Anterior Cruciate Ligament Reconstruction in Children With A Quadrupled Semitendinosus Graft: Preliminary Results With Minimum 2 Years of Follow-up

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Background: The management of anterior cruciate ligament (ACL) tears in growing patients must balance activity modification with the risk of secondary (meniscal and cartilaginous) lesions, and surgical intervention, which could adversely affect skeletal growth. Many ACL reconstruction techniques have been developed or modified to decrease the risk of growth disturbance. We have not found any description of ACL reconstruction using a single hamstring, short graft implanted into intraepiphyseal, retroreamed sockets. Our hypothesis was that the technique that we used restored the knee stability and did not cause any growth disturbances.

Methods: We retrospectively studied 28 patients (20 boys, 8 girls) who presented with a unilateral ACL tear and open growth plates. We performed short graft ligament reconstruction with the semitendinosus folded into 4 strands around 2 polyethylene terephthalate tapes. The graft was implanted into sockets that were retroreamed in the femoral and tibial epiphysis and the tapes were fixed remotely by interference screws. After a minimum period of 2 years, we evaluated the comparative knee laxity, the radiographic limb morphology, the appearance of secondary lesions, and the functional outcomes using the Lysholm and Tegner scores. Comparative analyses were performed using the Student *t* test with subgroups depending on the type of fixation used.

Results: The mean age of the patients was 13 years (range, 9 to 15 y). The mean follow-up was 2.8 years (range, 2 to 5 y). The mean difference in laxity at 134 N was 0.3 mm, as determined using a GNRB arthrometer. No patients reported meniscal symptoms or degenerative changes. We found no angular deformity or leg length inequality. Two patients suffered a recurrent ACL tear.

Conclusions: The preliminary results from this series are consistent with prior studies demonstrating that intraepiphyseal ACL reconstruction is a safe reliable alternative for the pediatric population.

Study Design: Case series; level of evidence 4.

Key Words: ACL reconstruction, ST4, pediatrics

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The goal of surgical reconstruction of the anterior cruciate ligament (ACL) in children is to restore knee stability without adversely affecting growth. Reestablishing ACL function avoids secondary meniscal and cartilaginous lesions[1–4] that may occur in the short or medium term. It is an increasingly accepted approach for a child with a torn ACL that surgery is better than a wait-and-see attitude, if techniques are sensitive to the risk of injury to the growing skeleton.[3,5–10]

There are various technical solutions, to produce tunnels and then pass the graft, that have been proposed in the literature:

- Aichroth et al[5] described a complete transphyseal technique crossing the 2 growth plates.
- Physeal sparing technique: either intraepiphyseal, with the tunnels made in the epiphysis without crossing the growth plate in either the tibia or the femur, such as the method described by Anderson et al[11]; or extraepiphyseal, with a femoral fixation over the top, such as the Clocheville technique described by Bonnard et al.[12]
- A mixed technique, partial transphyseal: Lipscomb and Anderson[13] described a technique where the tunnels are transphyseal for the tibia and intraepiphyseal for the femur.

The child's residual growth may guide decision-making. Certainly, the child with limited growth remaining poses significantly different risk than a prepubescent with years of growth expected. The best compromise is between the risk of inadvertent growth arrest and finding the optimum anatomic position for the graft. According to some authors, transphyseal techniques in the tibia with hamstring tendons and remote fixation produce the best results in terms of efficacy and tolerance.[14,15] A novel hamstring graft technique, TLS (FH Orthopedics), is based on the use of the semitendinosus tendon alone in a 4-stranded closed loop (short graft), producing

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independent intraepiphyseal sockets and fixed remotely[16] (Fig. 1). The fixation system used is the nearest in strength to the natural ligament.[16]

The aim of this retrospective review is to assess joint laxity, the occurrence of secondary lesions, functional results and impact on skeletal growth of this ACL reconstruction technique in skeletally immature patients.

