



# ACL Reconstruction with Augmentation: a Scoping Review

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## Abstract

**Purpose of Review** We reviewed the recent literature to identify and summarize new research surrounding anterior cruciate ligament reconstruction (ACLR) with augmentation in the form of additional soft tissue procedures or biologic augmentation. Specifically, we wanted to review the failure rates of these procedures in both the primary and revision settings.

**Methods** The databases Embase, PubMed, and Medline were searched on August 13, 2018, for English-language studies that reported on the use of anterior cruciate ligament reconstruction (primary and revision) in conjunction with either soft tissue or biologic augmentation. The studies were systematically screened and data abstracted in duplicates.

**Recent Findings** Advancements in ACLR surgery, including soft tissue augmentation, may decrease primary and revision surgery failure rates for high-risk patients. The use of biological augmentation has shown histologic and radiographic improvements. These differences, however, have failed to be statistically significant and have not resulted in clinically significant improvements in outcome.

**Summary** The limited body of evidence has shown that the addition of soft tissue procedures may in fact lower the risk of graft re-rupture rates particularly in revision or in patients wishing to return to high-risk sports and activities. The use of biologic augmentation although promising in laboratory studies has yet to show any significant clinical results and therefore will require further studies to prove any efficacy.

**Keywords** Anterior cruciate ligament · Anterolateral ligament · Lateral tenodesis · Platelet-rich plasma · Lemaire

## Introduction

Anterior cruciate ligament reconstruction (ACLR), when done correctly, is a surgical procedure with successful outcomes. While the majority of patients who undergo ACLR will have good to excellent results, a subset of patients are at a higher risk for graft failure. For those that require revision surgery, the second operation often fails. Anterior cruciate ligament injuries account for 50% of knee ligament injuries for high

school-aged adults. The incidence of native ACL rupture is 0.081 and 0.05 per 1000 females and males, respectively [1]. Reconstruction of the ACL restores normal-joint kinematics provides stability and prevents secondary injury to the articular cartilage, menisci, and associated ligaments of the knee. Despite the excellent result that most patients have with ACLR, graft re-rupture still occurs in 1.7–7.7% of primary repairs and 2.0–5.4% of revision ACLR [2]. Current research in ACL reconstruction surgery intends to discover new methods to either accelerate the rehabilitation phase post-surgery or decrease graft failure rates.

The process of graft healing in ACLR involves the osteointegration of the graft-tunnel interface on both the tibial and femoral sides, as well as the remodeling of the intra-articular component of the graft (referred to as ligamentization). When compared to the native ACL entheses, the graft heals with an inferior fibrovascular scar tissue. Biologic augmentation seeks to either accelerate scar tissue formation or alter the integration to one that more closely resembles the native ACL entheses. Theoretically, this allows for more aggressive rehabilitation and a faster return to pre-injury activity levels [3].

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The “Segond” fracture was first described in 1879 as an avulsion fracture of the proximal lateral tibia seen on X-ray. This radiographic marker has become pathognomonic for significant knee injury involving the ACL [4]. In addition, anatomical studies have identified this fracture’s location as the tibial attachment site of the anterolateral ligament of the knee, which contributes to the knee’s rotatory stability. Injury of the anterolateral ligament (ALL) in combination with the ACL accounts for the pivot-shift phenomenon in knee instability found on clinical examination [5]. Despite surgical repair of both ligaments, residual rotatory instability of the knee persists in 11–30% of patients. This form of instability places higher stresses on the graft, ultimately leading to increased rates of graft re-rupture [6]. The use of additional soft tissue augmentation aims to eliminate residual rotatory instability and therefore lower the risk of graft re-rupture rates upon returning to high-risk activities or sports.

