee. Some surgeons prefer to harvest the graft from the uninjured contralateral knee to reduce further insult to the injured knee. Common allografts used in multiligament knee reconstruction include

Table 4. Graft choices

Graft type	Uses	Advantages	Disadvantages
Hamstring tendon (gracilis and semitendinosus)	ACL, PCL, PLC, PMC, sMCL	Length of graft Can be quadrupled to increase diameter Easy to harvest Low donor site morbidity	Soft tissue fixation Some patients have small hamstring tendons Graft harvesting increases operating duration
BPTB autograft	ACL, PCL	Bone-to-bone fixation on both ends of graft Thick and strong graft	Anterior knee pain Patella fracture (rare) Patella tendon rupture (rare) Cannot be used if quadriceps tendon (QT) graft harvested from same knee Graft harvesting increases operating duration
Quadriceps tendon (QT) autograft	ACL, PCL	Bone-to-bone fixation on one end of graft Thick and strong graft Low donor site morbidity	Patella fracture (rare) Quadriceps rupture (rare) Cannot be used if BPTB graft harvested from same knee Graft harvesting increases operating duration
Achilles tendon allograft	ACL, PCL, PLC	Length and width of graft Bone-to-bone fixation on one end of graft No donor site morbidity Less operating time	Possible disease transmission Expensive May not be readily available
Tibialis anterior allograft	ACL, PCL, PLC	Good length No donor site morbidity Less operating time	Soft tissue fixation Possible disease transmission Expensive May not be readily available
BPTB allograft	ACL, PCL	Same as BPTB autograft No donor site morbidity Less operating time	Possible disease transmission Expensive May not be readily available
LARS	ACL, PCL, PLC, PMC, sMCL	No donor site morbidity Less operating time Readily available, inexpensive	Possible reactive synovitis

Note. ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; PLC, posterolateral corner; PMC, posteromedial corner; sMCL, superficial medial collateral ligament; BPTB, bone-patella tendon-bone; LARS, Ligament Augmentation and Reconstruction System.

Achilles tendon, extensor mechanism apparatus, BPTB or tibialis anterior tendon. Allograft is expensive and may not be readily available.[28,29] Synthetic grafts such as the Ligament Augmentation and Reconstruction System (LARS) can also be used in multiligament knee reconstruction. Several studies have shown good outcomes with the use of LARS ligaments in acute multiligament knee reconstruction (Table 4).[30–32]

Repair vs. reconstruction

In general, injured ligaments around the knee can only be repaired if surgery is performed acutely (i.e. within three weeks of injury). If surgery is undertaken later than three weeks, reconstruction of the ligaments is preferred due to lack of integrity of the soft tissues and poor definition of soft tissue planes.

Medial structures

Medial collateral ligament (MCL)

Isolated MCL injury can often be treated conservatively with a period of immobilization in a hinged knee brace. Surgery is performed if there is ongoing laxity or instability. However, a damaged MCL in the context of MLKI should be repaired/reconstructed if it is found to be unstable during examination under anaesthesia. A systematic review by Kovachevich et al showed satisfactory outcomes for both MCL repair and reconstruction in the context of MLKI.[33] In addition, location of the tear and quality of tissue also determines whether it can be repaired or reconstructed. Mid-substance tears of MCL often cannot be repaired satisfactorily and will require augmentation.

In combined anterior cruciate ligament (ACL) and MCL injury, conservative treatment of the MCL with ACL reconstruction has been shown to provide good outcomes.[34,35] Halinen et al[34] reported, in their randomized controlled trial, that non-operative and operative treatment of MCL injury with early ACL reconstruction yielded similar clinical and functional outcomes. However, the non-operative group had greater medial opening on valgus stress.[34] Biomechanical studies also showed that there is increased force on the ACL graft in the presence of MCL injury and there is greater laxity.[36–39]

Combined early ACL and MCL reconstruction should stabilize both structures simultaneously and reduce the risk of graft loosening and failure, but it has a higher risk of arthrofibrosis and a reduced range of movement. Therefore, our preferred approach is to initially manage the MCL injury in a knee brace with rehabilitation and undertake a delayed ACL reconstruction six weeks following the injury with examination of the knee under anaesthesia. MCL reconstruction is only be performed if there is any residual laxity with valgus stress at 30 degrees of knee flexion. This approach is also supported by other authors.[40]

