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REVIEW

# Evaluation of Failed ACL Reconstruction: An Updated Review

Bryson Kemler[1], Carlo Coladonato[1], John Hayden Sonnier[1], Michael P Campbell[1], Danielle Darius[2], Brandon J Erickson[1], Fotios Paul Tjoumakaris[1], Kevin B Freedman[1]

[1]Department of Orthopaedic Surgery, Rothman Institute, Philadelphia, PA, USA; [2]Department of Education, Drexel University College of Medicine, Philadelphia, PA, USA

Correspondence: Kevin B Freedman, Rothman Orthopaedics at Thomas Jefferson University, 825 Old Lancaster Road, Suite 200, Bryn Mawr, Philadelphia, PA, 19010, USA, Email Kevin.Freedman@rothmanortho.com



**Abstract:** Failure rates among primary Anterior Cruciate Ligament Reconstruction (ACLR) range from 3.2% to 11.1%. Recently, there has been increased focus on surgical and anatomic considerations which predispose patients to failure, including excessive posterior tibial slope (PTS), unaddressed high-grade pivot shift, and improper tunnel placement. The purpose of this review was to provide a current summary and analysis of the literature regarding patient-related and technical factors surrounding revision ACLR, rehabilitation considerations, overall outcomes and return to sport (RTS) for patients who undergo revision ACLR. There is a convincingly higher re-tear and revision rate in patients who undergo ACLR with allograft than autograft, especially amongst the young, athletic population. Unrecognized Posterior Cruciate Ligament (PLC) injury is a common cause of ACLR failure and current literature suggests concurrent operative management of high-grade PLC injuries. Given the high rates of revision surgery in young active patients who return to pivoting sports, the authors recommend strong consideration of a combined ACLR + Anterolateral Ligament (ALL) or Lateral extra-articular tenodesis (LET) procedure in this population. Excessive PTS has been identified as an independent risk factor for ACL graft failure. Careful consideration of patient-specific factors such as age and activity level may influence the success of ACL reconstruction. Additional technical considerations including graft choice and fixation method, tunnel position, evaluation of concomitant posterolateral corner and high-grade pivot shift injuries, and the role of excessive posterior tibial slope may play a significant role in preventing failure.
**Keywords:** ACL, anterior cruciate ligament, anterior cruciate ligament reconstruction, failed ACL graft, posterior tibial slope, revision ACL reconstruction

## Introduction

Anterior Cruciate Ligament Reconstruction (ACLR) tear rates have consistently increased over the past several years.[1–4] Consequently, so too have the number of revision ACLR.[5,6] Failure rates among primary ACLR range from 3.2% to 11.1% but have been reported to be as high as 34.2% when including high-risk cohorts such as young athletes.[7,8] There are multiple factors which may lead to ACLR failure. Erickson et al published a review in 2017 outlining several of these including graft morphology, graft types, surgical technique, and timing of return to sport, all of which can affect outcomes in this patient population.[9] Recently, there has been focus on surgical and anatomic considerations which predispose patients to failure, including excessive posterior tibial slope (PTS), unaddressed high grade pivot shift, and improper tunnel placement. As outcomes for revision ACLR are inferior compared to primary procedures,[10–14] it is paramount to elucidate historical and contemporary reasons for failure. The purpose of this review is therefore to provide a current summary and analysis of the literature regarding patient-related and technical factors surrounding primary ACLR failure.

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# Methods

## Review Process

A current concepts review was performed identifying 116 studies of interest pertaining to outcomes following primary ACLR with the most impactful articles shown in Table 1. PubMed, SCOPUS, and Cochrane databases were searched for any combination or variation of: "failed ACL reconstruction", "rehabilitation considerations following ACL reconstruction", and overall outcomes and return to sport (RTS) for patients who undergo revision ACLR. Studies were excluded if they were not in English, did not pertain to ACL reconstruction, were studies including animal subjects, or were done with cadaveric specimens.

