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OUTCOMES RESEARCH IN ORTHOPEDICS (O AYENI, SECTION EDITOR)

Etiology of Failed Anterior Cruciate Ligament Reconstruction: a Scoping Review

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Abstract

Purpose of Review Recent literature was reviewed to identify and summarize the etiology of primary anterior cruciate ligament (ACL) reconstruction (ACLR) failure reported.

Methods The databases Embase, PubMed, and Medline were searched on March 10, 2022, for English-language, clinical studies that reported on the etiology of failure of primary ACLR. The studies were systematically screened in duplicate and data abstracted.

Recent Findings Forty-three studies were identified that reported mode of failure in primary ACLR. Trauma (43 studies), technical error (11 studies), and biology (9 studies) remain the most reported etiologies of ACLR failure. A combination of causes was listed in three studies. No reported cause or "other" was listed in 22 studies.

Summary Many clinical studies fail to report etiology of ACLR failure. Level of detail provided regarding mode of failure varies widely. Trauma, technical error, and biological failure remain the leading etiologies of ACLR failure reported in recent literature. Technical error is likely underreported and a contributing factor in traumatic failures.

Keywords Anterior cruciate ligament · Reconstruction · Failure · Trauma · Technical · Biological

Introduction

Anterior cruciate ligament (ACL) rupture is one of the most common orthopedic injuries with reported incidences as high as 68 per 100 000 person years and are often treated with ACL reconstruction (ACLR) surgery [1]. In a large population study, the incidence of ACLR has seen a sharp rise from 7.5 per 100 000 persons in 1980 to 48.5 per 100 000 persons in 2015 [2]. ACLR aims to restore stability and prevent future chondral and meniscal injury. With the increase in primary ACLR, there has also been an increase in the prevalence of revision ACLR with reported rates ranging from 3 to 25% of primary reconstructions [3, 4].

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There is no consensus agreement regarding the definition of ACLR failure. Failure can be defined as graft rupture or recurrent instability (early or late), loss of motion or arthrofibrosis, extensor mechanism dysfunction, arthritis, and poor patient-reported outcomes (such as pain or inability to return to sport) among others [5•]. For the purposes of the current scoping review, recurrent instability leading to revision ACLR will be considered. The Multicenter ACL Revision Study (MARS) Group was developed to perform a multisurgeon, multicenter prospective longitudinal study to obtain sufficient subjects to allow multivariable analysis to determine predictors of clinical outcome in revision ACL surgery. The MARS group proposed a classification system for mode of ACLR failure [6]. The causes of ACLR failure can generally be divided into technical errors, biologic factors, and repeat traumatic injury. A subset of patients may also experience failure due to a combination of causes. Identifying the precise etiology of ACLR failure is critically important to properly plan revision ACL surgery. Furthermore, identifying the cause of failure is valuable so that surgeons may educate themselves regarding techniques to prevent future failure. This is especially true given the inferior patient-reported outcomes seen with revision versus primary ACLR [7]. A

systematic review of the Scandinavian knee ligament registries performed in 2019 reported revision ACLR patients had statistically significant inferior KOOS and European Quality of Life-5 dimensions (EQ-5D) compared with primary ACLR [8]. Additionally, return to sport has been demonstrated to be inferior in revision ACLR compared to primary ACLR [9] with literature demonstrating revision ACLR had a 49% return to pre-injury sport comparted to 63% in the primary ACLR [10].

The purpose of the current scoping review, therefore, is to provide an up-to-date summary regarding the most common causes of failure in ACLR surgery reported in the literature.

Materials and Methods

Identification of Studies

Online electronic databases (PubMed, Medline, and Embase) were searched for studies reporting on etiology of ACLR failure. The search included those studies that were published between January 1, 2017, and March 10, 2022. The search terms used included are as follows: anterior cruciate ligament/ACL, revision/failure, and reconstruction. Studies were eligible if they were a [1] clinical study, [2] English language study, [3] ACLR (primary or revision) with any graft type, and [4] results included cause of primary ACLR failure. The exclusion criteria included studies that did not explicitly discuss etiology of the ACLR failure, non-English studies, no full text available, cadaveric studies, biomechanical studies, book chapters, and conference papers. When multiple studies had overlapping patient populations, the most recent study was selected for inclusion.

