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Good mid-term outcomes and low rates of residual rotatory laxity, complications and failures after revision anterior cruciate ligament reconstruction (ACL) and lateral extra-articular tenodesis (LET)

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Abstract

Background Residual rotational instability remains a controversial factor when analysing failure rates of anterior cruciate ligament (ACL) reconstruction. Anatomical and biomechanical studies have demonstrated a very important role of anterolateral structures for rotational control. Revision ACL is considered one of the main indications for a lateral extra-articular tenodesis (LET). Yet, few series evaluating these procedures are published.

Purpose To perform a systematic review of studies that assessed outcomes in patients treated with revision ACL surgery associated with a lateral extra-articular procedure.

Study design Systematic review.

Methods A comprehensive literature search was performed in February 2018 using PubMed, Scopus, Web of Search and Cochrane. Inclusion criteria were series of ACL revision reconstructions associated with lateral extra-articular procedures. Clinical outcomes (Lysholm, subjective IKDC, KOOS, Cincinnati and WOMAC), joint stability measures (Lachman test, pivot-shift, arthrometer assessment and navigation assessment), graft type, reported chondral and meniscal injury, radiographic outcomes, complications and failures were recorded. Articles were assessed for level of evidence and methodology using a modification of the ACL Methodology Score (AMS) system.

Results Twelve studies met the inclusion criteria out of the 231 abstracts; 9 retrospective evaluations, two prospective cohorts and one combination of two populations (a retrospective and prospective series). A total of 851 patients evaluated with a mean age of 28.8 years (range 16–68 years) and a weighted mean follow-up of 4.9 years (range 1–10 years). The mean time from primary ACL reconstruction to revision was 5.3 years (reported in 7 studies, including 710 patients). The Lysholm, IKDC, and KOOS scores indicated favorable results in studies that reported these outcomes. Objective evaluations reported 86% objective A and B IKDC results, 2.6 mm mean side-to-side arthrometric difference and 80% negative pivot-shift. About 74% of patients returned to their previous sport (evaluated in six studies). Few studies reported radiological evaluation. Fifty-nine complications (8.0%) and 24 failures (3.6%) were reported. The mean modified ACL Methodology Score was 55.5 (range 32–72).

Conclusion Good mid-term results were obtained for combined revision ACL reconstruction and lateral extra-articular procedures. Despite the fact that in clinical practice LET are a common indication associated with revision ACL, there are no high-level studies supporting this technique.

Level of evidence IV.

Keywords Revision anterior cruciate ligament · Anterior cruciate ligament re-rupture · Lateral extra-articular plasty · Lateral tenodesis · Anterolateral ligament

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Extended author information available on the last page of the article

Introduction

According to the published literature the failure rate for primary anterior cruciate ligament (ACL) reconstruction is 3–5% and it increases to 15–20% for revision ACL [15, 16]. Residual rotatory laxity is a possible cause for the higher failure rate [14].

Following the description by Claes et al. of the anterolateral ligament (ALL), there has been much renewed interest in the "Anterolateral Complex" of the knee [6]. This has been supported by a growing body of literature attributed to the ALL and in particular the biomechanical role in controlling rotational laxity, internal rotation and the pivot-shift [17, 23, 27, 34, 37, 48]. For these reasons, extra-articular augmentations and lateral extra-articular tenodesis (LET) procedures have been proposed as adjunctive procedures in the setting of revision ACL reconstruction, with the aim to decrease rotational laxity and in the hope that this will reduce the failure rate.

There is a consensus amongst many authors that the main indication for LET is in the context of revision ACL surgery [33]; however, the evidence for this practice is limited with only a few case series having been reported in the literature [2, 41, 49].

In the very recent years, several authors have reported their results of combined intra and extra-articular procedures carried out in the revision setting [4, 11, 26, 27, 32, 38, 45]. However, the results in terms of objective outcomes, subjective clinical scores, complications and re-ruptures, have never been investigated in a systematic manner, making aware the clinicians of the general expectation after such combined procedure. Therefore, the main purpose of the present study was to perform a systematic review of the literature to evaluate the outcome of revision ACL reconstructions carried out in conjunction with lateral extra-articular procedures. The hypothesis was that the combined procedure is safe and likely to produce good clinical results, especially in terms of residual rotatory laxity and failure rates.

Materials and methods

A systematic review of PubMed, Scopus, Web of Search (WOS) and Cochrane was performed on February 2018 by two independent reviewers (J. P. Z. and A. G.) with the aim to identify all the relevant studies which have evaluated ACL revision surgery carried out with a concomitant LET. The bibliographies of all included studies were then further searched for any other relevant articles. The search was performed using the following terms, combined with the Boolean operators "AND" or "OR": "Revision OR re-rupture" AND "ACL OR anterior cruciate ligament" AND "plasty OR tenodesis OR extra-articular OR augmentation OR anterolateral". The titles and abstracts were also independently screened by the two reviewers, and the full-text of the relevant articles was obtained. The inclusion criteria were for articles presenting clinical and/or functional outcomes of Revision ACL reconstruction combined with lateral extra-articular plasty or reconstruction. No exclusion was performed based on language, follow-up or for surgical technique either for intra or for the extra-articular reconstruction carried out. Our exclusion criteria included and any articles which included: Posterior Cruciate Ligament, Medial or lateral ligament or Posterolateral ligament surgery; any biomechanical or radiological studies; any surgical technique papers or ex vivo analysis (cadaveric, histologic or anatomic) and case reports.