Posteromedial corner

The posteromedial corner is a structure located between the posterior longitudinal fibres of superficial MCL and PCL on the medial aspect of the knee.[41,42] The important structures in this area contributing to the posteromedial corner include the posterior oblique ligament (POL), expansions of semimembranosus, the oblique popliteal ligament and the posterior horn of the medial meniscus.[42,43]

The posterior oblique ligament (POL) is the most commonly injured structure of the posteromedial corner.[41] It was reported by Sims et al that the POL was injured in 99% of patients with anteromedial rotatory instability.[43] The POL is a primary stabilizer for internal rotation of the tibia during knee flexion. It also prevents posterior tibial translation and valgus stress in full extension.[41] The importance of POL has been demonstrated in biomechanical studies.[44–46]

The POL ligament can be repaired or reconstructed in the setting of MLKI after MCL repair or reconstruction.[41] Several techniques have been described to repair or reconstruct the POL but there is no evidence to show that one technique is superior to the other.[47–51] In the acute setting, the tissue quality of the damaged medial structures is usually robust enough to facilitate a satisfactory repair.[41]

Lateral structures

Posterolateral corner (PLC)

Multiple techniques to repair or reconstruct the PLC of the knee have been described in the literature. However, recent studies have shown a significantly higher failure rate of PLC repair as compared to reconstruction.[52–54] A systematic review by Geeslin et al reported a 38% failure rate in acute PLC repair with delayed cruciate ligament reconstruction and a 9% failure rate in PLC reconstruction with concurrent cruciate ligament reconstruction. There are non-anatomical and anatomical reconstructions of the PLC.[53,55] Non-anatomical reconstructions are either fibular based (e.g. Larson's reconstruction) or tibial based two-tailed reconstructions.[53,55] More recently, with better understanding of the anatomy and biomechanics of the PLC, some authors have advocated that anatomical reconstruction of the PLC restores the normal load sharing and anatomical relationship of the PLC structures, thereby reducing the risk of graft failure.[56–60]

Although different techniques have been described to reconstruct the PLC, there is a paucity of high-level evidence to recommend the best reconstructive method.[53,61] Avulsion of the lateral collateral ligament (LCL) from femoral and fibular attachment can be repaired acutely but mid-substance tears have to be reconstructed (Figs 5, 6 & 7).[56]

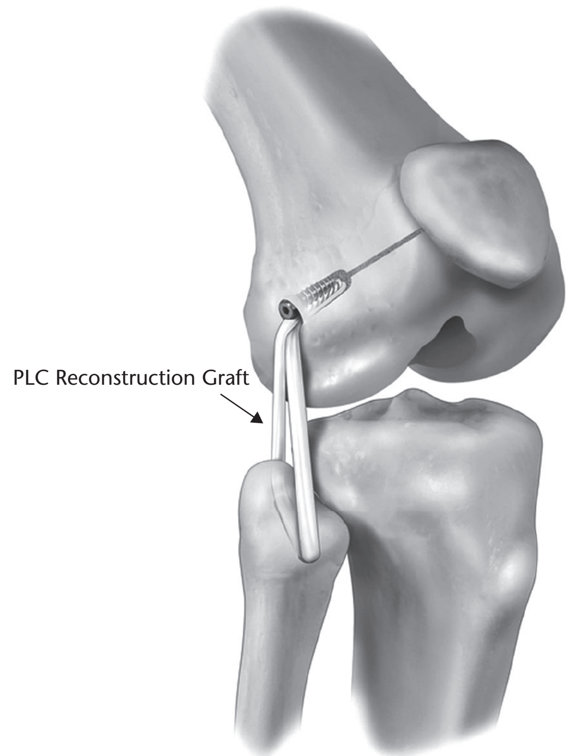

Fig. 5 Fibular sling reconstruction with one femoral tunnel (Larson).

