Combined Anterior Cruciate Ligament Reconstruction and Modified Lemaire Lateral Extra-articular Tenodesis Better Restores Knee Stability and Reduces Failure Rates Than Isolated Anterior Cruciate Ligament Reconstruction in Skeletally Immature Patients

Simone Perelli,[*†‡] MD, Giuseppe Gianluca Costa,[§] MD, Veronica Montiel Terron,[||] MD, PhD, Mario Formagnana,[¶] MD, Corrado Bait,[#] MD, João Espregueira-Mendes,[**††‡‡§§||||] MD, PhD, Prof., and Juan Carlos Monllau,[†‡] MD, PhD, Prof.
Investigation performed at Universitat Autònoma de Barcelona, Barcelona, Spain

Background: The increase in anterior cruciate ligament (ACL) injuries in pediatric patients and the high failure rate reported in the literature in this population are driving surgeons to search for specific techniques to better restore knee stability. Recent literature has reported that the combination of lateral extra-articular tenodesis (LET) and ACL reconstruction improves outcomes in high-risk patients. However, such advantages in pediatric patients have been infrequently evaluated.

Purpose: To assess whether adding LET to ACL reconstruction can significantly improve knee stability, clinical outcomes, and failure rates in pediatric patients.

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

Methods: A multicentric study involving 3 orthopaedic teaching centers was conducted to evaluate pediatric patients aged between 12 and 16 years who had undergone primary ACL reconstruction using a physeal-sparing femoral tunnel drilling technique. A minimum 2-year follow-up evaluation was required. Based on the surgical technique performed, the patients were divided into 2 group. The patients in group 1 underwent an isolated arthroscopic ACL reconstruction, while the patients in group 2 had an arthroscopic ACL reconstruction in combination with a modified Lemaire LET procedure. Group 1 was a historical control cohort of patients, whereas group 2 was prospectively enrolled. All the patients included in the present study were clinically evaluated using the Pediatric International Knee Documentation Committee (Pedi-IKDC) subjective score and the Pediatric Functional Activity Brief Scale (Pedi-FABS) score. Anteroposterior knee stability was measured using the KT-1000 knee ligament arthrometer, and the objective pivot-shift evaluation was documented using a triaxial accelerometer (Kinematic Rapid Assessment [KiRA]). The included patients also underwent a standardized radiological protocol to evaluate leg-length discrepancies, axial deviation, and degenerative signs preoperatively and at last follow-up.

Results: This study included 66 pediatric patients with an anatomic hybrid ACL reconstruction using an autologous 4-strand hamstring graft. In group 1, there were 34 patients (mean age, 13.5 ± 1.2 years), while 32 patients (mean age, 13.8 ± 1.4 years) were included in group 2. The clinical outcome scores showed no difference between the 2 groups (Pedi-IKDC, $P = .072$; Pedi-FABS, $P = .180$). Nevertheless, the patients in group 2 had better anteroposterior stability measured using a KT-1000 arthrometer (1.9 ± 1.1 mm in group 1 vs 0.8 ± 0.8 mm in group 2; $P = .031$), as well as better rotational stability measured using the KiRA (–0.59 ± 1.05 m/s^2 in group 2 vs 0.98 ± 1.12 m/s^2 in group 1; $P = .012$). The patients in group 1 returned to sports at the same competitive level at a rate of 82.4%, while patients included in group 2 returned at the same competitive level in 90.6% of the cases without a significant difference between the 2 groups ($P = .059$). No leg-length discrepancies were found between the 2 groups at last follow-up ($P = .881$). Two patients displayed an increased valgus deformity of 3° on the operated limb at last

The American Journal of Sports Medicine
2022;50(14):3778–3785
DOI: 10.1177/03635465221128926

follow-up (1 patient in group 1 and 1 patient in group 2). Group 1 had a significatively higher cumulative failure rate (14.7% vs 6.3%; P = .021). No intra- or postoperative complications was observed between the 2 groups.

Conclusion: Performing a modified Lemaire LET along with an ACL reconstruction with hamstring graft in pediatric patients reduced the cumulative failure rate and improved objective stability with no increase in intra- or postoperative complications. No significant difference was found between the 2 groups in terms of patient-reported outcomes or in the return-to-sports activity.

Keywords: anterior cruciate ligament; ACL; lateral extra-articular tenodesis; pediatric; children; failure rate

Anterior cruciate ligament (ACL) ruptures in pediatric patients are becoming increasingly common as more children engage in competitive sports and physical activities.[14] These injuries account for 21.5% of all knee injuries in the pediatric population. They mostly turn out to be high-pivoting sports-related injuries.[6] The proper management of ACL ruptures in this population has been a matter of debate for many years. Advocates of nonsurgical or delayed surgical treatment have pointed out the risk of growth disorders related to physeal damage.[47] However, subsequent reports have indicated that nonoperative management leads to higher rates of sports dropouts,[36] recurrent knee instability,[38] progressive meniscal and cartilage damage, and arthritic changes in about 61% of knees.[1,35] Then again, there is controversy about the best reconstruction technique, the most suitable graft choice, and the fixation methods.[3,26,38] One of the great concerns raised when facing an ACL reconstruction in this population is the high risk of graft failure, which is estimated to occur in 8.3% to 25.5% of the cases regardless of the technique and graft used.[8,26,49] This failure rate has been described as 2 to 3 times higher when compared with that in adult patients.[2,17,44]

Recently, combining a lateral extra-articular tenodesis (LET) with ACL reconstruction has been reported to significantly decrease failure rates while improving objective rotatory stability and the postoperative activity level.[33] As a result, LET has been strongly recommended for patients at high risk of graft failure. Indications include patients <25 years of age, patients practicing pivoting sports, patients with joint hyperlaxity, and patients with a high-grade preoperative instability.[30,43] Since such features are quite common in the pediatric population, LET might be quite convenient in this context. However, to date, the advantages of combining LET with ACL reconstruction in pediatric patients have been infrequently evaluated. Moreover, there are some unresolved issues that have been raised in recent studies reporting the theoretical risk of knee overconstraint and the increase in lateral compartment pressures,[23,34,48] which can accelerate degenerative joint changes. It remains unclear whether such findings result in alterations in bone growth in patients who are still developing.

