J Med Sci 2023;43 (5):197-201
DOI: 10.4103/jmedsci.jmedsci_75_23

REVIEW ARTICLE

Risk Factors for Failures in Anterior Cruciate Ligament Reconstruction: A Narrative Review

Wen-Chun Yen[1], Zhi-Hong Zheng[1,2,3]

[1]*Department of Orthopedic Surgery, Tri-Service General Hospital, National Defense Medical Center,* [3]*Department of Orthopedic Surgery, Tri-Service General Hospital Songshan Branch, National Defense Medical Center, Taipei,* [2]*Department of Orthopedic Surgery, Hualien Armed Forces General Hospital, Hualien, Taiwan*

This article provides a narrative review of the risk factors for anterior cruciate ligament reconstruction (ACLR) failures, as well as strategies to prevent such failures. Early timing for ACLR is not a risk factor for arthrofibrosis anymore according to recent studies. Vancomycin-soaked grafts appear to decrease infection rates after ACLR and are cost-effective. Proper tunnel placement is critical for anatomic ACLR to restore knee kinematics and joint stability. The article proposes a reproducible and accurate method for tunnel positioning. Increased sagittal plane tibial slope has been identified as a risk factor for primary ACLR failure. An anterior closing wedge proximal tibial osteotomy is suggested as a viable option for reducing posterior tibial slope. The lateral extra-articular tenodesis procedure in ACLR is effective in restoring both anterior tibial translation and rotatory stability.

Key words: Anterior cruciate ligament reconstruction, lateral extra-articular tenodesis procedure, tibial slope, graft, infection, arthrofibrosis, tunnel

INTRODUCTION

Anatomic anterior cruciate ligament reconstruction (ACLR) improves knee kinematics and joint stability in symptomatic patients who have anterior cruciate ligament (ACL) deficiency or a torn ACL. According to our knowledge, reasons for ACLR failure included: repeated trauma (32%–38%), biologic failure (7%–8%, including infections), technical failure (22%–75%, >60% was femoral tunnel malposition), and combined (19%–37%) [Table 1].[1,2] Many reported failures were caused by technical errors, with femoral tunnel malposition being the most common cause. In both bone-patellar tendon-bone (BPTB) and hamstrings (HT) grafts, trauma was also the most common failure mode.[2] In this article, we reviewed articles to understand the reasons for failure in ACLR, and how to prevent it from happening again.

ARTHROFIBROSIS AND SURGICAL TIMING

The primary source for the recommendation to delay ACLR for at least 3 weeks is the landmark study by Shelbourne *et al*. This study was a retrospective review of 169 ACLR. The patients were followed for 13 weeks. Their stratification of patients was by time from injury to surgery. Group I was <8 days, Group II 8–21 days, and Group III >21 days. The authors reported a significantly increased incidence of arthrofibrosis in patients with acute reconstructions (Group I) versus those with reconstructions 21 days or longer (Group III).[3]

There is a traditional belief that reconstruction of a torn ACL in an acute setting should be delayed for at least 3 weeks because of the increased incidence of postoperative arthrofibrosis and unsatisfied clinical outcomes. The author believes that the reason for this is the "second hit" theory. If the surgery is performed in close proximity to the injury, then the body has only one "hit" from which to heal. On the other hand, if the surgery is delayed, the knee will recover from the first injury. The healing of the hemarthrosis and the restoration of motion are the results. However, the subsequent surgery is seen by the body as a "second hit" from which to begin healing again.[4]

Received: March 16, 2023; Revised: April 20, 2023; Accepted: April 21, 2023; Published: July 19, 2023
Corresponding Author: Dr. Zhi-Hong Zheng, Department of Orthopedic Surgery, Tri-Service General Hospital, National Defense Medical Center, No. 325, Sec. 2, Chenggong Rd., Neihu Dist., Taipei 114, Taiwan.
E-mail: rara540@gmail.com

How to cite this article: Yen WC, Zheng ZH. Risk factors for failures in anterior cruciate ligament reconstruction: A narrative review. J Med Sci 2023;43:197-201.