Two reviewers (A.U., P.Y.) completed the title and abstract review screening for eligible studies independently and in duplicate. A full-text review was subsequently conducted. Disagreements were resolved through consensus discussions with the senior author (M.A.). References of included studies were screened to identify any additional studies meeting search criteria. The search strategy is outlined in Fig. 1.

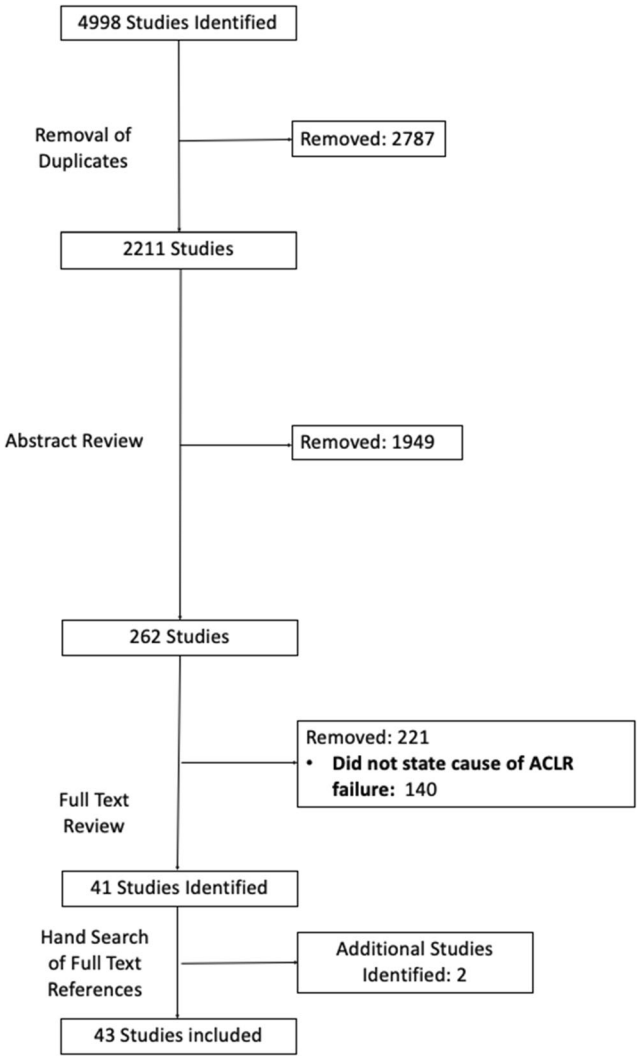

Fig. 1 PRISMA flow diagram demonstrating the search strategy for etiologies of ACLR failure

Results

Search Results

A total of 43 studies were identified with mode of failure reported on 2073 patients. Thirty-nine studies included cause of failure for primary ACLR [11–49]. Four studies included both primary and revision ACL failure but reported data separately [10, 50–52]. A description of clinical articles and reported mode of failure can be found in Table 1.

Trauma

Failure was attributed to trauma in 43 studies (1349 cases). Trauma accounted for 16.2–100% of case failure of primary ACLR in these studies. Trauma was most frequently reported related to sporting injury (20 studies, 625 cases). Pivoting sports (soccer, football, handball) were frequently listed as activity causing re-injury. Other reported causes of traumatic graft rupture reported include motor vehicle accident (4 studies, 4 cases) and workplace accident (1 study, 5 cases).

Technical Error

Technical error was the second most common mode of failure reported in recent literature (1.1–100%). Technical error was listed as mode of failure in 11 studies (258 cases). When specifics relating to technical error were reported, tunnel malposition was the most discussed error (6 studies, 180 cases).

