Isolated ACL Reconstruction Versus ACL Reconstruction Combined With Lateral Extra-articular Tenodesis

A Comparative Study of Clinical Outcomes in Adolescent Patients

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Background: Young patients undergoing anterior cruciate ligament (ACL) reconstruction (ACLR) are at a particularly high risk of graft ruptures compared with adults. Recent studies have demonstrated significant reductions in ACL graft rupture rates in high-risk adult populations when a lateral extra-articular procedure is performed, but comparative studies in pediatric and adolescent populations are currently lacking in the literature.

Purpose/Hypothesis: The purpose of this study was to compare the clinical outcomes of isolated ACLR versus combined ACLR and lateral extra-articular tenodesis (LET) when using the Arnold-Coker modification of the MacIntosh procedure in early adolescent patients. The hypothesis was that combined procedures would be associated with a significantly reduced risk of graft ruptures.

Study Design: Cohort study; Level of evidence, 3.

Methods: A retrospective analysis of consecutive early adolescent patients who underwent ACLR using a hamstring tendon autograft with or without the Arnold-Coker modification of the MacIntosh procedure was conducted. Patients with $\geq$1 additional risk factors for a graft rupture were offered LET in addition to ACLR (pivot-shift grade 2 or 3, high level of sporting activity defined as Tegner activity score $\geq$7, participation in pivoting sports, and Segond fractures). Clinical outcomes including graft rupture rates, patient-reported outcome measure scores (Knee injury and Osteoarthritis Outcome Score and subjective International Knee Documentation Committee), knee stability, return-to-sports rates, reoperation rates, and complications were assessed. Comparisons between variables were assessed with the chi-square or Fisher exact test for categorical variables and the Student or Wilcoxon test for quantitative variables. Multivariate analyses were undertaken to evaluate risk factors for a graft rupture.

Results: A total of 111 patients with a mean follow-up of 43.8 $\pm$ 17.6 months (range, 24-89 months) were included in the study; 40 patients underwent isolated ACLR, and 71 underwent ACLR + LET. The addition of LET to ACLR was associated with a significantly lower graft rupture rate compared with isolated ACLR (0.0% vs 15.0%, respectively; odds ratio, 15.91 [95% CI, 1.81-139.44]; P = .012). It was also associated with significantly better knee stability (pivot-shift grade 3: 0.0% vs 11.4%, respectively; P = .021) (side-to-side anteroposterior laxity difference >5 mm: 0.0% vs 17.1%, respectively; P = .003) and Tegner activity scores (7 vs 6, respectively; P = .010). There were no significant differences between the groups regarding the Patient Acceptable Symptom State for the patient-reported outcome measures, nor for any of the other outcome measures evaluated, and no differences in the rate of non–graft rupture related reoperations or complications. The ACLR + LET group exceeded the minimal clinically important difference with respect to the Tegner activity scale.

Conclusion: In a retrospective comparative cohort study of adolescents, combined ACLR and LET was associated with a significantly lower graft rupture rate and no difference in non–graft rupture related reoperations or complications compared with isolated ACLR.

Keywords: knee; ligaments; ACL; pediatric sports medicine; anterior cruciate ligament reconstruction; lateral extra-articular tenodesis; graft failure

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Numerous epidemiological studies have demonstrated an increase in the incidence of anterior cruciate ligament (ACL) injuries occurring in pediatric and adolescent patients over the past 2 decades, likely as a result of

increased participation in competitive sports.[6,8,29,32,35,46,47] These findings are concerning because rates of secondary ACL injuries are considerably higher than in adult populations. Another issue regarding the management of these patients is the controversy regarding whether operative versus nonoperative treatment is optimum in pediatric patients (except in those who have repairable additional injuries in whom there is agreement that early ACL reconstruction [ACLR] and meniscal repair should be performed). The 2018 International Olympic Committee consensus statement reflects that there are conflicting opinions, with some authors advocating for early reconstruction in all children and others supporting primary nonoperative management with the option of late ACLR if the child sustains secondary intra-articular injuries or suffers recurrent instability.[2] Although both of these strategies are considered acceptable, each is associated with important concerns. The main concerns with an operative approach for all pediatric patients are based on the risk of growth disturbances, especially for patients with open physes. Also, the very high rates of ACL graft ruptures (up to 25%) are an important concern in adolescent patients compared with adults.[7,16,51,52] However, the nonoperative approach is associated with increased risks of persistent instability, secondary meniscal and cartilage lesions, and early osteoarthritis.[15,27,33]

Recent comparative clinical studies have demonstrated that the risk of graft ruptures in other high-risk populations (including young adults participating in pivoting sports, professional athletes, those with chronic ACL injuries, those with hyperlaxity, and those undergoing revision ACLR) can be significantly reduced by the addition of lateral extra-articular tenodesis (LET) or anterolateral ligament (ALL) reconstruction at the time of ACLR.[17,18,20,21,45,49] These observations are supported by biomechanical studies that have demonstrated that combined procedures more reliably restore normal knee kinematics (compared with isolated ACLR) and confer a protective effect on the ACL graft through load sharing.[9,11,31] It therefore seems logical that the benefits of combined reconstruction observed in other high-risk populations would also be seen in pediatric and adolescent patients. However, the literature related to the clinical outcomes and complications associated with combined ACLR and LET in the pediatric and adolescent populations is sparse.

The extra-articular procedure for ACL-deficient knees, first presented by D.L. MacIntosh in 1964,[30] intended to substitute ACL function with the iliotibial band (ITB) extra-articularly. The MacIntosh procedure was meant to control anterolateral subluxation of the tibia by not allowing the ITB to slide forward toward the axis of rotation. Then, T.P. Coker utilized a more simplified approach of ITB tenodesis to aim for earlier mobilization.[3]

The purpose of this study was to compare the clinical outcomes of isolated ACLR versus combined ACLR and LET when using the Arnold-Coker modification of the MacIntosh procedure in early adolescent patients. The hypothesis was that combined procedures would be associated with a significantly reduced risk of graft ruptures.