Table 1: Reasons of anterior cruciate ligament reconstruction failure[1,2]

Reasons for ACLR failure	Percentage range
Repeated trauma	32–38
Biologic failure (including infections)	7–8
Technical failure	22–75 (femoral tunnel malposition >60)
Combined	19–37

ACLR=Anterior cruciate ligament reconstruction

Table 2: Infection rate of the graft in anterior cruciate ligament reconstruction (P=0.005)[7]

The choice of graft	Total (n=11,451), n (%)	Noninfection (n=11,403), n (%)	Infection (n=48), n (%)
Autograft	9295 (81.2)	9255 (99.6)	40 (0.4)
BPTB	5306 (46.3)	5294 (99.8)	12 (0.2)
HT tendon	3798 (33.2)	3771 (99.3)	27 (0.7)
Quadriceps tendon	169 (1.5)	168 (99.4)	1 (0.6)
Allograft	2156 (18.8)	2148 (99.6)	8 (0.4)

BPTB=Both bone-patellar tendon-bone; HT=Hamstrings

Table 3: The effect of vancomycin soaking graft[9]

Type of graft	Infection rate (%)
HT autografts	1.1 (0.1 with presoaking)
BPTB autografts	0.7
Allografts	0.5
Overall	0.9

BPTB=Both bone-patellar tendon-bone; HT=Hamstrings

Table 4: The effect of vancomycin soaking graft[8,9]

Intervention	Early septic arthritis[8]	Re-rupture (nonsignificant)[9] (%)	IKDC score (P=0.049)[9] (%)
Additional soaking of graft in vancomycin solution (5 mg/mL)	0 in total 2976 patients	3.9	83.9
Preoperative IV antibiotics only	44 (2.1%) in total 2099 patients	4.7	82

IV=Intravenous; IKDC=The international knee documentation committee

Table 5: The tunnel position in single-bundle graft[11]

Femoral or tibial side	Tunnel drilling position
Femoral side	34% from posterior condyle and 33% from Blumensaat's line
Tibial side	No measurements available

Clinical contraindications for early ACLR included: Limited preoperative range of motion of the injured knee joint, persistent hemarthrosis, or <3 weeks (21 days) after the initial ACL injury.[4] Recently, Bottoni *et al*.[4] and Millett *et al*.[5] concluded that early surgical reconstruction of the ACL does not lead to loss of motion and results in excellent clinical and functional outcomes.

However, the results of these studies in a military population may not be applicable to an orthopedic practice in a community setting. The captive population and relatively rapid referrals allowed physicians to perform surgery acutely. Furthermore, in the military population, we were able to adequately prevent patients in the delayed group from returning to activities that could cause further injury to the ACL-deficient knee.[4]

When the medial collateral ligament has been injured in a combined ACL injury, it is acceptable to treat the patient with nonoperative management with a brace after ACLR.[5] In a comparative study from a multicenter orthopedic outcomes network database, early ACLR resulted in an incremental gain of 0.28 quality-adjusted life-years and a reduction in total society costs of $1572. Early ACLR should be the preferred treatment strategy from a social healthcare perspective.[6]

INFECTION

In these studies, it was found that the incidence of infection after ACLR was 0.14%–1.76%, with autografts being associated with the lowest risk of infection after ACLR when compared to allografts. However, BPTB grafts were found to be associated with the lowest infection rate when compared to HT grafts [Table 2].[7] Vancomycin-soaked grafts appear to decrease infection rates after ACLR and are cost-effective: which cost $660 per patient and reduce infection rates to below 0.014%.[8,9] In the study conducted by Naendrup *et al*., they found that in 2976 patients who received additional perioperative soaking of the graft in a vancomycin solution (5 mg/ml) compared to 2099 patients who received preoperative intravenous (IV) antibiotics only, early septic arthritis was 0 in the vancomycin soaking group and 44 (2.1%) in the control group.[8] The overall infection rate was 0.9% in Rodriguez-Merchan and Ribbans who reviewed 68,453 ACLRs. HT autografts had an infection rate of 1.1%, BPTB autografts had an infection rate of 0.7%, and allografts had an infection rate of 0.5%. The infection rate was reduced to 0.1% with presoaking of HT autografts [Table 3]. It was concluded that presoaking of HT autografts had a 10-fold reduction in the incidence of infection. They also evaluated the effect of vancomycin soaking on re-rupture rates and functional outcomes. The minimum follow-up was 5 years. 4.7% experienced re-rupture with preoperative IV antibiotics alone (the control group) and 3.9% with preoperative IV antibiotics combined with vancomycin soaking (the study group) (not significant). The The international knee documentation committee score (IKDC

Table 6: The tunnel position in single-bundle graft[11]

Femoral or tibial side	AM tunnel position	PL tunnel position
Femoral side	22.75% from posterior condyle and 23.23% from Blumensaat's line	32.48% from posterior condyle and 49.96% from Blumensaat's line
Tibial side	35.09% from anterior tibial edge	47.32% from anterior tibial edge