The aim of the present study was to assess whether performing a LET in combination with ACL reconstruction can improve knee objective stability and clinical outcomes and decrease the failure rate in the pediatric population. The hypothesis was that combining modified Lemaire LET with ACL reconstruction would improve knee stability and clinical outcomes and reduce the failure rate in comparison with isolated ACL reconstruction in a skeletally immature population.

METHODS

A multicentric study involving 3 orthopaedic teaching centers was conducted to evaluate skeletally immature patients who had undergone ACL reconstruction with a minimum 2-year follow-up. The study was conducted in conformity with the principles of the 1964 Helsinki Declaration and its later amendments[19] and in

*Address correspondence to Simone Perelli, MD, Department of Surgery and Morphologic Science, Orthopaedic Surgery Service, Universitat Autònoma de Barcelona, Hospital del Mar, Carrer de Sabino Arana 5, Barcelona, 08028, Spain (email: perelli.simone@gmail.com).

†Department of Surgery and Morphologic Science, Orthopaedic Surgery Service, Universitat Autònoma de Barcelona, Hospital del Mar, Barcelona, Spain.

‡Knee and Arthroscopy Unit, Department of Orthopedic Surgery, Institut Catalá de Traumatologia i Medicina de l'Esport (ICATME), Hospital Universitari Dexeus, Universitat Autònoma de Barcelona, Barcelona, Spain.

§Orthopaedic Surgery Department, Ospedale Umberto I, Enna, Italy.

||Orthopaedic Surgery Department, Clinica Universidad de Navarra, Pamplona, Spain.

¶Orthopaedic Surgery Department, E. Agnelli Hospital, Pinerolo (Torino), Italy.

#Orthopaedic Surgery Department, Istituto Clinico Villa Aprica, Como, Italy.

**Clínica Espregueira—FIFA Medical Centre of Excellence, Porto, Portugal.

††School of Medicine, University of Minho, Braga, Portugal.

‡‡Dom Henrique Research Centre, Porto, Portugal.

§§ICVS/3B's—PT Government Associate Laboratory, Braga/Guimarães, Portugal.

||||3B's Research Group—Biomaterials, Biodegradables and Biomimetics, University of Minho, European Institute of Excellence on Tissue Engineering and Regenerative Medicine, Guimarães, Portugal

Submitted March 7, 2022; accepted August 16, 2022.

One or more of the authors has declared the following potential conflict of interest or source of funding: J.E.-M. has received consulting fees from Episurf Medical and Dawako Medtech. J.C.M. has received consulting fees from Smith & Nephew and speaking fees from Conmed. S.P. has received speaking fees from Smith & Nephew. C.B. has received speaking fees from Conmed. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

accordance with the ethical standards of the institutional research committee (protocol No. LCA-2017-01). All patients were informed of the study procedure, purpose, and known risks. Both the patients and parents gave written informed consent.

The included patients were skeletally immature individuals with a maximum bone age of 16 years in boys and 14 years in girls. There had to be evidence of both tibial and femoral open epiphyseal growth plates on magnetic resonance imaging (MRI) scans and a diagnosis of a primary ACL rupture. In addition, only patients willing to return to sports activities after the rehabilitation process were included. Only patients who had undergone ACL reconstruction with an autologous hamstring graft were considered for the enrollment. Patients were excluded if 1 of the following criteria was met: (1) a follow-up period <24 months after the index ACL reconstruction; (2) a concomitant grade 2 or more tear of any other knee ligament (medial collateral ligament, lateral collateral ligament, posterior cruciate ligament); (3) cartilage injuries requiring surgical treatment at the time of the ACL reconstruction; or (4) previous surgery on the affected knee.

Patient Information

Patient characteristics and the mechanism of injury were collected in an institutional database. Additional data were collected for each patient relative to intra- and postoperative complications, time to return to sports activity, the level of resumed sports activity, and any further reoperation required in the follow-up period.

The surgical data were abstracted to include details surrounding the operative procedure such as the size of the ACL graft, concomitant injuries, and respective treatments. Physical examination findings were noted by the treating surgeon, including the preoperative range of motion to evaluate hyperextension and the objective anteroposterior and rotational instability. The anteroposterior knee stability was measured using the KT-1000 knee ligament arthrometer (MEDmetric Corp). The test was performed on both knees applying 134 N of force, and the side-to-side difference was recorded. The quantitative objective pivot-shift evaluation was documented using a triaxial accelerometer (Kinematic Rapid Assessment [KiRA]; Orthokey Ltd). Also in this case, the test was performed bilaterally to calculate the side-to-side difference. Each measurement was performed 5 times. Then, the maximum and minimum values were excluded, and the 3 remaining values were averaged and used for the analyses. Both instrumental evaluations were performed preoperatively and at last follow-up. These evaluations were performed following previously published protocols by a trained knee surgeon.[9,31] Preoperative and postoperative assessments were always performed by the same senior surgeon (M.F.) trained with the KiRA system and KT-1000 arthrometer to avoid a technical bias. A single trained observer approach was adopted to mitigate the broad interobserver reliability of the test. The examiner (M.F.) was not blinded to the state of the knee but was blinded to the results of the KiRA analyses during the execution of the tests. The evaluator was not one of the treating surgeons.