METHODS

Institutional review board approval was granted for this study. All participants and their guardians gave valid consent to participate. A retrospective analysis of prospectively collected data for consecutive early and middle adolescent patients (defined as ages 10-13 years and 14-17 years, respectively)[50] who underwent ACLR at Sant'Andrea University Hospital between January 1, 2013, and December 31, 2017, was conducted. Patients with Tanner stage[10] 1 and 2 were excluded from the study, as were those older than 18 years. Tanner stage was determined by a pediatrician and not by the surgical team. Additional exclusion criteria comprised those who sustained concomitant fractures (with the exception of Segond fractures) or had multiligamentous injuries that required surgery in addition to ACLR. Patients with meniscal and cartilage lesions were included in the study.

Surgical Procedures

All surgical procedures were performed by two senior surgeons (E.M. and A.F.). ACLR was performed using a transphyseal approach, outside-in femoral tunnel retrodrilling, and an anatomic single-bundle technique with a quadrupled hamstring tendon autograft (semitendinosus and gracilis tendons). The entry point of the femoral tunnel was at the center of the anatomic femoral footprint of the ACL, located midway between the resident ridge and over-the-top position, with the guide set at 110°. A tibial tunnel was constructed with a standard guide at 65°. Tibial fixation was performed with interference screws (Biocomposite; Arthrex) and femoral fixation with a cortical suspensory device (TightRope; Arthrex).[13]

Only patients with $\geq$1 of the following additional risk factors for a graft rupture (pivot-shift grade 2 or 3, high level of sporting activity defined as Tegner activity score $\geq$7, participation in pivoting sports, and Segond fractures)

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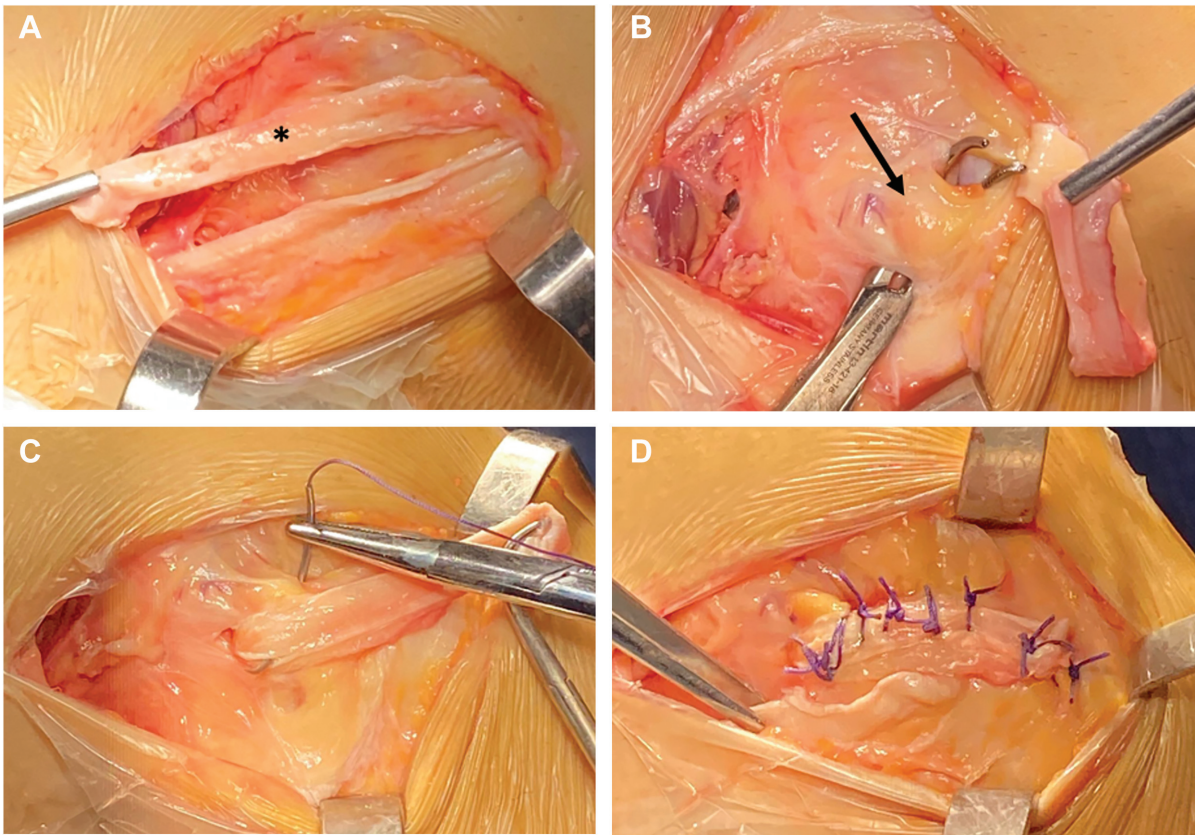

Figure 1. Intraoperative photographs demonstrating the Arnold-Coker modification of the MacIntosh procedure (lateral extra-articular tenodesis). The lateral aspect of a right knee is shown. (A) After the identification of the portion of the iliotibial band (ITB) approximately 3 cm anterior to its posterior border, a strip was harvested in line with its fibers in a distal-to-proximal direction (asterisk), leaving the insertion to the Gerdy tubercle intact. (B) The lateral collateral ligament (LCL; arrow) was identified and the ITB graft was passed deep to it from distal to proximal. (C) The graft was then reflected over the LCL of the strip, manually tensioned, and sutured to itself with the knee in 90° of flexion and the tibia held in external rotation to achieve maximal shortening of the fascial strip. (D) Final appearance of the tenodesis construct after suturing was complete.

