Original Article

Combining Anterior Cruciate Ligament Reconstruction With Lateral Extra-Articular Procedures in Skeletally Immature Patients Is Safe and Associated With a Low Failure Rate

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Purpose: To analyze the rates of graft ruptures and growth disorders, the level of return to sport, and the clinical results of 2 lateral extra-articular procedures in growing children. **Methods:** This study was a retrospective, single-center study of patients undergoing anterior cruciate ligament (ACL) surgery combined with 2 different lateral extra-articular procedures (anatomic reconstruction with a gracilis graft or modified Lemaire technique with a strip of fascia lata). The measurements of side-to-side anterior laxity and pivot shift were performed preoperatively and at the last follow-up. The sports level and the complications rate were assessed. The minimal clinically important differences (MCID) and patient acceptable symptoms state threshold scores were calculated. **Results:** Thirty-nine patients (40 ACLs) were included (20 anatomic and 20 modified Lemaire) at an average follow-up of 57 months ± 10 [42-74]. One patient (2.5%) was lost to follow-up. The mean age at surgery was 13.8 ± 1.4 years old [9.8; 16.5]. One graft failure was reported (2.6% [0.06-13.5]) at 35.6 months after surgery. Two cases (5.4%) of femoral overgrowth were observed, and one of them required distal femoral epiphysiodesis. Ninety-two percent of the patients returned to sports. At the final follow-up, side-to-side anterior laxity was significantly improved, and no residual pivot shift was recorded in 95% of patients. Eighty-nine percent of the patients presented a Pedi-International Knee Documentation Committee score greater than the MCID postoperatively, and 77% presented a Lysholm score greater than the MCID. **Conclusions:** This series of ACL reconstructions combined with 2 different lateral extra-articular procedures in skeletally immature patients demonstrated promising findings. The low rate of observed complications, including graft rupture and growth disturbance, is encouraging, but the small study population and lack of comparative group precludes reliable conclusions. **Level of Evidence:** IV, therapeutic case series.

The management of anterior cruciate ligament (ACL) ruptures in skeletally immature patients has been undergoing rapid development since the early 2000s. Historically, in the absence of anatomical reconstruction techniques and because of the risk of secondary growth disorders, nonsurgical treatments were favored. These treatments were based on an adapted rehabilitation program and modification or restriction of the patient's sporting activities.[1-3] However, failures of nonoperative management, with meniscus and cartilage consequences,[4-6] the desire to return to sports, the increasing incidence of ACL ruptures in children,[7-12] and the development of pediatric surgical procedures are at the origin of the increase in surgical treatment of ACL reconstruction.[13] Nevertheless, the conclusions of the meta-analysis by Ramski et al.[14] favored early surgical management in children. ACL reconstruction in young patients remains linked to a high rate of graft failure[15-17] and to potential growth disorders[18,19]: being a child has been described as a major risk factor for graft failure in comparison with an

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The authors report the following potential conflicts of interest or sources of funding: M.T. and B.S.-C. report personal fees from Arthrex during the conduct of the study and outside the submitted work. J.-M.F. reports nonfinancial support from Arthrex, New Clip Technics, and X Nov, outside the submitted work. DRE Ramsay Santé funds the studies as the Centre Orthopédique Santy. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received December 3, 2021; accepted August 1, 2022.

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2666-061X/211681

https://doi.org/10.1016/j.asmr.2022.08.002

adult population in a large cohort of 5,479 patients (18.0% [pediatric <20 years old] vs 9.2% [adults 20-29 years old] and 7.1% [adults 30-39 years old]; $P < .0001$ at 5 years postoperatively).[20]

Additionally, persistent poor rotational control is reported in 17% to 30% of patients who undergo ACL surgery.[21,22] The existence of the anterolateral ligament (ALL) was mentioned by Paul Segond in 1879,[23,24] which he defined at that time as "a pearly fibrous strip" on the anterolateral portion of the capsule. It was then updated in 2013 by Claes et al.[25] ALL tears in association with ACL tears have been reported by several authors.[26,27] The role of the ALL has now been demonstrated in rotational control of the knee,[21,28] and its reconstruction during ACL surgery has shown its effectiveness in adults[29,30] by significantly reducing the rate of iterative rupture.[31,32] Few studies have analyzed the results of ACL reconstruction associated with anterolateral procedures in children.[33-37] Kocher et al.[36] published an article in 2018 with encouraging results over a short-term follow-up with excellent functional outcomes, minimal risk of growth disturbance (0%), and a low graft rupture rate (6.6%).