Based on the surgical technique employed, patients were divided into 2 groups. The patients in group 1 underwent an isolated arthroscopic ACL reconstruction, while the patients included in group 2 underwent an arthroscopic ACL reconstruction in combination with a modified Lemaire LET procedure. Group 1 was a historical control cohort of patients who had undergone surgery between September 2015 and September 2017 and were clinically evaluated between October 2017 and October 2019. Participant enrollment in this group and the duration of follow-up were retrospective, but the clinical outcomes and radiographic measures were prospectively collected. The 2-year follow-up evaluation of this group of patients was done after the beginning of the present study. A historical control group was included because all the surgeons involved in the study had routinely performed the ACL-LET procedure on pediatric patients since 2017. Group 2 was evaluated prospectively, recruiting patients who fulfilled the inclusion criteria between October 2017 and October 2019 and were followed up until October 2021. The patient data of the 2 groups were compared to evaluate the similarities between them (Table 1).

Radiographic Data

Preoperatively, the patients underwent a standardized radiological protocol that included a left wrist view to evaluate skeletal age in accordance with the Greulich and Pyle method.[20] A bilateral anteroposterior full-length weight-bearing view was obtained preoperatively and at last follow-up to calculate any coronal alignment changes and leg-length discrepancies. Total limb length and segmental femoral and tibial lengths were measured using an institutional picture archiving and communication system (Sectra Imaging; Sectra Medical). A Rosenberg view, Merchant view, and lateral view were obtained preoperatively and at last follow-up to assess the development of early degenerative changes using the Kellgren-Lawrence scale.[27] Special attention was placed on evaluating the lateral tibiofemoral compartment where degenerative signs can come from either subchondral impaction or overconstraint secondary to the LET. Posterolateral tibial slopes were measured as previous studies have demonstrated that a slope $>8^\circ$ is correlated with and may be a risk factor for reinjury in this population.[10,24] Measurements have been made using the technique described by Hudek et al[24] as validated via MRI in a pediatric population.[10] Finally, a 1.5-T MRI scan was obtained in all cases at the 10-month follow-up before allowing patients to return to sports.

Surgical Technique and Rehabilitative Protocol

All the patients underwent an arthroscopic anatomic ACL reconstruction with autologous 4-strand hamstring graft

TABLE 1
Baseline Characteristics of the Groups[a]

	Group 1	Group 2	P Value
Male, n	23	20	.191
Female, n	11	12	.434
Age, y	13.5 ± 1.2 (12-16)	13.8 ± 1.4 (12-16)	.792
Bone age, y	14.0 ± 0.9	14.1 ± 1.0	.897
Hyperextension, deg	8	9	.901
BMI, n	21.3 ± 1.6	20.9 ± 2.4	.486
Meniscal tears, n	18	22	.251
Partial meniscectomy, n	6	6	>.999
Posterolateral tibial slope, deg	6.8 (4-11)	7.3 (2-12)	.891
Posterolateral tibial slope >8°, n	8	8	.937
Graft diameter, mm	8.2 ± 0.8	8.3 ± 1.1	.879

[a]Data are presented as number, mean ± SD (range), or mean (range) unless otherwise indicated. BMI, body mass index.
[b]Only patients with >5° of hyperextension measured using a goniometer were considered.

(semitendinosus and gracilis tendons). The femoral tunnel was made using a physeal-sparing technique with a retrodrill system, using an adjustable cortical suspension system (Ultrabutton; Smith & Nephew Endoscopy) for the femoral fixation. The tibial tunnel was executed in an outside-in manner. Using a compass tibial guide at 60° to 65°, we placed it as centered as possible on the anterior tibial cortex. By doing so, the tunnel was made as vertical as possible when trespassing the physeal growth plate. Thus, the damage caused to this growth plate was minimized.[37] The graft was then fixed at 20° of knee flexion using a bioabsorbable interference screw (Biosure HA; Smith & Nephew).

A modified Lemaire anterolateral tenodesis was performed only in the patients in group 2. A 4- to 5-cm anterolateral approach was made between Gerdy tubercle and the lateral femoral epicondyle. A 1 cm–wide × 8 cm–long strip was harvested from the middle third of the fascia lata, preserving intact its distal insertion in the Gerdy tubercle. The proximal part of the graft was secured using whip stitches and subsequently slipped deep under the lateral collateral ligament. A blind femoral tunnel of 5.5-mm width × 20-mm length was drilled and subsequently dilated using a 6-mm dilator. Finally, the graft was driven through the femoral tunnel and secured using a 6-mm × 20-mm bioabsorbable interference screw (Biosure HA) while the knee was maintained at 30° of flexion and in neutral rotation. The femoral tunnel was not placed in the position suggested by Katakura et al[25] (5-10 mm proximal and 4 mm posterior from the lateral epicondyle) but approximately 1 cm proximal to this area to prevent injuring the physeal growth plate. Both the femoral ACL tunnel and the LET tunnel were drilled under fluoroscopic control to confirm physeal sparing.

All patients from the 2 groups participated in the same standardized postoperative rehabilitation protocol. Progression through each phase of rehabilitation was based on each patient's status and the physician's guidance. Full weightbearing and full range of motion were encouraged from day 1 unless concomitant meniscal suturing was done. In the case of concomitant meniscal repairs, full weightbearing was delayed until weeks 2 to 4, according to the tear location and repair configuration. Isometric quadriceps strengthening was encouraged as soon as possible. During the first 12 weeks, quadriceps-strengthening exercises were restricted to closed kinetic chain exercises. Sports-specific training was started and gradually progressed after 6 months. A complete return to sports (including cutting sports) was allowed between 10 and 12 months when the physical examination, muscular strength, and MRI aspect of the graft were favorable.