# Results

## Traumatic vs Atraumatic Causes of Failure

The MARS cohort published their findings on mechanism of failure in single-revision ACLR from 2006 to 2011 and reported that a traumatic, noncontact injury to the ACL graft was the most common cause (55%) of re-rupture.[15] Approximately 25% of patients in the cohort had a nontraumatic, gradual-onset recurrent injury, which contrasts with previously reported rates at high as 75%.[24,25] Nontraumatic, gradual-onset recurrent injury was the most common cause (47%) of recurrent tear in patients who underwent multiple revisions, and the revising surgeon deemed technical error to be a contributing cause 58% of the time.[15] The authors postulated femoral tunnel malposition was the main technical error contributing to failure, which is in agreement with current literature. Jaecker et al found in their cohort of 147 patients that non-anatomical femoral tunnel position was the most common cause of failure in patients deemed to fail due to technical error, followed by non-anatomical tibial tunnel position.[16] A recent systematic review of 28 studies corroborated this, identifying technical error to contribute to 17% of failures, with femoral tunnel malposition being the leading cause.[26]

## Patient Risk Factors for Re-Rupture

Several studies have analyzed patient-related risk factors on ACLR failure and have consistently found younger age to be the most significant factor.[5,27–29] Maletis et al published data from the Kaiser Permanente ACL registry with mean

**Table 1** Demographics of Included Studies

| Author, Year | Journal | Study Design | LOE | Number of Patients/Knees | % Male | % Female | Average Age |
|---|---|---|---|---|---|---|---|
| Chen, 2013[15] | *Am J Sports Med* | Prospective | 3 | 1200 | 58 | 42 | 26 |
| Jaecker, 2018[16] | *Arch Orthop Trauma Surg* | Retrospective | 4 | 110 | 67.2 | 32.7 | 25.05 |
| Maletis, 2016[17] | *Am J Sports Med* | Retrospective Cohort | 2 | 21,304 | 62.8 | 37.2 | 4 age groups |
| Wiggins, 2016[8] | *Am J Sports Med* | Systematic Review and Meta Analysis | 1 | 72,054 | 56.7 | 43.3 | 24.4 |
| Shelbourne, 2009[18] | *Am J Sports Med* | Prospective Cohort | 2 | 1415 | 61 | 39 | 21 |
| Spindler, 2020[19] | *Am J Sports Med* | Prospective Cohort | 2 | 839 | 52 | 48 | 17 |
| Snaebjörnsson, 2017[20] | *Am J Sports Med* | Prospective Cohort | 2 | 2240 | 52.9 | 47.1 | 21.7 |
| Spragg, 2016[21] | *Am J Sports Med* | Case-control | 3 | 491 | 52.6 | 47.4 | 17.6 |
| Wasserstein, 2015[22] | *Sports Health* | Systematic Review and Meta Analysis | 3 | 1016 | 64 | 36 | 21.7 |
| Boyle, 2015[23] | *The Knee* | Retrospective Cohort | 3 | 188 | 60.7 | 39.3 | 26 |

follow-up of 2.2 years and divided patients into five cohorts based on age. The authors found that the youngest group (<21 yo) had the highest 5-year revision probability, and the risk of both ipsilateral and contralateral ACL injury decreases with age.[17] Wiggins et al reported similar findings in their 2016 systematic review; overall, patients had a 15% second ACL reinjury rate (ipsilateral 7% and contralateral injury 8%), but patients younger than 25 years had a reinjury rate (ipsilateral + contralateral) of 21%. They found RTS to be a significant risk factor as well and concluded young athletes who RTS after ACLR have a 30 to 40 times greater risk of an ACL injury compared with uninjured adolescents.[8] Considering the elevated incidence of recurrent injuries among younger athletes, patient age may actually serve as a surrogate marker for other predisposing elements. Greater risk-taking behaviors, sport-related factors such as aggressive play style and neuromuscular impairments have been theorized to contribute to these higher reinjury rates.[30] Further, fear of reinjury has been reported as a major psychological barrier to rehabilitation progression following ACL injury, which may add to the risk profile of this population.[31]