were offered LET in addition to ACLR. This was performed using the Arnold-Coker modification of the MacIntosh procedure.[3] With the knee at 90° of flexion, a 10 cm– to 12 cm–long incision was made from the lateral femoral condyle to the Gerdy tubercle. The ITB was exposed, and a 1 cm–wide and 13 cm–long strip was harvested from approximately 3 cm anterior to the posterior border, leaving intact its distal attachment on the Gerdy tubercle. The fibular collateral ligament was identified, and the proximal part of the strip was passed below the ligament. The tibia was held in maximal external rotation,[3,14] and the strip was then reflected and sutured to itself, while under tension with the knee at 90° of flexion, using absorbable periosteal stitches (No. 2 Vicryl; Ethicon) placed at the level of the Gerdy tubercle and the lateral collateral ligament (Figure 1). This achieved maximal shortening of the fascial strip and thus eventual tightness of the repair construct. This procedure has been described as a simplification of MacIntosh and Darby's[30] original technique, which instead involved creating an osteoperiosteal tunnel posterior to the fibular collateral ligament's femoral attachment in which a strip of the ITB was passed before being looped through the lateral intermuscular septum and sutured back onto itself at the Gerdy tubercle with the knee flexed to 90° and held in external rotation.

Revision surgery in patients who had a graft rupture was performed using either contralateral quadrupled hamstring tendon or bone–patellar tendon–bone autografts.

Rehabilitation

Postoperatively, patients were immediately permitted to bear weight as tolerated with crutches. However, when concomitant meniscal repair was performed, patients remained nonweightbearing for 2 weeks. All patients utilized a knee extension brace for 4 weeks. During the first 2 weeks, this was only removed for formal physical therapy, which commenced on the second postoperative day. At 2 weeks postoperatively, the brace was adjusted to allow a range of 0° to 90°. The early focus of rehabilitation was to regain full range of motion and full weightbearing within 4 weeks. From the second month postoperatively, a more intensive muscle-strengthening program was prescribed. Patients

began gradual noncontact athletic activities and sport-specific training at 3 months. Return to full sports activities was allowed when rehabilitation was complete, between 9 and 12 months, and not before 9 months after ACLR.

Follow-up

Patients were reviewed at 2 and 6 weeks and at 3, 6, 12, and 24 months postoperatively. In addition, all patients were recalled for an in-office evaluation between September 2019 and June 2020 for a final follow-up. Patients who were not readily able to attend an in-office final follow-up (because of either restrictions related to the COVID-19 pandemic or having geographically relocated away from the locality) participated in a telemedicine interview instead. Regardless of the type of final follow-up, all patients were invited to complete patient-reported outcome measures (PROMs) including the Knee injury and Osteoarthritis Outcome Score (KOOS)[43] and International Knee Documentation Committee (IKDC)[22] questionnaires, which were administered via Google Forms (Google). Additionally, all patients were asked whether they had been able to return to sports postoperatively; if they had experienced any complications, reinjuries, or reoperations; and if they had any symptoms of instability, effusion, or pain. Those who had symptoms suggestive of a graft rupture were recalled for a physical examination and magnetic resonance imaging (MRI) if they were not already being seen in the office for a final follow-up. The face-to-face final evaluation was standardized and comprised a physical examination conducted by a senior surgeon (E.M.), evaluating range of motion, pivot-shift grade, Lachman grade, and side-to-side anteroposterior laxity difference with the KT-1000 arthrometer (MEDmetric), and a clinical evaluation of limb length discrepancy and deformity (not routinely performing lower extremity scanography). A physical examination of the knee was conducted on patients who attended the consultation, and PROM scores and range of motion were assessed by a telemedicine interview. Graft failure was defined by the following criteria and/or MRI confirmation: side-to-side maximum manual difference of >5 mm using the KT-1000 arthrometer and a pivot-shift grade of 2 + /3 + . A review of medical notes was conducted to extract data regarding demographics, Tanner stage at the time of surgery, and level of preoperative sports participation.

Statistical Analysis

Descriptive data were analyzed for the entire patient cohort. All analyses were performed with SPSS Statistics software (Version 25.0; IBM). Statistical significance was set at $P < .05$. Descriptive data analyses were conducted depending on the nature of the considered criteria. For quantitative data, this included the number of observed values (and missing values, if any), mean, standard deviation, range median and interquartile range. For qualitative data, this included the number of observed and missing values as well as the number and percentage of patients. Comparisons between variables were assessed with the chi-square or Fisher exact test for categorical variables and the Student or Wilcoxon test for quantitative variables. The normality of variables was assessed with the Kolmogorov-Smirnov test. The primary endpoint was graft failure after ACLR. The characteristics of the studied population were described according to group (ACLR or ACLR + LET). Multivariate logistic regression was used to identify risk factors associated with graft failure. Factors considered were those selected as statistically significant at the 25% threshold and those of clinical interest. The odds ratio of a graft rupture for each group was calculated after applying the Haldane-Anscombe correction. Cumulative survivorship was evaluated with the Kaplan-Meier method. Regarding the PROMs, as stated by Muller et al,[36] the Patient Acceptable Symptom State (PASS) was 75 for the subjective IKDC, 88.9 for the KOOS Pain, 57.1 for the KOOS Symptoms, 100.0 for the KOOS Activities of Daily Living, 75.0 for the KOOS Sport/Recreation, and 62.5 for the KOOS Quality of Life. The minimal clinically important difference (MCID) for the Tegner activity scale was 1.[19]

RESULTS

Patients

Overall, 734 patients underwent ACLR during the study period, and 118 met the inclusion criteria. The study flow is presented in Figure 2. There were 7 patients (5.9%) who were lost to follow-up. Additionally, 15 patients (12.7%) did not attend the final in-office evaluation at the end of the study period and underwent a telemedicine interview only; none had symptoms suggestive of a graft rupture, and all completed PROMs. The final study population, after applying exclusion and inclusion criteria and excluding patients lost to follow-up, was therefore composed of 111 patients with a mean follow-up of 43.8 ± 17.6 months (range, 24-89 months), 40 of whom underwent isolated ACLR and 71 of whom underwent ACLR + LET. The mean age of the entire population was 16.2 ± 1.4 years, and there were no significant differences in the mean age between the 2 groups. The mean age was 16.3 years (range, 13.9-17.6 years) in the isolated ACLR group and 16.1 years (range, 13.0-17.6 years) in the ACLR + LET group. Female patients comprised 37.5% and 38.0% of the isolated ACLR group and ACLR + LET group, respectively. Furthermore, 37.5% and 50.7% of patients were defined as having Tanner stage 5 in the isolated ACLR group and ACLR + LET group, respectively. During the study period, there were no patients with congenital abnormalities of the ACL. The characteristics of the study population are summarized in Table 1 and surgical characteristics in Table 2.