The purposes of this study were to analyze the rates of graft ruptures and growth disorders, the level of return to sport, and the clinical results of 2 lateral extra-articular procedures in growing children. Our hypothesis was that combined ACL and lateral extra-articular procedure would provide good clinical results and low failure and complications rates.

Methods

Institutional review board approval (COS-RGDS-2021-04-001) was granted for this study, and all of the participants provided valid consent to participate.

Patients

This study was a single-center retrospective study undertaken between April 2014 and December 2016. The inclusion criteria were as follows: any child with growth potential (bone age younger than 13.5 years old for girls and younger than 15.5 years old for boys) who underwent a surgical technique combining ACL and lateral extra-articular procedure. In our institution, all patients younger than 25 years old undergo a lateral extra-articular procedure when an ACL reconstruction is performed. The exclusion criteria were the absence of follow-up until skeletal maturity bone age >13.5 for girls and 15.5 for boys or fusion of the proximal tibial or distal femoral epiphyseal growth plate on preoperative radiographs, previous knee injury, and multi-ligamenteous injuries

Operating Methods

Expert surgeons were involved (M.T., B.S.C. and J.M.F.). Two different surgical techniques were performed, chosen according to the preference of the surgeon (Fig 1). These surgical procedures were based on a vertical transphyseal tibial tunnel and a physeal-sparing femoral tunnel using an outside-in technique on both side without any fluoroscopy. Entry point on the lateral side of the femur was located slightly posterior and proximal to the lateral epicondyle to match with the natural insertion of the ALL.[38] Hamstrings were left pediculated on the tibia so that no extra fixation were used at this level. The target diameter of the tunnels was ≤9 mm. ACL graft was fixed at 25° of flexion, anterolateral procedure was fixed in full extension. The first method (method A) consisted in ACL reconstruction with a tripled semitendinosus (ST) and 1 strand of gracilis graft and ALL reconstruction using a gracilis graft: the ACL graft was composed of 3 strands of ST and one strand of gracilis; femoral fixation was provided by a screw; a double bundle of gracilis was used to reconstruct the ALL, the anterior tunnel was positioned slightly posterior to Gerdy's tubercle and the posterior tunnel was placed midway between Gerdy's tubercle and the fibular head. The second method (method B) consisted in ACL reconstruction with a tripled ST graft fixed on the femur with a button through a blind tunnel performed with a retrodrill device; anterolateral procedure, inspired by the modified Lemaire technique,[39] was performed using a strip of fascia lata left pediculaled on Gerdy's tubercle passed medially to the lateral collateral ligament and fixed on the femoral side using the wires of the button.

Evaluation Methods

All the patients and all measurements were assessed by experimented orthopaedic surgeons (C.F., E.C., I.H. and L.G.). Preoperatively, anthropometric data, range of motion, evaluation of anterior laxity with the Lachman test, a measurement of side-to-side anterior laxity at 30° of flexion with the Rolimeter (Aircast Europa, Neubeuern, Germany), and an analysis of the pivot shift were recorded. Sports activity level was quantified using the Tegner score.[40] ACL rupture was confirmed by magnetic resonance imaging. In addition, standard anteroposterior and lateral radiographic views, as well as wrist radiographs, were performed to confirm the residual growth potential.[41] Intraoperatively, cruciate ligament, cartilage and meniscus status, and their various treatments were clearly noted on the operative report.

Patients were reviewed with a minimum of 3.5 years of follow-up. At the last follow-up, complete clinical assessment was performed again. Physical activity was evaluated by the Tegner score, and subjective evaluation of the knee was conducted using the Lysholm score[42] and the Pedi International Knee Documentation Committee (Pedi-IKDC) score.[43,44] Postoperative complications also were noted, as well as subsequent