Source. With permission from Geeslin AG, Moulton SG, LaPrade RF. A systematic review of the outcomes of posterolateral corner knee injuries, part 1: Surgical treatment of acute injuries. *Am J Sports Med* 2016;44:1336–1342.[53]

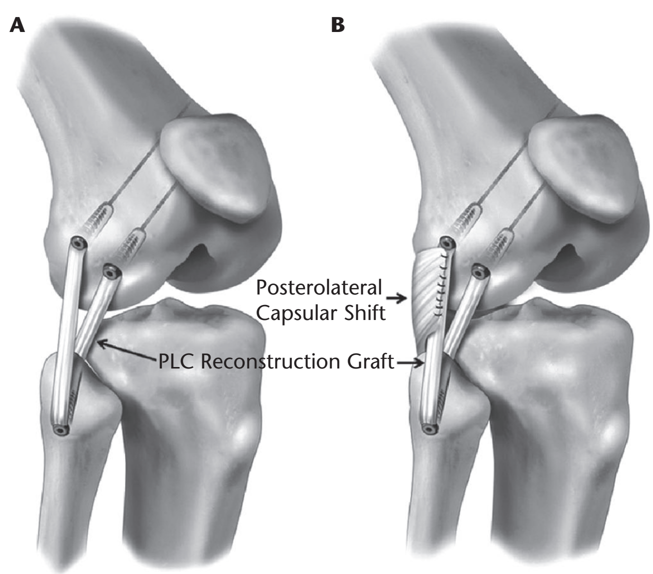

Fig. 6 Fibular sling reconstruction with two femoral tunnels (non-anatomic).

Source. With permission from Geeslin AG, Moulton SG, LaPrade RF. A systematic review of the outcomes of posterolateral corner knee injuries, part 1: Surgical treatment of acute injuries. *Am J Sports Med* 2016;44:1336–1342.[53]

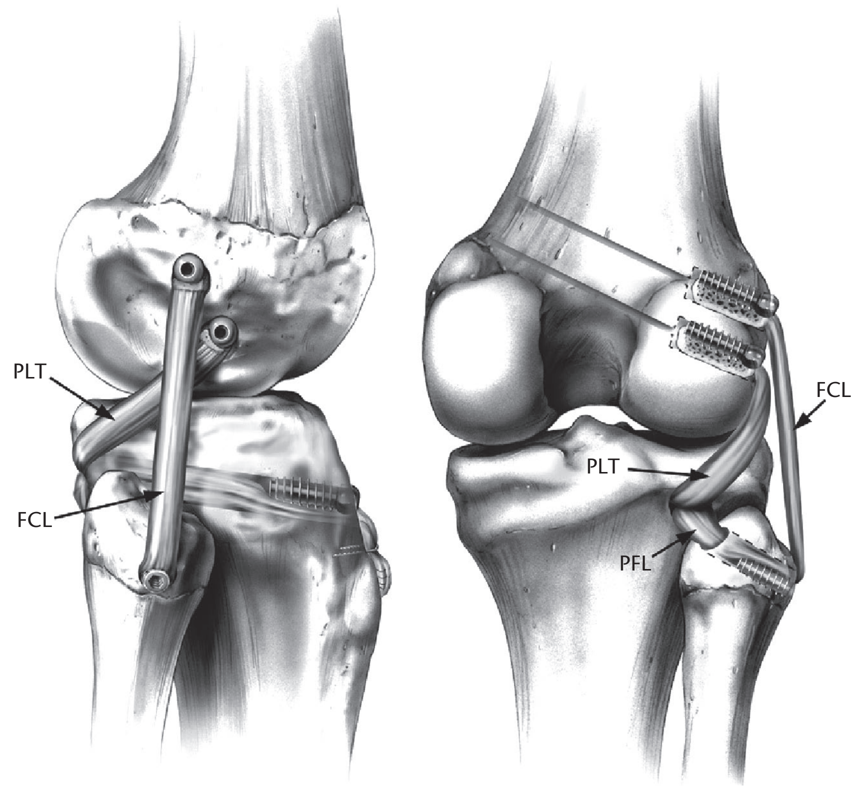

Fig. 7 Anatomic posterolateral corner reconstruction as described by LaPrade.