## Materials and Methods

### Identification of Studies

Two reviewers searched the online electronic databases PubMed, Medline, and Embase for studies regarding ACLR with augmentation using soft tissue procedures or some form of biologic enhancement in the clinical setting. The search encompassed studies published between 1 January 1946 and 13 August 2018. The search terms utilized included anterior cruciate ligament (ACL), anterolateral ligament (ALL), lateral tenodesis, platelet-rich plasma (PRP), and Lemaire. Studies were eligible if they met the following inclusion criteria: [1] human clinical trial, [2] English language studies, [3] ACL reconstruction, and [4] had documented outcomes in the form of ACLR graft failure or residual laxity. The exclusion criteria included cadaveric studies, conference papers, book chapters, review articles, and technical reports.

Two reviewers initially completed the title and abstract review screening for eligible studies independently and in duplicates. Following this, a full-text review was conducted and the references for each article were hand-searched for other eligible studies. Disagreements were resolved through consensus discussions with the senior author. The search strategy is outlined in Fig. 1.

## Results and Discussion

A search of the literature was carried out using Embase, Medline, and Pubmed using the keyword search terms. The search was then narrowed to include only papers published from the year 2015 to the present to encompass the most recent body of evidence in the clinical setting. A total of 12

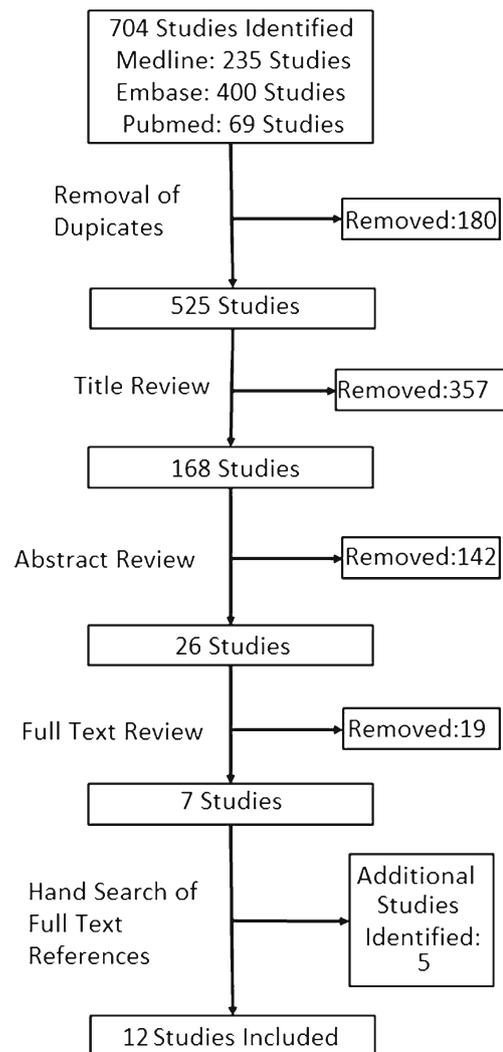


Fig. 1 Flow diagram describing systematic review of literature

studies were identified. Their characteristics and demographics are included in Table 1.

We identified four randomized control trials (RCTs), three prospective cohort studies, one retrospective cohorts, one combined prospective and retrospective cohort, and two case series. Six of the studies examine the effects of combined ACL with ALL reconstruction; three examined the combined procedure of ACL with LET reconstruction. Two of the studies examined the effects of PRP on donor site BTB pain and healing. Finally, only a single study examined the use of PRP on ACL graft healing. In total, there were 2132 patients who underwent ACL reconstruction surgery with a mean age range of 22.4–29.9 years. Follow-up ranged from intra-operative findings to 8.7 years post-operatively.

### ACL with Soft Tissue Augmentation

ACLR with soft tissue augmentation includes anatomic (reconstruction of the ALL in its anatomic position using auto-