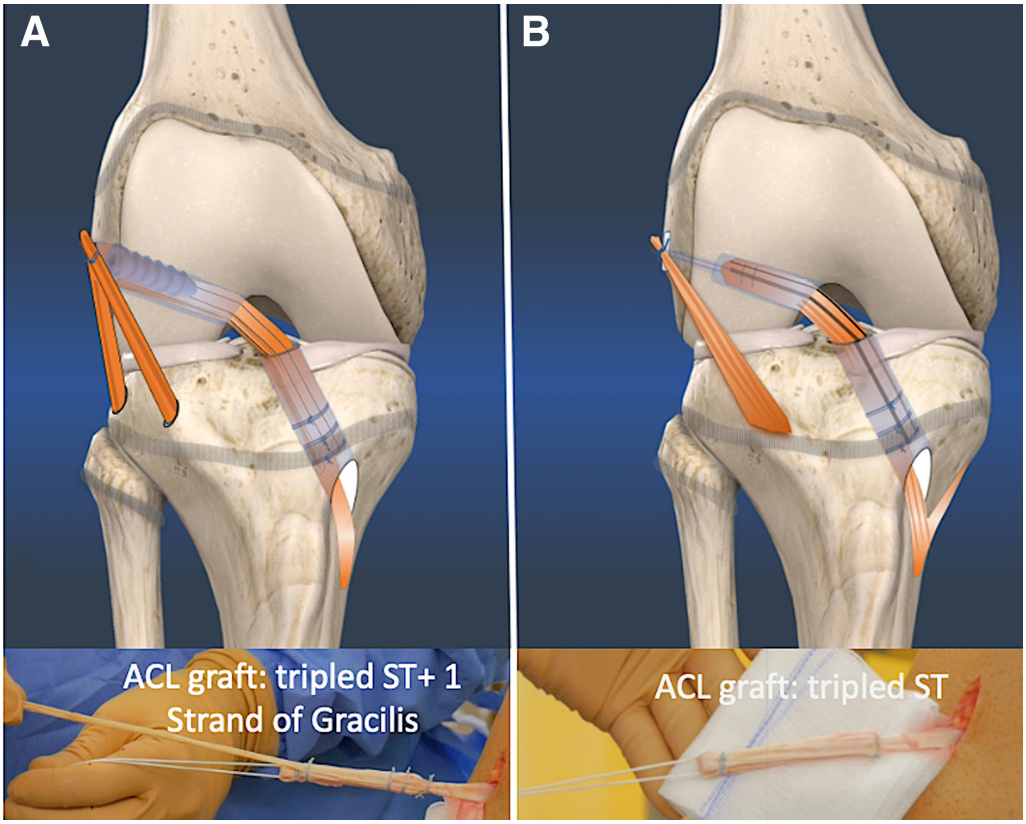

Fig 1. Operative technique. Common points: tunnel diameter ≤9 mm; tibial tunnel = transphyseal; femoral tunnel = intra-epiphyseal, no screw in the tibial tunnel. (A) ST/G + G (right knee): ST and G are left pediculated on the tibia. The ACL graft is composed of 3 strands of ST and one strand of G. Femoral fixation is provided by a screw. A double bundle of G is used to reconstruct the ALL, the anterior tunnel is positioned slightly posterior to Gerdy's tubercle, and the posterior tunnel is placed midway between Gerdy's tubercle and the fibular head. (B) ST + FL (right knee): ST is left pediculated on the tibia. The ACL graft is composed of tripled strands of ST. All of the inside femoral sockets were performed, and the graft was fixed with a button. Lateral extra-articular procedure was performed using the fascia lata left pediculated on Gerdy's tubercule and fixed on the femoral side using the wires of the button. (ACL, anterior cruciate ligament; ALL, anterolateral ligament; FL, fascia lata; G, gracilis; ST, semitendinosus.)

trauma. Leg length discrepancy was evaluated clinically by measuring the intermalleolar gap with the patient in the supine position.[45] In the case of clinical suspicion, growth disorders were confirmed using an EOS protocol[46] (EOS Imaging, Paris, France); the length of the lower limb was the sum of the measurements of the femur and the tibia (with femoral length = from the top of the intercondylar notch to the center of the femoral head and tibial length = from the distal tibial articular surface to the center of the tibial spine).[47] The search for axis disorders of the lower limbs was performed in the same manner.

Two patients could not be clinically reassessed but were interviewed by telephone and answered the various questionnaires sent by e-mail following the telephone interview. One patient who sustained a bilateral ACL rupture during the same trauma was excluded from side-to-side anterior laxity measurements and from the evaluation of growth disorders.

Statistical Analysis

Quantitative variables are expressed as the mean, standard deviation, median, minimum and maximum.

Table 1. MCID Threshold Scores

Score	MCID
Pedi-IKDC	9.25
Lysholm	12.85
KOOS Symptoms	9.30
KOOS Pain	8.60
KOOS Daily Living	8.10
KOOS Sport	16.25
KOOS Quality of life	14.60

The MCID is calculated with the distribution-based method using half the standard deviation for each delta between preoperative and postoperative outcomes.

KOOS, Knee Injury and Osteoarthritis Outcome Score; MCID, Minimally Clinically Important Difference; Pedi-IKDC, Pedi International Knee Documentation Committee.

