Anterior cruciate ligament reconstruction failure and revision surgery: current concepts

Santiago Pache 1,2, Juan Del Castillo,3,4 Gilbert Moatshe,5,6 Robert F LaPrade7

ABSTRACT
Anterior cruciate ligament reconstruction (ACLR) is one of the most commonly performed procedures in orthopaedic sports medicine. Despite developments in understanding the anatomy and biomechanics of the knee joint, a fairly large subset of patients has ACLR failure. Outcomes after revision ACLR are historically inferior to primary ACLR. Thus, a systematic approach is necessary to identify all potential causes of failure and addressing them in conjunction with a revision ACLR to mitigate the risk of revision failure and to maximise improved patient outcomes.

INTRODUCTION
Anterior cruciate ligament reconstruction (ACLR) is a common procedure in sports medicine, and revision ACLR accounts for 4.1% to 13.3% of these procedures.1-3 Despite improved surgical techniques and fixation devices, a subset of patients has inferior outcomes and persistent instability. Return to pre-injury level sport has been recently reported to be between 13% and 69% at an average of 6.7 to 12 months.1-2 Follow-up, although the group who obtained the least percentage had a relatively short follow-up period (1 year) and the method of evaluation was patient self-assessment.1 Furthermore, this systematic review reported a 20% revision graft re-rupture rate. However, ACLR failure definition was not detailed.3 Therefore, a significant number of young and active population who undergo ACLR will require a revision surgery.4

The goals of revision ACLR are to restore knee function, improve patient-reported outcomes, provide adequate knee stability, and protect the articular cartilage and menisci from further injury. The success of revision ACLR surgery depends on determining and addressing the cause of failure of the index surgery. As ACLR failure has heterogeneous definitions, ACLR clinical failure can be defined as a combination of persistent rotational laxity evidenced by pivot-shift manoeuvre or a graft rupture; being this confirmed by clinical examination, MRI or arthroscopic examination.3,4 A proper work-up and all potential causative factors should be identified to achieve optimal clinical results. Revision ACLR can be challenging and should be approached as a different entity than primary ACLR reconstructions. The purpose of this review was to describe our applied algorithm to treat this patient subset to maximise revision ACLR success.

ANATOMY AND RADIOGRAPHIC OVERVIEW
Placement of the ACL femoral tunnel is one of the most important factors in restoring knee kinematics and improving clinical outcomes. With the improved understanding of quantitative ACL anatomy, surgical techniques have been modified to a more anatomical single-bundle reconstruction by creating a femoral tunnel from an accessory antero-medial portal or an outside-in technique.7

On the femur, the ACL attachment centre is essentially adjacent to the posterior lateral femoral condyle articular cartilage margin at 6.1 mm posterior to the lateral intercondylar ridge and 8.5 mm anterior to the posterior margin cartilage (figure 1). Radiological studies have reported that the centre of the single-bundle ACL insertion on the femoral side is 29% from proximal to distal and 25%
from posterior to anterior according to the Bernard and Hertel method with the knee in 90° of flexion. Meanwhile, Pietrini et al reported that the ACL should be anatomically positioned at 28.75% from proximal to distal (‘maximal notch height’) on average between the anteromedial bundle (AMB) and posterolateral bundle (PLB) attachments with a knee flexion angle of 90°.

The ACL tibial attachment is 7.5 mm medial to the anterior root attachment of the lateral meniscus. Histological and electron microscopy studies have demonstrated a significant overlap between the ACL tibial insertion and the anterolateral meniscal root (ALMR). The overlap of the ACL attachment comprises 63.2% of the ALMR insertion area, while the overlap of the ALMR attachment on the ACL comprises 41% of the ACL insertion site. This is important during ACL tibial tunnel reaming to avoid iatrogenic injury to the ALMR which can lead to lateral meniscal extrusion and predispose the knee to degenerative arthritis.

The ACL has also an important role as a secondary restraint against varus forces. When a posterolateral corner (PLC) or mainly a fibular collateral ligament (FCL) tear is present, forces on the ACL are increased significantly, predisposing an ACL graft to early failure.

Secondary restraints in the ACL-deficient knee
Secondary restraints in the ACL-deficient knee are those structures whose injury increase knee instability only when the ACL is concomitantly deficient to resist the same externally applied load. Injury to secondary stabilisers can cause persistent knee instability after an ACLR and can lead to an indirect ACL graft rupture. These secondary restraints include the medial collateral ligament (MCL), posteriormedial corner, lateral meniscus, posterior horn of medial meniscus (PHMM) and the PLC of the knee.