Source. With permission from Geeslin AG, Moulton SG, LaPrade RF. A systematic review of the outcomes of posterolateral corner knee injuries, part 1: Surgical treatment of acute injuries. *Am J Sports Med* 2016;44:1336–1342.[53]

Anterior cruciate ligament (ACL)

It is not within the scope of this review to discuss all the controversies in ACL reconstructions. Our preferred strategy to manage ACL rupture in the setting of MLKI is to perform a staged reconstruction using an anatomical single bundle reconstruction. We would use semitendinosus and gracilis autografts from the ipsilateral or contralateral knee. However, if ACL reconstruction is performed acutely in the setting of MLKI, or if autograft options are not available, the use of allograft will be required. Some authors advocate double bundle ACL reconstruction, but studies have shown similar outcomes with single bundle reconstruction.[62,63] Recently, some studies have reported good results in repairing the ACL if the tissue quality allows. However, these are case series with small numbers.[64–67] A recent multicentre prospective study reported satisfactory results with primary repair of MLKI with suture augmentation. However, the follow-up period is short with a revision rate for instability of 14.5% and a post-operative manipulation rate of 23.2%.[68]

Posterior cruciate ligament

Several methods have been described to reconstruct the PCL. These include transtibial or tibial inlay single bundle reconstructions and transtibial or tibial inlay double bundle reconstructions.[69,70] In recent studies, double bundle reconstructive techniques have been shown to more closely restore knee kinematics and to have less residual posterior translation as compared with single bundle reconstruction.[71,72] However, there was no difference in clinical outcomes.[71,72] Primary repair of PCL has also been shown to give good outcomes.[64,67] Bony avulsions should be repaired if possible.

Levy et al concluded in their systematic review that PCL reconstructions may yield better clinical outcomes than surgical repair in MLKI.[21] However, the level of evidence is low and further studies are required.

Rehabilitation

It is difficult to draw definite conclusions from the literature regarding the best rehabilitation protocol due to the paucity of high-level evidence and the differences in rehabilitation protocols.[73] Mook et al showed in the their systematic review that early mobilization following surgery for acute surgery MLKI resulted in better range of motion and stability.[26] Most authors would also recommend an initial period of non-weight-bearing for 4–6 weeks followed by active mobilization and progressive weight-bearing and avoiding passive stretching.[73]

Conclusions

In conclusion, multiligament knee injuries are devastating injuries which require careful clinical assessment. The best management strategy for these injuries remains unclear due to the paucity of high-level evidence. Prospective, randomized studies involving multiple centres are likely required to produce more definite conclusions.

AUTHOR INFORMATION

Chesterfield Royal Hospital NHS Foundation Trust, Calow, Chesterfield, UK.

Correspondence should be sent to: Jimmy Wui Guan Ng, Chesterfield Royal Hospital NHS Foundation Trust, Calow, Chesterfield, Derbyshire, S44 5BL, UK.
Email: jimmyng@nhs.net

ICMJE CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest relevant to this work.

FUNDING STATEMENT

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES

1. **Ng JWG, Price K, Deepak S.** Knee pain in children. *Paediatr Child Health* 2019;29:521–527.

2. **Schenck RC.** Classification of knee dislocations. In: Fanelli GC, ed. *The multiple ligament injured knee: a practical guide to management*. New York, NY: Springer, 2004:37–49.

3. **Howells NR, Brunton LR, Robinson J, Porteus AJ, Eldridge JD, Murray JR.** Acute knee dislocation: an evidence based approach to the management of the multiligament injured knee. *Injury* 2011;42:1198–1204.

4. **Peskun CJ, Whelan DB.** Outcomes of operative and nonoperative treatment of multiligament knee injuries: an evidence-based review. *Sports Med Arthrosc Rev* 2011;19:167–173.

5. **Dedmond BT, Almekinders LC.** Operative versus nonoperative treatment of knee dislocations: a meta-analysis. *Am J Knee Surg* 2001;14:33–38.