Table 2. PASS Threshold Scores

PROMs	PASS	Sensibility (%)	Specificity (%)	AUC
Pedi-IKDC	66.17	66.7	100.0	0.84
Lysholm	86	100.0	88.9	0.96
KOOS Symptoms	45.68	66.7	97.2	0.86
KOOS Pain	88.89	100.0	91.7	0.96
KOOS Daily Living	77.22	66.7	97.2	0.88
KOOS Sport	80	100.0	66.7	0.89
KOOS Quality of Life	75	100.0	80.6	0.93

AUC, area under the curve; KOOS, Knee Injury and Osteoarthritis Outcome Score; PASS, patient acceptable symptoms state; Pedi-IKDC, Pedi International Knee Documentation Committee; PROMs, patient-reported outcome measures.

Qualitative variables are expressed as the number and frequency. The exact binomial confidence interval was given for the frequencies of ACL rerupture after surgery. Comparisons between preoperative and postoperative factors were analyzed with the Student *t* test for matched data for normally distributed variables and the Wilcoxon test for nonnormally distributed variables for qualitative data. For quantitative data, the McNemar test for binary data and the Bhapkar test for nominal qualitative data with more than 2 classes were used. The factors associated with the resumption of sports at a lower level after the operation were explored by multinomial logistic regression. Significancy was set at $P < .05$.

Calculation of Minimal Clinically Important Differences (MCID) and Patient Acceptable Symptoms State (PASS) Threshold Scores

MCIDs were calculated via the distribution-based method using half the standard deviation for each delta between preoperative and postoperative outcomes (Table 1). The PASS was calculated using an anchor-based method. PASS values were defined via receiver operating characteristic curve analysis. Using the Youden index, the optimal cutoff to maximize sensitivity and specificity for each outcome score was identified. The area under the curve (AUC) was calculated to assess reliability. An AUC value of 0.7 to 0.8 was considered acceptable, and an AUC value greater than 0.8 was considered excellent (Table 2).

Results

Thirty-nine patients (40 knees) were included with a mean follow-up of 57 ± 10 months (42-74 months). Twenty knees (50%, 20/40) each sustained different operating methods. One knee from method A (2.5%, 1/40) was lost to follow-up and excluded from the postoperative analysis. Five patients (13.2%, 5/38) had a contralateral ACL rupture. Demographic data are summarized in Table 3. The causes of primary injury were 1 road traffic accident (2.5% 1/40), 17 traumas during pivot sports (42.5%, 17/40), and 22 traumas during contact–pivot sports (55%, 22/40). The mean time between accident and surgery was 6.8 ± 8.4 months (0.2; 40.9) (median = 4.3 months); 3 patients (7.5%, 3/40) underwent surgery more than 2 years after the injury.

Twenty-two knees (55%, 22/40) had associated meniscal lesions (10/40 [25%] of the medial meniscus and 13/40 [32.5%] of the lateral meniscus). One knee (2.5%, 1/40) had a lesion of both menisci. Among the medial meniscal lesions, 8 (80%, 8/10) were meniscocapsular lesions.

All medial meniscocapsular lesions were repaired using an all inside suture hook.[48] One failure of medial meniscocapsular repair was recorded (12.5%, 1/8). The patient underwent reoperation at 16.5 months for revision suturing. The 2 other medial meniscal tears were treated by partial meniscectomy (25%, 2/8).

Concerning the lateral meniscus, 9 tears (69%, 9/13) were repaired with an all-inside suture,[49] 3 tears (23%, 3/13) were treated with a partial meniscectomy, and 1 stable tear (8%, 1/13) was left in place. One suture required revision surgery at 44.1 months for partial menisectomy. One (2.5%, 1/40) International Cartilage Repair Society grade 2 cartilage lesion of the medial condyle was recorded.[39]

Clinical and functional results are reported in Table 4. At the last follow-up, anterior and rotational control was significantly improved: the mean side-to-side anterior laxity was 1.7 mm ± 1.6 (−2-5), 95% of patients had no pivot shift, and no patients complained of rotational instability. Pedi-IKDC, Knee Injury and Osteoarthritis Outcome Score (KOOS), and Lysholm scores were significantly improved. Eighty-nine percent of the patients presented a Pedi-IKDC greater than the

Table 3. Demographic Preoperative Data

	Total (n = 40)	Method A (n=20)	Method B (n=20)	*P* value (A vs B)
Sex (% male)	32 (80%)	14 (70%)	18 (90%)	0.24
Injured side (% left)	23 (58%)	12 (60%)	11 (55%)	1
Average age, y	13.8 ± 1.4 [9.8-16.5]	13.6 ± 1.7 [9.8-16.5]	14 ± 1.2 [10.9-16.1]	.35
Average height, cm	165 ± 12 [138-186]	162 ± 12 [141-183]	167 ± 11 [138-186]	.22
Average weight, kg	54 ± 11 [30-85]	51 ± 11 [32-72]	56 ± 12 [30-85]	.07
Average BMI	19.6 ± 2.6 [15.1-27.8]	19.2 ± 2.6 [15.1-26.4]	20 ± 2.7 [15.6-27.8]	.28

BMI, body mass index.