It is important to highlight that there were significant differences between the groups with respect to the preoperative Tegner activity score (isolated ACLR group: 6; ACLR + LET group: 7; $P = .008$) and preoperative pivot-shift grade (grade 2 + /3 +) (isolated ACLR group: 0.0%; ACLR + LET group: 52.1%; $P = .023$), reflecting the previously mentioned eligibility criteria and a higher risk of graft ruptures for patients selected for combined procedures. Despite

TABLE 1
Characteristics of Participants[a]

Characteristic	All (N = 111)	Isolated ACLR (n = 40)	ACLR + LET (n = 71)	*P* Value
Age, y	16.2 ± 1.4 (13.0-17.6)	16.3 ± 1.3 (13.9-17.6)	16.1 ± 1.5 (13.0-17.6)	.471
Tanner stage, n (%)				.127
3/4	60 (54.1)	25 (62.5)	35 (49.3)	
5	51 (45.9)	15 (37.5)	36 (50.7)	
Sex, n (%)				.199
Male	69 (62.2)	25 (62.5)	44 (62.0)	
Female	42 (37.8)	15 (37.5)	27 (38.0)	
Side, n (%)				.121
Right	50 (45.0)	14 (35.0)	36 (50.7)	
Left	61 (55.0)	26 (65.0)	35 (49.3)	
Time from injury to surgery, d	155.1 ± 278.5 (2-1577)	156.9 ± 244.0 (3-1420)	154.1 ± 299.3 (2-1577)	.897
Follow-up, mo	43.8 ± 17.6 (24-89)	36.5 ± 15.6 (24-89)	47.9 ± 17.2 (24-89)	**.001**
Tegner activity score, median	7	6	7	**.008**

[a]Data are presented as mean ± SD (range) unless otherwise indicated. Boldface indicates statistical significance ($P < .05$). ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis.

these differences, there were no significant differences with respect to other characteristics including age, sex, Tanner stage, and time from injury to surgery.

Graft Ruptures

At a mean final follow-up of 43.8 months, the graft rupture rate in the entire population was 5.4% (6/111). All 6 patients underwent revision ACLR with either a contralateral doubled gracilis and semitendinosus tendon graft or ipsilateral bone–patellar tendon–bone graft. In the isolated ACLR group, the graft rupture rate was 15.0% (6/40), and in the ACLR + LET group, it was 0.0% (0/71) ($P = .003$). One patient experienced a contralateral ACL injury in the isolated ACLR group and none in the ACLR + LET group. Kaplan-Meier cumulative survivorship of grafts, stratified by group, is reported in Figure 3.

Analysis of Potential Risk Factors for a Graft Rupture

Univariate analysis demonstrated that failure to perform a lateral extra-articular procedure was associated with a significantly increased risk of graft ruptures but that none of the other variables assessed held significance. Variables included in the multivariate model were sex, age, Tanner stage, and whether LET was performed. Multivariate analysis (Table 3) demonstrated that failure to perform a lateral extra-articular procedure was associated with a 15.91-fold increased risk of graft ruptures compared with patients who underwent combined procedures.

Knee Stability and PROMs

There were significant differences between the groups with respect to knee stability, and this information is provided in detail in Table 4. In summary, none of the patients in the ACLR + LET group had a postoperative pivot-shift grade 2+ or 3+ or a side-to-side anteroposterior laxity difference >5 mm compared with 5.7% ($P = .141$), 11.4% ($P = .021$), and 17.1% ($P = .003$), respectively, in the isolated ACLR group.

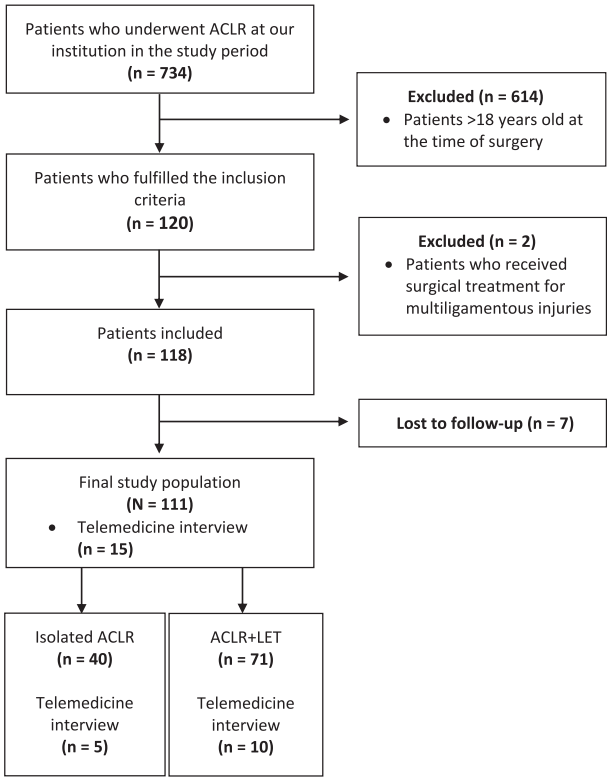

Figure 2. The study flowchart in line with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement (http://www.strobestatement.org). ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis.