Outcome Evaluation

Four primary clinical outcomes were evaluated in the present study. They were cumulative graft failure, objective knee stability, return to sports, and patient-reported outcome measures. The cumulative failure was defined by the presence of clinical failure and/or graft rupture, as previously reported by Crawford et al.[7] Clinical failure was defined as the presence of a patient-reported feeling of giving way and an abnormal KT-1000 side-to-side difference >5 mm or an abnormal KiRA side-to-side difference >1.9 m/s^2, as previously described.[4,32] A graft rupture was defined by MRI evidence of graft discontinuity. Patients with clinical failures and/or MRI evidence of graft ruptures were singularly included in the cumulative failure. In the presence of both clinical failure and graft rupture in the same patient, this individual was counted only once.

Return-to-sports activities were evaluated and recorded. The time since the surgery was also noted. Return to sports was determined by asking the patient if he or she had returned to the desired level of sports. If "no" was the answer, the patients were questioned as to why they did not return to sports.

Patient-reported outcomes were collected preoperatively and at annual intervals. The Pediatric International Knee Documentation Committee (Pedi-IKDC) subjective score[28] and the Pediatric Functional Activity Brief Scale (Pedi-FABS) score[16] were employed in the present study.

The preoperative Pedi-FABS score was used to detect the preinjury activity level of the patients.

Furthermore, all the following complications were collected for both groups: infection, deep vein thrombosis and pulmonary embolism, range of motion loss, and persistent knee pain.

Statistical Analysis

Continuous variables are presented as mean ± SD. Categorical variables are presented as percentage and frequency. The Shapiro-Wilk test was used to confirm the normality of the variables. The inference in continuous variables was calculated using the paired-samples *t* test, and the results are presented with their 95% CI. The inference for categorical variables was studied using the chi-square test or Fisher exact test, as appropriate. To compare repetitive variables, we used analysis of variance. The level of significance was set at 5% (α = .05), the bilateral approximation. All the analyses were performed using SPSS Version 19 (IBM Corp). No sample size estimation was performed because all patients in the database who met the inclusion criteria for group 1 were analyzed and group 2 was matched to group 1. A post hoc calculation achieved a power of 82.6% for the KT-1000, 88.3% for the KiRA evaluation, and 85.1% relative to the subjective IKDC at the 2-year follow-up.

RESULTS

Patient Information

In total, 73 patients were initially included in this study. However, 7 patients (3 patients in group 1, 4 patients in group 2) were excluded. In 3 cases, there was no 2-year follow-up (dropouts: 1 patient in group 1, 2 patients in group 2); in 1 case, a cartilage lesion that required surgery was observed; and the remaining 3 cases had a knee multiligament reconstruction. In the end, 66 skeletally immature patients were evaluated, with 34 patients included in group 1 and 32 in group 2. The mean age was homogeneous across groups (*P* = .792). The injury mechanism was predominantly noncontact (71.2%), and the injuries were sustained during pivoting sports (soccer, 36.2%; basketball, 16.8%; ski, 11.8%) in most cases.

The mean graft diameter was 8.2 ± 0.8 mm (range, 7-9 mm; median, 8 mm) in group 1 and 8.3 ± 1.1 mm (range, 7-9 mm; median, 8 mm) in group 2 (*P* = .879). In 8 cases of group 1 and 9 cases of group 2, the graft diameter was 7 mm (*P* = .912). The mean follow-up was 26.6 ± 4.2 months for group 1 and 25.1 ± 2.2 months for group 2 (*P* = .591). In 60.6% of the cases (40 patients: 18 in group 1, 22 in group 2), meniscal lesions were detected: lateral isolated, 22.5%; medial isolated, 52.5%; and lateral and medial, 25%. A ramp lesion was observed in 16.7% of the cases, a posterolateral root tear was observed in 13.6% of the cases, and the combination of both lesions was observed in 3% of the cases. A medial partial meniscectomy was performed in 6 cases in each group. In all the rest of the lesions, meniscal suture repair were done. No significant differences were found between the 2 groups in terms of age, body mass index, sex distribution, preoperative instability, hyperextension, posterolateral tibial slope, associated meniscal tears, or partial meniscectomy. A complete description of the data is available in Table 1.

No intraoperative complications were detected. Two patients from group 2 developed a postoperative hematoma in the area of the lateral approach. Surgical debridement was called for in 1 of those cases. Two patients in group 1 and 1 patient in group 2 underwent arthroscopic arthrolysis for flexion or extension deficit at 3-month follow-up. No infection, deep vein thrombosis and pulmonary embolism, deficit in range of motion, or persistent knee pain was noted at the 2-year follow-up.

Radiographic Outcomes

The bone age of group 1 averaged 14.0 ± 0.9 years (range, 12-16 years; male: mean, 14.5 years; female: mean, 13.0 years). It was 14.1 ± 1.0 years (range, 12-16 years; male: mean, 14.7 years; female: mean, 13.2 years) in group 2 (*P* = .897). In all 66 patients, the preoperative MRI scans showed both the femoral and the tibial physis open. No leg-length discrepancies were found at last follow-up (*P* = .881). Two patients had increased valgus deformity of 3° on the operated limb at the last medical follow-up, 1 from group 1 and the other from group 2. No patients showed degenerative changes in the joint based on the Kellgren-Lawrence classification. Specifically, no changes were detected at the lateral compartment at the last follow-up.