Table 4. Comparison of Pre- and Postoperative Data

	Preoperative Data (n = 39)	Postoperative Data (n = 39)	*P* Value
Clinical examination			
Lachman test			
Hard	1 (3%)	36 (92%)	
Soft	37 (94%)	1 (3%)	<.001
Delayed hard	1 (3%)	2 (5%)	
Pivot shift			
0	1 (3%)	37 (95%)	
Glide	7 (18%)	2 (5%)	
++	13 (33%)	0	.04
+++	14 (36%)	0	
Nontestable	4 (10%)	0	
Differential anterior laxity, mm			
Mean ± SD [min-max]	6.9 ± 1.2 [4-10]	1.7 ± 1.6 [−2 to 5]	<.0001
Median	7.0	2.0	
Clinical score			
Pedi-IKDC (/100)			
Mean ± SD [min-max]	58 ± 14 [33-93]	89 ± 9 [66-100]	
Median	59	93	<.0001
≥MCID		35 (89%)	
≥PASS		37 (95%)	
KOOS symptom (/100)			
Mean ± SD [min-max]	81 ± 13 [50-100]	91 ± 14 [36-100]	
Median	82	96	<.0001
≥MCID		21 (53%)	
≥PASS		33 (85%)	
KOOS pain (/100)			
Mean ± SD [min-max]	80 ± 15 [39-100]	95 ± 10 [56-100]	
Median	81	100	<.0001
≥MCID		25 (64%)	
≥PASS		34 (87%)	
KOOS daily living (/100)			
Mean ± SD [min-max]	88 ± 13 [56-100]	97 ± 6 [72-100]	
Median	90	100	<.0001
≥MCID		17 (44%)	
≥PASS		38 (97%)	
KOOS sports (/100)			
Mean ± SD [min-max]	47 ± 24 [0-95]	85 ± 18 [25-100]	
Median	45	95	<.0001
≥MCID		28 (71%)	
≥PASS		27 (69%)	
KOOS quality of life (/100)			
Mean ± SD [min-max]	35 ± 24 [0-100]	88 ± 16 [35-100]	
Median	31	94	<.0001
≥MCID		35 (90%)	
≥PASS		33 (85%)	
Lysholm (/100)			
Mean ± SD [min-max]	70 ± 15 [40-100]	92 ± 15 [13-100]	
Median	71	95	<.0001
≥MCID		30 (77%)	
≥PASS		33 (85%)	
Tegner (/10)			
Mean ± SD [min-max]	7.2 ± 1 [4-10]	6.8 ± 1.8 [3-10]	
Median	7.0	7.0	.06

(continued)

Table 4. Continued

MCID, Minimally Clinically Important Difference; Pedi-IKDC, Pedi International Knee Documentation Committee; PASS, patient acceptable symptoms state; SD, standard deviation.

MCID postoperatively, and 77% presented a Lysholm greater than the MCID (Table 4).

Ninety-two percent (35/38) of the patients returned to sports. Fifteen patients (39%, 15/38) did not return to their initial Tegner level, and 23 (61%, 23/38) returned to an identical or better Tegner level. Among the 15 patients who did not return to their initial Tegner level, 6 (40%, 6/15) had a graft injury or a rupture of the contralateral ACL. There were no predictive factor influencing the return to sports among all those studied (sex, body mass index, preoperative Tegner, meniscal lesion, graft rupture, or contralateral ACL rupture), although having a contralateral ACL rupture or graft rupture was at the edge of significance ($P = .05$) (Table 5).

Six knees required reoperation (15.4%, 6/39): 1 ACL graft rupture (2.6% [0.06-13.5], 1/39) at the 32.9 months of follow-up, 2 cases for meniscal suture failure (5.3%, 2/38), 2 cases for anterior arthrofibrosis (5.3%, 2/38), and 1 for contralateral epiphysiodesis (2.6%, 1/38). Reoperations occurred at a mean 29 months ± 19 (3; 44). No infection was recorded.