It has been well-documented females are prone to higher risk of sustaining an ACL tear than males.[32,33] Attempts have been made to link this to anatomical differences such as increased quadriceps angle and PTS in females, smaller notch width and ACL cross-sectional area, and hormonal contributions, however no conclusive correlation has been established.[34–40] Interestingly, studies have consistently shown females to have similar or even slightly decreased rates of graft rupture and failure as males,[17,33,41–43] however their rates of contralateral ACL injury are significantly greater following ACLR. Shelbourne et al published a 7.8% contralateral injury rate in female patients compared to a 4.3% ipsilateral reinjury rate ($p > 0.001$). This was in contrast to the study's male population, in which there was no significant difference between the reinjury rate (4.1%) and contralateral injury rate (3.7%).[18], indicating female-specific inherent risk factors which place them at higher risk for contralateral ACL rupture. Lindanger et al examined patients who returned to pivoting sports after ACLR and found 32% of females in the cohort sustained a contralateral tear compared to only 12% who required ipsilateral revision surgery. In their review, Erickson et al reported on the senior author's (B.R.B.) 30-year outcome data and found a significantly higher percentage of female patients who went on to require contralateral ACLR than male patients (6.4% for female patients compared with 4.4% for male patients; $p = 0.048$). The contralateral procedure was performed at a mean of 34 months following the index ACLR in female patients, implying that the contralateral tear was not a compensatory phenomenon.[9]

# Results

## Tunnel Placement

Femoral tunnel malposition has consistently been cited as a significant factor in atraumatic ACLR failures.[15,24–26] Biomechanical studies have confirmed the importance of femoral tunnel positioning on the force exerted on the ACL graft.[44,45] Anterior tunnel placement causes the graft to stretch during knee flexion, which ultimately results in plastic deformation and eventual graft incompetence.[46,47] Driscoll et al, in a cadaveric study of 6 specimens, found femoral tunnel placement in either the center of the bundles or the anteromedial portion of the ACL footprint resulted in similar anterior translation as the intact-ACL model in response to loading at $0^0$ to $60^0$. However, internal tibial rotation was greater in the anteromedial bundle tunnel model than the center tunnel model at all flexion angles, indicating improved rotatory stability without sacrificing anterior stability with femoral tunnel positioning in the center of the femoral footprint.[45] Reliance on the native ACL footprint, however, assumes this anatomic location is ideal.[48,49] Studies have reported substantial anatomic variability in location and size of ACL femoral and tibial footprints, with ranges from 83 $mm^2$ to 197 $mm^2$ and from 114 $mm^2$to 229 $mm^2$, respectively.[50–52] In a study of 12 cadaveric specimens, Araujo et al assessed vertical tunnel placement on graft force. The authors found that at lower flexion angles ($\leq 30^0$), tunnel positioning in the center of the femoral footprint resulted in similar in situ graft forces as the native ACL during both anterior tibial loading and simulated pivot shift loading, while in situ graft force with more vertical tunnel placement more closely resembled the native ACL at greater flexion angles ($>45^0$).[44] Transtibial drilling is particularly prone to excess tunnel verticality, although this may be counteracted through hyperflexion of the knee during drilling.[53] Alternatively, contemporary surgical techniques utilize independent tibial and femoral drilling, with outside-in reamers, or straight and flexible reamers drilled inside-out through the anteromedial portal.[54] Despite the importance of tunnel placement, agreement on ideal positioning amongst surgeons varies significantly.[55]

## Graft Choice

Graft choice for primary ACLR has undergone continued debate. Hamstring tendon (HT) and bone-patellar tendon-bone (BPTB) autograft remain the two most utilized and studied grafts. As surgeon preference and experience factor heavily into graft choice, it is difficult to make an incontrovertible recommendation. A multicenter study consisting of 839 patients aged 14 to 22 years found autograft type to be 1 of the 3 most influential predictors of ACL graft revision at 6 years. Patients who underwent a hamstring autograft were found to have 2.1 times greater odds of requiring ACL graft revision compared to those who received a BPTB autograft (95% CI, 1.3–3.5; P = 0.004).[19]