METHODS

This is a single-surgeon, single-center, retrospective series. The study complied with ethical rules by the committee responsible for ethics in our institution. Our group included consecutive patients who had open growth plates and a ligament replacement using the TLS technique and had a minimum of 2-year follow-up. There were 30 patients in the series, and 2 were lost to follow-up. The analysis included 28 patients (20 boys, 8 girls) with a mean age of 13 years (range, 9 to 15 y) at the date of surgery. The girls had a mean age of 12.8 years (range, 11.3 to 15 y) and the boys had a mean age of 13.2 years (range, 9 to 14.8 y). The mean length of time between the accident (a sports accident in all cases) and surgery was 14.8 months. The mean follow-up was 2.8 years (range, 2 to 5 y). Eight patients had a meniscal lesion at the time of ligament reconstruction: 2 involved the lateral meniscus, 6 the medial meniscus; 3 underwent a meniscal repair, 1 had a partial meniscectomy after failed meniscus repair, the other lesions were felt to be stable and were left untreated. Table 1 summarizes the demographic data of the population.

The surgical technique was consistent in all patients. The surgery was performed under general anesthesia, with the leg stabilized using a thigh holder. An image intensifier confirmed production of a profile of the knee was preoperatively in all cases (Figs. 2A, B). In all cases the graft used was an autologous semitendinosus graft prepared in a 4-stranded closed loop around a polyethylene terephthalate TLS tape passed through each end. The positioning aid allowed the graft to be passed around 2 pins at the distance desired for the length of the graft. This was calibrated at 5 mm by 5 mm. Using calibrated frontal and lateral x-rays of the knee, the theoretical length of the graft can be calculated by adding the lengths of the 2 sockets to the measured length of the intra-articular graft. This calculates the distance between the 2 pins, which is closest to the theoretical size of the graft. The pins were then replaced by the tapes. The graft and tapes were then tensioned to 250 N for 1 minute using the ancillary device (Fig. 3). The diameter of each end was measured following the application of traction.

The femoral tunnel was prepared outside-in using a guide (FH Orthopedics, Heimsbrunn, France) placed through the medial portal. A 2.4-mm guide pin was introduced away from the growth plate and confirmed arthroscopically and with the image intensifier to be all intraepiphyseal (Fig. 4). The guide pin was then overdrilled using a 4.5-mm drill from outside to inside through the whole length of the tunnel. The recess, of a diameter corresponding to that of the graft, was hollowed

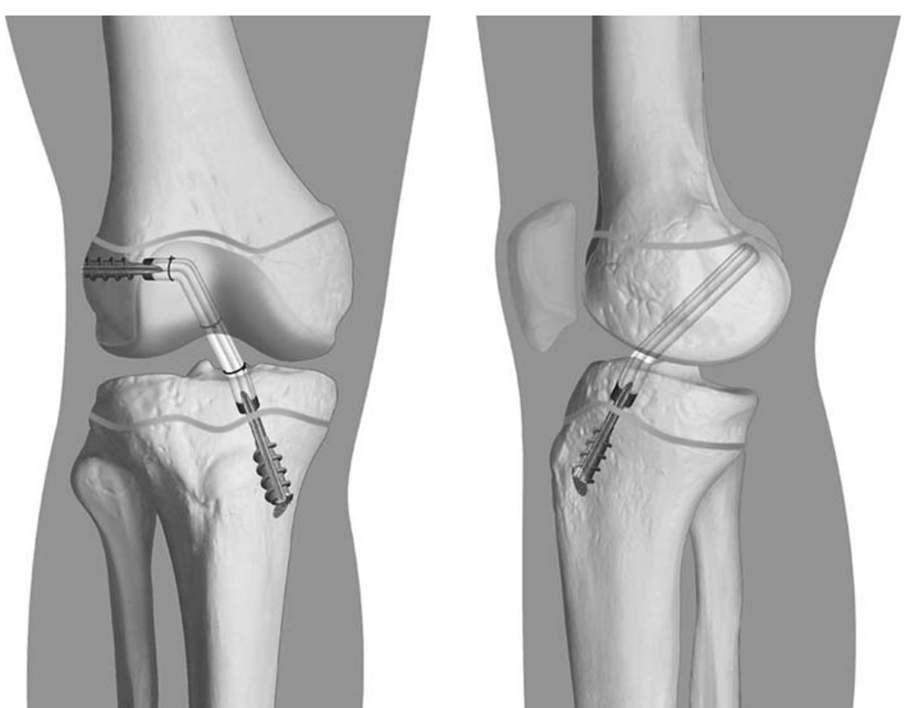

FIGURE 1. Overview of the pediatric TLS technique with the relative position of the growth cartilages and the graft. One can clearly see that the interference screws fix the tapes, which themselves secure the graft.