Table 1 Clinical studies reporting etiology of failure in primary ACLR

Authors	Year	Number of failed ACLR	Graft choice	Trauma	Technical	Biological	Combination	Other/not reported
Alm et al. [11]	2020	111	NR	16.2%	83.8%	0.0%	60.4%	0.0%
Attia et al. [12]	2020	11	HT	81.8%	0.0%	0.0%	0.0%	18.2%
Batailler et al. [13]	2018	3	NR	33.3%	0.0%	0.0%	0.0%	66.7%
Boyle et al. [50]	2019	51	BTB, HT	62.7%	25.5%	11.8%	0.0%	0.0%
Byrne et al. [14]	2021	59	NR	52.5%	0.0%	0.0%	0.0%	47.5%
Christino et al. [15]	2020	90	HT (58.8%), BTB (15.3%), QT (1.2%), allograft (24.8%)	87.8%	1.1%	0.0%	0.0%	11.1%
Desai et al. [16]	2019	18	HT	100.0%	0.0%	0.0%	0.0%	0.0%
Dini et al. [17]	2021	17	Allograft (17.6%), HT (58.8%), BTB (17.6%), synthetic ligament (5.9%)	76.5%	0.0%	0.0%	0.0%	23.5%
Favreau et al. [18]	2020	14	Fascia lata autograft (85.7%), BTB (14.3%)	85.7%	0.0%	0.0%	0.0%	14.3%
Gupta et al. [19]	2019	8	BTB (12.5%), HT (87.5%)	75.0%	0.0%	0.0%	0.0%	25.0%
Hansson et al. [20]	2021	24	NR	87.5%	0.0%	0.0%	0.0%	12.5%
Iio et al. [21]	2017	21	BTB	66.7%	0.0%	0.0%	0.0%	33.3%
Imbert et al. [53]	2017	26	HT (80%), BTB (17%), QT (3%)	73.0%	0.0%	0.0%	0.0%	27.0%
Inderhaug et al. [22]	2017	38	BTB (5%), HT (95%)	23.7%	5.3%	2.6%	0.0%	71.1%
Jaecker et al. [23••]	2018	110	HT (80.9%), BTB (16.4%), QT (0.9%), allograft (1.8%)	29.1%	64.5%	6.4%	0.0%	0.0%
Jaecker et al. [24]	2018	79	HT (86%), BTB (14%)	16.5%	53.2%	11.4%	0.0%	19.0%
Lee et al. [25]	2019	87	NR	83.9%	16.1%	0.0%	78.2%	0.0%
Lefevre et al. [10]	2017	63	NR	100.0%	0.0%	0.0%	0.0%	0.0%
Mantell et al. [26]	2019	12	Allograft	100.0%	0.0%	0.0%	0.0%	0.0%
Nagai et al. [29]	2020	21	NR	0.0%	100.0%	0.0%	0.0%	0.0%
Nagaraj et al. [30]	2019	33	BTB, HT	63.6%	36.4%	0.0%	0.0%	0.0%
Ouillette et al. [31]	2019	57	BTB (29.8%), QT (5.3%), allograft (64.9%)	89.5%	0.0%	1.8%	0.0%	8.7%
Pennock et al. [49]	2017	7	HT (85.7%), HT+allograft (14.3%)	71.4%	0.0%	0.0%	0.0%	28.6%
Perelli et al. [32]	2019	2	HT	100.0%	0.0%	0.0%	0.0%	0.0%
Putnis et al. [33]	2021	9	HT	100.0%	0.0%	0.0%	0.0%	0.0%
Ragab et al. [28]	2020	59	HT (67.8%), BTB (22%), QT (1.7%), synthetic ligament (8.5%)	44.1%	30.5%	25.4%	0.0%	0.0%
Rayes et al. [34]	2022	36	BTB (22.2%), HT (8.3%)	88.9%	0.0%	0.0%	0.0%	11.1%
Redler et al. [35]	2018	118	BTB (40.7%), HT (54.2%), allograft (5.1%)	40.7%	48.3%	0.0%	0.0%	11.0%
Roach et al. [27]	2021	16	BTB (100%)	100.0%	0.0%	0.0%	0.0%	0.0%
Saper et al. [36]	2018	21	BTB	81.0%	0.0%	0.0%	0.0%	19.0%
Schlumberger et al. [52]	2017	73	HT (99%), QT (1%)	100.0%	0.0%	0.0%	0.0%	0.0%
Sonnery-Cottet et al. [37]	2021	15	BTB, HT	100.0%	0.0%	0.0%	0.0%	0.0%
Takazawa et al. [38]	2017	18	HT	83.3%	0.0%	16.7%	0.0%	0.0%
Tang et al. [39]	2020	20	HT	100.0%	0.0%	0.0%	0.0%	0.0%