AM=Anterior-medial; PL=Posterior-lateral

Table 7: The pearls of anterior closing wedge proximal tibial osteotomy[15]

Pearls	Pitfalls
Allows the surgeon to fluoroscopically access the osteotomy without removing it by using a radiolucent retractor to protect the posterior neurovascular structures	Nonparallel cut may result from lack of aiming device and osteotomy guide
To ensure proper closure and minimize the risk of tibial fracture, the closing wedge osteotomy should be performed slowly using passive force	Posterior tibial cortex fracture risk
Allows fixation of the closing wedge osteotomy prior to refixation of the tibial tubercle using multiple staples	Concomitant osteotomy of the tibial tubercle is required
Live fluoroscopic use of curette to complete osteotomy	Relying on oscillating saw alone to complete anterior resection may result in posterior cortical penetration and hinge fracture
To allow for proper posterior hinge, the closing wedge osteotomy cut must include the entire medial and lateral cortex	Osteotomy based on measured anterior cortical resection with freehand pins converging on posterior cortex

score) was 82 in the control group and 83.9 in the study group ($P = 0.049$) [Table 4].[9]

TUNNEL POSITION

The accuracy of tunnel placement is critical in anatomic ACLR to restore the kinematics and joint stability of a knee joint. The majority of technical errors occur on the femur side: The tunnel was drilled too anteriorly and shallowly, vertically, or the Lachman test/KT-3000 result was negative, but rotational instability persisted. The technical errors occur on the tibial side: The tunnel was drilled too posterior. The preferred tibial footprint should be placed at a 2 mm medial and 5 mm posterior to the native ACL footprint. [10] Sullivan *et al*. provided a reproducible and accurate method for tunnel positioning in ACLR. The lateral radiograph of the knee was utilized intraoperatively. Femoral side: For a single bundle graft, the femoral tunnel should be drilled at 34% from the posterior condyle and 33% from Blumensaat's line [Table 5]. For a double-bundle graft, the anterior-medial (AM) tunnel should be drilled at 22.75% from the posterior condyle and 23.23% from Blumensaat's line, and the posterior-lateral (PL) tunnel should be drilled at 32.48% from the posterior condyle and 49.96% from Blumensaat's line. Tibial side: For a single bundle graft, the author had no measurements available. For a double-bundle graft, the AM tunnel should be drilled at 35.09% from the anterior tibial edge, and the PL tunnel should be drilled at 47.32% from the anterior tibial edge [Table 6]. [11]

FIXATION

According to a case series study conducted by O'Brien *et al*., 25% of suture buttons were not properly flipped during ACLR despite proper manual sensation. Correction of malpositioning is not technically demanding. The author advocates that it should be routine to confirm proper suture button flipping with a C-arm during surgery. [12]

TIBIAL SLOPE

The native average tibial slope is around 7°–10°. Increased sagittal plane tibial slope >12° has been identified as a risk factor for primary ACLR failure. [13] Samuelsen *et al*. conducted a controlled laboratory study to reveal when the tibial slope increases, there is a proportionate rise in the forces exerted on an ACL or ACLR graft. Subsequently, an increased posterior tibial slope has been associated with an increased risk of graft failure. In cases where a posterior medial meniscus root tear is present, this effect is even greater. If the slope >12°, a slope-changing osteotomy may be a viable option for individuals undergoing revision ACLR in conjunction with a medial meniscus root tear. [14] DePhillipo *et al*. demonstrated an anterior closing wedge proximal tibial osteotomy could reduce posterior tibial slope which was an effective procedure to reduce the risk of ACLR graft failure [Table 7]. [15]

ANTEROLATERAL LIGAMENT AND LATERAL EXTRA-ARTICULAR TENODESIS PROCEDURES

The anterolateral ligament (ALL) runs along the lateral outer aspect of the knee, between the femur and the tibia, and under the lateral collateral ligament. The ALL tightens when the knee is internally rotated and provides rotational stability of the knee joint. Slette *et al*. conducted a systemic review study showing that the lateral extra-articular tenodesis (LET) procedure in ACLR is effective in restoring both anterior tibial translation and rotatory stability, and decreases pivot shift clinically. [16] During the LET procedure, a femoral insertion

site should be located proximal and posterior to the lateral epicondyle. This is because it showed a lower total strain range compared with the insertion located anterior to the epicondyle, and it yielded the desired graft behavior. [17] ALL is associated with significantly reduced ACL graft failure rates. The failure rate of isolated ACLR with BPTB grafts was 2.5 times higher than HT tendon grafts with the LET procedure. Isolated ACLR with HT tendon grafts had a graft failure rate that was 3.1 times higher than HT tendon grafts with LET.[18]