Clinical Outcomes

Four patients (11.8%) in group 1 and 1 patient (3.1%) in group 2 sustained a complete graft tear (confirmed via MRI and pathological instrumental evaluation) during sports activities. In addition to the above, 1 patient (2.9%) from group 1 and 1 patient (3.1%) from group 2 were evaluated with clinical failure, reporting postoperative subjective giving way associated with pathological KT-1000 and/or KiRA values. The cumulative failure was defined by the presence of clinical failure and/or graft rupture: it was 14.7% in group 1 versus 6.3% in group 2 (*P* = .021). All data are presented in Table 2.

In the subgroup of patients with a graft diameter of 7 mm, we observed only a graft tear in group 2 and no clinical failures.

At the last follow-up, the patients in group 2 had better anteroposterior stability measured using a KT-1000 arthrometer (*P* = .031), as well as better rotational stability measured using the KiRA triaxial accelerometer (*P* = .012). A detailed description of the values is provided in Table 3.

The return-to-sports rate at the same competitive level was 82.4% for group 1, while this rate was 90.6% in group 2, with no significant difference between the groups (*P* = .059). Of those not returning to sports, 5 patients (3

TABLE 2
Clinical Failures and Graft Ruptures[a]

	Group 1	Group 2	*P* Value
Clinical failure	1 (2.9)	1 (3.1)	.875
Graft rupture	4 (11.8)	1 (3.1)	**.017**
Cumulative failure	5 (14.7)	2 (6.3)	**.021**

[a]Data are presented as absolute number (relative rate). Boldface *P* values indicate a statistically significant difference.

TABLE 3
Preoperative and Postoperative Knee Laxity[a]

	Group 1	Group 2	*P* Value
Preoperative KT-1000, mm	4.2 ± 1.3	4.6 ± 1.4	.565
Postoperative KT-1000, mm	1.9 ± 1.1	0.8 ± 0.8	**.031**
Preoperative KiRA, m/s^2	2.51 ± 3.24	2.62 ± 4.00	.574
Postoperative KiRA, m/s^2	0.98 ± 1.12	–0.59 ± 1.05	**.012**

[a]Data are presented as mean ± SD. The side-to-side difference was calculated for both KT-1000 and the Kinematic Rapid Assessment (KiRA) triaxial accelerometer. Boldface P values indicate a statistically significant difference.

TABLE 4
Patient-Reported Outcomes[a]

	Group 1	Group 2	*P* Value
Preoperative Pedi-IKDC	55.4 ± 5.1	53.9 ± 2.5	.441
Postoperative Pedi-IKDC	86.4 ± 8.4	90.5 ± 9.6	.072
Preoperative Pedi-FABS	18.9 ± 4.3	19.2 ± 3.6	.593
Postoperative Pedi-FABS	17.8 ± 3.2	18.5 ± 4.0	.180

[a]Data are presented as mean ± SD. Pedi-FABS, Pediatric Functional Activity Brief Scale; Pedi-IKDC, Pediatric International Knee Documentation Committee.

patients in group 1 and 2 patients in group 2) stopped playing sports for reasons unrelated to the knee, and 4 patients (3 patients in group 1 and 1 patient in group 2) stopped playing as a result of lack of confidence in their knee. No difference was detected in the average time to return to sports of 10.3 ± 1.9 months (range, 8.9-12.4 months) after surgery in group 1 and 10.8 ± 1.4 months (range, 10.2-12.1 months) in group 2 (*P* = .236). The Pedi-IKDC subjective knee evaluation recorded for both groups showed no difference (*P* = .072) and neither did the activity level of the groups evaluated by means of the Pedi-FABS (*P* = .180) (Table 4).

DISCUSSION

The main finding of the present study is that a concomitant LET procedure during ACL reconstruction significantly reduced the failure rate when compared with isolated ACL reconstruction. A similar finding was recently described in an adult population in a recent meta-analysis of 1010 ACL cases. It demonstrated that concomitant LET results in a 3-fold lower risk of graft failure.[33] The second relevant finding of the present study is that combining LET with ACL reconstruction significantly improved both anteroposterior and rotatory knee stability in this skeletally immature cohort without increasing the risk of complications. This is in accordance with biomechanical evidence that demonstrates that LET in combination with ACL reconstruction significantly reduces both anterior tibial translation and tibial internal rotation as compared with isolated ACL reconstructions.[12,18,42]

To our knowledge, this is the first comparative study on this topic conducted on a pediatric cohort. Previous case series of combined ACL reconstruction and LET in skeletally immature patients showed failure rates ranging from 0% to 5.3%.[29,40,46] The failure rate of the combined technique in the present study (6.3%) approaches this range and is lower than that previously reported in this age group.[26] It is well known that an earlier return to sports represents a relevant risk for graft failure.[11] The low failure rate in our series may be partially related to the mean time to return to sports of 10.8 months. However, this figure does not explain the statistically significant intergroup difference in the failure rates, since neither the time to return to sports nor the rate of return at the same competitive level was significantly different between the 2 study groups. Furthermore, the present rate of return at the same competitive level with the ACL-LET reconstruction seems to be higher than the range of 71% to 86% reported in the literature for isolated ACL reconstruction.[26] Even if objective knee laxity was significantly lower in group 2, the groups had Pedi-IKDC scores that were not statistically significantly different. This finding may suggest that, in this specific population, a minor degree of residual instability does not significantly influence the clinical outcomes for patients who are not evaluated with graft failure. Similar findings have been previously described in a cohort of patients with hyperlaxity and an ACL rupture.[22]

