Surgical reconstruction of the posterior cruciate ligament: current perspectives

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Abstract

After over a century of orthopaedic attention, injuries to the posterior cruciate ligament (PCL) continue to pose a significant management challenge. Isolated PCL tears constitute the minority of cases, with multiligament trauma (most commonly posterolateral corner injuries) predominating. Surgical reconstruction of the PCL remains technically demanding. Historical long-term outcomes have been associated with persisting knee instability and secondary degenerative arthrosis, irrespective of surgical intervention. The past two decades have witnessed a renewed focus on understanding the anatomy and biomechanics of the PCL, and its spectrum of injury. This, along with advancements in surgical technology and techniques, has heralded a renewed impetus for operative reconstruction. While there remains no clinically demonstrated difference in outcomes of double-bundle surgery over single-bundle reconstruction, many prefer a double bundle approach due to empirical data supporting its biomechanical superiority. Concomitant bony realignment in the coronal and sagittal plane should be considered where necessary. Graft reinforcement is an emerging concept that may aid in protecting the neoligament during the early healing phase. With modern approaches, there are increasing reports of more favourable short and mid-term postoperative outcomes. Despite this, most studies remain of a low level of evidence, with relatively small case series, and there is a paucity of well-designed controlled studies contrasting operative techniques.

Keywords operative; PCL; posterior cruciate ligament; reconstruction; surgery

Introduction

Surgical reconstruction of the posterior cruciate ligament (PCL) has been described since the early 20th century.[1] However, in over a century of orthopaedic attention, injuries to the PCL continue to pose a management challenge. Historical long-term outcomes have been associated with persisting knee instability and secondary degenerative arthrosis, irrespective of surgical intervention.[2] The past two decades have witnessed a renewed focus on understanding the anatomy and biomechanics of the PCL and its injury spectrum. This, along with advancements in surgical technology and techniques, has heralded a renewed impetus for operative reconstruction, and authors are increasingly reporting more favourable short and mid-term outcomes. Despite this, most studies remain of a low level of evidence, with relatively small case series, and there is a paucity of well-designed controlled studies comparing operative *versus* non-operative management or contrasting operative techniques.

PCL injuries are relatively uncommon, with an approximate incidence of only 3% of outpatient knee trauma. However, up to 40% of patients presenting with an acute haemarthrosis may have a PCL tear.[3] Isolated PCL tears constitute the minority of cases, with multiligament trauma (most commonly associated posterolateral corner injuries) predominating. Surgical reconstruction of the PCL remains technically demanding, and managing patients with PCL injury requires the surgeon to be proficient with the management of all aspects of the ligamentously-injured knee, in both the acute and chronic setting. This also produces significant heterogeneity in patient groups, and hence reported outcome studies, as concomitant injuries may influence management approaches.

This article will briefly review the anatomy, biomechanics and diagnosis of PCL injuries, while focusing on surgical reconstruction strategies and outcomes. More recent developments in arthroscopic surgery using all-inside approaches and graft reinforcement will also be explored.

Anatomy

The PCL is a stout intra-articular but extra-synovial ligament, averaging 38 mm in length and 13 mm in width.[4] It receives a blood supply from the middle geniculate artery. The ligament is functionally divided into two bundles; the major anterolateral (AL) bundle, and the more minor posteromedial (PM) bundle. These bundles can each be further subdivided into two fascicles, but this is not of significant surgical relevance. The AL and PM bundles are relatively easy to define on the lateral face of the medial femoral condyle, where they spread out in a fan-like structure, occupying an elliptical footprint, whereas they are more compactly orientated at their tibial attachment. Single-bundle reconstructions focus on the larger AL footprint and, on the femur, the most distal fibres of this lie in a juxta-articular location, that is, shallow and high in the notch when viewed arthroscopically with the knee at 90° of flexion. The centre of the PM bundle sits an average of 12 mm proximal and posterior to the centre of the AL femoral footprint.[5]

The tibial footprint is typically said to lie 10–15 mm below the posterior aspect of the tibia in a depression between the medial and lateral tibial plateaus. However, the arthroscopic appreciation of the AL and PM bundles has been further defined more recently, and referencing against the lateral plateau, the shiny white fibres of the medial meniscus and an osseous 'bundle ridge' allows better appreciation of this attachment.[5] The bundle centres are on average less than 9 mm apart on the tibia, making true double-bundle reconstruction more challenging due to potential tunnel confluence.