**Table 1** Study characteristics

Study	Study type	LOE	Intervention	Control group	Sample size	Mean age	Mean follow-up (month)	Outcome measures
Ibrahim et al. (2017) [7*]	RCT	2	ACL + ALL recon	ACL	103	26	27	A
Thaunat et al. (2017) [8]	Case series	4	ACL + ALL recon	None	548	24.3	24	B
Sonnery-Coffet et al. (2017) [9]	Cohort study	2	ACL + ALL recon	ACL (BTB or 4HT)	502	22.4	38.4	B,C,D
Louis et al. (2017) [10]	Retrospective and prospective Cohort	4	Revision ACL + ALL	None	349	28.5	Prospective 6–24 Retrospective 8.7 years	A,F,G
Zaffagnini et al. (2017) [11]	Case series	4	ACL + LET	None	52	25.5	20 years	A,D,E
Imbert et al. (2017) [12]	Prospective cohort	4	ACL + ALL recon	None	478	28	36	A,G,H
Imbert et al. (2015) [13]	Prospective cohort	3	ACL + ALL recon	None	32	NA	Intra-operative	F,G
Panisset et al. (2017) [14]	Prospective cohort	4	ACL + LET	None	392	29.9	12	A,B,C,D,E,F
Alessio-Mazzola et al. (2018) [15]	Retrospective cohort	4	ACL + LET	None	24	23.8	42.2	A,B,C,D,E,F,G
Walters et al. (2018) [16]	RCT	2	PRP in donor site BTB	ACL	50	30	24	D,I
Azcarate et al. (2015) [17]	RCT	2	ACL + PRP	ACL	150	24.3	26.9	A,D,G
Seijas et al. (2015) [18]	RCT	1	PRP in donor site BTB	BTB	43	NA	24	I

The level of evidence (level I to IV) was assigned to each abstract using the American Academy of Orthopedic Surgeons classification scheme (e.g., randomized controlled trials were deemed level I evidence and case series or reports were deemed level IV evidence). Measures are as follows: (A) KT-1000, (B) re-operation, (C) re-rupture, (D) IKDC, (E) lysholm, (F) lachman, (G) pivot shift, (H) OA, and (I) advanced imaging

LOE, level of evidence; RCT, randomized control trial; ACL, anterior cruciate ligament; ALL anterolateral ligament; BTB, bone-patellar-bone; LET, lateral extra-articular tenodesis; PRP, platelet-rich plasma

allograft) and non-anatomic in the form of lateral extra-articular tenodesis.

### Anterolateral Ligament Reconstruction

Gaunders et al. was able to show that in 552 patients with ACL disruption the Segond fracture was only present in 6% of the injuries. Second is that the fracture healed in 90% of patients at follow-up. Their conclusion was that a patient with Segond fracture is at no higher risk for ACLR graft failure compared with those without the fracture. Also, if the Segond fracture is present, it may be ignored at the time for ACLR, and repair may be attributed to its high union rate after restoring the secondary restraint for rotatory stability [19].

The SANTI group in 2018 published a prospective study of 502 patients undergoing ACLR. Included were 105 bone-patellar-bone (BTB) patients, 176 quadrupled Hamstrings (4HT) patients, and 221 patients requiring hamstring with anterolateral ligament (HT + ALL) grafts. At a mean follow-up of 38.4 months, the graft rupture rates were 10.77% for 4HT grafts, 16.77% for BTB grafts, and 4.13% for HT + ALL grafts. The study's conclusion was that the HT + ALL grafts had 2.5 times less failure than BTB (hazard ratio (HR), 0.393; 95% CI, 0.153–0.953) and 3.1 times lower than 4HT (HR, 0.327; 95% CI, 0.130–0.758). In addition, the HT + ALL group of patients had greater odds of returning to the pre-injury level of activity when compared to 4HT but not BTB [9].

A separate study by the SANTI group, investigated the failure rates of the HT + ALL procedure. The overall re-operation rate for the 548 patients was 14%. Of the 77 patients requiring re-operation, only 14 (2.6%) were for ACLR graft failure. The conclusion from this paper was that HT + ALL reconstruction was NOT associated with higher risk of infection, postoperative over constraint or loss of motion [8].

Combined ACLR with augmentation of soft tissue structures (such as an extra-articular lateral tenodesis or reconstruction of the anterolateral ligament) increases knee stability. Recent studies demonstrated that ACLR with augmentation can decrease the graft failure rate in high-risk patients including those returning to pivoting sports or those with high-grade pivot shifts pre-operatively.