Where any relevant studies that included revision ACL combined with lateral extra-articular procedures were identified the respective authors were contacted to obtain the data of the specific patients subgroups. Where we identified any small case series from similar authors and to avoid any possible overlap, only the series with larger sample sizes and longer follow-up were included. We then went on to evaluate the references for all included studies and identified any other relevant articles. Where there were any differences of opinion between the two reviewers with regards to the importance and relevance of any studies identified a further discussion took place to find an agreement. A third reviewer was used to resolve any residual difference in opinion.

Data extraction and synthesis

The information that was extracted from the original studies included: demographic data, follow-up, surgical techniques for intra and extra-articular reconstructions, and finally meniscal and cartilage status. The mean values of the subjective clinical scores (Lysholm, subjective IKDC, KOOS, Cincinnati and WOMAC) were extracted. The objective clinical evaluation was performed by extracting the IKDC, pivot-shift, arthrometric evaluation and KT1000 measurements. The number of patients with knee function classified as normal (IKDC category A), nearly normal (IKDC category B), abnormal (IKDC category C) and severely abnormal (IKDC category D) were obtained. For knee laxity, the mean side-to-side difference and SD measured in millimeters (mm) together with the number of patients with side-to-side difference of < 3 mm, 3–5 mm and > 5 mm were extracted. The number of patients with pivot-shift tests classified as normal (negative), nearly normal (1 +), abnormal (2 +) or severely abnormal (3 +) were also extracted. Radiographic outcomes were obtained and reported in a narrative manner. Finally, complications and failures that occurred

during the follow-up period were noted. In particular we identified any cases of traumatic re-rupture and of repeated revision preformed or scheduled. Due to the inconsistent reporting of clinical evaluation, objective criteria such as the Lachman test, pivot-shift of objective IKDC were not considered as failure criteria in this review. Data were extracted and tabulated in an Excel database by one author (J. P. Z.).

Level of evidence and methodological assessment

The selected articles were assessed for level of evidence and methodology using a modification of the ACL Methodology Score (AMS) system as described by Brown et al. [3]. This performed a modification from the original Coleman Methodology Score (CMS) for us to be able to analyze relevant ACL publications. As well as carrying out an analysis of ACL revision surgeries, we also performed a modification for meniscal and cartilage intraoperative results, as well as the type of surgery or associated procedures performed to fit with ACL revision results [41]. As a result, the inferior percentage cutoff for patients who underwent a meniscus or cartilage procedure was increased from 10 to 30%, which is the minimum incidence reported for revision ACL procedures [41]. As the highest percentage of partial meniscectomies or cartilage procedures described after revision surgeries was 70%, the median value (50%) was used to avoid a ceiling or floor effect (Online Appendix 1).

Statistical analysis

Due to the lack of randomized controlled studies (RCT) and case–control studies, a meta-analysis was not performed. An average pooled mean was calculated for the patients' age, follow-up and for the clinical scores that were reported in more than three studies. Categorical variables were pooled as proportions of the whole patients and percentages.

Results

The systematic search generated 85 abstracts from PubMed, 115 from Scopus, 21 from WOS and 10 from Cochrane. Out of the 231 abstracts, 187 were not relevant and 30 studies were excluded because they did not meet the inclusion criteria (6 anatomic studies [5, 20, 25, 40, 42, 46], 3 biomechanical studies [23, 34, 37], 5 reviews [9, 14, 15, 29, 44], 8 surgical techniques [12, 13, 24, 30, 31, 33, 35, 43] and 8 primary ACL reconstructions [3, 10, 18, 19, 21, 22, 36, 47, 50]). Of the remaining 14, 2 were further excluded: one [8], because the authors published on the same population with recent results and the other [7] because it only analyzed intraoperative tibial translation and internal rotation using a navigation system and had no clinical outcomes. Twelve articles met the inclusion criteria and were therefore included in the systematic review and analyzed (Fig. 1). Nine studies were retrospective evaluations (one of those seven was a multi-centric study), two were prospective cohorts and one combination of two populations (a retrospective and a prospective series evaluated in the same study). The mean Modified AMS was 55.5, ranging from 32 to 72 (Table 1); the items that most affected the overall quality of the studies were: meniscal and cartilage status, the number of patients evaluated in each series and the retrospective type of analysis.

Demographic results (Table 1)

A total of 851 (range 8–349 patients) patients were evaluated. Six of the articles where from Italy, four from France, one from Argentina and one from Australia. The weighted mean of patient's age at revision ACL reconstruction was 28.8 years (range 13–68 years); 77% of patients were men and the weighted mean follow-up was 4.9 years (range 1–10 years). The mean time from primary ACL reconstruction to revision reported in seven studies [1, 11, 28, 38, 39, 41, 45] which included 710 patients was 5.3 years.