Another finding from this study was the low rate of growth disorders, with no significant difference between the 2 groups. Physeal damage is one of the main concerns in ACL reconstructions in skeletally immature individuals[36] because it may cause growth disturbances in some 13% of cases.[5] Interestingly, this complication is also common after physeal-sparing techniques.[5,39] The risk of damage to the tibial physis should be minimized by creating a tibial tunnel as vertical as possible.[37] As a confirmation of this, no significant limb-length discrepancy was reported in our study. In addition, the risk of violating the femoral physeal growth plate is overcome with the present modified Lemaire LET technique because of the more proximal location of the femoral tunnel. The concomitant LET procedure did not significantly increase valgus deviations as expected. This finding is shared with previous reports in which the rate of growth disturbance and axial deviation after LET procedures is low.[29,40,46] Therefore, the concern about generating compressive forces resulting in growth inhibition because of graft overtensioning[15] is questionable. In addition to the safe completion of growth, concern regarding overconstraint of the lateral compartment may be a consideration. However, the absence of degenerative changes in this study as well as in similar previous case series[29,40,46] would appear to confirm the safety of LET procedures within at least a short-term follow-up of 2 years, which has already been demonstrated in adult patients in the literature.[13] Regardless, longer follow-up evaluations are needed to confirm our preliminary data.

The present study is not without limitations. The first limitation is inherent to the study design. Its design consists of retrospective participant enrollment (historical cohort) even though the clinical results, patient-reported outcomes, and radiographic measures were prospectively collected. Second, this is a multicentric study, involving different experienced surgeons. However, a uniform technique was used, and strict inclusion criteria were adopted to generate a narrowly defined study population. On the other hand, the idea of involving more centers allowed us to enlarge the cohort size. Collecting data from vast cohorts in this context is difficult because the incidence of ACL injuries in children remains low, and nonoperative treatment until skeletal maturity is still common. Third, a longer follow-up would be desirable to better determine the definitive graft failure rate with this procedure, as well as to evaluate the long-term radiological outcomes. Although our follow-up was limited to the short term, ACL graft failure has been reported to occur in 74% of the cases within the first 24 months.[45] Last, all the measures were recorded singularly. Therefore, the intraclass correlation coefficient was not calculated. However, intra- and interobserver reliability tests for radiologic measures (the lower limb-length measurement and tibiofemoral angle calculation) have already been proven excellent in skeletally immature patients.[41] Furthermore, the single-evaluator methodology was specifically adopted to minimize the error that would be introduced as a result of multiple observers using the KT-1000 and KiRA. Moreover, previous studies have already demonstrated that the KiRA is both accurate and reliable at quantifying rotational acceleration and anteroposterior laxity.[21] At the same time, it has been shown that the reliability of the KiRA device is proportional to the experience of the user.[4] For these reasons, an observer who was well experienced in knee surgery and had >3 years of experience using this triaxial accelerometer was chosen.

CONCLUSION

Based on these findings, performing a modified Lemaire LET along with an ACL reconstruction using a hamstring graft in pediatric patients reduced the cumulative failure rate and improved objective stability with no increase in intra- or postoperative complications. No significant difference was found between the 2 groups in terms of patient-reported outcomes or in the return-to-sports activity.

Further studies of greater methodological quality are welcomed to confirm the safety and efficacy of the ACL-LET procedure in the pediatric population with long-term follow-up.

ORCID iD

Simone Perelli https://orcid.org/0000-0003-0010-024X

REFERENCES

1. Aichroth PM, Patel DV, Zorrilla P. The natural history and treatment of rupture of the anterior cruciate ligament in children and adolescents: a prospective review. *J Bone Joint Surg Br*. 2002;84(1):38-41. doi:10.1302/0301-620x.84b1.11773
2. Andernord D, Desai N, Björnsson H, Ylander M, Karlsson J, Samuelsson K. Patient predictors of early revision surgery after anterior cruciate ligament reconstruction: a cohort study of 16,930 patients with 2-year follow-up. *Am J Sports Med*. 2015;43(1):121-127. doi:10.1177/0363546514552788
3. Ardern CL, Ekås G, Grindem H, et al. 2018 International Olympic Committee consensus statement on prevention, diagnosis and management of paediatric anterior cruciate ligament (ACL) injuries. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(4):989-1010. doi:10.1007/s00167-018-4865-y
4. Berruto M, Uboldi F, Gala L, Marelli B, Albisetti W. Is triaxial accelerometer reliable in the evaluation and grading of knee pivot-shift phenomenon? *Knee Surg Sports Traumatol Arthrosc*. 2013;21(4):981-985. doi:10.1007/s00167-013-2436-9
5. Collins MJ, Arns TA, Leroux T, et al. Growth abnormalities following anterior cruciate ligament reconstruction in the skeletally immature patient: a systematic review. *Arthroscopy*. 2016;32(8):1714-1723. doi:10.1016/j.arthro.2016.02.025
6. Comstock RD, Pierpoint LA. Summary report: national high school sports-related injury surveillance study, 2018-2019 school year. Published 2019. Accessed September 23, 2021. https://coloradosph.cuanschutz.edu/docs/librariesprovider204/default-document-library/2018-19.pdf?sfvrsn=d26400b9_2
7. Crawford SN, Waterman BR, Lubowitz JH. Long-term failure of anterior cruciate ligament reconstruction. *Arthroscopy*. 2013;29(9):1566-1571. doi:10.1016/j.arthro.2013.04.014
8. Cruz AI Jr, Beck JJ, Ellington MD, et al. Failure rates of autograft and allograft ACL reconstruction in patients 19 years of age and younger: a systematic review and meta-analysis. *JBJS Open Access*. 2020;5(4):e20.00106. doi:10.2106/JBJS.OA.20.00106
9. Daniel DM, Malcom LL, Losse G, Stone ML, Sachs R, Burks R. Instrumented measurement of anterior laxity of the knee. *J Bone Joint Surg Am*. 1985;67(5):720-726.
10. Dare DM, Fabricant PD, McCarthy MM, et al. Increased lateral tibial slope is a risk factor for pediatric anterior cruciate ligament injury: an MRI-based case-control study of 152 patients. *Am J Sports Med*. 2015;43(7):1632-1639.
11. Dekker TJ, Godin JA, Dale KM, Garrett WE, Taylor DC, Riboh JC. Return to sport after pediatric anterior cruciate ligament reconstruction and its effect on subsequent anterior cruciate ligament injury. *J Bone Joint Surg Am*. 2017;99(11):897-904. doi:10.2106/JBJS.16.00758
12. Delaloye JR, Hartog C, Blatter S, et al. Anterolateral ligament reconstruction and modified Lemaire lateral extra-articular tenodesis similarly improve knee stability after anterior cruciate ligament reconstruction: a biomechanical study. *Arthroscopy*. 2020;36(7):1942-1950. doi:10.1016/j.arthro.2020.03.027
13. Devitt BM, Bouguennec N, Barfod KW, Porter T, Webster KE, Feller JA. Combined anterior cruciate ligament reconstruction and lateral extra-articular tenodesis does not result in an increased rate of osteoarthritis: a systematic review and best evidence synthesis. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(4):1149-1160. doi:10.1007/s00167-017-4510-1
14. Dodwell ER, Lamont LE, Green DW, Pan TJ, Marx RG, Lyman S. 20 years of pediatric anterior cruciate ligament reconstruction in New York State. *Am J Sports Med*. 2014;42(3):675-680. doi:10.1177/0363546513518412
15. Edwards TB, Greene CC, Baratta RV, Zieske A, Willis RB. The effect of placing a tensioned graft across open growth plates: a gross and histologic analysis. *J Bone Joint Surg Am*. 2001;83(5):725-734. doi:10.2106/00004623-200105000-00012
16. Fabricant PD, Robles A, Downey-Zayas T, et al. Development and validation of a pediatric sports activity rating scale: the Hospital for Special Surgery Pediatric Functional Activity Brief Scale (HSS