On the medial side, at 90° of knee flexion, the deep MCL and superficial MCL provide stability against ATT. Anteromedial rotational and valgus instability due to MCL injury can cause subjective instability and increased forces on the ACL graft which can ultimately lead to ACLR failure.

A recent study from the Swedish Knee Ligament Registry compared patients with isolated ACL and combined ACL–MCL failure rate (graft re-rupture undergoing revision ACLR) with DB ACLR technique. Meanwhile, a more recent level II prospective randomised trial at 10 years reported a significantly fewer graft failure rate (graft re-rupture undergoing revision ACLR) with DB ACLR technique.

The CLCL also plays an important role as a secondary restraint against varus forces.

CLINICALLY RELEVANT BIOMECHANICS
Isolated ACL biomechanical function
The ACL is the primary static stabiliser against anterior tibial translation (ATT), providing up to 86% of the total force resisting ATT. The AMB and PLB of the ACL provide key roles in both anteroposterior and rotational stability of the knee. Some authors advocate for a double bundle (DB) ACLR to better reproduce these anatomical structures. In a systematic review of 60 papers comparing SB versus DB, 23 studies reported on graft failures (as graft re-ruptures), whereas two of them (the same group) reported significant differences in favour of DB ACLR. Superior results with DB ACLR in terms of anteroposterior and rotatory laxity were also reported. However, no significant differences in clinical subjective outcome were reported. Meanwhile, a more recent level II prospective randomised trial at 10 years reported a significantly fewer graft failure rate (graft re-rupture undergoing revision ACLR) with DB ACLR technique.

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Aetiologies of ACLR Failure

Classically, three main categories including surgical technique, graft incorporation and trauma-related factors were reported as the main contributors for persistent knee instability after primary ACLR.\(^{40}\) Graft over-tensioning, immobilisation, infection and immunological reaction may be causes of detrimental graft vascularity and delayed incorporation.\(^{41}\) Time to return to high-level sports and quadriceps strength are important factors in preventing knee reinjury.\(^{42}\) However, the most common cause of ACLR failure is related to errors in surgical technique (70% to 80%), such as tunnel malposition, especially on the femoral side.\(^{43,44}\) Poor tunnel placement in a non-anatomic position may lead to excess graft forces due to changes of graft length throughout knee range of motion, leading to plastic deformation of the graft and ultimately ACLR failure. A femoral tunnel that is too close to the central axis of the femur may result in adequate anterior restraint, but poor rotational stability.\(^{45}\) Some studies have reported decreased graft re-rupture rates with transtibial ACLR compared with transportal technique.\(^{46}\) However, significantly higher odds of OA and repeat surgery in transportal techniques have been reported, probably secondary to a decreased loading of a non-anatomic ACL graft and decreased rotational control, resulting in higher forces on the meniscus and altered pressure distribution on the articular cartilage.\(^{47}\)

The ideal placement of the femoral tunnel is midway between the AMB and PLB, posterior to the lateral intercondylar ridge, as far posteriorly in the notch as possible, without violation of the posterior cortical wall (figure 3). On a full extension profile lateral view radiograph, the tunnel should be posterior to Blumensaat’s line.

Other causes of ACLR failure may be due to missed or untreated concomitant ligament injuries, insufficient meniscal volume or meniscal tears, and bony geometry issues given the important biomechanical function and tear consequences mentioned. Graft impingement on the intercondylar roof secondary to an oversized graft and inadequate notchplasty in chronic cases with osteophytes may also result in a poor outcome.\(^{40}\)

Clinical and Radiographic Examination of the Failed ACLR

A thorough clinical history and physical examination are performed. The operative report and intraoperative images from the index surgery should be obtained when possible. ACL tears risk factors such as female sex, age, sport level, generalised joint laxity, tibial and meniscal slope, and notch width index are also assessed.\(^{48,49}\) It is also important to determine if the patient has had persistent instability or whether there has been...
a new traumatic episode. Early failure usually within the first 6 months postoperatively is more related to non-anatomic ACLR graft positioning, biologic issues such as graft incorporation, too aggressive rehabilitation or a premature return to sports. Later failure (>1 year) is more consistent with a traumatic event. A comprehensive algorithm flowchart approach based on many factors over the past two decades since the study by Johnson and Fu is illustrated (figure 4).

Preoperative clinical evaluation includes mechanism of injury, preferred sport(s), level of participation, patient expectations and knee function after index ACL surgery. Physical examination includes limb alignment, range of motion, Lachman test and anterolateral rotational laxity with the pivot-shift manoeuvre. Patients with a high-grade Lachman and pivot-shift test should be evaluated for possible meniscus and/or meniscus root tears which should be repaired when possible to prevent increased graft forces.

