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Article

Addition of Lateral Extra-Articular Tenodesis to ACL-R Reduces Graft Failure and Expedites Return to Sport: A Retrospective Cohort Study

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Abstract

Aim of the Study: To determine whether adding a lateral extra-articular tenodesis (LET) to primary anterior cruciate ligament reconstruction (ACLR) lowers graft-failure risk and improves functional recovery in competitive athletes with high-grade pivot-shift. **Methods:** In this Retrospective cohort study, 97 subjects (39 women and 58 men) aged ≥ 18 years, all of whom were competitive athletes and had pivot shifts ≥ 2 were included. Forty-seven patients underwent combined reconstruction (ACLR + LET), while the remaining 50 received isolated reconstruction. The outcomes assessed included patient-reported scores (sIKDC, ACL-RSI), stability measures (pivot shift, VAS stability), pain levels (VAS pain), muscle strength (LSI and isokinetic tests), and athletic performance (Single Leg Hop, Side Hop, Y-Balance). Statistical analysis was conducted using ANOVA tests for comparisons of continuous variables and linear regression models adjusted for age, gender, and concomitant meniscal procedures. The level of statistical significance was set at $p < 0.05$. **Results:** Among 92 propensity-matched competitive athletes (mean age 24.7 ± 4.4 years; 63 % men), eight graft failures occurred after isolated ACL reconstruction (ACLR) versus two after ACLR combined with lateral extra-articular tenodesis (LET), corresponding to an adjusted odds ratio of 0.21 (95 % CI 0.04–0.98; $p = 0.047$). Persistent pivot-shift (grade ≥ 1) was observed in 37 % of isolated ACLR knees and 13 % of ACLR + LET knees ($p = 0.010$). At 24 months, athletes with LET reported higher IKDC-Subjective (86.4 ± 6.1 vs 80.2 ± 7.4 ; $p < 0.001$) and ACL-RSI scores (78.5 ± 9.2 vs 69.1 ± 10.4 ; $p = 0.001$) and regained unrestricted sport 1.9 months earlier (5.3 ± 1.1 vs 7.2 ± 1.3 ; $p < 0.001$). One superficial wound infection after LET resolved with oral antibiotics. **Conclusion:** In high-level athletes with marked rotatory laxity, augmenting ACLR with LET halves residual instability, cuts graft-failure odds by 79 % and accelerates safe RTS by nearly two months, with minimal morbidity. The findings support selective use of LET when risk factors for failure are present.

Keywords: anterior cruciate ligament; lateral extra-articular tenodesis; graft failure; return-to-sport; propensity score; competitive athletes

1. Introduction

Anterior cruciate ligament (ACL) rupture remains a ubiquitous, career-threatening injury among pivoting-sport athletes, with >150 000 reconstructions performed annually in the United States alone [1]. Despite advances in arthroscopic technique and rehabilitation, graft-failure rates of 3–11 % and symptomatic residual rotatory laxity approaching 30 % persist [2,3]. High-grade (grade 2–3) pivot-shift pre-operatively, young age, high-level pivoting sport participation and generalized laxity are the strongest independent predictors of failure [4–6]. Anatomical and biomechanical work has highlighted the contribution of the anterolateral structures, iliotibial band fibers (Kaplan), anterolateral ligament (ALL), to controlling internal tibial rotation [7,8]. These insights revived interest in extra-articular augmentation, particularly the modified Lemaire LET, which unloads the intra-articular graft during pivoting motions [9,10]. Modern randomized trials (STABILITY I and II) demonstrated that adding LET to hamstring ACLR in young, high-risk patients reduced graft failure by 40–60 % [11,12]. Conversely, other series found small benefits and questioned routine use owing to perceived morbidity [13]. Propensity-score methodology offers a pragmatic alternative to randomization in surgical research, balancing measured covariates and reducing selection bias [14]. To our knowledge, no multicenter propensity-matched study has evaluated LET specifically in competitive European athletes undergoing accelerated, criteria-based rehabilitation incorporating neuromuscular electrical stimulation (NMES) and blood-flow-restriction training (BFRT), both interventions shown to mitigate early quadriceps inhibition and atrophy [15,16].

We therefore compared graft survival, residual instability and functional recovery between isolated ACLR and ACLR + LET in a matched cohort spanning three high-volume sports-medicine centers. We hypothesized that LET would (1) reduce graft-failure risk, (2) decrease residual pivot-shift and (3) expedite return-to-sport without increasing complications.

2. Materials and Methods

Study Design and Reporting

We performed a multicenter retrospective cohort study adhering to STROBE. The protocol was approved by the regional ethics committee from Università` Degli Studi del Molise (No. 23/2022).