Two cases (5.4%, 2/37) of growth disorders were recorded, one of 1 cm measured clinically but not

Table 5. Multinomial Logistic Regression: Parameters Influencing Return to Sport

Tegner Score	Postoperative < Pretrauma (n = 15)	Postoperative ≥ Pretrauma (n = 32)	*P* Value
Male	11 (73%)	19 (83%)	.62
BMI	20 ± 3 [17-28]	19 ± 2 [15-22]	.37
Preoperative Tegner (/10)	7 ± 1 [6-10]	7 ± 1 [4-10]	.71
Meniscal lesion	8 (53%)	13 (57%)	.94
Graft rupture or contralateral ACL rupture	6 (40%)	0	.05

ACL, anterior cruciate ligament; BMI, body mass index.

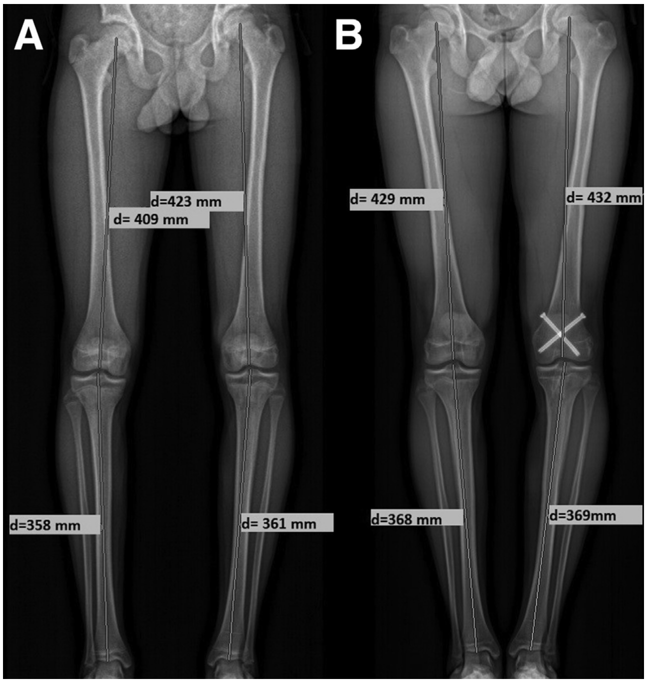

Fig 2. Management of the overgrowth of 1.82 cm). (A) EOS radiography showing overgrowth prevailing on the left femur. (B) EOS radiography after distal left femoral epiphysiodesis with 2 screws at the last follow-up showing good recovery of the length. (d, distance.)

perceived by the patient and the second one of 1.8 cm identified clinically and confirmed on the EOS because it was perceived by the patient. In both cases, the operated side was longer than the healthy side without frontal or sagittal deformity. The case of overgrowth of 1.8 cm required surgical epiphysiodesis on the other knee at 40 months postoperatively allowing correction of the deformity (Fig 2). The other patient was treated functionally with foot ortheses. Both patients reported good functional results (PEDI-IKDC= 97.7 for the patient reoperated, 86.21 for the patient with foot orthesis) and stabilized their sports level (Tegner = 8 and 7, respectively) at the last follow-up. All complications are presented according to the 2 subgroups (method A or B) in Table 6.

Discussion

The most important findings of our study are that combined ACL reconstruction associated with the lateral extra-articular procedure in skeletally immature patients is associated with a low graft rupture rate, and it provides good functional outcomes and a low clinically detectable growth disturbance rate over a medium-term follow-up (mean = 4.8 years).

ACL reconstruction associated with the lateral extra-articular procedure in our series was associated with a low graft rupture rate. Table 7[33-37,50-56] compares our results with those in the literature. Similar series with lateral extra-articular procedure in the pediatric population reported graft failure rates from 0% to 6.6% with similar follow-up.[33-36] Only Willimon et al.[37] reported up to 14% failure with the lateral extra-articular procedure, but the surgical technique included a non-anatomical tibial tunnel. In contrast, a series of isolated ACL reconstructions was associated with greater failure rates, with an average graft rupture rate ranging from 7.1% to 24.6%. These results echo those obtained in the adult population. In 2017, Sonnery-Cottet et al.[31] found graft failure rates of 10.77% for hamstring tendon grafts in isolated ACL reconstruction, 16.77% for bone—patellar tendon—bone grafts, and 4.13% for combined ACL and ALL reconstruction grafts at a mean follow-up of 38.4 months.

The absence of recurrence of ACL injuries may appear to be protective of the knee; however, several studies have raised concerns about the risk of overconstraints induced by anterolateral procedures, particularly when performed in a nonanatomical manner such as during the Lemaire procedure.[57,58] Then caution should be applied when using such a technique in a pediatric population, only a very long-term study, as was already performed in adults,[59] will be able to tell us whether this benefit comes at the expense of an increased risk of osteoarthritis in the external compartment.