### Failed Anterior Cruciate Ligament Reconstruction Workup Algorithm

<table>
<thead>
<tr>
<th>Clinical background and patient perspectives</th>
<th>Physical Examination</th>
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<tbody>
<tr>
<td>Standing X-rays: Anteroposterior, Lateral, sunrise and Rosenberg.</td>
<td>Stress X-rays (if necessary).</td>
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<tr>
<td>Long leg alignment radiograph.</td>
<td>CT scan: MRI</td>
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**Risk factors assessment:** Age < 20. Female sex, professional athlete, narrow intercondylar notch (match width index (NWI) < 0.2), generalised joint laxity, larger TT-TG distance, posterior tibial slope > 7.4°.

**Primary anterior cruciate ligament reconstruction (ACLR) assessment:** previous skin incisions, anatomicity of anatomic, autograft/allograft, bone-tendon-bone, hamstrings, quadriceps tendon, graft fixation.

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<tr>
<td>- Acute trauma.</td>
<td>- Coronal plane malalignment. (Varus &gt; 41%)</td>
</tr>
<tr>
<td>- Tunnel malposition/osteolysis.</td>
<td>- Coronal plane malalignment. (Valgus &gt; 56%)</td>
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<tr>
<td>-Residual anterolateral rotatory instability</td>
<td>- Sagittal tibial slope ≥ 12°</td>
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<tr>
<td>- Pivot shift 3+</td>
<td>- Residual anterolateral rotatory instability</td>
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<thead>
<tr>
<th>Tunnels CT scan diameter &gt; 12-14mm</th>
<th>No</th>
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<tr>
<td>Single-stage revision ACLR +/- ACLR</td>
<td>Yes</td>
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<tr>
<th>1st stage: ACL tunnel bone grafting and Meniscal insdie-out/transitibial repair.</th>
<th>1st stage:</th>
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<tr>
<td>2nd Stage: Revision ACLR +/- ACLR</td>
<td>-MOPTO -VPDFO -ACPTO</td>
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<th>Consider MAT</th>
<th>-Concomitant ligament reconstruction.</th>
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<tr>
<td>Meniscal tear repair when possible.</td>
<td>-Meniscal tears (Roots, Ramp, Body, deficiency).</td>
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### Figure 4
Failed anterior cruciate ligament reconstruction (ACLR) workup algorithm.49 50 55 59 61 72 ACLR, Anterolateral complex reconstruction; PHVMM, Posterior horn volume of medial meniscus; MOPTO, Medial open wedge proximal tibial osteotomy; VPDFO, Varus-producing distal femoral osteotomy; ACPTO, Anterior closing wedge proximal tibial osteotomy; MAT, Meniscal allograft transplantation.
Collateral ligament stability should be assessed with varus and valgus stress testing at 0° and 30° of knee flexion. The PLC integrity is examined, and it is important to be aware of a pseudo-positive Lachman caused by PLC insufficiency. Integrity of the PLC should be confirmed with the posterolateral drawer test and the dial test for external rotation asymmetry at 30° and 90° of knee flexion. A positive external recurvatum test usually indicates a combined ACL and PLC tears, and increased heel height with a side-to-side difference >2.5 cm has been reported to be present with a combined ACL and FCL injury.

Gait examination should be performed to evaluate for a varus, or valgus, thrust or abnormal tibial rotation. When a concomitant ligament injury is suspected on clinical examination, bilateral varus, valgus and/or posterior knee stress radiographs should be performed. Chronic FCL and posterior cruciate ligament (PCL) tears may not be accurately diagnosed on MRI alone, with a sensitivity as low as 48% and 62.5%, respectively.

We recommend obtaining plain anteroposterior, lateral radiographs, Rosenberg views and systematically long leg alignment radiographs to assess coronal plain alignment and tibial slope. An MRI is performed to evaluate graft integrity and concomitant meniscal and chondral injuries. A CT scan is also systematically obtained to evaluate reconstruction tunnel diameter, given its higher reliability than other image methods.

**ONE-STAGE VERSUS TWO-STAGE REVISION ALCR RECONSTRUCTION PROCEDURE**

A well-positioned tunnel with less than 12–14 mm diameter is revised with a single-stage revision. If previous fixation graft hardware interferes with the anatomic tunnel placement, it should be removed. Indications for a two-stage ACL revision procedure include (1) malpositioned bone tunnels that will interfere with new revision reconstruction tunnel placement or (2) the presence of tunnel osteolysis in which the tunnel diameters are too large (≥14 mm) to securely place a new reconstruction graft, without a risk of a lack of biological incorporation. Graft incorporation may be put at risk if limited contact exists between the surrounding bone and graft tissue.