No significant differences were found between the groups concerning the postoperative KOOS and subjective IKDC scores, return-to-sports rate, or rate of secondary

TABLE 2
Intraoperative Characteristics of Participants[a]

Variable	All (N = 111)	Isolated ACLR (n = 40)	ACLR + LET (n = 71)	*P* Value
Pivot-shift grade				**.023**
0 or 1 +	74/111 (66.7)	40/40 (100.0)	34/71 (47.9)	
2 + or 3 +	37/111 (33.3)	0/40 (0.0)	37/71 (52.1)	
Meniscal tear				.831
None	80/111 (72.1)	28/40 (70.0)	52/71 (73.2)	
Medial	15/111 (13.5)	6/40 (15.0)	9/71 (12.7)	
Lateral	14/111 (12.6)	6/40 (15.0)	8/71 (11.3)	
Both	2/111 (1.8)	0/40 (0.0)	2/71 (2.8)	
Meniscal suturing				.809
Medial	16/17 (94.1)	6/6 (100.0)	10/11 (90.9)	
Lateral	15/16 (93.8)	5/6 (83.3)	10/10 (100.0)	
Meniscectomy				.412
Medial	1/17 (5.9)	0/6 (0.0)	1/11 (9.1)	
Lateral	1/16 (6.3)	1/6 (16.7)	0/10 (0.0)	
Graft diameter, mean ± SD (range), mm	8.29 ± 0.59 (7-10)	8.33 ± 0.65 (7-9)	8.27 ± 0.56 (7-10)	.644
Chondral full-thickness lesion				.603
None	104/111 (93.7)	38/40 (95.0)	66/71 (93.0)	
Yes	7/111 (6.3)	2/40 (5.0)	5/71 (7.0)	
Microfracture	7/7 (100.0)	2/2 (100.0)	5/5 (100.0)	.999
Segond fracture	3/111 (2.7)	0/40 (0.0)	3/71 (4.2)	.538

[a]Data are presented as n (%) unless otherwise indicated. Boldface indicates statistical significance ($P < .05$). ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis.

surgical procedures for non–graft rupture related indications. There were no differences in the rate of achieving the PASS for the IKDC and KOOS. However, there was a significant difference in the postoperative Tegner activity score between the groups (isolated ACLR group: 6; ACLR + LET group: 7; $P = .010$), which reached the minimal detectable change of 1.[4] Postoperative PROM data are shown in Table 5.

Non–Graft Rupture Related Reoperations and Other Complications

There were no significant differences between the groups with respect to non–graft rupture related reoperation rates (isolated ACLR group: n = 4 [10.0%]; ACLR + LET group: n = 8 [11.3%]; $P = .882$). Indications included secondary meniscectomy, meniscal repair, manipulation under anesthesia, excision of cyclops lesion, contralateral ACLR, and arthroscopic lavage. Specific rates for each group are reported in Table 6.

There were also no significant differences between the groups with respect to the rate of postoperative complications that did not require surgery (isolated ACLR group: n = 4 [10.0%]; ACLR + LET group: n = 9 (12.7%); $P = .769$) (Table 7).

DISCUSSION

The most important findings of this study were that early and middle adolescent patients who underwent isolated ACLR were significantly more likely to experience a graft rupture than those who underwent combined ACLR and

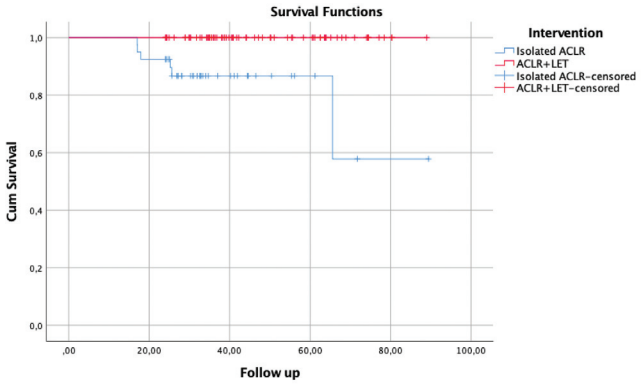

Figure 3. Kaplan-Meier plot demonstrating differences in graft survivorship between groups. There was a significant difference in graft survivorship at a mean final follow-up of 89 months (isolated ACLR group: 85.0%; ACLR + LET group: 100.0%) ($P < .001$). ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis. Horizontal axis is measured in months.

LET. Furthermore, isolated procedures were also associated with significantly worse postoperative knee laxity. These findings are particularly notable because even though lateral extra-articular procedures are frequently advocated in pediatric and adolescent patients, the available evidence to support this strategy has previously been lacking, and to our knowledge, earlier comparative studies do not exist. Despite that, the main findings of this study are consistent with comparative studies in adult

TABLE 3
Multivariate Analysis of Potential Risk Factors Associated With a Graft Rupture[a]

Comparison	Odds Ratio (95% CI)	*P* Value
Group: isolated ACLR vs ACLR + LET	15.91 (1.81-139.44)	**.012**
Age at time of surgery: ≥16 y vs <16 y	3.04 (0.37-18.87)	.328
Tanner stage: 3/4 vs 5	1.03 (0.17-6.45)	.972
Sex: male vs female	1.48 (0.25-8.73)	.658

[a]Boldface indicates statistical significance ($P < .05$). ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis.

patients, reporting significantly better knee stability and reduced graft rupture rates when a lateral extra-articular procedure is added at the time of ACLR,[17,20,21,45,49] and with noncomparative series (specifically evaluating young patients) that have reported low graft rupture rates with other types of combined procedures (Table 8). Wilson et al,[53] performing intra-articular reconstruction with the hamstring tendon augmented by extra- and intra-articular reconstruction with the ITB, reported a 5.3% graft rupture rate at a mean follow-up of 38.5 months in 57 patients aged 11 to 16 years (mean age, 13 years). Roberti di Sarsina et al[42] reported the results of hamstring tendon–based "over-the-top" ACLR + LET in 20 patients aged 8 to 13 years (mean, 12.3 years), with no graft rupture at a mean follow-up of 49.3 months. Lanzetti et al,[26] also using the hamstring tendon–based over-the-top ACLR + LET technique, reported a 4.8% graft rupture rate at a mean follow-up of 96 months in 42 patients aged 11 to 14 years (mean, 12.5 years). Kocher et al,[25] performing ITB-based over-the-top ACLR + LET, reported a 6.6% graft rupture rate at a mean follow-up of 25.8 months in 225 patients aged 5.7 to 15.6 years (mean, 11.2 years).