Contraindication for ACLR with additional procedures such as ALL reconstruction and/or LET procedure: multiple ligament injuries of the knee joint, with collateral ligament injury, or undergoing other major concomitant procedures (e.g., high tibial osteotomy).[18] Indication for ALL reconstruction or LET procedure: a positive pivot-shift test and persistent rotatory laxity, because an ACL patient with a positive pivot test and persistent rotatory laxity has been shown to correlate with poor clinical outcomes, graft failure, and the subsequent need for revision surgery. Young patients returning to pivoting sports such as football, rugby, and basketball have been shown to have a higher rate of revision surgery.[19]

According to a randomized control trial,[19] ACLR alone had a failure rate of 11%, while ACLR with LET had a failure rate of 4%. ALL reconstruction offers advantages in biomechanics: it decreases internal rotation at flexion angle >25° and also decreases forces on ACL graft and pivot shift.[20]

THE OPTIMIZATIONS OF GRAFT?

The prospective longitudinal cohort study showed an ACLR failure rate of 2%–20% for allografts and 1%–6% for autografts at 2 years postoperatively. Younger age, higher activity level, and allograft were risk factors for the increased likelihood of ACLR graft failure.[21] The diameter of soft tissue grafts >8 mm seems to have a lower failure rate; for every 0.5 mm increase in diameter of soft tissue graft thickness, failure, and re-rupture rates seem to be 0.86 times lower. [22-24]

CONCLUSION

This article provides current concepts on risk factors and strategies to prevent ACLR failure. Technical errors, particularly femoral tunnel malposition, were found to be the most common risk factors for failure. Proper tunnel placement is critical for anatomic ACLR to restore knee kinematics and joint stability, and a reproducible and accurate method for tunnel positioning has been proposed to prevent fixation errors. Early surgical reconstruction of the ACL has been shown to produce excellent clinical and functional outcomes, but the outcome may not be suitable for military forces. An anterior closing wedge proximal tibial osteotomy can be used to reduce the posterior tibial slope. Finally, infections following ACLR are rare, with an incidence ranging from 0.14% to 1.76%, with autografts having the lowest risk of infection. A vancomycin-soaked graft procedure may reduce the rate of postoperative septic arthritis infection.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. MARS Group, Wright RW, Huston LJ, Spindler KP, Dunn WR, Haas AK, *et al*. Descriptive epidemiology of the Multicenter ACL Revision Study (MARS) cohort. Am J Sports Med 2010;38:1979-86.
2. Vermeijden HD, Yang XA, van der List JP, DiFelice GS, Rademakers MV, Kerkhoffs GM. Trauma and femoral tunnel position are the most common failure modes of anterior cruciate ligament reconstruction: A systematic review. Knee Surg Sports Traumatol Arthrosc 2020;28:3666-75.
3. Shelbourne KD, Wilckens JH, Mollabashy A, DeCarlo M. Arthrofibrosis in acute anterior cruciate ligament reconstruction. The effect of timing of reconstruction and rehabilitation. Am J Sports Med 1991;19:332-6.
4. Bottoni CR, Liddell TR, Trainor TJ, Freccero DM, Lindell KK. Postoperative range of motion following anterior cruciate ligament reconstruction using autograft hamstrings: A prospective, randomized clinical trial of early versus delayed reconstructions. Am J Sports Med 2008;36:656-62.
5. Millett PJ, Pennock AT, Sterett WI, Steadman JR. Early ACL reconstruction in combined ACL-MCL injuries. J Knee Surg 2004;17:94-8.
6. Mather RC 3rd, Hettrich CM, Dunn WR, Cole BJ, Bach BR Jr., Huston LJ, *et al*. Cost-Effectiveness analysis of early reconstruction versus rehabilitation and delayed reconstruction for anterior cruciate ligament tears. Am J Sports Med 2014;42:1583-91.
7. Marom N, Kapadia M, Nguyen JT, Ammerman B, Boyle C, Wolfe I, *et al*. Factors associated with an intra-articular infection after anterior cruciate ligament