A similar twofold higher failure rate after ACLR was seen with hamstring autograft compared to BPTB autograft in the Norwegian Cruciate Ligament Registry.[56] In a meta-analysis comprised of fourteen randomized controlled trials, ten prospective comparative studies, and one national registry study, Samuelsen et al found a small but significant difference in graft rupture rate between patients who received BPTB autograft (212 out of 7560, 2.80%) and those who received HT autograft (1123 out of 39,510, 2.84%; p = 0.01). The authors observed overall low rates of failure in both groups and few differences between graft types in terms of knee laxity, and they concluded both remain viable options for primary ACLR. Graft-specific caveats must also be considered when deciding on graft choice. Rates of anterior kneeling pain in patients who underwent ACLR with autograft BPTB have been reported between 6.1% and 17.4% and may have a significant effect on patient outcome and satisfaction.[57,58] The bone–bone interface, however, has been shown to fully incorporate histologically at 12 weeks in animal models, with the bone-tendon junction undergoing characteristic “ligamentization” over time.[59,60] HT autograft relies on the soft tissue interface for healing, which may translate to substandard mechanical properties after transplantation.[59]

Autograft HT diameter has also been found to have an influence on revision risk following primary hamstring ACLR. Snaebjornsson et al found that for every increment of 0.5mm in graft diameter, the likelihood of patient requiring revision surgery after primary ACLR was 0.86x lower.[20] Spragg et al found that ACLR patients with a 9 mm-diameter graft were 55% less likely to require revision than those with a 7 mm-diameter graft.[21] Quadriceps tendon (QT) autograft has recently gained popularity, as it appears to have similar outcomes and less donor-site morbidity than BPTB.[58] Shani et al reported cross-sectional area of the QT was almost double that of the BPTB (91mm$^2$ vs 48 mm$^2$, respectively), and found stiffness (466 N/mm vs 278 N/mm) and ultimate load to failure (2186 N vs 1581 N) were significantly greater for the QT graft compared with BPTB.[61] Additionally, studies examining short- and mid-term outcomes found comparable failure and revision rates.[62,63]

There is more conclusive evidence to guide surgeons when deciding between autograft and allograft in ACLR. Several studies have found higher re-tear and revision rates in patients who undergo ACLR with allograft than autograft, especially amongst the young, athletic population. Wasserstein et al found that the combined failure rate for allografts was 25%, while the failure rate for autografts stood at 9.6%, with a mean patient age of 21.7 years.[22] In patients younger than 18 years, Ellis et al found a 15x higher risk of re-tear in patients who received a BPTB allograft compared with those who received BPTB autograft.[64] The risk of re-injury extends to older patients as well, but the difference is not as profound. Kraeutler et al’s meta-analysis of 5182 patients (average age = 27.6 years for autograft and 32.3 years for allograft) found a three-fold higher risk of re-rupture in those patients receiving BPTB allograft compared to autograft ACLR (12.7% vs 4.3%).[65] While the exact reasoning behind this data is unknown, it is hypothesized allograft patients may feel better in the early months after ACLR and return to athletics sooner, increasing the risk of graft failure.[29] Additionally, time to biologic incorporation of autograft tissue is dissimilar to allograft; Shino et al performed biopsies of ACL allografts and found that full graft maturity was not obtained until 18 months postoperatively in a canine model.[66] Further, allograft tends to tear at different locations than autograft, which typically fails at the femoral insertion.[67]

## Inadequate Graft Fixation

It is important to consider ACLR graft fixation techniques as several are currently in use, and load to failure and graft slippage vary amongst the different techniques.[68] Tibial fixation is most commonly achieved with an interference screw, as it has been found to have satisfactory biomechanical properties to withstand the forces placed on the graft during the rehabilitation period.[69] Femoral fixation is more variable and often depends on surgeon preference. For aperture fixation and especially for BTB grafts, an interference screw is most often utilized; however, it comes with the known complication of widening of the femoral tunnel, reportedly between 3% and 45%.[70–74] Of note, the upper limit of 45% tunnel widening was in patients who underwent ACLR using single-bundle hamstring tendon with bioabsorbable screw fixation.[73] Screw divergence with loss of femoral bone-plug fixation and screw migration are also documented causes of failure.[75–79] Suspensory fixation is more commonly utilized for soft tissue grafts and has biomechanically superior results with soft-tissue graft slippage compared to aperture fixation.[80] Suspensory fixation is accomplished with either fixed-loop or adjustable-loop devices; the adjustable-loop device can pull the graft to the top of the femoral tunnel to decrease the distance between the graft and its fixation, however biomechanical studies suggest these constructs can loosen after deployment.[81,82] To counteract this, re-tensioning and knot tying over the device have been proposed after initial fixation of the graft and cycling of the knee.[82–84] Choi et al evaluated 117 patients (67 patients with fixed-loop cortical femoral fixation compared to 50 with adjustable-loop cortical femoral fixation) and found no difference in arthrometer-measured knee laxity or functional outcome.[85] Similarly, a recent large retrospective cohort series found no significant difference in postoperative knee stability or graft failure rates between adjustable- and fixed-loop cortical suspension in patients undergoing ACLR (10% vs 11%, $p = 0.71$).[23] Despite the seemingly adequate stability achieved with suspensory fixation, however, it has been shown to result in larger degrees of tunnel widening compared with interference screws fixation, which is an important caveat to consider when evaluating a patient for revision ACLR.[86]