TABLE 1. Demographic Data, Technical Details and Outcomes for All the Patients

Patients	Sex	Chronical Age (y)	Skeletal Age (Greulich et pyle)	Follow-up (y)	Screw	Remarks	Socket Diameter (mm)	Graft Length (mm)	Retears	Tegner	Lysholm	LLD (cm)	HKA (deg.)	GNRB (mm)
1	F	11.6	12	NA	Milagro		F: 8, T: 8	50	Yes	NA	NA	NA	NA	NA
2	M	13.4	13	NA	Milagro		F: 7, T: 8	50	Yes	NA	NA	NA	NA	NA
3	M	14.8	14	2.3	TLS	Meniscal tear left in situ	F: 9, T: 9	55	No	9	100	0.9	−1.5	2
4	M	14.8	15	3.1	Milagro	Lateral meniscal repair	F: 9, T: 8	55	No	6	99	1	3	1.8
5	M	11.2	11.6	3.3	Milagro		F: 6, T: 6	50	No	9	100	1	2	2
6	M	12.5	12	5	Milagro		F: 6, T: 7	50	No	8	90	−0.8	2	−0.6
7	M	14.3	15	2.3	TLS		F: 8, T: 8	55	No	8	94	1	−3	−2.5
8	F	13.7	13.6	2.1	TLS		F: 7, T: 7	55	No	8	94	0.4	2.4	1.9
9	F	11.3	11.6	2.5	TLS		F: 6, T: 7	50	No	8	95	1	−0.5	−0.6
10	F	12.9	12	3.2	TLS		F: 7, T: 7	50	No	9	87	−0.8	2.3	1.9
11	M	14.5	14	2.1	TLS		F: 7, T: 8	50	No	9	100	1	3	−1.4
12	M	12.9	12.6	3	Milagro		F: 8, T: 8	55	No	8	99	1	−3	−0.2
13	M	14.8	14	2	TLS		F: 8, T: 8	55	No	8	94	0.7	2.8	−1.7
14	M	13.5	13	4.6	Milagro	Meniscal tear left in situ	F: 7, T: 7	50	No	7	99	0	2.8	0
15	M	13.7	13.6	2.1	TLS		F: 6, T: 7	50	No	7	99	0	0.2	0.8
16	F	12.2	12.6	3.5	Milagro	Lateral meniscal repair	F: 7, T: 7	50	No	9	99	−0.5	−1.4	−1.6
17	M	12.9	12	2.2	TLS	Medial menical repair	F: 7, T: 7	50	No	9	94	1	−1	−1.3
18	F	11.9	12	2.3	Milagro		F: 7, T: 6	50	No	9	100	−0.4	−0.6	2
19	M	14.8	15	4.9	Milagro		F: 9, T: 9	55	No	8	99	−0.4	2.4	−1.9
20	M	14.6	14	2.4	Milagro	Medial menisectomy	F: 9, T: 8	55	No	9	99	0	3	0
21	M	11.5	11	2.8	TLS		F: 6, T: 7	50	No	9	94	−0.8	−1	−2.5
22	M	11.6	12	2.2	TLS		F: 6, T: 7	50	No	9	95	1	−1	2
23	F	13.8	13.6	2.1	TLS	Meniscal tear left in situ	F: 8, T: 9	55	No	9	90	−0.5	0	1.8
24	M	12.3	12	2.8	Milagro		F: 7, T: 7	50	No	9	90	−0.8	0.5	0
25	M	12.9	12	2.7	TLS		F: 7, T: 8	50	No	8	85	−0.3	−1	−0.6
26	F	15	15	2.5	TLS	Meniscal tear left in situ	F: 7, T: 8	55	No	8	95	1	0	2
27	M	13.5	13	2.3	TLS		F: 7, T: 7	50	No	9	95	0.8	0	2
28	M	9	10	2.4	TLS		F: 6, T: 6	50	No	9	95	0	−0.5	1.6