Surgical techniques (Table 2)

Most of the 688 patients of the 11 studies where graft and technique for revision ACL was reported had utilized either the IPSI or contra-lateral hamstrings (55.6%), followed by patella tendon grafts (37.4%) and finally allografts (7%). Several different techniques were used for the LET. These

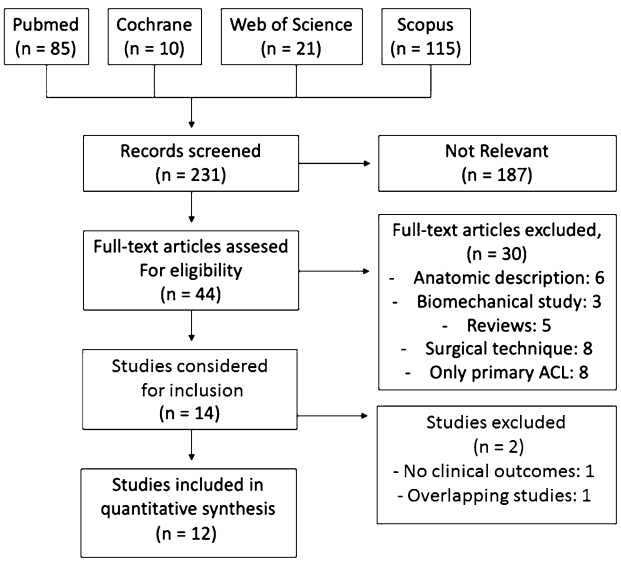

Fig. 1 PRISMA flow chart

Table 1 Summary of the demographic characteristics of the included studies

Author	Year	Journal	Country	Design	Period	LOE	AMS	Patients	Age	Follow-up (years)	Time ACL to rev (years)
Ferretti et al.	2006	*JBJS Am*	Italy	Retrospective	1997–2003	IV	69	30 (22M/8F)	34 (21–39)	5 (2–8)	5
Trojani et al.	2011	*KSSTA*	France	Retrospective multicentric	1994–2003	IV	32	163	23 (13–57)	3.6 (2–10)	5
Buda et al.	2013	*AJSM*	Italy	Retrospective	2002–2008	IV	49	24 (24M/0F)	30 (19–49)	2	NA
Zaffagnini et al.	2013	*KSSTA*	Italy	Retrospective	2004–2008	IV	51	8 (8M/0F)	39 ± 8.5	5 ± 1.6	10.9
Botto et al.	2016	*Artroscopia*	Argentina	Retrospective	2012–2013	IV	46	8 (7M/1F)	24 (19–29)	2.3	NA
Lefevre et al.	2016	*AJSM*	France	Prospective	2012–2014	III	63	55 (40M/15F)	32 ± 8.4	1	NA
Mirouse et al.	2016	*OTSR*	France	Retrospective	2004–2013	IV	44	30 (11M/19F)	27 ± 8.0)	4.6 ± 1.6	NA
Zanovello et al.	2017	*Joints*	Italy	Retrospective	2008–2015	IV	51	24 (19M/5F)	32 ± 11.0	2.5 ± 1.5	NA
Louis et al.	2017	*OTSR*	France	Prosp + retrosp multicentric	NA	IV	55	349 (283M/66F)	29 (15–68)	NA	6.5
Porter et al.	2018	*AJSM*	Australia	Prospective	2012–2014	II	66	18 (9M/9F)	28 ± 7.2	NA	1.25
Redler et al.	2018	*Arthroscopy*	Italy	Retrospective	1997–2013	IV	72	118 (92M/26F)	34 ± 8	10.6 (3–19)	2.4
Alessio-Mazzola et al.	2018	*J Knee Surg*	Italy	Retrospective	2011–2015	IV	68	24 (24M/0F)	23 ± 4	44.2 ± 16.9	5.2

LOE, level of evidence; AMS, ACL Methodology Score; JBJS, *Journal of Bone and Joint Surgery*; KSSTA, *Knee Surgery, Sports Traumatology, Arthroscopy*; AJSM, *American Journal of Sports Medicine*; OTSR, *Orthopaedics & Traumatology: Surgery & Research*

included: three studies which used the original or modified Lemaire technique (Fig. 2a, b) [1, 25, 37], three studies that used the Cocker-Arnold technique (Fig. 2c) [1, 11, 39], three studies that used the remnant of the intra-articular graft through the over-the-top technique (Fig. 3a, b) [4, 45, 49], one study that used the extra-articular portion of the ITB which was used also for intra-articular reconstruction (Fig. 3c) [32] and one study used both the latter technique and an ALL reconstruction using a free gracilis graft [28] (this last study did not describe the technique used [41]). In the 9 studies [1, 2, 4, 11, 28, 38, 45, 49] that described meniscal status, 167 patients (27.7%) underwent a partial medial meniscectomy, 65 (11%) underwent partial lateral meniscectomy, 17 (2.8%) underwent medial and 13 (2.2%) a lateral meniscus suture, respectively. Cartilage status was described inconsistently, with most of patients having low-grade cartilage lesions.