The addition of lateral extra-articular procedure was not done at the expense of clinical results. In the literature, the combination has led to good-to-excellent clinical outcomes[33-36] comparable with classical methods[50-53,55,56,60] regarding the mean scores (Table 7) and regarding MCID and PASS. The MCIDs presented in this study showed an excellent

Table 6. Complication Rate According to the Subgroup: Method A (ST+G) or Method B (ST+FL)

Complications	Total (n = 39)	Method A (n = 19)	Method B (n = 20)	*P* Value (A vs B)
Graft failure	1 (2.6%)	0	1 (5%)	1
Meniscal suture failure	2 (5.1%)	1 (5.3%)	1 (5%)	1
Arthrofibrosis	2 (5.1%)	1 (5.3%)	1 (5%)	1
Growth disorders	2 (5.1%)	1 (5.3%)	1 (5%)	1
With contralateral epiphysiodesis	1 (2.6%)	1 (5.3%)	0	1

FL, fascia lata; G, gracilis; ST, semitendinosus.

Table 7. Literature Review of ACL Lesions in Children With Open Physis According to Lateral Extra-Articular Procedure

Study	Mean Follow-up, y	Lateral Extra-Articular Procedure	Surgical Technique	Femoral Fixation (F) and Tibial Fixation (T)	Graft Rupture	Mean Tegner	Mean Lysholm	Mean IKDC	Growth Disorder
Current study, n = 39	4.8	Yes	ST + FL ST/G + G	F: Intraepiphyseal T: transphyseal	2.5%	6.8	90	88	5.4%
Lanzetti et al., 2020,[33] n = 42	8	Yes	ST/G + G	F: over the top T: Intraepiphyseal	4.8%	8	94.8	94.8	4.8%
Wilson et al., 2019,[34] n = 61	3.2	Yes	ST/G + FL	F: transphyseal T: transphyseal	5.3%	NA	NA	91.2	5.5%
Roberti di Sarsina et al., 2019,[35] n = 20	4.5	Yes	ST/G + G	F: over the top T: Intraepiphyseal	0%	7	100	NA	15%
Kocher et al., 2018,[36] n = 137	6.2	Yes	Mac FL	F: over the top T: extraosseous	6.6%	7.8	93.4	93.3	0%
Willimon et al., 2015,[37] n = 22	3	Yes	Mac FL	F: over the top T: extraosseous	14%	8	95	96.5	0%
Fourman et al., 2021[50]	5	No	ST/G allograft	F: Intraepiphyseal T: Intraepiphyseal	13.2%	NA	NA	91.3	26.5%
Nagai et al., 2020,[51] n = 35	2.2	No	NA	F: Over the top T: transphyseal	14.3%	NA	NA	NA	NA
Astur et al., 2018,[60] n = 46	Minimum 0.5	No	ST/G	F: transphyseal T: transphyseal	24.6%	NA	NA	NA	NA
Razi et al., 2019,[52] n = 31	6	No	ST allograft	F: Intraepiphyseal T: transphyseal	NA	NA	NA	85	3.2%
SFA prospective, 2018,[54] n = 100 (multicenter)	2	No	Multicenter	Multicenter	9%	7.8	93	92	NA
Dekker et al., 2017,[55] n = 112	4	No	ST/G BPTB	F: Intraepiphyseal + transphyseal T: transphyseal	19%	NA	NA	NA	NA
Schmale et al., 2014,[56] n = 29	4	No	4ST Allograft	F: transphyseal T: transphyseal	13.8%	7	NA	NA	0%

4ST, quadruple-bundle semitendinosus; ACL, anterior cruciate ligament; BPTB, bone−patellar tendon−bone; FL, fascia lata; G, gracilis; IKDC, International Knee Documentation Committee; NA, not available; ST, semitendinosus.

improvement in the scores most affected by ACL rupture (Pedi-IKDC, KOOS sport, KOOS quality of life and Lysholm). Scores with a low percentage of MCID were those least impacted by the trauma and had excellent PASS (KOOS symptom, KOOS pain, KOOS daily living).

Growth disorders are among the specific complications of ACL surgery in children. The fear of inducing length inequalities or lower-limb axis anomalies of iatrogenic origin has long been a hindrance to surgery.[14,61] In the literature, 3 types of growth disorders have been described.[18] Type A corresponds to growth arrest by epiphysiodesis or by injury to the perichondral ferrule. Type B corresponds to an acceleration of growth of the operated limb, and type C corresponds to slowing of growth by the tenodesis effect, leading to axis disorders of the lower limb. In 2016, Collins et al.[62] performed a meta-analysis of growth disorders after ACL reconstruction in children with growth potential. This meta-analysis analyzing 21 studies (n = 313) found 12.5% growth disorders of all types, including 3.5% type A, 5.8% type B, and 5.1% type C.