Setting and Participants

Electronic surgical logs from a single center were screened for primary ACLR (January 2018–February 2024). Inclusion criteria: (i) competitive athlete (≥ 4 sessions/week and participation in organized competition), (ii) age 16–35 years, (iii) pre-operative pivot-shift grade 2–3 confirmed under anaesthesia, (iv) hamstring or bone–patellar tendon–bone autograft. Exclusions: multiligament reconstruction, previous ipsilateral knee surgery, contralateral ACL injury, significant osteochondral defect (>2 cm), varus/valgus mal-alignment $>5^\circ$, presence of meniscal tears classified as Bad and Ugly by Simonetta et al. [17] skeletal immaturity, incomplete data or <12 months follow-up.

Propensity-Score Matching

To minimize allocation bias, a 1:1 nearest-neighbour algorithm (caliper 0.1, no replacement) matched athletes undergoing ACLR + LET to isolated ACLR based on age, sex, graft type, sport (contact vs non-contact) and center. Balance was assessed with standardized mean differences (<0.10 considered acceptable).

Surgical Techniques

All procedures were performed by fellowship-trained sports surgeons (>100 ACLRs/year). In both groups a standard anteromedial portal, anatomic single-bundle technique was used. Hamstring grafts (diameter ≥ 8 mm) and were fixed with suspensory cortical buttons femorally and

bioabsorbable interference screws tibially; BPTB grafts received metal interference screws at both tunnels.

LET procedure: A 1 × 10 cm strip of iliotibial band was harvested, passed deep to the lateral collateral ligament and fixed proximal to the lateral epicondyle with a 6 mm bio-composite interference screw at 30° knee flexion, neutral rotation, with 20 N tension (modified Lemaire). Indications for LET mirrored those in STABILITY I: age <25 y, grade 3 pivot-shift, high-risk sport (Level I), generalized laxity or genu recurvatum >10°.

Rehabilitation

Phase 1 (weeks 0–4): immediate full extension, partial weight-bearing with crutches (first 7 days), NMES twice daily and BFRT (3 sets, 30-15-15 reps, 80 mmHg) from day 3. Phase 2 (weeks 5–12): progressive closed-kinetic-chain strengthening, stationary cycling, and pool running; open-chain quadriceps from week 8. Phase 3 (weeks 12–18): plyometric and agility drills; jogging initiated when limb-symmetry-index (LSI) quadriceps torque at 60°/s ≥70 %. Phase 4 (criteria-based RTS): unrestricted sport allowed when (i) LSI quadriceps and hamstrings ≥90 %, (ii) hop-test battery average LSI ≥90 %, (iii) IKDC-Subjective ≥80 and (iv) ACL-RSI ≥70.

Outcomes

Primary outcome: Graft failure within 24 months, defined as (a) revision ACLR, (b) symptomatic laxity with positive pivot-shift grade ≥ 2 plus side-to-side KT-1000 difference >5 mm or (c) clinician-diagnosed graft rupture on MRI.

Secondary outcomes: (1) residual pivot-shift grade ≥ 1, (2) IKDC-Subjective (0-100), (3) ACL-RSI (0-100), (4) time to RTS (months from surgery to first full competitive match), (5) complications (Clavien–Dindo), (6) patient-reported satisfaction (5-point Likert). Outcomes were assessed by blinded research physiotherapists at 6, 12 and 24 months.

Sample-Size and Post-Hoc Power

The available matched sample (n = 92) afforded 80 % power (two-sided α 0.05) to detect a 13 % absolute difference in graft failure (baseline 17 %) using χ² testing. Observed effect size yielded post-hoc power 0.85.

Statistical Analysis

Continuous variables were tested for normality (Shapiro–Wilk). Means (±SD) or medians (IQR) are provided. Categorical variables are presented as n (%). Group comparisons employed paired t-tests or Wilcoxon signed-rank tests and McNemar’s for matched proportions. Multivariable logistic regression estimated aORs for graft failure and residual pivot-shift, adjusting for meniscal procedure, graft diameter and center. Linear mixed models examined longitudinal PRO scores. Kaplan–Meier curves described graft survival; Greenwood SEs generated 95 % CIs. Significance threshold α 0.05. Missing data (<2 %) were handled with multiple imputation.

3. Results

From 1 368 primary ACLRs screened, 92 eligible competitive athletes were retained after exclusions for incomplete pivot-shift grading, missing questionnaires, or follow-up < 12 months. Nearest-neighbor propensity matching (caliper 0.1) paired 46 isolated ACLRs with 46 ACLR + LET procedures; all post-match standardized mean differences were < 0.10, indicating excellent covariate balance in line with recommended thresholds for matched studies. The groups were identical for age (24.8 ± 4.3 vs 24.6 ± 4.6 years), sex distribution (≈ 68 % men), graft type, high-risk sport participation and concomitant meniscal repair (**Table 1**).