Subjective clinical scores (Table 3)

Lysholm The weighted mean of the 7 studies [1, 11, 26, 28, 32, 39, 49] that reported the Lysholm score for 630 patients was 67.1 at pre-operative status and 88.9 at final follow-up.

Subjective IKDC The weighted mean of the 8 studies [1, 4, 11, 26, 28, 32, 39, 45, 49] that reported the subjective IKDC score for 662 patients was 56.1 at the pre-operative status and 83.3 at the final follow-up.

KOOS The weighted mean of the 3 studies [27, 32, 49] that reported the KOOS score for 109 patients at the final follow-up was 76 for symptoms, 88.8 for pain, 89 for ADL, 68.3 for sport and 55.3 for QOL subscales.

Other scores The Cincinnati score [2] and the WOMAC score [45] were reported in only one study, and therefore data were not pooled.

Return to sport According to the eight studies that evaluated the return-to-sport outcome, 74% of patients returned to the same sport practiced before ACL failure; however, only 41% were involved also at the same level.

Objective clinical evaluation (Table 4)

Objective IKDC Seven studies [1, 2, 4, 11, 26, 39, 49] with a total of 312 patients utilized the objective IKDC form. The pre-operative score reported 0.4% of patients rated as B, 43.8% rated as C and 56.8% rated as D. At the final follow-up, 35.6% were rated as A, 50.6% as B, 6.4% as C and 1.4% as D. In addition, one study reported the Objective IKDC grouping A with B and C with D, with the overall rate of patient's grades at A or B was 86%, while the rate of patients graded as C or D was 14%.

Arthrometric evaluation Nine studies [1, 4, 11, 26, 28, 39, 41, 45, 49] included arthrometric evaluation outcomes; however, only 5 studies evaluating 170 patients reported

Table 2 Summary of the details of surgical characteristics and intraoperative findings of the included studies

Authors	*N*	ACL reconstruction primary		Revision ACL reconstruction		Lateral extra-articular Procedure		Meniscus					Cartilage			
		Graft	Technique	Graft	Technique	Graft	Technique	MPM	MMS	LPM	LMS	% MP	G1	G2	G3	G4
Ferretti et al.	30	86% BTB, 14% syn	NA	100% HS	SB	ITB	Coker-Arnold	3	0	6	0	30%			2	
Trojani et al.	84	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	–	–	–	–
Buda et al.	24	NA	NA	100% Allo	Over-the-top	Allo	Over-the-top	10	0	6	0	66%	8	4	2	4
Zaffagnini et al.	8	NA	NA	100% HS	Over-the-top	HS	Over-the-top	8	0	0	0	100%	–	–	–	–
Botto et al.	8	63% BTB, 37% HS	NA	63% HS, 37% BTB	SB	ITB	Lemaire	4	0	1	0	62%				
Lefevre et al.	55	NA	NA	51% HS, 49% BTB	SB	ITB	Lemaire	NA	NA	NA	NA	NA	–	–	–	–
Mirouse et al.	30	23% BTB, 64%, 3% syn, 10% HS + LET	NA	100% ITB	SB	ITB	Out-in	NA	NA	NA	NA	NA	–	–	–	–
Zanovello et al.	24	NA	NA	33% HS, 77% Allo	Over-the-top	Allo	Over-the-top	3	2	3	0	50%		1		
Louis et al.	349	NA	NA	58% HS, 42% BTB	NA	ITB 88%, Gr 12%	NA	91	15	24	12	40%				23
Porter et al.	18	NA	NA	100% CL-HS	SB	ITB	Lemaire (modified)	3	0	0	1	22%	0	0	0	0
Redler et al.	118	41% BTB, 54% HS, 5% allo	NA	46% IL-HS, 54% CL-HS	SB	ITB	Coker-Arnold	30	0	21	0	47%	–	–	–	–
Alessio-Mazzola et al.	24	80% BTB, 20% HS	NA	75% HS, 20% IL-BTB, 5% CL-BTB	SB	ITB	Coker-Arnold	10	0	4	0	58%		9	2	

ACL, anterior cruciate ligament; MPM, medial partial meniscectomy; MMS, medial meniscus suture; LPM, lateral partial meniscectomy; LMS, lateral meniscus suture; MP, meniscus procedures; BTB, bone–patellar tendon–bone; Syn, synthetic, HS, hamstrings; CL-HS, contra-lateral hamstrings; LET, lateral extra-articular tenodesis; Allo, allograft; ITB, ilio-tibial band; Gr, gracilis

Table 3 Summary of the subjective clinical scores and details on return to sport of the included patients