Closely related to the PCL are the two meniscofemoral ligaments, which create a hammock around the femoral attachment. The ligament of Humphrey lies anterior and the ligament of Wrisberg lies posterior (see Figure 1). Their presence is variable, but at least one meniscofemoral ligament is present in over 90%

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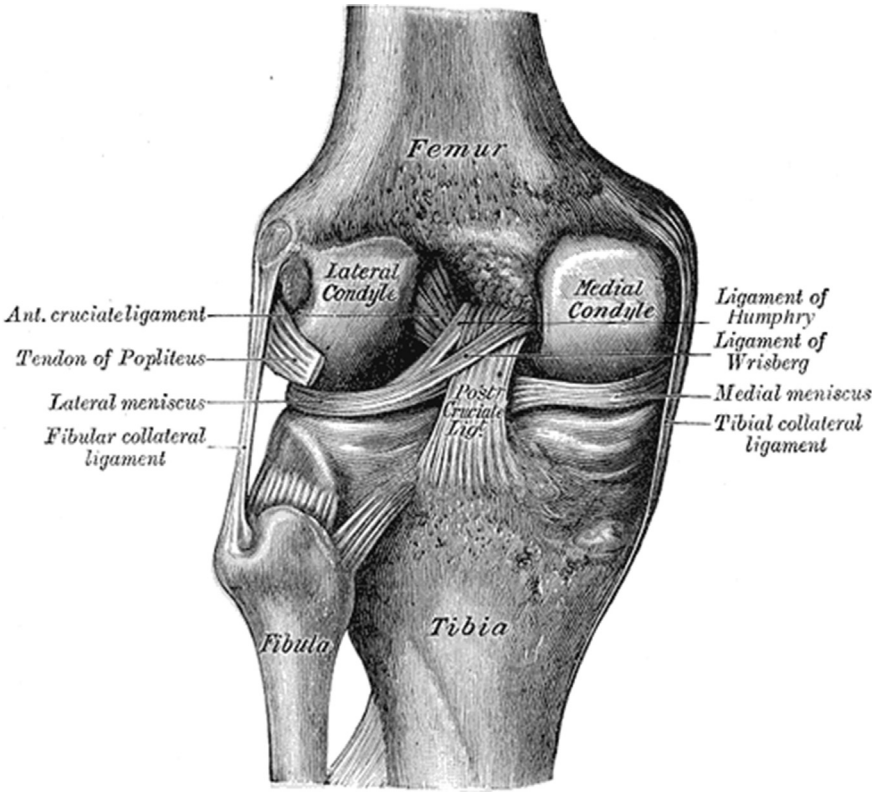

Figure 1 The posterior aspect of a left knee joint, identifying the principle deep ligamentous structures. The posterior cruciate ligament is surrounded by the ligament of Humphrey (anterior) and the ligament of Wrisberg (posterior). Image in public domain; source: https://en.m.wikipedia.org/wiki/Posterior_cruciate_ligament_injury#/media/File%3AGray348-2.png.

of individuals.[6] Both of these ligaments slant diagonally across the intra-articular aspect of the femoral notch to attach to the posterior horn of the lateral meniscus, stabilizing this and aiding the PCL in resisting posterior translation.

Biomechanics

In all angles of knee flexion, the PCL is the dominant restraint to posterior tibial translation, with its most significant contribution being at 90° of flexion. PCL injury is therefore best assessed with the knee at this angle. Generally, the PM bundle is thought to have a greater contribution in knee extension, and the AL bundle a more significant role in higher degrees of knee flexion, but this relationship has been questioned.[7] There is also a developing understanding that the PM bundle may have a more significant contribution to controlling rotational laxity in the flexed knee, specifically resisting internal rotation.[8] Cadaveric testing suggests that the tensile strength to failure of the PCL is in the order of 2000N, with most of this load (approximately 85%) being carried through the AL bundle. However, cadaveric specimens are typically from older individuals, and the true strength of the ligament in young adults is likely to be in excess of 4000N.[9]

The consequences of a PCL-deficient knee are an increase in the medial and patellofemoral contact pressures.[10] This correlates with the frequent clinical finding of early degenerative arthrosis affecting these compartments in patients presenting with chronic PCL deficiency. Such patients, who are ultimately managed with total knee arthroplasty, should have an implant with a PCL-substituting design. Early degenerative changes, with pain, are a relative indication for PCL reconstruction, although long-term data have not shown that surgical reconstructions reduces the risk of osteoarthritis.[11] Similar to the literature surrounding anterior cruciate reconstructed knees, this may understandably represent a lag effect, in that long-term data delineate historical attempts at reconstruction, which may not approximate native knee kinematics as well as some of the more recent surgical techniques.

Diagnosis and grading

The classic cause of an isolated PCL injury is a dashboard impact, where a posteriorly directed force is applied to the anterior aspect of the tibia with the femur relatively fixed. A similar mechanism is encountered with a fall onto a flexed knee in sporting situations. In addition, the PCL may be injured in hyperextension or with significant varus or valgus loading after failure of the primary varus/valgus restraints of the posterolateral corner or the medial collateral ligament (MCL). Significant axial rotation of the tibia against the femur may also lead to PCL injury.[12] Most high energy injuries are sustained through road traffic collisions, and these are often associated with multiligament injury and/or additional neurovascular compromise. Assessment of patients presenting with an acute injury therefore mandates careful neurological and vascular examination.