### Lateral Extra-Articular Tenodesis Procedures

Lateral extra-articular tenodesis (LET) is a term used for the non-anatomic reconstruction of the secondary lateral restraints of the knee. LET encompasses numerous surgical techniques: Lemaire, Ellison, MacIntosh, Arnold-Coker, Losee, and Andrews procedures [6]. All of these procedures were initially introduced to control anterior tibial translation. However, they were criticized due to high failure rates (greater than 50%) [20]. As a result, isolated LET procedures are no longer recommended. Combination procedures, however, have proven

to be more effective, decreasing stress on the ACL graft by 43%. This can lead to fewer graft failures [21]. Therefore, Cerciello et al. recommended ACL + LET procedures be considered in patients with any of the following criteria: major 3+ pivot shift and intact medial meniscus and collateral, patients under 25 years, genu recurvatum > 10, patients in contact sports, patients with generalized ligamentous laxity, and finally cases of revision ACL with no clear reason for the failure [6].

A retrospective review of studied 24 high-level soccer players who suffered an atraumatic ACLR graft rupture and subsequently underwent revision ACLR + LET for stabilization. Post-procedure anterior-posterior laxity was significantly reduced. Twenty-two (91.7%) had a negative pivot shift and only two (8.3%) had a residual glide. Two failures occurred; one was caused by a new traumatic event and a second by septic arthritis. The rate of return to sport (at the same level) was 91.7% and the average time from surgery was an average of 9.2 months [15]. Guzzini et al. [22] showed similar results in 16 elite female soccer players undergoing primary ACLR + LET. At an average of 72.6 months follow-up, no patients experienced complications or graft rupture, and all had returned to the pre-injury level of sport.

Early criticisms of the LET procedures included the concept that it may lead to over-constraint and subsequent altered tibiofemoral contact pressures. These changes could result in early arthritic changes. Zaffagnini et al. [11] presented a series of 52 patients who had “over the top” ACLR + LET procedure. All had a minimum of 22 years follow-up. Of the 52 patients, only one was reported to have graft rupture. Interestingly, radiographic analysis showed no significant change in the medial and lateral joint line space compared to the uninjured limb. This study, therefore, contradicted previous claims of arthritic changes following ACLR + LET. With more data collection and better reporting, we hope to see robust studies on the clinically relevant complications of ACLR + LET procedures.

In summary, ACLR with soft tissue augmentation can largely be broken down into the anatomic reconstruction of the anterolateral structures and non-anatomic in the form of lateral extra-articular tenodesis procedures of which there are many. All of the aforementioned procedures, regardless of technique, aim to improve rotatory stability of the knee joint. No single procedure has been declared superior, and there remains no current consensus regarding the indications of ACLR augmentation. A recent resurgence in the interest of ALL and its importance in rotatory stability of the knee will result in several new publications in the coming years.

### ACL with Biologic Augmentation

A handful of clinical studies have investigated the effects of biologic augmentation of ACLR, which includes autologous

growth factors such as platelet-rich plasma, fibrin matrix, platelet-leukocyte gel, and autologous platelet concentration [23••]. The authors only reviewed trials which used human subjects, therefore focusing on clinical relevance.

### Platelet-Rich Plasma

Platelets contain growth factors that stimulate local cellular proliferation and differentiation. For this reason, there has been a surge in clinical research surrounding the use of PRP in musculoskeletal injuries.

The use of PRP in ACLR can be administered in several different ways to exert the desired effect. This coupled with the variety of PRP preparations on the market makes interpretation of previous clinical studies difficult to compare. In the current literature, however, the primary focus of PRP application to ACLR surgery seems to involve in the following: (1) harvest site healing, (2) tendon graft maturation, and (3) osteointegration [24].