Table 1 (continued)

Authors	Year	Number of failed ACLR	Graft choice	Trauma	Technical	Biological	Combination	Other/not reported
Tulloch et al. [40]	2019	15	NR	73.3%	0.0%	0.0%	0.0%	26.7%
Vincelot-Chainard et al. [41]	2021	39	QT (0.02%) HT (64.1%), BTB (28%)	92.3%	0.0%	0.0%	0.0%	7.7%
Vindfeld et al. [42]	2020	100	BTB, HT	100.0%	0.0%	0.0%	0.0%	0.0%
von Recum et al. [43]	2020	37	HT	48.6%	0.0%	0.0%	0.0%	51.4%
White et al. [44]	2021	91	BTB (23.1%), HT (65.9%), allograft (6.6%), synthetic ligament (4.4%)	31.9%	38.5%	13.2%	16.5%	0.0%
Winkler et al. [45]	2022	102	HT (42%), allograft (25%), QT (<0.01%)	67.6%	0.0%	0.0%	0.0%	32.4%
Yoon et al. [51]	2020	62	HT (12.9%), allograft (77.4%), mixed (9.7%)	48.4%	0.0%	0.0%	0.0%	51.6%
Yumashev et al. [46]	2021	218	BTB (44%), HT (38%), synthetic ligament (18%)	88.1%	0.0%	0.0%	0.0%	11.9%
Zaffagnini et al. [47]	2018	26	Allograft (100%)	65.4%	19.2%	15.4%	0.0%	0.0%
Total		2073						

Combination, multiple causes attributed to failure; *NR*, not reported; *HT*, hamstring tendon graft; *BTB*, bone patellar tendon bone graft; *QT*, quads tendon graft

One study specially discussed femoral versus tibial tunnel malposition and found femoral tunnel malposition to be more common (26 versus 13 failures). Transtibial tunnel drilling was to correlate to femoral tunnel malposition. Hardware failure was discussed as cause of ACLR failure in one study (1 case), though exact details were not given (screw pull out, suspensory fixation failure, etc.). Missed concomitant injury was reported in one study (54 cases). Specifics of missed injuries were not discussed within the study.

Biological

Biological failures were reported in 9 studies (58 cases). In those studies, biology contributed to 1.8–25.4% of failures. The most common specific biological cause of failure listed was infection (4 studies, 15 cases). Biological was also chosen as mode of failure if no traumatic injury had occurred, and no technical error was appreciated (6 studies, 43 cases).

Other/Not Reported

Twenty-two studies reported causes of failure as "other" or failed to report specific mode of failure. There were 256 cases of primary ACLR failure with no specific mode of failure identified. In many of these studies, failures were classified as "traumatic" and "non-traumatic" or "other", with no comment on technical or biological modes of failure.

Discussion

The main finding of the current study is that traumatic re-injury and technical error were the most reported modes of failure in the recent literature. Technical error was most attributed to tunnel malposition. The current study also found that details on mode of failure provided in the studies varied widely across the literature. Additionally, there perhaps exists bias given that classification of failure relied upon the surgeon/investigator's judgment.

The findings are in keeping with previous literature that report trauma as the most common etiology of ACLR failure [6, 54, 55••]. Early return to sport can be a risk factor for traumatic graft failure. One study reported that the majority of traumatic graft ruptures occurred between 6 and 9 months post injury [52]. Another study reported that 20.8% of failures occurred less than 6 months post-surgery and 52.3% of failures occurred less than 1 year post-surgery [15]. This is in keeping with previous literature demonstrating delay in return to sport reduces risk of graft failure. A 2016 study demonstrated that for every month that return to sport was delayed, until 9 months post-surgery, the rate of re-injury was reduced by 51% [56].