Although isolated PCL tears are often missed, a detailed history and physical examination has been showed to have high diagnostic accuracy with 90% sensitivity and 99% specificity.[13]

However, in the acute setting, a large haemarthrosis and pain inhibition may prevent one from undertaking many of the classic PCL examination manoeuvres and may mask any potential positive findings. Magnetic resonance imaging (MRI) is therefore recommended in all patients presenting with an acute haemarthrosis in the absence of a fracture on plain radiographs.

The hallmark of PCL injury is posterior translation of the tibia relative to the femur, which is most easily assessed at 90° of knee flexion. A static posterior sag may be identified, and this can be evaluated dynamically with a posterior drawer manoeuvre, which serves to further sublux the tibia posteriorly. The surgeon should palpate and reference the position of the anteromedial tibial plateau relative to the distal articular aspect of the medial femoral condyle during this test. The tibia should normally lie distal to the condyle, and this relationship remains unchanged if the PCL is intact. A Lachman test, assessing anteroposterior movement in the semi-flexed knee, will also be positive if the PCL is injured. It should be noted that objective KT-1000 arthrometer assessments are typically undertaken with the knee in a semi-flexed position. Therefore, tibial translation measured in this position may not be directly comparable to grading the knee at 90° of flexion, or indeed stress radiographs, which are taken at higher degrees of flexion. A Telos machine or Rollimeter may alternatively be used to quantify posterior translation, but these tend to be isolated to the research setting.

With the knee remaining at 90°, the quadriceps active test can be undertaken, where the patient attempts to extend the knee while the foot is stabilized against the examination couch (typically by the surgeon gently sitting on the foot).[14] Activation of the quadriceps applies an anterior force vector on the tibia, which may dynamically reduce tibial subluxation. This test is highly specific for PCL injury but lacks the sensitivity of the posterior sag sign.[15] An increased range of internal rotation with the knee flexed may also signify a PCL tear.

Posterior translation increases further when secondary restraints, such as the posterolateral corner or posteromedial corner of the knee are injured. This forms the basis for several grading systems for PCL injury. Secondary ligamentous injuries may complicate physical examination findings, however, as rotational laxity may be influenced more by failure of these secondary restraints rather than the PCL. The posterolateral corner is a primary restraint to external rotation and is frequently concomitantly injured, leading to an examination pattern of increased posterior drawer and increased external rotation, as identified through a dial test at 30° and 90° of knee flexion.

While there remains no absolute consensus on grading PCL injuries, with multiple differing definitions proposed in the literature, most systems converge on a three-point scale; with Grade 1 and 2 injuries representing partial thickness tears and Grade 3 injuries representing full thickness disruption. Grading systems may include a fourth level, to signify concomitant ligamentous injury. A Grade 1 (partial) thickness 'sprain' will typically involve up to 5 mm of posterior translation, such that the anteromedial tibial plateau remains distal to the medial femoral condyle on posterior drawer. A Grade 2 injury allows the tibia to sublux as far as being flush to the femoral condyle, which approximates 10 mm of translation, and a Grade 3 injury will allow the tibia to be pushed further posterior. Significantly more translation almost always signifies additional ligamentous injury.

Imaging

Plain radiographs and MRI scanning are the routine imaging modalities. Radiographs may show PCL or posterolateral corner avulsion fractures, which are best managed by early operative fixation. MRI scanning is nearly 100% accurate in the acute setting but may be misleading in the chronic setting, as the PCL does have a propensity to heal, albeit with residual laxity.[16] In chronic cases, secondary degenerative changes may be identified, and limb alignment must be evaluated, including the use of weight-bearing long-limb radiographs, as indicated. Significant varus coronal plane malalignment is a risk factor for failure of surgical reconstruction, especially when the posterolateral corner is injured, and is also a significant additional risk factor for medial compartment overload and degenerative arthritis. The sagittal tibial slope should also be assessed on the lateral knee radiograph, as a flattened slope predisposes to persistent PCL laxity.[17]

Where plain radiographs and MRI scanning are inconclusive, kneeling stress radiographs may be beneficial. This has not become commonplace in UK practice, however, and often relies on individualized approaches to achieving such imaging. LaPrade and colleagues have defined up to 7 mm of side-to-side difference in posterior translation of the tibia on stress radiographs to represent partial thickness PCL injury, 8–11 mm constituting isolated full thickness tears, and 12 mm or greater to signify combined ligamentous injury patterns.[18] These figures closely correlate to the millimetres of total posterior drawer described in the grading systems above.

In modern practice, clinical examination and appropriate imaging mean that it is very seldom necessary to contemplate examination under general anaesthesia in order to plan treatment. Management for the vast majority of patients can be defined from examination findings, plain radiographs and an MRI scan of the injured knee.