Coronal plane malalignment in ACL-deficient knees with concomitant medial knee compartment OA, chronic PLC, concurrent cartilage restoration procedure and meniscal allograft transplantation is corrected when indicated. Our aim with realignment is to restore the mechanical axis through the apex of the lateral tibial eminence (56% across the tibial plateau). The main indication for an anterior closing wedge high tibial osteotomy (HTO) is an increased sagittal plane posterior slope (>12°) in patients with failed ACLR, aiming to achieve 6° to 8° posterior tibial slope (figure 5). Hypercorrection may increase the risk of a PCL tear.

Staging the surgery may provide better conditions for anatomic revision ACLR with well-placed tunnels, and good incorporation and fixation of the graft. It promotes and enhances a biological bone healing environment, preserves bone stock and allows a precise anatomic tunnel placement for the definitive revision ACLR, typically performed after 4 to 6 months after first-stage procedure (figure 6).

**REVISION ALCR GRAFT SELECTION**

Our preference is to use an ipsilateral or contralateral bone patellar–tendon bone (BTB) autograft when possible, especially in patients younger than 50 years. Other options include an ipsilateral or contralateral hamstring or quadriceps tendon autograft. A BTB allograft is considered in patients older than 50 years, any patient with an insufficient patellar tendon or patients who choose not to have their contralateral patellar tendon harvested.

**ANTEROLATERAL COMPLEX RECONSTRUCTION/REPAIR**

Surgical treatment of the ALC can consist of a lateral extra-articular tenodesis (LET), an ALL reconstruction (ALLR) and/or a distal Kaplan fibre repair. We prefer to perform a combined ACLR and an anatomic ALLR or a LET of the knee in selected cases: residual anterolateral rotatory instability after anatomic ACLR, generalised ligamentous laxity, and in patients with ACL deficiency and a 3+ pivot shift on examination without associated meniscal, collateral or PLC injury. An additional indication is in the setting of a primary ACL tear with a tibial slope >12°, especially in younger patients.

Furthermore, we advocate to perform meniscal repair with an inside-out and/or transtibial repair for meniscal root tears whenever possible on the first stage of a two-stage procedure. There have been good clinical outcomes reported with this approach, with the additional advantages of second-look and revising the repair at the second-stage surgery if the procedure has failed, or an immediate transitioning to protected weightbearing after second-stage ACLR.
DISCUSSION

Several studies have reported improved clinical outcomes in revision ACLR with the use of autografts in addition to primary ACLR. \cite{62,66} Results reported by the MARS group on revision ACLR (level II study) showed significant better functional outcomes and 2.78 times less likely to sustain a subsequent ACL graft rupture with autografts compared with allografts. \cite{67}

Meanwhile, Legnani et al. \cite{68} reported that patients undergoing revision ACLR with autografts experienced a quicker return to sports compared with patients who underwent allograft revision surgery. On another study, Mayr et al. \cite{69} reported greater extension deficits in patients who underwent revision ACLR with autografts compared with patellar tendon allografts. Although reharvesting the BTB is an option when autografts are not available, the reharvested tissue has been reported to have inferior tissue quality for revision cases and it is not generally recommended. \cite{70}

Regarding meniscal volume, no high-level studies have been reported to date, although a meniscal allograft transplantation (MAT) should be considered as a concomitant procedure for revision ACLR to aid in joint stability when meniscus deficiency is believed to be a contributing factor to failure. \cite{71,72} There are no high-level studies to support one-stage or two-stage surgery for concomitant MAT or HTO and ACLR. Performing MAT with a revision ACLR is possible and recommended to stabilise the knee after MAT. A second stage is sometimes not necessary for HTO patients who achieve adequate stability, and additionally, hardware from HTO may interfere with tunnel reaming for revision ACL. \cite{73}

Although there has historically been controversy regarding ALC surgical management, many authors have reported no significant benefits for this procedure in a primary ACLR setting. \cite{74} However, recent studies have reported significant lower graft re-rupture rates and higher rate of return to the preinjury level with the use of hamstring autograft and ALL reconstruction. \cite{64} Cadaveric studies demonstrated increased rotational knee laxity with combined ACL and ALC knee injury. \cite{17} Moreover, normal knee kinematics were not restored after isolated ACLR in presence of an ACL-deficient knee combined to ALC tears. \cite{75} Although some studies have reported an over-constrained knee secondary to ALLR, a recent meta-analysis found no correlation between LET and OA. \cite{14,76} Moreover, in a recent level I prospective randomised clinical trial, Getgood et al. \cite{30} compared ACLR and ALCR with concurrent LET using hamstring autografts. They demonstrated a significantly higher rate of clinical ACLR failure (40% vs 25%; p<0.0001) and graft rupture rates (11% vs 4%; p<0.001) with ALCR without LET, with a minimum 24 months’ follow-up and an average age of 18.9 years. \cite{5}