6. **Murphy A.** Lateral knee dislocation. *Radiopaedia*. https://radiopaedia.org/cases/lateral-knee-dislocation-1 (date last accessed 6 February 2020).

7. **Medina O, Arom GA, Yeranosian MG, Petrigliano FA, McAllister DR.** Vascular and nerve injury after knee dislocation: a systematic review. *Clin Orthop Relat Res* 2014;472:2621–2629.

8. **Barnes CJ, Pietrobon R, Higgins LD.** Does the pulse examination in patients with traumatic knee dislocation predict a surgical arterial injury? A meta-analysis. *J Trauma* 2002;53:1109–1114.

9. **McDonough EB Jr, Wojtys EM.** Multiligamentous injuries of the knee and associated vascular injuries. *Am J Sports Med* 2009;37:156–159.

10. **Mills WJ, Barei DP, McNair P.** The value of the ankle-brachial index for diagnosing arterial injury after knee dislocation: a prospective study. *J Trauma* 2004;56:1261–1265.

11. **Samson D, Ng CY, Power D.** An evidence-based algorithm for the management of common peroneal nerve injury associated with traumatic knee dislocation. *EFORT Open Rev* 2017;1:362–367.

12. **Robertson A, Nutton RW, Keating JF.** Dislocation of the knee. *J Bone Joint Surg Br* 2006;88:706–711.

13. **Woodmass JM, Romatowski NPJ, Esposito JG, Mohtadi NGH, Longino PD.** A systematic review of peroneal nerve palsy and recovery following traumatic knee dislocation. *Knee Surg Sports Traumatol Arthrosc* 2015;23:2992–3002.

14. **Bonnevialle P, Dubrana F, Galau B, et al; la Société française de chirurgie orthopédique et traumatologique.** Common peroneal nerve palsy complicating knee dislocation and bicruciate ligaments tears. *Orthop Traumatol Surg Res* 2010;96:64–69.

15. **Kim DH, Murovic JA, Tiel RL, Kline DG.** Management and outcomes in 318 operative common peroneal nerve lesions at the Louisiana State University Health Sciences Center. *Neurosurgery* 2004;54:1421–1428.

16. **Niall DM, Nutton RW, Keating JF.** Palsy of the common peroneal nerve after traumatic dislocation of the knee. *J Bone Joint Surg Br* 2005;87:664–667.

17. **Krych AJ, Sousa PL, King AH, Engasser WM, Stuart MJ, Levy BA.** Meniscal tears and articular cartilage damage in the dislocated knee. *Knee Surg Sports Traumatol Arthrosc* 2015;23:3019–3025.

18. **Moatshe G, Dornan GJ, Løken S, Ludvigsen TC, LaPrade RF, Engebretsen L.** Demographics and injuries associated with knee dislocation: a prospective review of 303 patients. *Orthop J Sports Med* 2017;5:2325967117706521.

19. **Richter M, Bosch U, Wippermann B, Hofmann A, Krettek C.** Comparison of surgical repair or reconstruction of the cruciate ligaments versus nonsurgical treatment in patients with traumatic knee dislocations. *Am J Sports Med* 2002;30:718–727.

20. **King AH, Krych AJ, Prince MR, Sousa PL, Stuart MJ, Levy BA.** Are meniscal tears and articular cartilage injury predictive of inferior patient outcome after surgical reconstruction for the dislocated knee? *Knee Surg Sports Traumatol Arthrosc* 2015;23:3008–3011.

21. **Levy BA, Dajani KA, Whelan DB, et al.** Decision making in the multiligament-injured knee: an evidence-based systematic review. *Arthroscopy* 2009;25:430–438.

22. **Ríos A, Villa A, Fahandezh H, de José C, Vaquero J.** Results after treatment of traumatic knee dislocations: a report of 26 cases. *J Trauma* 2003;55:489–494.

23. **Wong C-H, Tan J-L, Chang H-C, Khin L-W, Low C-O.** Knee dislocations: a retrospective study comparing operative versus closed immobilization treatment outcomes. *Knee Surg Sports Traumatol Arthrosc* 2004;12:540–544.