Non-operative management

Unlike the ACL, the PCL has been shown to have good intrinsic healing potential.[19] Traditionally, with wilful neglect (either on behalf of the patient or the treating surgeon) the PCL will heal in an elongated manner with residual laxity. An MRI may show a serpentine nature to the PCL or a secondarily lax ACL. The importance of recognizing the capacity for healing of the PCL is such that appropriate early conservative management may have a significant impact on residual laxity. The availability and quality of knee braces has improved significantly, and their use in the acute setting and for the postoperative rehabilitation period cannot be underestimated. Braces aimed at treating the PCL-deficient knee centre around the premise of producing an anteriorly directed force against the posterior aspect of the tibia. Static and dynamic brace options are now available from a number of manufacturers, examples of which are shown in Figure 2. Static braces can be employed during the acute injury phase and/or during a diagnostic workup, as they do not interfere with MRI scanning. Range of motion braces can be instituted once the acute phase of the injury has started to settle, typically from 2 weeks.

Figure 2 Knee braces designed for posterior cruciate ligament injuries. On the left, a static immobilization brace with an additional element, which lies posterior to the tibia. On the right, a dynamic brace that allows range of motion. The addition of a posterior strap that can have its tension adjusted serves to apply an anteriorly directed force to the tibia to prevent posterior sag during knee flexion. Images courtesy of medi UK. Reproduced with permission.

A previous appraisal of PCL bracing reviewing the literature from 1967 to 2011 identified little empirical evidence to support any brace providing the necessary biomechanical properties to address PCL-deficiency throughout knee range of motion.[20] However, more recent research does confirm that dynamic PCL braces are effective in reducing posterior translation of the tibia in the clinical setting at short-term follow-up in patients with up to 10 mm of posterior translation at index injury.[21]

With early application of modern braces, all isolated PCL injuries can be potentially treated non-operatively. This is certainly indicated for Grade 1 and Grade 2 injuries, which represent partial thickness tears. Some authors advocate early operative intervention for complete (Grade 3) injuries, while many prefer to treat non-operatively first. Combined ligamentous injury is often best addressed with early or staged surgery (see below). Non-operatively treated PCL injuries have been shown to have good mid-term outcomes, with a reasonable return to sport; a mean Tegner activity level decrease from seven pre-injury to only 6.6 post-injury was recorded in one study.[22] Failure of non-operative management, either due to persisting instability or pain, is an indication for surgical reconstruction. Direct comparative studies on outcomes of non-operative treatment *versus* surgery are currently lacking.

Surgical reconstruction

Almost every aspect of surgical reconstruction of the PCL and postoperative rehabilitation is still debated, as the optimal technique is yet to be established. PCL avulsion fractures from the posterior aspect of the tibia are a relatively clear indication for early operative intervention and may typically be accessed via a posteromedial approach with mobilization of the medial head of gastrocnemius. Simple screw and washer fixation constructs are often sufficient for such injuries.

Early forms of PCL reconstruction utilized similar open approaches, and often grafts with bone blocks that could be affixed directly to the posterior tibia. These evolved into arthroscopic transtibial approaches, with tunnels being drilled through the tibia to minimise surgical morbidity. However, concerns about the acute angulation that the graft experiences in transtibial approaches[23] as it passes around the posterior aspect of the tibia towards the femur (often referred to as the 'killer turn') led to authors developing 'inlay' techniques utilizing a trough to avoid graft impingement.

Numerous open tibial inlay techniques have been described and are still used and advocated by some authors in the modern era.[24] Such techniques often mandate turning the patient from the supine position to the prone position, and back again, during the operative procedure while maintaining the sterile field. This has its obvious drawbacks. More recently, arthroscopic inlay approaches have been described,[25] which mitigate this requirement. There have also been advancements in transtibial techniques utilizing 'all-inside' arthroscopic approaches with inside-to-out drilling of sockets rather than complete tunnels. These allow intra-articular graft deployment, resolving the risk to the graft as it is passed around the 'killer turn', and facilitating graft tensioning.[26,27] Despite concerns, a systematic review of Level III evidence studies of transtibial *versus* tibial inlay single-bundle reconstruction techniques found no significant differences in clinical outcomes, although of note, around a quarter of patients had persisting posterior laxity of Grade 2 or more at follow-up.[28]

Arthroscopic reconstruction remains technically demanding, and operative challenges include visualization of the PCL tibial