## Missed Posterolateral Corner Injury

The posterolateral corner (PLC) of the knee consists of three major stabilizers: the fibular collateral ligament (FCL), the popliteus tendon (PLT), and the popliteofibular ligament (PFL).[87,88] Unrecognized PLC injury has been increasingly recognized as a cause of ACLR failure.[87] Biomechanically, force exerted on the ACL graft is significantly higher in the presence of an FCL injury than with an intact PLC.[89] Clinically, conservative management of Fanelli type B PLC injuries has been shown to lead to poor outcomes as compared to Fanelli type A PLC injuries in patients who underwent ACLR.[90] This suggests concurrent operative management of higher-grade PLC injuries to be necessary to achieve optimal outcomes.

## High-Grade Pivot Shift

The ACL functions as the primary restraint to anterior tibial translation (ATT) but also is an important stabilizer to internal rotation.[91,92] Studies have shown patients who experience persistent rotatory instability in the setting of a reconstructed ACL have worse outcomes, as well as higher rates of graft failure and revision surgery.[93–95] In addition to the ACL, the IT band and anterolateral ligament (ALL) are lateral structures which function as adjunct stabilizers to anterolateral rotatory laxity.[96–98] Cadaveric studies have shown LET in conjunction with ACLR improved rotatory laxity control, and this correlates with decreased pivot shift on exam.[99–104] A recent multicenter randomized control trial found young, active patients (age 14–25) presenting with ACL rupture and high-grade rotatory laxity who underwent HT ACLR + LET had a clinical failure rate of 25% and a graft rupture rate of 4% compared to 40% and 11%, respectively, who underwent ACLR alone. Furthermore, ACL-deficient knees with a high-grade pivot shift have an increased risk of persistent instability with resultant medial meniscal tears and lateral compartment chondral damage. For these high-risk patients, early intervention is of the utmost importance.[93,95,104] Given the high rates of revision surgery in young patients who return to pivoting sports, the authors recommend consideration of a combined ACLR + LET procedure in this population.[30,105]

## Excessive Posterior Tibial Slope

Excessive PTS has been identified as an independent risk factor for ACL graft failure. Tibial slope has a strong, linear relationship to the level of force exerted on the ACL graft in an axially loaded knee; as slope increases, the force on the graft also increases.[106] Christensen et al demonstrated a magnitude–response relationship, with an escalating risk for graft failure with increasing posterior slope.[107] Winkler et al found that multiple ACL graft failures were associated with steeper medial posterior tibial slope, and the authors recommended strong consideration of posterior tibial slope in the re-revision setting. Biomechanical studies have shown that slope-reducing osteotomy significantly decreases anterior tibial translation in ACL deficient knees, and in the same study, ACL graft-forces decreased by 33.1% under a 400N axial load after a slope-reducing osteotomy compared to isolated reconstruction.[108–110] Akoto et al published a case series of twenty patients with ACLR failure and found PTS >12$^0$ was associated with increased shear forces on the ACL graft and resulted in a failure rate 11x higher than patients with PTS <12$^0$.[111] Song et al examined a case series of 18 patients who underwent slope-reducing osteotomy with combined primary ACLR for excessively steep PTS (range, 17$^0$-18$^0$) with a mean follow-up of 33.2 months. At final follow-up, they found mean medial and lateral tibial subluxation was significantly decreased with all patients returning to preinjury level.[112] While posterior tibial slope is gaining increased awareness as an independent risk factor for ACLR failure, a slope-reducing osteotomy represents a much more complex and morbid procedure, and at this point should only be considered in the revision or re-revision setting.