Technical error accounted for the second most common mode of ACLR failure. Non-anatomic tunnel placement was frequently reported as the error causing failure. Accurate tunnel placement is vital to the success of ACLR. Inadequate reproduction of the native ACL anatomical footprints may increase graft stress and produce unwanted modifications in graft length and/or tension [57, 58]. Though specifics of tunnel malposition were not frequently reported in the recent literature, previous studies have demonstrated anterior and vertical tunnel placement to be a risk factor for ACLR failure. Anterior or posterior placement can cause limited motion and laxity in flexion or extension, respectively. Vertical tunnel malposition can result in rotational instability and gradual elongation of the graft [5]. A recent study examined femoral tunnel position with relation to patient-reported outcome measures and ACLR failure [59••]. Seventy-eight patients were followed for a mean of 11.4 years. There were 16 reported failures. In 15 of the ACLR failures, the femoral tunnel aperture was placed too anterior. The study identified a safe zone located at the most posterior 35% of the femoral condyle parallel to Blumensaat's line [59••]. A 2012 study specifically looking at femoral tunnel malposition had similar findings. In the study of 460 revision ACLR, 276 patients had technical error as the cause of failure. Femoral tunnel malposition was a contributing factor in 47.6% of all cases. It was deemed the sole cause of failure in 25.4% of cases. The femoral tunnel was deemed too vertical in 35.9% of cases, too anterior in 29.9% of cases, and too anterior and vertical in 26.5% of cases [60].

A 2020 systematic review specifically examined mode of failure in ACLR [55••]. In the study of 24 cohort studies and 4 registry studies, it was reported that the most common mode of failure in ACLR was trauma (38%) at a mean follow-up of 4.2years. This was followed by technical errors (22%), combined causes (19%), and biological failures (8%). Technical error was described as tunnel malpositioning (96%), graft fixation failure (2%), tunnel enlargement (1%), missed concomitant injury (1%). The study also concluded that technical error played a contributing role of 17% of all failures. Femoral tunnel malposition was again reported as the most common cause of technical error. The authors also noted that transtibial tunnel drilling was associated with increased rate of femoral tunnel malposition [55••].

As noted in the above systematic review, technical errors are not always assessed in studies and the incidence of technical causes for graft failure may be higher [55••]. Technical errors were reported more commonly in studies looking specifically to assess tunnel position radiographically. Additionally, technical errors may be present in traumatic failures thus potentially contributing to failure but not accounted for. One study reported that in the traumatic failure group, non-anatomic femoral tunnel position was noted in 62.5% of cases, while non-anatomic tibial tunnel position was noted in 37.5% of cases [23••].

Reporting on biological failure varied significantly. This may be in part due to a lack of clear definition of biological failure. Biological failure was reported when there was a history of a postoperative knee infection and in cases in which no mechanism of trauma or technical cause could be identified. In this instance, biological failure was used as a diagnosis of exclusion. Other possible causes of biological graft failure include lack of graft incorporation, graft rejection, and a failure in the ligamentization process [61].

An important finding of the current review is that etiology of failure is infrequently reported. During full-text review, 140 studies were excluded due to lack of reporting on etiology of failure. Secondly, when etiology was reported, it was done so with varying levels of detail. Some studies reported only on traumatic re-ruptures or traumatic versus "non-traumatic" failures. In this instance, non-traumatic could be attributed to technical or biological or a combination of causes. Additionally, the purpose of many clinical studies was not to report failure specifically thus potentially not accurate. Finally, classification of failure relies upon the surgeon and/or investigator's best judgment. Previous study of classification of failure has demonstrated that it is associated with low inter- and intraobserver reliability, even with experienced surgeons [62].

Conclusion

Accurate classification of ACLR failure remains a challenging but important task. While many studies do not list etiology of ACLR failure, trauma and technical error remain the leading etiologies of ACLR failure reported in recent literature. Tunnel malpositioning (specifically femoral tunnel) is the most reported technical error. Technical error is likely underreported and a contributing factor in traumatic failures.

Declarations

Conflict of Interest The authors of this paper each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- •• Of major importance

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