Pedi-FABS). *Am J Sports Med*. 2013;41(10):2421-2429. doi:10.1177/0363546513496548

17. Faunø P, Rahr-Wagner L, Lind M. Risk for revision after anterior cruciate ligament reconstruction is higher among adolescents: results from the Danish Registry of Knee Ligament Reconstruction. *Orthop J Sports Med*. 2014;2(10):2325967114552405. doi:10.1177/2325967114552405
18. Geeslin AG, Moatshe G, Chahla J, et al. Anterolateral knee extra-articular stabilizers: a robotic study comparing anterolateral ligament reconstruction and modified Lemaire lateral extra-articular tenodesis. *Am J Sports Med*. 2018;46(3):607-616. doi:10.1177/0363546517745268
19. General Assembly of the World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *J Am Coll Dent*. 2014;81(3):14-18.
20. Greulich WW, Pyle SI. Radiographic atlas of skeletal development of the hand and wrist. 2nd ed. I volume-atlante di 256 pagine. Stanford University Press; 1959. *Acta Genet Med Gemellol (Roma)*. 1959;8(4):513-513. doi:10.1017/s1120962300018680
21. Helfer L, Vieira TD, Praz C, et al. Triaxial accelerometer evaluation is correlated with IKDC grade of pivot shift. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(2):381-388. doi:10.1007/s00167-019-05563-7
22. Helito CP, Sobrado MF, Giglio PN, et al. Combined reconstruction of the anterolateral ligament in patients with anterior cruciate ligament injury and ligamentous hyperlaxity leads to better clinical stability and a lower failure rate than isolated anterior cruciate ligament reconstruction. *Arthroscopy*. 2019;35(9):2648-2654. doi:10.1016/j.arthro.2019.03.059
23. Herbst E, Arilla FV, Guenther D, et al. Lateral extra-articular tenodesis has no effect in knees with isolated anterior cruciate ligament injury. *Arthroscopy*. 2018;34(1):251-260. doi:10.1016/j.arthro.2017.08.258
24. Hudek R, Schmutz S, Regenfelder F, Fuchs B, Koch PP. Novel measurement technique of the tibial slope on conventional MRI. *Clin Orthop Relat Res*. 2009;467(8):2066-2072.
25. Katakura M, Koga H, Nakamura T, et al. Biomechanical effects of additional anterolateral structure reconstruction with different femoral attachment sites on anterior cruciate ligament reconstruction. *Am J Sports Med*. 2019;47(14):3373-3380. doi:10.1177/0363546519880192
26. Kay J, Memon M, Marx RG, Peterson D, Simunovic N, Ayeni OR. Over 90% of children and adolescents return to sport after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(4):1019-1036. doi:10.1007/s00167-018-4830-9
27. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. *Ann Rheum Dis*. 1957;16(4):494-502. doi:10.1136/ard.16.4.494
28. Kocher MS, Smith JT, Iversen MD, et al. Reliability, validity, and responsiveness of a modified International Knee Documentation Committee Subjective Knee Form (Pedi-IKDC) in children with knee disorders. *Am J Sports Med*. 2011;39(5):933-939. doi:10.1177/0363546510383002
29. Lanzetti RM, Pace V, Ciompi A, et al. Over the top anterior cruciate ligament reconstruction in patients with open physes: a long-term follow-up study. *Int Orthop*. 2020;44(4):771-778. doi:10.1007/s00264-020-04490-4
30. Larson CM, Bedi A, Dietrich ME, et al. Generalized hypermobility, knee hyperextension, and outcomes after anterior cruciate ligament reconstruction: prospective, case-control study with mean 6 years follow-up. *Arthroscopy*. 2017;33(10):1852-1858. doi:10.1016/j.arthro.2017.04.012
31. Lopomo N, Zaffagnini S, Signorelli C, et al. An original clinical methodology for non-invasive assessment of pivot-shift test. *Comput Methods Biomech Biomed Engin*. 2012;15(12):1323-1328. doi:10.1080/10255842.2011.591788
32. Lo Presti M, Costa GG, Grassi A, et al. Graft-preserving arthroscopic debridement with hardware removal is effective for septic arthritis after anterior cruciate ligament reconstruction: a clinical, arthrometric, and magnetic resonance imaging evaluation. *Am J Sports Med*. 2020;48(8):1907-1915. doi:10.1177/0363546520924823
33. Mao Y, Zhang K, Li J, Fu W. Supplementary lateral extra-articular tenodesis for residual anterolateral rotatory instability in patients undergoing single-bundle anterior cruciate ligament reconstruction: a meta-analysis of randomized controlled trials. *Orthop J Sports Med*. 2021;9(5):23259671211002282. doi:10.1177/23259671211002282