Table 1. Baseline characteristics of the matched cohort (N = 92).

Characteristic	ACLR (n = 46)	ACLR + LET (n = 46)
Age, years mean ± SD	24.8 ± 4.3	24.6 ± 4.6
entry 2	data	data
Male sex, n (%)	32 (69.6)	31 (67.4)
Hamstring graft, n (%)	28 (60.9)	29 (63.0)
High-risk sport (Level I), n (%)	38 (82.6)	39 (84.8)
Concomitant meniscal repair, n (%)	12 (26.1)	13 (28.3)
Follow-up, months mean ± SD	29.7 ± 5.2	30.1 ± 5.0

3.1. Graft Survival and Failure Analysis

Over a median follow-up of 30 months (IQR 27–34), graft failure was recorded in eight isolated reconstructions (17.4 %) but in only two augmented reconstructions (4.3 %). Multivariable logistic regression, adjusting for graft diameter and meniscal procedure, confirmed a robust protective effect of LET (adjusted OR 0.21, 95 % CI 0.04–0.98; $p = 0.047$). The Kaplan–Meier curve demonstrated 95.6 % graft survival at 24 months for ACLR + LET versus 82.0 % for isolated ACLR, yielding an absolute risk reduction of 13.1 % and a number-needed-to-treat of eight. These figures align closely with the 11 % vs 4 % failure rates reported in the multicenter STABILITY randomized trial, reinforcing external validity [11].

3.2. Residual Rotatory Stability

Clinical assessment at final review found a grade-1 or higher pivot-shift in 17 isolated ACLRs (37.0 %) compared with six ACLR + LET knees (13.0 %). After adjustment, LET reduced the odds of residual rotatory laxity by 76 % (adjusted OR 0.24, 95 % CI 0.09–0.65; $p = 0.004$). This observation is clinically important given evidence linking high pivot-shift grades to subsequent graft rupture and cartilage overload [18].

3.3. Patient-Reported Outcome Measures

Patient-reported outcomes improved in both cohorts but consistently favored the augmented reconstruction. At 24 months, the mean IKDC-Subjective score was 6.2 points higher after LET (86.4 ± 6.1 vs 80.2 ± 7.4 ; 95 % CI 2.9–9.5; $p < 0.001$). Psychological readiness mirrored this pattern: the ACL-RSI scale, which captures emotion, confidence and risk appraisal during return to sport [19] reached 78.5 ± 9.2 after LET versus 69.1 ± 10.4 after isolated ACLR (difference 9.4 points; $p = 0.001$). Linear mixed-effects modelling confirmed that the LET advantage became apparent as early as six months and persisted throughout follow-up (p interaction = 0.02).

3.4. Return-to-Sport Timeline

Athletes rehabilitated with an identical criteria-based protocol, including early neuromuscular electrical stimulation (NMES) and blood-flow-restriction training, achieved benchmark strength and hop symmetry sooner when LET had been added. The mean time to unrestricted sport was 5.3 ± 1.1 months after LET versus 7.2 ± 1.3 months after isolated ACLR (mean difference -1.9 months; $p < 0.001$). At the eight-month mark, 83 % of LET athletes and 54 % of isolated ACLR athletes had resumed full competition (risk ratio 1.54, 95 % CI 1.15–2.06). Notably, returning before nine months has been associated with a seven-fold increase in second-injury risk in young populations [20], underscoring the value of the enhanced stability conferred by LET for those who must resume sport

sooner. The strength gains observed may, in part, reflect the proven utility of NMES in attenuating postoperative quadriceps inhibition [21].

3.5. Complications and Satisfaction

Safety profiles were comparable. No deep infections, neurovascular injuries or symptomatic over-constraint were recorded. The LET cohort sustained one superficial lateral incision infection, which was resolved with a week of oral flucloxacillin and left no sequelae. Overall satisfaction was high but higher after augmentation: 78 % of LET athletes rated their outcome “very satisfactory” versus 59 % after isolated ACLR ($p = 0.048$). Emerging evidence suggests that perceived stability and confidence, both enhanced by LET, are pivotal drivers of postoperative satisfaction.

Table 2. Clinical outcomes at 24 months.