Author	*N*	Subjective IKDC		Lysholm		KOOS (post-operative only)					Tegner		Sport activity		
		Pre	Post	Pre	Post	Symptoms	Pain	ADL	Sport	QOL	Pre	Post	Same sport, same level	Same sport, lower level	Another sport, lower level
Ferretti et al.	30	NA	84 ± 12	65.4 ± 20	90 ± 10	NA	NA	NA	NA	NA	3.7	6.2	6/30 (20%)	9/30 (30%)	15/30 (50%)
Trojani et al.	84	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Buda et al.	24	41 ± 7	81 ± 14	NA	NA	NA	NA	NA	NA	NA	NA	NA	17/24 (71%)	3/24 (13%)	NA
Zaffagnini et al.	8	51 ± 13	69 ± 19	NA	NA	NA	NA	NA	NA	NA	3.0	4.0	NA	NA	NA
Botto et al.	8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8/8 (100%)	0/8 (0%)	NA
Lefevre et al.	55	61 ± 16	78 ± 17	70 ± 20	87.5 ± 13	67.7	88.1	94.3	69.1	54.7	NA	NA	7/55 (12%)	27/55 (49%)	NA
Mirouse et al.	30	57 (54–58)	83 (64–90)	46 (42–51)	90.5 (81–97)	94.7	97.2	80	75	NA	NA	NA	12/30 (40%)	15/30 (50%)	3/30 (10%)
Zanovello et al.	24	51 ± 14	64 ± 14	64.5 ± 25	75.8 ± 26	71.6	80	86.7	58.1	56.8	4.1	6	8/18 (44%)	10/18 (65%)	NA
Louis et al.	349	56 ± 15	85 ± 13	69.5 ± 15	89 ± 11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Porter et al.	18	NA	NA	NA	NA	NA	NA	NA	NA	NA	7	7.2	NA	NA	NA
Redler et al.	118	70 ± 8	85 ± 12	67 ± 20	90 ± 7	NA	NA	NA	NA	NA	3.6	5.7	49/118 (41.5%)	38/118 (32%)	31/118 (26.3%)
Alessio-Mazzola et al.	24	69 ± 11	88 ± 9	58 ± 11	97 ± 3	NA	NA	NA	NA	NA	9.5	9.2	22/24 (91.7%)		

IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; ADL, activity of daily living; QOL, quality of life

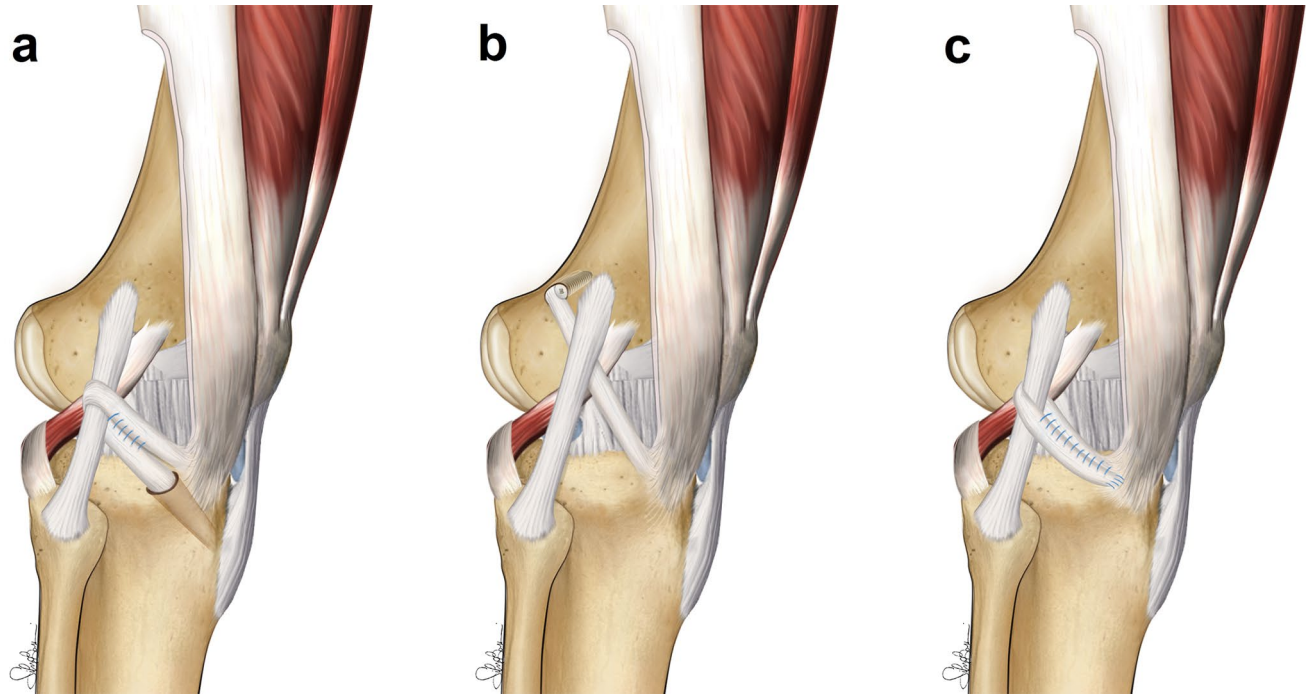

Fig. 2 Lateral extra-articular plasties. **a** Ilio-tibial band (ITB) tenodesis technique (modified Lemaire). The graft is passed around the lateral collateral ligament (LCL), stitched to itself and fixed intraosseous with an interference screw [38]. **b** The graft is passed below the LCL and fixed posterior an proximal to the epicondyle (Lemaire technique) [2, 26]. **c** Cocker-Arnold modification of the MacIntosh procedure. A portion of the ITB is detached proximally, reflected and passed under the LCL, and sutured with periosteal stitches to Gerdy's tubercule [1, 11, 39]