24. **Burrus MT, Werner BC, Griffin JW, Gwathmey FW, Miller MD.** Diagnostic and management strategies for multiligament knee injuries: a critical analysis review. *JBJS Rev* 2016;4:01874474-201602000-00001. https://journals.lww.com/jbjsreviews/subjects/Knee/Fulltext/2016/02000/Diagnostic_and_Management_Strategies_for.1.aspx (date last accessed 21 June 2018).

25. Jiang W, Yao J, He Y, Sun W, Huang Y, Kong D. The timing of surgical treatment of knee dislocations: a systematic review. *Knee Surg Sports Traumatol Arthrosc* 2015;23:3108–3113.

26. Mook WR, Miller MD, Diduch DR, Hertel J, Boachie-Adjei Y, Hart JM. Multiple-ligament knee injuries: a systematic review of the timing of operative intervention and postoperative rehabilitation. *J Bone Joint Surg Am* 2009;91:2946–2957.

27. Hohmann E, Glatt V, Tetsworth K. Early or delayed reconstruction in multi-ligament knee injuries: a systematic review and meta-analysis. *Knee* 2017;24:909–916.

28. Weiss NG, Kaplan LD, Graf BK. Graft selection in surgical reconstruction of the multiple-ligament-injured knee. *Oper Tech Sports Med* 2003;11:218–225.

29. Billières J, Labruyère C, Steltzlen C, et al. Multiligament knee injuries treated by one-stage reconstruction using allograft: postoperative laxity assessment using stress radiography and clinical outcomes. *Orthop Traumatol Surg Res* 2019. doi:10.1016/j.otsr.2019.08.001 [Epub ahead of print].

30. Batty LM, Norsworthy CJ, Lash NJ, Wasiak J, Richmond AK, Feller JA. Synthetic devices for reconstructive surgery of the cruciate ligaments: a systematic review. *Arthroscopy* 2015;31:957–968.

31. Ranger P, Renaud A, Phan P, Dahan P, De Oliveira E Jr, Delisle J. Evaluation of reconstructive surgery using artificial ligaments in 71 acute knee dislocations. *Int Orthop* 2011;35:1477–1482.

32. Ranger P, Senay A, Gratton GR, Lacelle M, Delisle J. LARS synthetic ligaments for the acute management of 111 acute knee dislocations: effective surgical treatment for most ligaments. *Knee Surg Sports Traumatol Arthrosc* 2018;26:3673–3681.

33. Kovachevich R, Shah JP, Arens AM, Stuart MJ, Dahm DL, Levy BA. Operative management of the medial collateral ligament in the multi-ligament injured knee: an evidence-based systematic review. *Knee Surg Sports Traumatol Arthrosc* 2009;17:823–829.

34. Halinen J, Lindahl J, Hirvensalo E, Santavirta S. Operative and nonoperative treatments of medial collateral ligament rupture with early anterior cruciate ligament reconstruction: a prospective randomized study. *Am J Sports Med* 2006;34:1134–1140.

35. Shelbourne KD, Porter DA. Anterior cruciate ligament-medial collateral ligament injury: nonoperative management of medial collateral ligament tears with anterior cruciate ligament reconstruction. A preliminary report. *Am J Sports Med* 1992;20:283–286.

36. Battaglia MJ II, Lenhoff MW, Ehteshami JR, et al. Medial collateral ligament injuries and subsequent load on the anterior cruciate ligament: a biomechanical evaluation in a cadaveric model. *Am J Sports Med* 2009;37:305–311.

37. Ichiba A, Nakajima M, Fujita A, Abe M. The effect of medial collateral ligament insufficiency on the reconstructed anterior cruciate ligament: a study in the rabbit. *Acta Orthop Scand* 2003;74:196–200.

38. Matsumoto H, Suda Y, Otani T, Niki Y, Seedhom BB, Fujikawa K. Roles of the anterior cruciate ligament and the medial collateral ligament in preventing valgus instability. *J Orthop Sci* 2001;6:28–32.

39. Zaffagnini S, Bignozzi S, Martelli S, Lopomo N, Marcacci M. Does ACL reconstruction restore knee stability in combined lesions? An in vivo study. *Clin Orthop Relat Res* 2007;454:95–99.