There are 3 main factors that explain the effectiveness of lateral extra-articular procedures in improving rotational stability and preventing graft failure. The first is the ability of LET to share loads with the ACL graft and reduce rotational and translational forces transmitted to it by up to 70%.[9,11,31] This is also postulated to account for the finding that ACL grafts "protected" by LET demonstrate better incorporation and maturation on postoperative MRI than do isolated ACL procedures.[5] Second is the longer and more efficient lever arm of extra-articular reconstruction (compared with intra-articular ACLR, close to the center of rotation) being better able to control rotational forces,[24] and third is the observation that ALL injuries frequently occur in the ACL-injured knee, and when they occur, isolated ACLR fails to restore normal knee kinematics.[13,34,40]

Although it is promising that low ACL graft rupture rates in young patients undergoing combined procedures are a consistent finding across the aforementioned studies, it is important to note that a range of techniques have been used, and this heterogeneity precludes the pooling of data or a direct comparison between them. As a result, each of these techniques must be evaluated with respect to its individual nuances and published data on outcomes and complications. This is of particular importance given the historically widespread abandonment of ITB-based lateral extra-articular procedures because of concerns about high rates of complication, which understandably are heightened in young patients because of the potentially greater effect of overconstraint and the additional possibility of growth disorders.[39] However, this abandonment of lateral extra-articular procedures was not based on an objective review of the literature and was related to a different historical context, with different knowledge and surgical and rehabilitation techniques of that time.[12] It is therefore a further important finding of the current study that the addition of LET was not associated with any significant increase in the rates of non–graft rupture related reoperations or complications and specifically that there were no cases of growth disorders or overconstraint identified. In contrast, the modified Lemaire[23] procedure (another popular ITB-based LET) has been associated with a 15.2% (23/151) rate of complications specifically attributed to the extra-articular procedure, including overconstraint of the lateral compartment, hardware irritation requiring removal, ITB snapping, and increased early pain and

TABLE 4
Knee Stability Outcomes[a]

Outcome	All (n = 96)	Isolated ACLR (n = 35)	ACLR + LET (n = 61)	*P* Value
Pivot-shift grade				**.016**
0	80 (83.3)	25 (71.4)	55 (90.2)	**.008**
1+	19 (19.8)	4 (11.4)	15 (24.6)	.289
2+	2 (2.1)	2 (5.7)	0 (0.0)	.141
3+	4 (4.2)	4 (11.4)	0 (0.0)	**.021**
Side-to-side laxity, mean ± SD, mm	2.0 ± 1.4	2.7 ± 1.7	1.6 ± 1.1	**<.001**
<3 mm	74 (77.1)	20 (57.1)	54 (88.5)	.247
3-5 mm	16 (16.7)	9 (25.7)	7 (11.5)	.169
>5 mm	6 (6.2)	6 (17.1)	0 (0.0)	**.003**

[a]Data are presented as n (%) unless otherwise indicated. Boldface indicates statistical significance ($P < .05$). Patients who had graft failure, evaluated before revision surgery, were included. ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis.

TABLE 5
Patient-Reported Outcomes[a]

Outcome	All (n = 105)	Isolated ACLR (n = 34)[b]	ACLR + LET (n = 71)	*P* Value
Overall KOOS	89.4 ± 8.3	89.1 ± 8.2	90.5 ± 8.1	.548
KOOS Symptoms	86.7 ± 10.8	87.2 ± 10.6	87.2 ± 10.4	.996
Achieved PASS, n (%)	103 (98.1)	33 (97.1)	70 (98.6)	.999
KOOS Pain	88.5 ± 13.1	90.1 ± 11.3	88.4 ± 14.1	.420
Achieved PASS, n (%)	68 (64.8)	24 (70.6)	44 (62.0)	.743
KOOS Activities of Daily Living	96.6 ± 7.1	94.9 ± 10.7	97.7 ± 4.2	.065
Achieved PASS, n (%)	104 (99.1)	33 (97.1)	71 (100.0)	.999
KOOS Sport/Recreation	79.4 ± 17.7	79.4 ± 17.4	81.8 ± 17.6	.760
Achieved PASS, n (%)	67 (63.8)	19 (55.9)	48 (67.6)	.615
KOOS Quality of Life	78.5 ± 17.7	81.5 ± 16.4	79.0 ± 17.8	.437
Achieved PASS, n (%)	93 (88.6)	30 (88.2)	63 (88.7)	.999
Subjective IKDC	86.0 ± 10.0	86.4 ± 9.5	87.3 ± 9.8	.502
Achieved PASS, n (%)	90 (85.7)	31 (91.2)	59 (83.1)	.763
Side-to-side loss of extension,[c] deg	1.3 ± 1.1	1.1 ± 0.8	1.3 ± 1.1	.110
Side-to-side loss of flexion,[c] deg	4.8 ± 1.8	4.4 ± 2.1	4.9 ± 1.9	.712
Return to sports activities, n (%)	94 (89.5)	29 (85.3)	65 (91.5)	.523
Tegner activity score, median	7	6	7	**.010**

[a]Data are presented as mean ± SD unless otherwise indicated. Boldface indicates statistical significance ($P < .05$). ACLR, anterior cruciate ligament reconstruction; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; LET, lateral extra-articular tenodesis; PASS, Patient Acceptable Symptom State.
[b]Patients who had graft failure were excluded.
[c]Side-to-side data are reported only for those patients (n = 91) who underwent a physical examination at the final follow-up.