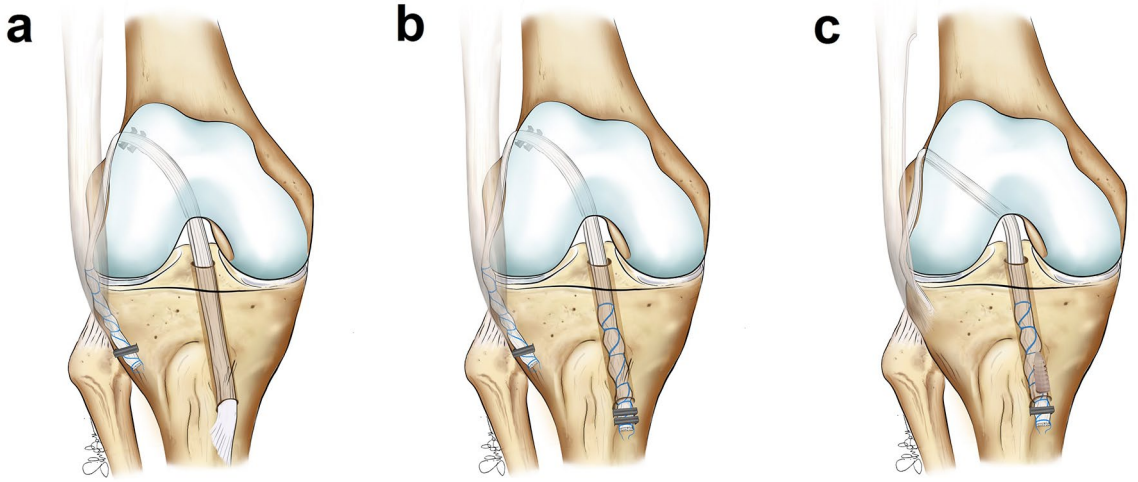

Fig. 3 Combined intra- and extra-articular techniques. **a** Preserving the gracilis and semitendinosus tibial insertion, the graft is passed through the tibial tunnel and through the superolateral portion of the intercondylar groove (over-the-top technique), fixed with two staples in lateral cortex of the femur, passed deep into the ilio-tibial band (ITB) and over the lateral collateral ligament (LCL) and fixed with a staple below Gerdy's tubercule [45, 49]. **b** The same technique, but using allograft, the graft is fixed in the tibia with two staples [4]. **c** Modified MacIntosh fascia lata technique, preserving the tibial insertion of the ITB, passed through a femoral out-in tunnel and fixed in the tibia with an interference screw and a staple [32]

Table 4 Summary of the objective evaluation and laxity measurement of the included patients

Author	*N*	Objective IKDC								Pivot-shift								KT-1000 evaluation							
		Pre				Post				Pre				Post				Pre				Post			
		A	B	C	D	A	B	C	D	Neg	+	++	+++	Neg	+	++	+++	SSD (mm)	< 3 mm	3–5 mm	> 5 mm	SSD (mm)	< 3 mm	3–5 mm	> 5 mm
Ferretti et al.	30	0	0	12	18	15	11	2	0	NA	NA	NA	NA	15	11	2	0	7.2	NA	NA	NA	2.5	20	6	2
Trojani et al.	84	NA	NA	NA	NA	25	48	0	0	NA	NA	NA	NA	67	NA	NA	NA	7.1	NA	NA	NA	2.5	NA	NA	NA
Buda et al.	24	0	0	12	12	4	16	2	2	NA	NA	NA	NA	4	18	0	2	NA	NA	NA	NA	3.1	NA	NA	NA
Zaffagnini et al.	8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.2	NA	NA	NA
Botto et al.	8	0	0	6	2	7	1	0	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lefevre et al.	55	0	1	34	20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mirouse et al.	30	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zanovello et al.	24	0	0	18	6	1	12	4	1	NA	NA	NA	NA	7	10	0	1	NA	NA	NA	NA	3.1	NA	NA	4
Louis et al.	349	NA	NA	NA	NA	300 (A + B)		49 (A + B)		NA	NA	NA	269	324	21	0	4	NA	NA	NA	NA	NA	178	124	47
Porter et al.	18	NA	NA	NA	NA	NA	NA	NA	NA	0	0	8	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Redler et al.	118	0	0	36	82	53	56	9	0	0	26	51	41	82	32	4	0	NA	0	19	99	NA	61	48	9
Alessio-Mazzola et al.	24	0	0	6	18	6	14	3	1	0	0	6	18	22	2	0	0	NA	0	0	24	NA	15	8	2

IKDC, International Knee Documentation Committee; SSD, side-to-side difference

the side-to-side of the anterior tibial displacement at final follow-up with a weighted mean of 2.6 mm. Those studies that reported the KT-1000 cutoffs identified: 96 patients (55%) having a side-to-side difference of < 3 mm; 62 (35%) between 3 and 5 mm; and 17 (10%) > 5 mm.