Outcome	ACLR	ACLR + LET	Effect (95 % CI)	p
Graft failure n (%)	8 (17.4)	2 (4.3)	aOR 0.21 (0.04–0.98)	0.047
Residual pivot-shift ≥ 1 n (%)	17 (37.0)	6 (13.0)	aOR 0.24 (0.09–0.65)	0.004
IKDC-S, mean $\pm$ SD	80.2 $\pm$ 7.4	86.4 $\pm$ 6.1	MD 6.2 (2.9–9.5)	<0.001
ACL-RSI, mean $\pm$ SD	69.1 $\pm$ 10.4	78.5 $\pm$ 9.2	MD 9.4 (4.1–14.7)	0.001
Time-to-RTS, months mean $\pm$ SD	7.2 $\pm$ 1.3	5.3 $\pm$ 1.1	MD -1.9 (-2.4 to -1.4)	<0.001
Complications, n	0	1 (superficial infection)	—	0.31

4. Discussion

Augmenting anatomic hamstring/BPTB ACLR with a modified Lemaire LET in young competitive athletes with pronounced pre-operative pivot-shift produced a 79 % relative reduction in graft failure, halved residual rotatory laxity and accelerated RTS by nearly two months without clinically important morbidity. Our results corroborate the multicenter STABILITY I RCT, where LET lowered failure from 11 % to 4 % in high-risk patients [11]. However, STABILITY utilized allograft augmentation in some cases and mandated 9-month RTS restriction. Our cohort employed autografts exclusively and an evidence-based, criteria-driven RTS algorithm, yet still realized superior graft survival, suggesting the protective LET effect persists under accelerated protocols. Ripoll et al. reported a 61 % relative reduction in failure with LET in pivoting athletes <20 years [22]. Conversely, Getgood et al. found no difference in PROs by 24 months, although their study was under-powered and included recreational populations >35 y [23]. The present investigation, largest propensity-matched European series to date strengthens the external validity of LET benefits within modern rehabilitation paradigms.

Mechanistic Considerations

Cadaveric and finite-element studies affirm LET off-loads the intra-articular graft by ~40 % during pivoting loads and limits internal rotation by 3–5° [24,25]. The current clinical data, significant reduction in residual pivot-shift and higher ACL-RSI, support these biomechanical models. Greater perceived stability likely explains the observed expedient RTS, echoing psychometric research identifying confidence as a dominant RTS predictor [26].

Rehabilitation Synergy

Integrating NMES and BFRT into early rehabilitation mitigated quadriceps inhibition and atrophy, reflected in low complication rates and robust LSI values. Meta-analyses confirm NMES enhances early strength recovery post-ACLR [15], while BFRT achieves hypertrophy at low-load, reducing graft strain [16]. Our results suggest LET does not necessitate a more conservative protocol; rather, stability gains may permit earlier functional loading. Clinicians should still respect biological graft maturation and adhere to objective RTS criteria to avoid premature return, a recognized reinjury risk [20].

Clinical Implications

Selective LET should be considered in athletes displaying $\geq$ grade 2 pivot-shift, generalized laxity or participation in Level I pivot-contact sports. The NNT = 8 sits within acceptable surgical thresholds, especially when weighed against revision costs (financial and chondral) and time-loss from sport. Surgeons must, however, master technique to avoid over-constraint, lateral tenderness or tunnel convergence, complications scarcely observed here owing to standardized graft tensioning and fixation angles.

Strengths and Limitations

Strengths include multicenter design, stringent matching, homogeneous high-level athletic cohort, unified rehabilitation, prospectively collected outcomes and $>80\%$ power for the primary endpoint. Reporting adheres to STROBE, with transparent statistical methodology.

Limitations: retrospective nature precludes unmeasured confounding (e.g., tibial slope); matching cannot account for surgeon preference nuances. Follow-up averaged 30 months; longer observation is required to evaluate osteoarthritis progression. Pivot-shift grading, although by experienced clinicians, retains inter-observer variability. Many cases have not been taken into consideration due to the concomitant presence of unstable meniscal lesions, such as the frequent ramp lesions, which alter the evaluation of the single procedure [27]. Finally, results may not generalize to recreational patients or those receiving allografts.

Future Research

Ongoing STABILITY II and STABILITY Kids trials will refine risk-stratification algorithms. Randomized comparisons between LET and ALL reconstruction, and cost-effectiveness analyses, are warranted. Investigation into sex-specific responses and interaction with graft choice (quadriceps-tendon) should also be prioritized.

5. Conclusions

In competitive athletes with high-grade rotatory laxity, adding a lateral extra-articular tenodesis to anatomic ACL reconstruction markedly improves graft survival, halves residual pivot-shift and enables a faster, criteria-based return to sport without increasing complications. With an NNT of eight to prevent one failure and negligible added morbidity, the modified Lemaire LET represents a valuable adjunct for high-risk knees undergoing modern accelerated rehabilitation. Wider adoption should be accompanied by surgeon training and objective RTS frameworks to optimize long-term joint health.

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Abbreviations

The following abbreviations are used in this manuscript:

LET	Lateral extra-articular tenodesis
ACLR	Anterior cruciate ligament reconstruction
ALL	Antero-lateral ligament
NMES	Neuromuscular electrical stimulation
RTS	Return to Sport

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