TABLE 6
Reoperations[a]

Reoperations	All (N = 111)	Isolated ACLR (n = 40)	ACLR + LET (n = 71)	*P* Value
Revision ACLR after graft rupture	6 (5.4)	6 (15.0)	0 (0.0)	**.003**
Non–graft rupture related reoperation	12 (10.8)	4 (10.0)	8 (11.3)	.882
Secondary meniscal procedure	8 (7.2)	3 (7.5)	5 (7.0)	.930
Excision of cyclops lesion	1 (0.9)	0 (0.0)	1 (1.4)	.907
Arthroscopic arthrolysis	0 (0.0)	0 (0.0)	0 (0.0)	n.a.
Manipulation under anesthesia	1 (0.9)	0 (0.0)	1 (1.4)	.907
Arthroscopic lavage for septic arthritis	1 (0.9)	0 (0.0)	1 (1.4)	.907
Hardware removal	0 (0.0)	0 (0.0)	0 (0.0)	n.a.
Contralateral ACLR	1 (0.9)	1 (2.5)	0 (0.0)	.284
Reoperation for growth disturbance	0 (0.0)	0 (0.0)	0 (0.0)	n.a.

[a]Data are presented as n (%). Boldface indicates statistical significance ($P < .05$). ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis; n.a., not applicable.

TABLE 7
Complications Not Requiring a Reoperation[a]

Complication	All (N = 111)	Isolated ACLR (n = 40)	ACLR + LET (n = 71)	*P* Value
Anterior knee pain	7 (6.3)	3 (7.5)	4 (5.6)	.698
Symptomatic tibial tunnel cyst	1 (0.9)	0 (0.0)	1 (1.4)	.907
Dysesthesia	4 (3.6)	1 (2.5)	3 (4.2)	.640
Hemarthrosis	1 (0.9)	0 (0.0)	1 (1.4)	.907
Growth disturbance	0 (0.0)	0 (0.0)	0 (0.0)	n.a.
Total	13 (11.7)	4 (10.0)	9 (12.7)	.769

[a]Data are presented as n (%). ACLR, anterior cruciate ligament reconstruction; LET, lateral extra-articular tenodesis; n.a., not applicable.

TABLE 8
Surgical Techniques for ACLR Associated With a Lateral Extra-articular Procedure[a]

Author	Description
Kocher et al[25]	ITB-based reconstruction: The ITB was harvested and left attached distally at the Gerdy tubercle. The graft was tubularized and brought "over the top" at the femoral side and "over the front" under the intermeniscal ligament in a groove previously excavated. Fixation was performed on the femoral side with the knee at 90° of flexion and 15° of external rotation using mattress sutures to the lateral condyle. The tibial side was then fixed in the proximal medial metaphyseal cortex with mattress sutures with the knee flexed 20°.
Lanzetti et al[26] and Roberti di Sarsina et al[42]	Hamstring tendon–based reconstruction: After the tendons were harvested and sutured together, the tibial tunnel was drilled under fluoroscopic control in the epiphysis. The graft passage was directed from the tibial tunnel into the notch, then around the lateral femoral condyle through a lateral incision of the fascia, and fixed in the over-the-top position with 2 staples. The residual graft was passed between the fascia and the lateral collateral ligament and fixed with a staple on the Gerdy tubercle under fluoroscopic control. Fixation on both the femoral and the tibial sides was performed with the knee at 90° of flexion and with external rotation.
Wilson et al[53]	Hamstring tendon–based intra-articular reconstruction augmented by ITB-based extra- and intra-articular reconstruction: Both the femoral and the tibial tunnels were drilled in a transphyseal fashion. The ITB was harvested and left attached distally at the Gerdy tubercle. Once the ITB was harvested, lateral tenodesis was performed, suturing the graft to the periosteum with the leg in terminal extension and in neutral rotation. Then, the ITB autograft was passed into the tibial tunnel, and the hamstring tendon graft was pulled into the joint. Afterward, the graft was secured with suspensory fixation on the femur and interference screw fixation in the tibial tunnel with the knee in extension.

[a]ACLR, anterior cruciate ligament reconstruction; ITB, iliotibial band.

delayed functional recovery (including a delayed return to sports).[17] Potential explanations for these observed differences in complication profiles between different types of ITB-based procedures lie in the fact that the technique used in the current study did not require the use of any implant or osseous fixation, unlike the modified Lemaire procedure that uses a staple (which is reportedly a pain generator in ~10% of patients) and risks overconstraint through a combination of overtensioning and rigid fixation (bone staple), as well as malpositioning of the femoral fixation construct, resulting in unfavorable biomechanics. Of course, the main concern with overconstraint is the subsequent risk of osteoarthritis at a young age. Similar to almost all "old-fashioned" LET procedures, the original technique described by Arnold and Coker involves fixation with the foot in external rotation.[48] Although some authors have reported in biomechanical studies that fixing the LET construct in external rotation can lead to overconstraint, a previous long-term study showed that combined ACLR and the Arnold-Coker modification of the MacIntosh procedure does not appear to confer any increased risk of early osteoarthritis at a minimum follow-up of 10 years and may even be protective (by restoring more normal knee kinematics).[14,44] That overconstraint is not observed could be explained by the fact that there is no rigid bony fixation.