Transmedial arthroscopic all-inside posterior cruciate ligament reconstruction	
Patient positioning	Supine Thigh tourniquet Knee flexed to 90° Side support and foot bolster
Arthroscopic portals	High anterolateral (AL) viewing portal Low anteromedial (AM) working portal Standard posteromedial (PM) portal
Instrumentation	Standard 30° arthroscope (optional 70°, often not required) Passport cannula to be placed in working portal for suture management Specifically designed instrumentation for navigating around the medial femoral condyle and protecting posterior neurovascular structures Inside-to-out drills (FlipCutter, Arthrex, Naples, FL) for creation of retrograde sockets on tibia and femur Stiffened plastic tubes for shuttling passing sutures through sockets Radiofrequency ablation device and arthroscopic shaver for tissue clearance Image intensifier for fluoroscopy use optional
Graft	Autograft or allograft prepared for either: Single-bundle reconstruction being loaded onto two adjustable cortical suspensory fixation devices Double-bundle reconstruction utilizing a trifurcate graft loaded onto three adjustable cortical fixation buttons (single tibial end, with independent limbs for AL and PM bundles). Optional graft reinforcement with FibreTape (Arthrex)
Procedure	Graft preparation on back table Routine diagnostic arthroscopy and establish PM portal Preparation of tibial socket to a depth of 30 mm with retrograde drill Shuttle passing suture through tibial socket and retrieve through AM portal Preparation of one or two femoral sockets to a depth of 20 mm (depending on intended single-bundle or double-bundle surgery) Shuttle passing suture(s) through femoral socket(s) and retrieve through AM portal Attach shuttling sutures to graft and deploy intra-articularly through AM portal, first reducing into the tibial socket and then docking into the femoral socket(s) Provisional tensioning on all adjustable cortical fixation devices Knee cycled and adjustable fixation devices re-tensioned. In double-bundle surgery, AL bundle tensioned in flexion and PM near extension Optional (recommended) back-up fixation using a bone anchor device for the FibreTape reinforcement suture
Important notes	Total length of graft must be less than the depth of the tibial socket (30 mm) plus the femoral socket(s) (20 mm) plus the intra-articular distance (approximately 35 mm) to allow for adequate tensioning (total 85 mm). Meticulous suture management required to prevent entanglement Over-constraining the knee is possible by over-tensioning cortical fixation loops

Table 1

footprint, drilling the tibial tunnel or socket without damaging the posterior neurovascular structures, and graft passage, tensioning and fixation. The TransMedial all-inside technique simplifies many of these steps and is briefly described in Table 1, and typical postoperative radiographs shown in Figure 3. This approach allows visualization of the medial femoral condyle through a standard anterolateral portal, while specifically designed instruments are used through the anteromedial portal for preparation of the femoral and tibial sockets. Retrograde drilling is employed to create bony sockets rather than complete tunnels, which is bone conserving, and adjustable loop cortical suspensory fixation devices allow for sequential tensioning of the graft construct. Mid- to long-term outcomes are currently awaited from such techniques.

Single bundle *versus* double bundle

Whether to reconstruct the PCL using a single bundle approach, where the AL bundle is targeted, or with two independent bundles remains debated. Biomechanical evidence suggests that double bundle surgery is superior and more closely replicates normal knee kinematics.[29] There is an emerging sentiment that reconstructing the PM bundle improves rotational stability, especially in higher degrees of knee flexion. Most biomechanical studies, however, do not standardize for the amount of graft tissue utilized, and given that most double-bundle reconstructions have a greater total cross-sectional area of tissue resisting posterior translation than single-bundle reconstructions, this may represent a significant confounding variable. A meta-analysis of clinical outcomes has not demonstrated any measurable difference in subjective or objective patient results.[30]

Double-bundle surgery is also associated with increased complexity and greater potential for surgical error. Tunnel coalescence and graft entanglement are specific concerns. Due to the more compact nature of the tibial attachment of the native PCL, tunnel convergence is more of an issue here than upon the femur. Consequently, most authors advocate a single tibial tunnel to pass both grafts through while maintaining separate orifices on the femoral side. Trifurcate graft configurations, as described below, attend to this philosophy while minimizing additional hardware considerations on the tibial side, and reducing difficulties with graft passage. Double-bundle surgery