Pivot-shift evaluation Seven studies [1, 4, 11, 28, 39, 41, 49] with a total of 628 patients included a pivot-shift evaluation at final follow-up: 521 (83%) had grade 0 pivot-shift, 94 (15%) had grade I, 6 (1%) had grade II and 7 (1%) had grade III. In one study [41] the authors did not grade the maneuver, but reported 80% of patients having a negative pivot-shift.

Navigation One study of 18 patients [38] included the pre and postoperative anterior translation and internal rotation evaluation using a navigation system. The internal rotation significantly decreased from 14.6° to 8.3° after extra-articular lateral tenodesis, while no significant differences were reported for anterior translation.

Radiologic evaluation (Table 5)

Radiographs Four studies [1, 11, 28, 39, 41] with a total of 568 patients performed radiographs at final follow-up. Ferretti et al. [11] reported 75% of his series with degenerative changes at 5-years follow-up and Redler et al. [39] 25% with severe changes after 10 years. Trojani et al. [41] reported no radiographic changes at 3.6-years follow-up and Louis et al. [28] reported an increase from 12.3% of arthritic changes pre-operative to 21% at final follow-up with a mean of 8.7-years follow-up.

Magnetic resonance imaging (MRI) One study [2] including eight patients reported a good signal intensity of the graft at 2.3-years follow-up.

Complications and reoperations (Table 6)

Complications Eleven studies [1, 2, 4, 26, 28, 32, 38, 39, 41, 45, 49] reported 59 complications in a total of 742 patients (8.0%). The most frequent complications were: wound hematoma (14), implant removal due to local pain (7), peroneal nerve palsy (2), stiffness requiring arthroscopic arthrolysis (2) superficial infection treated with oral antibiotics (1) and muscular hernia in the lateral approach (1).

Failures Twenty-four failures were reported in a total of 658 patients [1, 2, 4, 11, 26, 39, 45, 49] with an overall rate of 3.6%.

Table 6 Summary of complications and failures reported in the included studies

Author	*n*	Failure rev ACL		Complications	
		Failure Rev ACL	Rate	*n*	Rate
Ferretti et al.	30	1/30	3%	NA	NA
Trojani et al.	84	NA	NA	7/84	8%
Buda et al.	24	4/24	16%	0/24	0
Zaffagnini et al.	8	0/8	0%	1/8	12%
Botto et al.	8	0/8	0%	0/8	0
Lefevre et al.	55	1/55	1.8%	5/55	9.1%
Mirouse et al.	30	NA	NA	4/30	13.3%
Zanovello et al.	24	3/24	12.5%	4/24	16%
Louis et al.	349	4/349	1.2%	36/349	10.5%
Porter et al.	18	0/18	0%	1/18	5.5%
Redler et al.	118	9/118	7.6%	0/118	0%
Alessio-Mazzola et al.	24	2/24	8.3%	1/24	4.1%

Rev ACL, revision anterior cruciate ligament

Table 5 Summary of radiologic findings of the included studies

Author	*N*	Methodology	Findings
Ferretti et al.	30	Radiographs	25% without arthritic changes, 7% severe degeneration
Trojani et al.	84	Radiographs	No post-operative arthritic changes
Buda et al.	24	NA	NA
Zaffagnini et al.	8	NA	NA
Botto et al.	8	Magnetic Resonance	Good graft signal intensity
Lefevre et al.	55	NA	NA
Mirouse et al.	30	NA	NA
Zanovello et al.	24	NA	NA
Louis et al.	349	Radiographs	12.3% pre-operative arthritis, 21% post-operative arthritis
Porter et al.	18	NA	NA
Redler et al.	105[a]	Radiographs	25% severe degenerative joint disease
Alessio-Mazzola et al.	24	NA	NA

[a]Nine failures and five patients were not included in radiographic

Table 7 Comparison of the characteristics and outcomes between the data from the present systematic review and series published in literature

Author	Type of surgery	*n*	Age (years)	Sex (M%)	FU (years)	Time ACL to rev (years)	ACL graft	Meniscus	Cartilage	IKDC subj	IKDC AB (*n*%)	IKDC CD (*n*%)	Pivot neg/I (*n*%)	Pivot II/III (*n*%)	KT1000 SSD > 5 mm (*n*%)	Re-rupture (*n*%)
Grassi 2016 [13]	Primary ACL	413	28.3	59	3.9	NA	100% auto (87% HS/13% BTB)	41% MPM/25% LPM	20% GII-GIII	84	94	6	98	2	5	NA
	Revision ACL	300	30.3	63	4.5	NA	80% auto (43% HS/37% BTB)/20% allo	51% MPM/27% LPM	20–54% GII-GIII	75	78	22	71	7	6	NA
Wright 2012 [42]	Revision ACL	1004	30.6	66	5.4	4.6	89% auto (48% BTB/40% HS/12% quad)/11% allo	35% MPM/20% LPM	35% GI/63% GII–GIII/3% GIV	74	71	29	NA	NA	NA	13*
MARS 2014 [28]	Revision ACL	1205	26	58	2	3.4	48% auto (54% BTB/41% HS)/49% allo	30% MPM/16% LPM	NA	77	NA	NA	NA	NA	NA	3.3
Current	Revision ACL + LEP	709	28.1	77	4.2	5.9	92% auto (55% HS/32% BTB/13% quad)/8% allo	26% MPM/9% LPM	NA	83	93	7	98	2	10	3.6