Recently, Getgood et al[17] published a randomized controlled study comparing single-bundle ACLR using the hamstring tendon with or without LET performed using a modified Lemaire technique. With a total of 618 patients, they analyzed a population of young patients aged 14 to 25 years and reported a lower rate of graft failure in those who underwent LET, including in the youngest subgroup of patients aged 14 to 19 years. However, specific complications that occur in pediatric populations were not explicitly reported, the Tanner stage was not recorded, no survival analysis was performed to follow patients through the risky period of adolescence, the follow-up was limited to 2 years, and multivariate analysis was not performed to see what other factors might affect ruptures in this population. The current study sought to address some of these deficiencies in the literature. In addition, although a direct comparison between studies is not possible, it seems logical to suggest that the Arnold-Coker LET technique used in the current study might be safer than a modified Lemaire procedure, as Getgood et al reported the occurrence of important complications, including persistent knee pain, a high reoperation rate for staple removal (with no assessment of the effect on growth disturbance), and overconstraint. In contrast, in the current study, there were no identified cases of overconstraint, and the technique utilized does not use hardware that could cause growth disturbance or require removal.

One of the possible concerns with the ACLR technique used in the current study is that the full tibial tunnel and the femoral socket are transphyseal and therefore could potentially lead to growth disturbance, but none was observed in the current study, and no patients underwent a reoperation for growth disturbance. Also, Millett et al[33] conducted a systematic review in which they compared transphyseal and physeal-sparing techniques for ACLR in pediatric patients. They reported deformity data from 24 studies that included 653 patients. Their analysis showed no significant difference in the rate of angular or length deformities between patients undergoing transphyseal (1.42%) or physeal-sparing (1.23%) techniques.

Additional advantages of the Arnold-Coker technique used in this study are that it is entirely extraphyseal, does not require additional tunnels on the lateral side of

the distal femur or proximal tibia, and avoids the need for additional hardware that might risk physeal injuries. However, even though no growth disorders were identified in the current study, it is important to note that patients with only Tanner stages 3, 4 and 5 were included, and therefore, these results cannot be extrapolated to patients at a higher risk of growth disorders with Tanner stages 1 and 2 (sexual maturity). Although a direct comparison with other techniques is precluded, it is clear from the literature that growth disorders have occasionally been reported with other types of combined ACLR and lateral extra-articular procedures, and this should be a consideration when selecting the surgical technique.[26,42,53] Clear guidance cannot be provided on this topic because reports are sparse, and it is often unclear if the growth disorder is related to the LET or ACLR. However, it is our opinion that avoiding additional fixation and using an extraphyseal technique for LET minimize the risk.

There were significant differences between the groups with respect to the anteroposterior laxity difference, favoring the ACLR + LET group. This finding is consistent with the previous literature. Specifically, Rezende et al[41] demonstrated in a systematic review that combined reconstruction is associated with significantly better knee stability based on not only the pivot-shift test (risk ratio, 0.95 [95% CI, 0.91-0.99]; $P = .02$) but also the Lachman test (risk ratio, 0.93 [95% CI, 0.88-0.98]; $P = .01$). Similarly, Na et al,[37] in a more recent systematic review and meta-analysis, demonstrated that the proportion of patients with Lachman grade 2 or 3 was significantly lower in the combined reconstruction group than in the isolated ACLR group (odds ratio, 0.42 [95% CI, 0.20-0.89]; $P = .02$; $I^2 = 0\%$).

A further finding of the current study was that there were no significant differences between the groups with respect to the proportion of patients who returned to sports or achieved the PASS for the KOOS and/or IKDC. There was a significant difference with respect to the MCID being reached for the Tegner activity scale (isolated ACLR group: 6; ACLR + LET group: 7; $P = .010$). However, it is important to note that these differences in the Tegner activity score matched the baseline differences between groups, reflecting the fact that combined procedures were only indicated in patients with specific risk factors for a graft rupture (including high activity levels and a high-grade pivot shift).

Limitations of this study include the well-recognized inherent weaknesses of a retrospective design. It is clear that treatment selection bias resulted in significant baseline differences between the groups. However, it is also apparent that any treatment selection bias likely favored the control group (isolated ACLR) because patients only underwent combined procedures if they had specific risk factors for a graft rupture. This observation is reflected in the fact that those undergoing combined procedures had significantly higher preoperative rates of a high-grade pivot shift and higher preoperative Tegner activity scores. These significant baseline differences between the groups serve to further highlight the remarkably low graft rupture rate in the ACLR + LET group. However, it should be noted that generalized joint laxity and recurvatum were not specifically assessed, despite being recognized risk factors for recurrent instability.

A further limitation of the study was that a specific MRI evaluation of the presence or absence of an ALL injury was not performed. In part, this is because MRI of the ALL in pediatric patients seems to be less reliable than in adults, and furthermore, the presence of an ALL injury is not a clearly defined indication for a lateral extra-articular procedure; instead, the main reason to consider an extra-articular procedure is the presence of risk factors for a graft rupture.[28]

Another limitation was that it was beyond the scope of this study to evaluate the long-term risk of osteoarthritis. This is obviously a major topic of interest given that over-constraint has been observed in clinical and laboratory studies with other types of ITB-based LET (eg, modified Lemaire).[1,17,38] It should also be noted that, to our knowledge, no specific biomechanical studies of the Arnold-Coker modification of the MacIntosh procedure are available. However, a long-term clinical study of combined ACLR and the Arnold-Coker modification did not show any evidence of early osteoarthritis but suggested that it may in fact be protective.[14] Future studies in skeletally immature patients are required to understand the long-term implications of this procedure with respect to the risk of osteoarthritis. Despite the insufficient duration to evaluate the risk of osteoarthritis, the mean follow-up time was considered adequate to reliably assess the primary outcome, which was the risk of graft ruptures. A final limitation is that a radiological evaluation of growth disturbance was not performed, and only physical examination findings were used. Therefore, subtle growth disturbance without a clinical effect may not have been detected. The relevance of this is that the effect of such disturbances may be greater in patients with Tanner stages 1 and 2, which were not studied, and therefore, the findings cannot be extrapolated to that population.

CONCLUSION

In a retrospective comparative cohort study of early and middle adolescents, ACLR (hamstring tendon autograft) combined with LET was associated with significant advantages over isolated ACLR. These advantages included a significantly lower graft rupture rate, better results on laxity, and no difference in non–graft rupture related reoperations or complications.

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