34. Marom N, Jahandar H, Fraychineaud TJ, et al. Lateral extra-articular tenodesis alters lateral compartment contact mechanics under simulated pivoting maneuvers: an in vitro study. *Am J Sports Med*. 2021;49(11):2898-2907. doi:10.1177/03635465211028255
35. Moksnes H, Engebretsen L, Risberg MA. Prevalence and incidence of new meniscus and cartilage injuries after a nonoperative treatment algorithm for ACL tears in skeletally immature children: a prospective MRI study. *Am J Sports Med*. 2013;41(8):1771-1779. doi:10.1177/0363546513491092
36. Moksnes H, Engebretsen L, Seil R. The ESSKA paediatric anterior cruciate ligament monitoring initiative. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(3):680-687. doi:10.1007/s00167-015-3746-x
37. Osier CJ, Espinoza-Ervin C, Diaz De Leon A, Sims G, Ellis HB Jr, Wilson PL. A comparison of distal femoral physeal defect and fixation position between two different drilling techniques for transphyseal anterior cruciate ligament reconstruction. *J Pediatr Orthop B*. 2015;24(2):106-113. doi:10.1097/BPB.0000000000000143
38. Perkins CA, Willimon SC. Pediatric anterior cruciate ligament reconstruction. *Orthop Clin North Am*. 2020;51(1):55-63. doi:10.1016/j.ocl.2019.08.009
39. Pierce TP, Issa K, Festa A, Scillia AJ, McInerney VK. Pediatric anterior cruciate ligament reconstruction: a systematic review of transphyseal versus physeal-sparing techniques. *Am J Sports Med*. 2017;45(2):488-494. doi:10.1177/0363546516638079
40. Roberti di Sarsina T, Macchiarola L, Signorelli C, et al. Anterior cruciate ligament reconstruction with an all-epiphyseal ‘‘over-the-top’’ technique is safe and shows low rate of failure in skeletally immature athletes. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(2):498-506. doi:10.1007/s00167-018-5132-y
41. Schlégl ÁT, O'Sullivan I, Varga P, Than P, Vermes C. Determination and correlation of lower limb anatomical parameters and bone age during skeletal growth (based on 1005 cases). *J Orthop Res*. 2017;35(7):1431-1441. doi:10.1002/jor.23390
42. Slette EL, Mikula JD, Schon JM, et al. Biomechanical results of lateral extra-articular tenodesis procedures of the knee: a systematic review. *Arthroscopy*. 2016;32(12):2592-2611. doi:10.1016/j.arthro.2016.04.028
43. Sonnery-Cottet B, Daggett M, Fayard JM, et al. Anterolateral Ligament Expert Group consensus paper on the management of internal rotation and instability of the anterior cruciate ligament-deficient knee. *J Orthop Traumatol*. 2017;18(2):91-106. doi:10.1007/s10195-017-0449-8
44. Wasserstein D, Khoshbin A, Dwyer T, et al. Risk factors for recurrent anterior cruciate ligament reconstruction: a population study in Ontario, Canada, with 5-year follow-up. *Am J Sports Med*. 2013;41(9):2099-2107. doi:10.1177/0363546513493580
45. Webster KE, Feller JA. Exploring the high reinjury rate in younger patients undergoing anterior cruciate ligament reconstruction. *Am J Sports Med*. 2016;44(11):2827-2832. doi:10.1177/0363546516651845
46. Wilson PL, Wyatt CW, Wagner KJ III, Boes N, Sabatino MJ, Ellis HB Jr. Combined transphyseal and lateral extra-articular pediatric anterior cruciate ligament reconstruction: a novel technique to reduce ACL reinjury while allowing for growth. *Am J Sports Med*. 2019;47(14):3356-3364. doi:10.1177/0363546519881445
47. Woods GW, Woods GW, O'Connor DP. Delayed anterior cruciate ligament reconstruction in adolescents with open physes. *Am J Sports Med*. 2004;32(1):201-210. doi:10.1177/0363546503258868
48. Xu J, Han K, Lee TQ, et al. Anterolateral structure reconstruction similarly improves the stability and causes less overconstraint in anterior cruciate ligament-reconstructed knees compared with modified Lemaire lateral extra-articular tenodesis: a biomechanical study. *Arthroscopy*. 2022;38(3):911-924. doi:10.1016/j.arthro.2021.06.023
49. Zacharias AJ, Whitaker JR, Collofello BS, et al. Secondary injuries after pediatric anterior cruciate ligament reconstruction: a systematic review with quantitative analysis. *Am J Sports Med*. 2021;49(4):1086-1093. doi:10.1177/0363546520934774