40. Marchant MH Jr, Tibor LM, Sekiya JK, Hardaker WT Jr, Garrett WE Jr, Taylor DC. Management of medial-sided knee injuries, part 1: medial collateral ligament. *Am J Sports Med* 2011;39:1102–1113.

41. Tibor LM, Marchant MH Jr, Taylor DC, Hardaker WT Jr, Garrett WE Jr, Sekiya JK. Management of medial-sided knee injuries, part 2: posteromedial corner. *Am J Sports Med* 2011;39:1332–1340.

42. Robinson JR, Sanchez-Ballester J, Bull AMJ, Thomas R de WM, Amis AA. The posteromedial corner revisited: an anatomical description of the passive restraining structures of the medial aspect of the human knee. *J Bone Joint Surg Br* 2004;86:674–681.

43. Sims WF, Jacobson KE. The posteromedial corner of the knee: medial-sided injury patterns revisited. *Am J Sports Med* 2004;32:337–345.

44. Petersen W, Loerch S, Schanz S, Raschke M, Zantop T. The role of the posterior oblique ligament in controlling posterior tibial translation in the posterior cruciate ligament-deficient knee. *Am J Sports Med* 2008;36:495–501.

45. Ritchie JR, Bergfeld JA, Kambic H, Manning T. Isolated sectioning of the medial and posteromedial capsular ligaments in the posterior cruciate ligament-deficient knee: influence on posterior tibial translation. *Am J Sports Med* 1998;26:389–394.

46. Robinson JR, Bull AMJ, Thomas RR, Amis AA. The role of the medial collateral ligament and posteromedial capsule in controlling knee laxity. *Am J Sports Med* 2006;34:1815–1823.

47. Fanelli GC, Harris JD. Surgical treatment of acute medial collateral ligament and posteromedial corner injuries of the knee. *Sports Med Arthrosc Rev* 2006;14:78–83.

48. Jacobson KE, Chi FS. Evaluation and treatment of medial collateral ligament and medial-sided injuries of the knee. *Sports Med Arthrosc Rev* 2006;14:58–66.

49. Kim S-J, Lee D-H, Kim T-E, Choi N-H. Concomitant reconstruction of the medial collateral and posterior oblique ligaments for medial instability of the knee. *J Bone Joint Surg Br* 2008;90:1323–1327.

50. Coobs BR, Wijdicks CA, Armitage BM, et al. An in vitro analysis of an anatomical medial knee reconstruction. *Am J Sports Med* 2010;38:339–347.

51. Lind M, Jakobsen BW, Lund B, Hansen MS, Abdallah O, Christiansen SE. Anatomical reconstruction of the medial collateral ligament and posteromedial corner of the knee in patients with chronic medial collateral ligament instability. *Am J Sports Med* 2009;37:1116–1122.

52. Levy BA, Dajani KA, Morgan JA, Shah JP, Dahm DL, Stuart MJ. Repair versus reconstruction of the fibular collateral ligament and posterolateral corner in the multiligament-injured knee. *Am J Sports Med* 2010;38:804–809.

53. Geeslin AG, Moulton SG, LaPrade RF. A systematic review of the outcomes of posterolateral corner knee injuries, part 1: surgical treatment of acute injuries. *Am J Sports Med* 2016;44:1336–1342.

54. Stannard JP, Brown SL, Farris RC, McGwin G Jr, Volgas DA. The posterolateral corner of the knee: repair versus reconstruction. *Am J Sports Med* 2005;33:881–888.

55. Franciozi CE, Kubota MS, Abdalla RJ, Cohen M, Luzo MVM, LaPrade RF. Posterolateral corner repair and reconstruction: overview of current techniques. *Ann Joint* 2018;3. http://aoj.amegroups.com/article/view/4756. (date last accessed 13 February 2019).

56. Laprade RF, Griffith CJ, Coobs BR, Geeslin AG, Johansen S, Engebretsen L. Improving outcomes for posterolateral knee injuries. *J Orthop Res* 2014;32:485–491.