Donor site morbidity can be a major source of pain post-operatively in ACLR. Three studies have examined the effectiveness of intra-operative PRP application to the BTB donor site. Two of these studies were randomized control trials from 2012. They both showed lower post-operative pain scores in the first 6 to 12 months, but no statistical difference at final follow-up. With respect to donor site healing, both studies noted better bone healing and smaller tendon gaps, although this difference was not statistically significant [17, 18]. A more recent 2018 RCT by Walters et al. [16] examined IKDC scores at 3, 6, 12, and 24 months as well as radiographical indices using MRI to assess healing at 6 months. They found no difference in kneeling pain, pain with activities of daily living (ADLs), or International Knee Documentation Committee (IKDC) scores at any point and no difference in healing indices by MRI between groups. All of these studies were poorly powered (less than 50 patients each). In future studies, larger sample sizes would be required to identify clinically significant differences between groups.

Osteointegration and graft maturation of hamstring autograft can be divided into four phases: the inflammatory phase, proliferative phase, matrix synthesis, and matrix remodeling (occurring around the 10-month post-operative) [25, 26]. A 2015 systematic review identified six studies measuring graft maturation using MRI. Four of these studies concluded PRP was beneficial while two showed no difference. Using PRP was shown to decrease time of graft maturation from 362 to 179 days [27]. In addition, studies that performed second-look arthroscopy have noted “superior tissue quality” and a synovial-type tissue enveloping the graft macroscopically [27, 28]. Despite these observed differences, PRP usage was not shown to be clinically superior.

Of the studies that have reported on clinical outcomes, all but one concluded no difference at 6- and 24-month follow-up

between PRP and the control group, regardless of injection timing or location [17, 29–32]. Only a single study by Magnussen et al. detected a difference in post-operative effusion 1–2 weeks after surgery. This difference, however, became insignificant at 8 weeks post-operative [33].

### Biomaterials

For the purposes of this review, we have chosen to only include research found in human clinical trials. The future of biologic augmentation, however, is currently being studied in animal models and includes the following sub-groups: biological fixation methods, biological coatings, synthetic bone substitutes, and other osteoconductive materials.

The use of biomaterials encompasses the sub-groups: biological fixation methods, biologic coatings, synthetic bone substitutes, and other osteoconductive materials. The only clinical study to examine the use of bone substitute in graft healing was performed by Iorio et al. A total of 40 patients were randomized to receive 4HT ACLR or a nanohydroxyapatite bone-based graft in combination with ACLR. Similar to many of the biologic studies in the short-term evaluation, there were superior radiologic outcomes but at the final follow-up there was no difference in the radiological or clinical outcomes.

The future of biologic augmentation is currently being studied at length in animal models. One main area of focus is the use of different biomaterials to enhance graft-tunnel interface healing. Studies have shown materials such as chitin [34], bioglass [35], gelatin [36] and hyaluronic acid polystyrene sodium sulfonate [37], and collagen matrix [38]. Pre-clinical research is also being conducted on the use of stem cells, gene therapy, alternate autologous tissues, and alterations in environment [23••].

### Conclusions

Biologic augmentation of ACLR is largely in the pre-clinical phase of research. A small number of studies have investigated a variety of biologic augmentation strategies. Currently, the most studied is the use of platelet-rich plasma (PRP). The research fails to show significant clinical benefit, therefore does not support the routine use in ACLR.

The review of current literature shows soft tissue augmentation in combination with ACLR may decrease graft failure rates in the high-risk patients. While the use of biologic augmentation with PRP has proven safe, the study results are controversial. There is some evidence that the use may promote graft harvest site healing, promote graft maturation, and reduce tunnel widening in the short term. However, these results failed to yield clinically significant differences. There

remains a need for more studies with larger sample sizes and longer follow-up periods.

## Compliance with Ethical Standards

**Conflict of Interest** Michael D. Riediger, Devon Stride, Sarah E. Coke, Adrian Z. Kurz, and Andrew Duong each declare no potential conflicts of interest.

Olufemi R. Ayeni is on the speaker's bureau for Conmed and Smith & Nephew and is a section editor for *Current Reviews in Musculoskeletal Medicine*.

**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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