## Rehabilitation

In the literature, two main rehabilitation approaches are commonly discussed: a conservative method, which typically targets a return to sports within 9 to 12 months post-reconstruction, and an accelerated approach, which aims to enable patients to resume sports activities within 6 months.[113,114] Unfortunately, the literature lacks a clear definition of the ideal timeframe for resuming sports activities following ACL reconstruction (ACLR), largely due to the significant influence of patient-specific factors on determining successful return-to-play (RTP). Further literature should seek to more clearly elucidate the role that various physiological and, importantly, psychological factors play in the RTP process.[115]

# Discussion

The rates of Anterior Cruciate Ligament Reconstruction (ACLR) tear rates, along with the number of ACLR revisions performed, have been consistently increasing in recent years. Failure rates among primary ACLR range from 3.2% to 11.1%, and in young athletes, rates as high as 34.2% have been reported.[7,8] Given the rise in revisions and established inferior outcomes following a revision ACLR, the purpose of this review was to analyze recent literature regarding patient related and technical factors surrounding revision ACLR and subsequent outcomes to provide the latest evidence-based data on the topic.

There are various mechanisms in which re-rupture occurs after ACLR, with the most common (55%) being a traumatic, noncontact injury to the graft.[15] In several studies, younger age was consistently reported as the most significant patient-related factor leading to rupture. While it also has been well documented that females are prone to higher risk of sustaining an ACL tears than males, there has yet to be a conclusive anatomical reason for this.[32,33] Furthermore, there are no differences in rates of graft rupture between males and females following ACLR.[17,33,41–43]

Due to the biomechanical force exerted on the ACL graft, femoral tunnel positioning is an important surgical consideration regarding rupture. However, there has yet to be a consensus or statistical evidence on optimal tunnel placement and the decision is largely made on surgeon preference. More concrete data on graft choice for primary ALCR has been shown, with the odds of revision being 2.1 times higher for patients receiving a hamstring autograft instead of a bone-patellar-bone autograft.[19] Further, a comparative study by Biz et al demonstrated no statistical difference in clinical outcomes between patients undergoing ACLR with BTB allograft or hamstring tendon autograft after 2 years.[116] Still, failure rates have been shown to be significantly higher in patients who undergo allograft compared to autograft.[19,56] Moreover, considering the evidence in the literature, both options remain viable, and their trade-offs should be considered in order to meet the specific needs of the patient.

ACLR graft fixation techniques are an important intraoperative consideration. Tibial fixation is most commonly achieved with an interference screw while femoral fixation is more variable. While the biomechanical properties have been shown to be satisfactory, there are sparse data for subsequent revision when comparing fixation techniques.[44,45] Unrecognized posterolateral corner injury is another intraoperative factor that has been increasingly linked to revision surgery in recent years.

Patients who experience persistent rotatory instability in the setting of a reconstructed ACL have worse outcomes and higher rates of both graft failure and revision surgery.[93–95] Patients returning to pivoting sports should be considered for a combined ACLR + LET procedure for this population. Another patient-related factor for ACLR revision is excessive posterior tibial slope. Tibial slope has a strong, linear relationship to the level of force exerted onto an ACL graft in an axially loaded knee, making excessive posterior tibial slope an independent risk factor for ACL graft failure.[106] However, a slope reducing osteotomy is not currently suggested for primary cases.

Finally, optimal patient rehabilitation is crucial to preventing ACLR revision. Unfortunately, patient-specific factors and the large variety of activities being performed by patients has made it difficult to determine an ideal timeline for returning to sport after ACLR. This topic remains poorly defined in the literature.

## Conclusion

Careful consideration of patient-specific factors such as age and activity level may influence the success of ACL reconstruction. Additional technical considerations including graft choice and fixation method, tunnel position, evaluation of concomitant posterolateral corner and high-grade pivot shift injuries, and the role of excessive posterior tibial slope may play a significant role in preventing failure.

## Disclosure

Dr Brandon J Erickson reports personal fees from Arthrex, outside the submitted work. The authors report no other conflicts of interest in this work.

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