57. LaPrade RF, Johansen S, Agel J, Risberg MA, Moksnes H, Engebretsen L. Outcomes of an anatomic posterolateral knee reconstruction. *J Bone Joint Surg Am* 2010;92:16–22.

58. LaPrade RF, Johansen S, Wentorf FA, Engebretsen L, Esterberg JL, Tso A. An analysis of an anatomical posterolateral knee reconstruction: an in vitro biomechanical study and development of a surgical technique. *Am J Sports Med* 2004;32:1405–1414.

59. Franciozi CE, Albertoni LJB, Gracitelli GC, et al. Anatomic posterolateral corner reconstruction with autografts. *Arthrosc Tech* 2018;7:e89–e95.

60. Arciero RA. Anatomic posterolateral corner knee reconstruction. *Arthroscopy* 2005;21:1147.

61. **Moulton SG, Geeslin AG, LaPrade RF.** A systematic review of the outcomes of posterolateral corner knee injuries, part 2: surgical treatment of chronic injuries. *Am J Sports Med* 2016;44:1616–1623.

62. **Aga C, Risberg MA, Fagerland MW, et al.** No difference in the KOOS quality of life subscore between anatomic double-bundle and anatomic single-bundle anterior cruciate ligament reconstruction of the knee: a prospective randomized controlled trial with 2 years' follow-up. *Am J Sports Med* 2018;46:2341–2354.

63. **Kongtharvonskul J, Attia J, Thamakaison S, Kijkunasathian C, Woratanarat P, Thakkinstian A.** Clinical outcomes of double- vs single-bundle anterior cruciate ligament reconstruction: a systematic review of randomized control trials. *Scand J Med Sci Sports* 2013;23:1–14.

64. **Owens BD, Neault M, Benson E, Busconi BD.** Primary repair of knee dislocations: results in 25 patients (28 knees) at a mean follow-up of four years. *J Orthop Trauma* 2007;21:92–96.

65. **Hua X, Tao H, Fang W, Tang J.** Single-stage in situ suture repair of multiple-ligament knee injury: a retrospective study of 17 patients (18 knees). *BMC Musculoskelet Disord* 2016;17:41.

66. **Jonkergouw A, van der List JP, DiFelice GS.** Multiligament repair with suture augmentation in a knee dislocation with medial-sided injury. *Arthrosc Tech* 2018; 7:e839–e843.

67. **Frosch K-H, Preiss A, Heider S, et al.** Primary ligament sutures as a treatment option of knee dislocations: a meta-analysis. *Knee Surg Sports Traumatol Arthrosc* 2013;21:1502–1509.

68. **Heitmann M, Akoto R, Krause M, et al.** Management of acute knee dislocations: anatomic repair and ligament bracing as a new treatment option-results of a multicentre study. *Knee Surg Sports Traumatol Arthrosc* 2019;27:2710–2718.

69. **Wijdicks CA, Kennedy NI, Goldsmith MT, et al.** Kinematic analysis of the posterior cruciate ligament, part 2: a comparison of anatomic single- versus double-bundle reconstruction. *Am J Sports Med* 2013;41:2839–2848.

70. **LaPrade CM, Civitarese DM, Rasmussen MT, LaPrade RF.** Emerging updates on the posterior cruciate ligament: a review of the current literature. *Am J Sports Med* 2015;43:3077–3092.

71. **Li Y, Li J, Wang J, Gao S, Zhang Y.** Comparison of single-bundle and double-bundle isolated posterior cruciate ligament reconstruction with allograft: a prospective, randomized study. *Arthroscopy* 2014;30:695–700.

72. **Yoon KH, Bae DK, Song SJ, Cho HJ, Lee JH.** A prospective randomized study comparing arthroscopic single-bundle and double-bundle posterior cruciate ligament reconstructions preserving remnant fibers. *Am J Sports Med* 2011;39:474–480.

73. **Lynch AD, Chmielewski T, Bailey L, et al; STaR Trial Investigators.** Current concepts and controversies in rehabilitation after surgery for multiple ligament knee injury. *Curr Rev Musculoskelet Med* 2017;10:328–345.