In our study, we found that a 5.4% rate of growth disorders, all of which were type B on the femur. This complication is related to local hypervascularization and stimulation of the open physis,[18] which could be caused by the proximity of the tunnel with the physis despite our physeal-sparing method on the femur (Fig 3) None of those 2 growth disorders could be attributed to the anterolateral procedure, as this procedure did not necessitate an extra or a wider femoral tunnel and none of those disturbances were observed on the tibia. The lack of repercussions on the tibia is not a surprise for method B, which did not create any extra tunnel and for method A, in which tunnels are strictly intraepiphyseal. None of the studies presented in Table 7 reported any growth disturbances linked to the anterolateral procedure.

A recent systematic review attempted to evaluate the benefit of the physeal-sparing technique over the transphyseal technique and showed no differences in terms of the incidence of growth disturbances or in terms of graft survivorship.[63] Regarding the 2 overgrowths, the patient who underwent reoperation for

Fig 3. Relationship between the physis and the tunnels: a postoperative radiograph of method B (left knee).

epiphysiodesis of the limb obtained very satisfactory results, providing an additional argument in favor of careful monitoring of the growth of young patients.

The creation of a transphyseal tunnel with a diameter less than 9 mm could partly explain the absence of type A complications, as according to Gicquel et al.[64] Our main concern in preoperative care was the risk of teno-epiphysiodesis with genu valgus deformity as described by Kocher et al.[61] due to the fusion of the lateral distal femoral physis. We did not find this complication in our series, suggesting that none of the growth disorders were linked to the tenodesis effect of lateral extra-articular procedure.

For sports practice, we found no significant decrease in the median patients' sporting level. Even though it may seem satisfactory, this result must be interpreted within the age category studied, which naturally tends to improve its Tegner level in the absence of a particular trauma. Indeed, when examining the findings more closely, 39% did not return to their former Tegner level. A large part of this result could be explained by injury to the graft or of the contralateral AC (Table 5). In addition, the high rate of injury of the contralateral knee (13.2%) is a good indicator of the return to sports and is comparable here to the review performed by Magnussen et al.[65] (12.5%). In 2017, Hamrin Senorski et al.[66] found that rupture of the ACL in children with growth potential was an important turning point in their sporting practice and a major obstacle to the practice of sports at an elite level. Indeed, several studies have found results similar to ours and agreed to fix the return to the pre-injury level in approximately two-thirds of the patients.[54,67,68] There are multiple reasons for the decrease in sporting level: fear of reliving the initial trauma, rupture of the contralateral ACL, entry into higher education, failure in high-level courses, and an uncomfortable knee at high intensity.[67,68]

Malatray et al.[69] in 2018 advised a systematic inspection through the intercondylar notch to diagnose ramp lesions in ACL-deficient knees. With this technique, they found a 23% rate of such knees in a pediatric population. This result was verified more recently by Sonnery-Cottet et al.[70] and Bernardini et al.,[71] who found respectively a prevalence of 23.9% and 28% of those lesions, very similar to our series (20%). This outcome finally echoes the overall prevalence in the adult population that was evaluated at 23.9% in the largest series evaluating incidence of ramp lesions[72] and 21.9% in a systematic review.[64]

Limitations

There are some limitations to our study, and the retrospective nature of the study itself is the first limitation. The absence of a previous protocol is the other limit of our study. Thus, the Tanner score was not reported in preoperative care, but all of the patients were evaluated with radiography assessing the physis and bone age. Also, we did not have any systematic orthostatic anteroposterior radiographs of the lower limbs to detect growth disorders. They were only detected clinically, and some of them may have been missed. One of the main limitations of this study is the lack of a control group; we unfortunately could not have a control group because in our institution we usually perform lateral extra-articular procedure in all patients younger than 25 years of age, which is why we chose to present our results within those of the literature.

Two different lateral extra- articular procedures have been used, which increase the heterogeneity of the series. In addition, the small population size limits the ability to draw strong conclusions about rates of complications including graft rupture, and larger studies are needed to determine this.

Conclusions

This series of ACL reconstructions combined with 2 different lateral extra-articular procedures in skeletally immature patients demonstrated promising findings. The low rate of observed complications, including graft rupture and growth disturbance, is encouraging, but the small study population and lack of comparative group precludes reliable conclusions.

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