Although there are no high-level comparative studies in the setting of significant tunnel enlargement, there has been a trend towards a two-stage surgery when trying to optimise patient outcomes. \cite{77} Several factors including the surgeon’s experience, team, tunnel diameter and position, concomitant pathology such as alignment, and meniscus loss/insufficiency play a role on the choice of two-stage versus single-stage surgery. Even in the presence of these possibilities, it is still often possible to perform a single-stage revision. The advantages of single-stage revision are one surgery to avoid multiple trauma to the knee with multiple surgeries and a shorter rehabilitation time frame. In order to avoid two stages, various surgical techniques have been described for a single-stage basis including cylindrical autograft, corticocancellous shims, retention of interference screws, larger interference screws, dilation of a new tunnel, bone dowel or a divergent tunnel concept technique. \cite{78,81}

Nevertheless, we acknowledge revision ACLR surgery is challenging, and it is important to optimise outcomes after an already failed surgery. Studies have demonstrated that outcomes after revision ACLR surgery are inferior to primary ACLR surgery. \cite{1} With that in mind, staging the surgery may provide better conditions for anatomic revision ACLR with well-placed tunnels, and good incorporation and fixation of the graft. The over the top (OTT) technique is another option for single-stage revision ACLR and no high-level studies have been compared with an anatomic ACLR. \cite{82} However, a trend towards anatomical techniques have been emphasised because anteroposterior and rotational stability are restored closer to knee intact kinematics, being considered more as a salvage open physis option. We also acknowledge that an OTT position tends to achieve an ACL graft that is potentially too tight in extension and too loose in flexion. \cite{43}

The senior author advocates a two-stage procedure with tunnel enlargement greater than 14 mm and found no significant clinical differences compared with the single-stage (no significant osteolysis) revision group. In this study, undergoing a two-stage procedure has not been reported to be a significant concern compared with the single-stage group of patients, but to have a more functional and healthier knee without subsequent failures. \cite{83} Although staging takes longer rehabilitation time and involves several surgeries, it is important to remember that it is a good option when conditions are not optimal. Ultimately, achieving a stable and functional knee is the goal, whether with a single-stage or two-stage procedure.

Failure rates of revision ACLR have been reported to be three to four times higher than primary ACLR. \cite{83} Moreover, subsequent re-revision for revision ACLR patients is 6.5% at 5 years and 9.0% at 8 years. \cite{84} A systematic review of the literature on revision ACLR by Liechti et al. reported that although re-revision ACLR could restore stability and improve functional outcomes compared with the preoperative state, outcomes were inferior when compared with primary ACLR regarding ability to return to pre-injury level of activity. \cite{85} Therefore, identifying patients who are at risk of ACLR failure and adequate preoperative counselling is important. Rehabilitation does not differ much from a primary ACLR other than progression through stages is slower to allow for graft incorporation; however, there are insufficient data on rehabilitation following revision surgery. It is known that aggressive early rehabilitation may result in early ACLR failure and a generally accepted return-to-sport (RTS) period is between 8 and 12 months. \cite{86} RTS is slower than primary cases and sometimes depends on addressing concomitant lesions present at the revision stage and on graft selection. On a recent level I study, it was reported that immediately postoperatively weight-bearing is recommended while evidence for the use of motion control and functional derotation bracing is sparse and contradictory. \cite{87}

CONCLUSIONS

Revision ACLR are challenging and require a thorough and systematic approach to identify the causes of primary ACLR failure to be addressed when possible. Causes of ACLR failure include surgical technique, failure of graft incorporation, trauma-related factors and unaddressed concomitant pathology. Imaging should be performed to diagnose concomitant pathology, alignment and tunnel size in order to plan surgery and optimise outcomes. Two-stage surgery is recommended if the bony
morphology including tunnel size (>14 mm) and limb alignment
tibial slope (>12°) are not optimal. Staging revision ACLR has
not been demonstrated to affect outcomes, although higher-level
comparative studies are needed. In a selected subset of patients,
a concurrent ALC procedure can improve outcomes.

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Current concepts review

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