FU, follow-up; ACL, anterior cruciate ligament; LEP, lateral extra-articular plasty; auto, autograft; HS, hamstrings; BTB, bone–patellar tendon–bone; allo, allograft; quad, quadriceps tendon; MPM, medial partial meniscectomy; LPM, lateral partial meniscectomy; IKDC, International Knee Documentation Committee; SSD, side-to-side difference

*Includes re-ruptures and objective outcomes failures

Discussion

Although the numbers of studies are few with relatively small data sets the most important finding of this systematic review of the literature was that combined revision ACL reconstruction and LET was found to have good mid-term follow-up results with a limited number of patients demonstrating residual rotatory laxity, relatively low re-ruptures rates and low rates of post-operative complications. The review further demonstrates that there are several different surgical techniques being carried out with no consensus (Figs. 2, 3), thus suggesting the lack of a gold-standard for extra-articular procedures. Moreover, the limited number of case series not only precluded the statistical comparison between the results of the various techniques, but also the comparison between the outcomes of revision reconstruction with or without lateral plasty.

Despite a recent systematic review by Weber et al. [43] on lateral augmentation in ACL reconstruction identified ACL revision surgery as a "common indication for combined procedures", this statement does is not reflected as "state of the art" treatment for ACL revision surgery. The lack of extensive literature on this topic could mean either that the outcomes of a combined LET procedure in the revision setting are under-reported, or that its indication has been neglected or not fully endorsed until recent years. Either way this highlights an important deficiency in the Sports Medicine research panorama, which should be filled with further high-quality studies. Moreover, the geographical distribution of the series included in the present review suggests how the combined procedure could be considered, at the moment, as a "continental" perspective dictated by local heritage and national surgical preferences, rather than concept strictly based on the available EBM.

Despite the paucity of data, the few studies published up to now could provide important insights regarding the role of extra-articular plasty in managing failed ACL reconstruction. Trojani et al. [41] reported a significantly higher rate of negative pivot-shift when lateral tenodesis was performed compared to isolated revision surgery, while Porter et al. [38] found that lateral tenodesis was able to neutralize persistent grade II or III rotatory laxity after isolate revision ACL reconstruction and reduce both internal rotation ad anterior translation using computer navigation. Regarding patient-reported outcomes (PRO), the lateral procedures were able to produce good results in complex patients, such as those with concomitant varus malalignment and medial OA [45], multiple recurrent graft failures [4] or professional athletes [1].

When interpreting the overall pooled results of the 12 studies, an abnormal or severely abnormal pivot-shift was reported in only 2% of the patients treated with combined revision ACL and LET. This result appears more similar to primary reconstruction (2%) rather than isolate revision (7%) [14]. A similar trend could also be noted for subjective IKDC, since a pooled mean of 83.3 points was reported in the present review; 77 points were reported in the MARS cohort [29]; 74 in a meta-analysis by Brophy et al. [44] and 75 in another meta-analysis by Grassi et al. [14] (Table 7). Finally, the low number of complications at final follow-up confirms the safety of combining an extra-articular procedure with the intra-articular revision ACL reconstruction [39].

The graft availability, previous surgeries or possible other concomitant abnormalities could prevent the clinician to perform routinely the same preferred procedure, thus resulting in the lack of a gold-standard procedure. However, due to the similar results across the various series, it is possible to conclude that the general control of rotation is more important than the specific technique itself, unless it is performed safely minimizing the chances of technical errors.

Based on the limited evidence available, it is not possible to consider LET as a mandatory procedure in case of revision ACL reconstruction, and the encouraging results and low morbidity should be confirmed in further high-quality studies to support its extensive employment. Moreover, lateral plasty should not be seen as the "panacea" in revision surgery. Rather, a "patient-tailored" approach should be used in the revision setting, considering all modalities of possible treatment such as HTO, slope-changing osteotomies, meniscal replacement or cartilage-repair procedures.

This review has several important limitations. First and foremost is the limited number of available studies and the different study designs, which could raise serious concerns related to the quality of the data and possible patients overlap [39]. Moreover, to increase the number of eligible studies, we selected heterogeneous case series including also those with combined HTO or multiple revisions, therefore increasing the possibility of bias. Despite the aforementioned limitations, the present review highlights the paucity of literature regarding the use of LET in revision ACL reconstruction and provides encouraging results for its future widespread use.

Conclusion

Based on the limited literature available, including mainly retrospective studies, combined Revision ACL reconstruction and LET procedures has been shown to provide good mid-term follow-up results with low rates of residual rotatory laxity, re-ruptures or complications. Further high-level studies, possibly comparing this approach to standard isolated revision surgery, are mandatory to support its wider adoption. Meanwhile, LET could be undertaken based on

surgical experience especially in complex cases, due to its safety and low morbidity.

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