reconstruction: A large single-institution cohort study. Am J Sports Med 2022;50:1229-36.
8. Naendrup JH, Marche B, de Sa D, Koenen P, Otchwemah R, Wafaisade A, *et al*. Vancomycin-soaking of the graft reduces the incidence of septic arthritis following ACL reconstruction: Results of a systematic review and meta-analysis. Knee Surg Sports Traumatol Arthrosc 2020;28:1005-13.
9. Rodriguez-Merchan EC, Ribbans WJ. The role of vancomycin-soaking of the graft in anterior cruciate ligament reconstruction. J ISAKOS 2022;7:94-8.
10. Pedneault C, Laverdière C, Hart A, Boily M, Burman M, Martineau PA. Evaluating the accuracy of tibial tunnel placement after anatomic single-bundle anterior cruciate ligament reconstruction. Am J Sports Med 2019;47:3187-94.
11. Sullivan JP, Cook S, Gao Y, Wolf BR. Radiographic anatomy of the native anterior cruciate ligament: A systematic review. HSS J 2015;11:154-65.
12. O'Brien DF, Fones L, Stoj V, Edgar C, Coyner K, Arciero RA. Confirming proper button deployment of suspensory fixation during ACL reconstruction. Orthop J Sports Med 2021;9:2325967120974349.
13. Dejour D, Saffarini M, Demey G, Baverel L. Tibial slope correction combined with second revision ACL produces good knee stability and prevents graft rupture. Knee Surg Sports Traumatol Arthrosc 2015;23:2846-52.
14. Samuelsen BT, Aman ZS, Kennedy MI, Dornan GJ, Storaci HW, Brady AW, *et al*. Posterior medial meniscus root tears potentiate the effect of increased Tibial slope on anterior cruciate ligament graft forces. Am J Sports Med 2020;48:334-40.
15. DePhillipo NN, Kennedy MI, Dekker TJ, Aman ZS, Grantham WJ, LaPrade RF. Anterior closing wedge proximal tibial osteotomy for slope correction in failed ACL reconstructions. Arthrosc Tech 2019;8:e451-7.
16. Slette EL, Mikula JD, Schon JM, Marchetti DC, Kheir MM, Turnbull TL, *et al*. Biomechanical results of lateral extra-articular tenodesis procedures of the knee: A systematic review. Arthroscopy 2016;32:2592-611.
17. Kittl C, Halewood C, Stephen JM, Gupte CM, Weiler A, Williams A, *et al*. Length change patterns in the lateral extra-articular structures of the knee and related reconstructions. Am J Sports Med 2015;43:354-62.
18. Sonnery-Cottet B, Saithna A, Cavalier M, Kajetanek C, Temponi EF, Daggett M, *et al*. Anterolateral ligament reconstruction is associated with significantly reduced ACL graft rupture rates at a minimum follow-up of 2 years: A prospective comparative study of 502 patients from the SANTI study group. Am J Sports Med 2017;45:1547-57.
19. Getgood AM, Bryant DM, Litchfield R, Heard M, McCormack RG, Rezansoff A, *et al*. Lateral extra-articular tenodesis reduces failure of hamstring tendon autograft anterior cruciate ligament reconstruction: 2-year outcomes from the stability study randomized clinical trial. Am J Sports Med 2020;48:285-97.
20. DePhillipo NN, Cinque ME, Chahla J, Geeslin AG, LaPrade RF. Anterolateral ligament reconstruction techniques, biomechanics, and clinical outcomes: A systematic review. Arthroscopy 2017;33:1575-83.
21. Kaeding CC, Pedroza AD, Reinke EK, Huston LJ, MOON Consortium, Spindler KP. Risk Factors and predictors of subsequent ACL injury in either knee after ACL reconstruction: Prospective analysis of 2488 primary ACL reconstructions from the MOON cohort. Am J Sports Med 2015;43:1583-90.
22. Magnussen RA, Lawrence JT, West RL, Toth AP, Taylor DC, Garrett WE. Graft size and patient age are predictors of early revision after anterior cruciate ligament reconstruction with hamstring autograft. Arthroscopy 2012;28:526-31.
23. Mariscalco MW, Flanigan DC, Mitchell J, Pedroza AD, Jones MH, Andrish JT, *et al*. The influence of hamstring autograft size on patient-reported outcomes and risk of revision after anterior cruciate ligament reconstruction: A Multicenter Orthopaedic Outcomes Network (MOON) cohort study. Arthroscopy 2013;29:1948-53.
24. Spragg L, Chen J, Mirzayan R, Love R, Maletis G. The effect of autologous hamstring graft diameter on the likelihood for revision of anterior cruciate ligament reconstruction. Am J Sports Med 2016;44:1475-81.