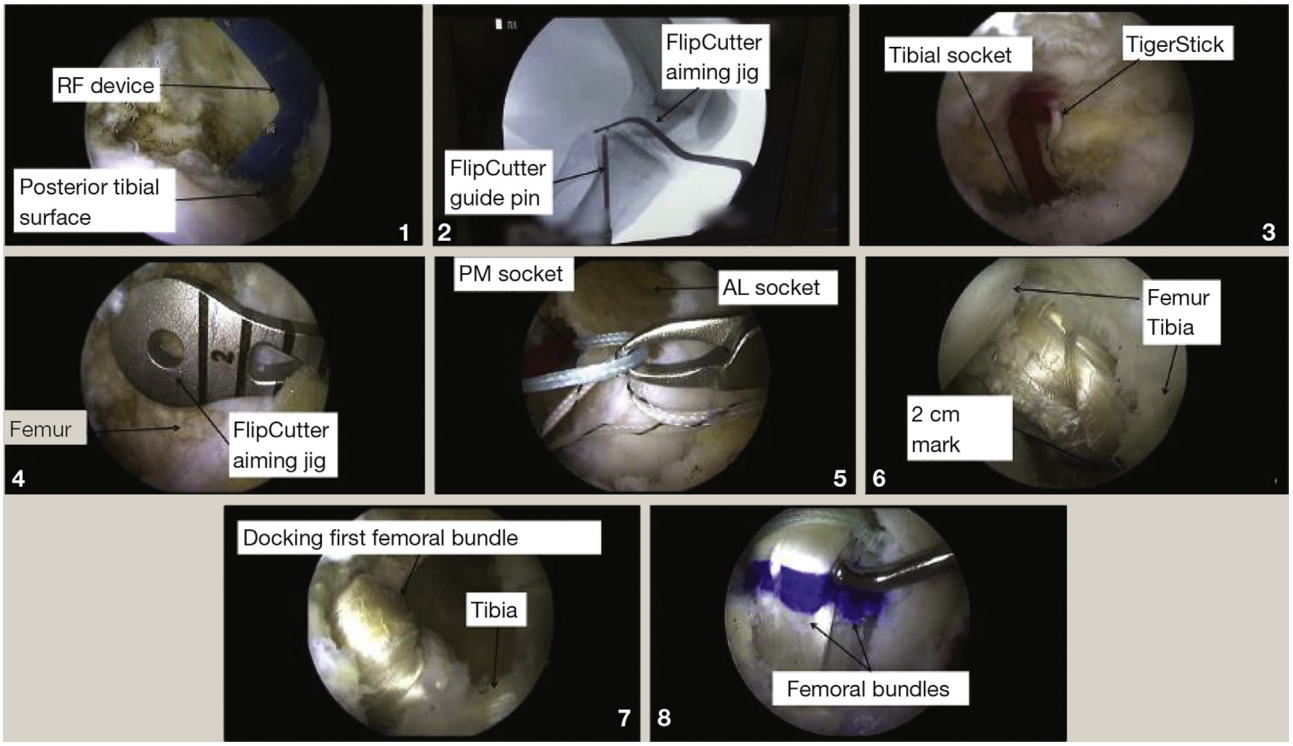

Figure 3 Postoperative radiographs following transmedial all-inside posterior cruciate ligament (PCL) reconstruction using a double-bundle technique. The PCL graft is suspended between three adjustable loop cortical fixation tightropes. The graft has been reinforced with a high strength non-elastic tape, which is secondarily anchored in the bone just distal to the tibial socket. RT, reverse tension; ABS, attachable button system.

may also be particularly challenging in multiligament reconstructions or those combined with osteotomy surgery due to an even greater potential for tunnel confluence or hardware conflict.

Graft choice

There is no consensus on optimal graft selection. Choices lie between autografts and allografts, and whether to incorporate bone blocks or utilize soft tissue grafts alone.[31] Fully synthetic grafts are not recommended, but reinforcement of soft tissue grafts with synthetic material is emerging as a potential option.

Autografts: autografts have the advantage of more rapid host tissue incorporation, but necessitate donor site morbidity, and unlike in ACL reconstruction, due to the size of the PCL it is more difficult to harvest tissue of adequate dimensions. Common choices are therefore patellar tendon or quadriceps tendon grafts. Hamstrings autograft were historically difficult to utilize due to limitations in resultant graft diameter. A typical 'four-strand' construct, such as used in ACL reconstruction, with a doubled semitendinosus and doubled gracilis tendon typically does not provide sufficient graft thickness for PCL reconstruction. Using all-inside techniques with bony sockets combined with cortical suspensory fixation means that shorter grafts can be fashioned, allowing both the semitendinosus and gracilis to be quadrupled to form an eight-strand graft. Graft diameter is consequently improved. Experimental evidence suggests a minimum of only 15 mm of graft is required within the bony sockets for adequate pull-out strength.[32]

These eight-strand hamstrings autograft constructs can be used in single-bundle PCL reconstruction or fashioned into a Y-shaped 'TriLink' configuration. Such a trifurcate graft has a single tibial limb (of eight strands) and two femoral limbs (each of four strands). TriLink grafts permit double bundle reconstruction, replicating the AL and PM bundles, while maintaining a single tibial socket with no risk of tunnel coalescence. In PCL reconstruction these have been described using hamstrings autograft[33] or allograft tissue.[26] With allograft tissue of greater diameter, a four-stranded tibial limb with double-stranded femoral limbs can be created.

Allografts: common allograft choices include Achilles tendon and patellar tendon for grafts with bone blocks, and tibialis anterior, peroneus longus, and hamstrings tendons for soft tissue grafts. Allograft tissue has been popular in the USA for some years, and while potentially costly, has several advantages. These include no limit on the number, size and shape of grafts, and no donor site morbidity.[34] Operative time is reduced and surgical considerations, such as placement of incisions, are negated. This is especially useful in the multiligament-injured knee, or when combined PCL reconstruction with osteotomy surgery is undertaken. The biological incorporation of allograft tissue is slower, however, and this must be borne in mind during the rehabilitation phase. A systematic review and meta-analysis of allograft *versus* autograft use in PCL reconstruction has not shown a difference in clinical outcomes.[35] In this review, although mean objective side-to-side laxity was greater in the allograft group, the difference between the two groups was small (3.1 mm for autograft and 3.8 mm for allograft). Allografts are therefore a viable alternative.

While disease transmission remains a risk, this is thought to be negligible; however, antigenicity and an inflammatory

response to the donated tissue are still possible. Traditional concerns regarding alterations in the biomechanical properties of the donated tissue through sterilization processes have largely been overcome with modern processing techniques. Most grafts utilized are now fresh-frozen allografts with no or minimal irradiation. More recently, parentally donated hamstrings tendons have been described as an alternative allograft option in paediatric PCL reconstruction.[36]

Graft reinforcement: the use of synthetic material for grafts in intra-articular knee ligament reconstruction is associated, historically, with poor outcomes, with significant detrimental effects such as chronic inflammatory reactions and early failures.[37] Synthetics have largely been abandoned for this reason. Combining graft tissue (autograft or allograft) with FibreTape (Arthrex, Naples, FL) as a back-up splint to prevent overstretching in the early healing phase is currently showing promise. FibreTape is a 2 mm-wide non-biodegradable ultra-high molecular weight tape with a polyethylene terephthalate core and a braided polyester jacket. The safety profile of this tape has been investigated over a 13-year period (July 2003 to January 2016), and after >1.5million product sales the potential reaction rate is less than 2 per 100,000. Incorporating this tape into graft tissue during ligament reconstructions is referred to as 'graft reinforcement',[38] and early outcomes in the knee show promising results (unpublished data).

Graft fixation: the optimal method for graft fixation has not been definitively established. Fixation must maintain graft position and tension until biological incorporation within the bone has occurred. Fixation devices must be strong enough to avoid failure, stiff enough to restore stability and must permit graft integration. The type of graft significantly influences the rate of healing, with bone-to-bone constructs integrating in around 6 weeks, soft tissue autografts in 8–12 weeks, and allografts up to 6 months.[38] When reviewing empirical biomechanical evidence, important factors to evaluate are maximum pull-out strength, stiffness, graft elongation and slippage in response to cyclical loading.[31] On a pragmatic level, ease of revision should also be considered.

Fixation devices can broadly be split into those that achieve fixation near the anatomic attachment site of the PCL, such as interference screws, or those that fix the graft at extra-anatomic sites. The latter include suspensory devices that fix either against cortical bone (such as a tightrope-style device) or within the cancellous bone (such as a transfixation pin). Staples can also be used for extra-articular fixation. Anatomic fixation shortens the working length of the graft and may effectively stiffen the construct. It also prevents the graft oscillating within the bony aperture in a 'windscreen wiper' effect, which is something that can cause tunnel widening over time. Fixation strength is a function of bone quality, tunnel diameter *versus* graft diameter and the type and size of screw inserted. Metal screws are commonly used in bone-tendon grafts, with non-metallic or biodegradable screws for soft tissue grafts, with the aim of avoiding graft laceration. Pull-out strengths of 200–800N have been reported for this type of fixation, with additional strength being achieved by incorporating a back-up fixation device, as required.[31]

Extra-anatomic cortical fixation has the advantage of primarily fixing against bone of higher density, which is less likely to fail and less likely to allow graft slippage. Fixed loop systems (such as the Endobutton, Smith & Nephew, Andover, MA) are highly resistant to elongation, whereas adjustable loop systems may be susceptible to slippage.[39] Slippage can be mitigated by knotting the cords after the device has been adjusted to the correct tension. Adjustable loop systems confer significant advantages by permitting independent tensioning of different limbs of the graft, and allow for cortical fixation on both the femur and tibia. In bi-cruciate ligament reconstructions, the ability to gradually increase the tension in each graft is valuable in setting the knee in the correct anteroposterior position.

Hybrid fixation with a secondary cortical back up on the tibial side has grown in popularity, as the soft cancellous bone in the tibia is more prone to allowing graft slippage. This can be achieved in several ways; from simply winding suture tails around a screw, to specifically designed bone anchors, like the Swivelock device (Arthrex, Naples, FL). Graft reinforcement tapes can also be secondarily anchored for back-up fixation.

PCL reconstruction with other ligaments or osteotomy

The PCL is often ruptured as part of a multiligament spectrum of injury. A detailed approach for managing such patients is beyond the scope of this article. As a broad guideline, early attention focusses on stabilizing the collateral ligaments of the knee and regaining range of motion, with many surgeons preferring to delay cruciate ligament reconstruction until after the acute injury phase has settled. Early arthroscopic PCL reconstruction is associated with extravasation of fluid due to capsular injury, and therefore risks iatrogenic compartment syndrome. If a staged surgical approach is adopted, with the collateral ligaments being addressed acutely and the cruciate ligaments during a subsequent procedure, careful consideration must be given at the outset to tunnel and hardware location.

The most common pattern of ligament disruption with the PCL is that of the posterolateral corner (PLC). A multitude of reconstructions have been described for the PLC, which vary between one or two femoral tunnels, and whether they are entirely based upon the fibular head or involve anchorage through the proximal tibia. Tunnel conflict is generally less of an issue with these, as they are based through the lateral femoral condyle, whereas with concomitant MCL injury, femoral fixation must be carefully orientated to avoid conflict with MCL reconstruction. Single-bundle PCL reconstruction may be favoured in the multiligament injured knee, to minimize the requirement for additional tunnels and to facilitate surgery.

Failure to address additional ligamentous injury is a risk factor for failure of PCL reconstruction. Additional risk to the graft may be present due to the underlying bony alignment of the knee. Significant coronal plane deformity or a flattening of the sagittal slope of the proximal tibia can lead to excessive stress on the graft, and early failure. In the revision setting, long-limb alignment radiographs are strongly recommended, with a view to planning a corrective osteotomy prior to, or as a single stage procedure, along with PCL reconstruction. Combined high tibial osteotomy with PCL reconstruction is technically demanding and should be the reserve of those suitably experienced with both techniques.

Coronal plane correction can be used to manage established early medial unicompartmental degenerative disease as well as

reducing the strain on the graft. Historically, opening wedge high tibial osteotomy has been associated with an attendant increase in the tibial slope, which is relatively protective of PCL strain, as this tends to apply an anterior drawer force upon the tibia during weight-bearing. A long-term follow-up study has confirmed a strong association between tibial slope and persisting posterior tibial translation after PCL reconstruction.[40] Although well-executed modern opening wedge techniques typically maintain the existing tibial slope, deliberate differential opening at the anterior and posterior aspects of the osteotomy can increase the slope for a favourable advantage. Medial tibial opening wedge techniques are preferred over lateral closing wedge techniques for this reason. Correcting coronal plane varus is also very important in protecting any posterolateral corner reconstruction. If the coronal plane does not require adjustment, osteotomies in the sagittal plane alone may be planned.

Postoperative rehabilitation

There remains no consensus on rehabilitation, and in many cases, postoperative protocols must be adjusted with respect to concomitant ligamentous or bony surgery. This underlies the fact that there is little scientific evidence, if any, to support one protocol over another, and protocols are therefore often based on surgical experience.[41] A suggested rehabilitation regime is shown in Table 2. Whilst weight-bearing in extension has not been experimentally demonstrated to overload the PCL, most regimes aim for a steady but progressive increase in weight-bearing status and permitted range of motion over the first 12 weeks. During the early rehabilitation period many surgeons restrict open kinetic chain exercises, favouring closed chain active movements or passive motion. This is especially true for knee flexion, which requires hamstrings activation, with the aim of avoiding a posterior drawer strain on the incorporating neoligament. Some authors continue to restrict open chain activity until nearly 3 months, whilst most allow this from around 6 weeks.

The use of knee braces cannot be undervalued, with many surgeons advocating functional braces to be worn for activity up to at least 6 months postoperatively.[20] The goal of bracing is to prevent early posterior tibial sag during the graft healing phase and while the quadriceps are being rehabilitated. Patients tend to be restricted from sudden deceleration movements for 6 months postoperatively, after which straight line running can be introduced. Once the patient can run at full speed, progression to lateral running, crossovers and cutting exercises are permitted, with a view to a return to sport at 9–12 months.

Guideline for suggested rehabilitation regime following PCL reconstruction

Post-operative timeframe	Rehabilitation notes
0–2 weeks	Static PCL brace while swelling settling Use of cryotherapy device Touch weight-bearing with crutches Prone passive knee flexion to 90 degrees Prevent hyperextension
3–6 weeks	Full-time dynamic PCL knee brace Partial weight-bearing with crutches while brace locked in extension Prone passive knee flexion to 90 degrees
7–12 weeks	Full-time dynamic PCL knee brace Weight-bearing as tolerated (weaning off crutches) Free range of motion Active exercises slowly introduced, generally in knee flexion angles lower than 70 degrees Focus on quadriceps strengthening and conditioning Avoid resisted open chain knee flexion
3–6 months	Full weight-bearing Brace only worn for activity Free range of motion with strengthening throughout range Sensory-motor training for proprioception
6–9 months	Brace discarded Impact activity/agility drills Sensory-motor training for proprioception
9–12 months	Sports specific training and return to sport

Table 2

Conclusion

The management of PCL injury continues to challenge the orthopaedic community. Most diagnoses are associated with concomitant ligamentous disruption and possible neurovascular compromise, which must be attended to. Surgical reconstruction of the PCL remains a technically challenging operative procedure and should be undertaken by surgeons experienced in the management of the multiligament injured knee. Bony realignment in the coronal and sagittal plane should be considered where necessary. While there remains no clinically demonstrated difference in patient reported outcomes of double-bundle surgery over single-bundle reconstruction, many favour a double-bundle approach due to empirical data supporting biomechanical superiority. Recent advances in surgical technology have facilitated arthroscopic double-bundle techniques and have permitted easier graft passage, tensioning and fixation. Graft reinforcement is an emerging concept that may aid in protecting the neoligament during the early healing phase. Longer-term outcomes of these modern approaches are awaited; however, obtaining high quality comparative evidence differentiating surgical techniques is difficult due to the heterogeneity of injury patterns. ◆

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