The operated limb is the reference, the – sign indicates that the value for operated limb is less.
F indicates femur; LLD, limb length discrepancy; T, tibia.

out manually using a special retrograde reamer (FH Orthopedics) to a depth of 10 mm.

The tibial tunnel was prepared according to the same principle. Using a tibial guide (FH Orthopedics), a pin is placed (guide set at 60 degrees) crossing the tibial growth plate into the tibial footprint, and then overdrilled with the 4.5 mm drill from outside to inside through the whole length of the tunnel. The retrograde recess was manually reamed using image intensifier to confirm that the socket was intraepiphyseal (Fig. 5). Traction threads were passed through each tunnel from the outside inward allowing the graft to be introduced through the anteriomedial arthroscopic portal by pulling on the tapes. The graft was introduced as a press-fit into the femoral socket and then into the tibial socket. Isometry was checked as the knee was moved into full extension.

Fixation was by screws locking the tapes in each tunnel: in 16 cases, these were TLS 20 × 10 mm screws and in 12 cases (the earlier ones), 7 × 25 mm resorbable screws (Milagro, Depuy-Mitek). Screw size was always the same because the screws were implanted to fix the tapes in the 4.5 mm tunnel.

Postoperative care depended on age. Patients aged less than 12 years were immobilized in extension in a long-leg resin cast, whereas for patients over 12 years, a splint in extension was fitted at the end of the procedure. In all cases the joint was immobilized for 1 month without weightbearing, with no physiotherapy.

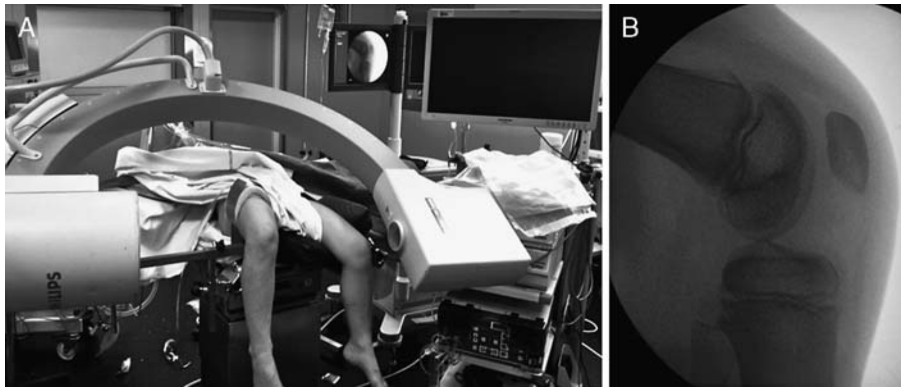

FIGURE 2. Installation of the patient on thigh holder with image intensifier (A) to obtain a profile image of the knee (B).

Each patient was reviewed by an independent examiner (E.C.) a minimum of 2 years after the surgery.

The impact on growth was measured using long-leg and lateral knee views. Measurements included: the lengths of the tibias and femurs, the mechanical axis angle—hip-knee-ankle (HKA) angle, the anatomic lateral distal femur angle (aLDFA), the posterior distal femur angle (PDFA), the proximal posterior tibial angle (PPTA), and the mechanic proximal tibial angle (MPTA) bilaterally (Fig. 6) following the measurement principles set out by Paley and Tetsworth[17] for the management of leg deformations.

Laxity at the last follow-up was studied using GeNouRoB arthrometer (GNRB),[18] allowing comparison of the differential laxity with the healthy knee at 134 N measured in millimeters and the difference in slope of the 2 curves expressed in mm/N.

Functional results were assessed using the Lysholm and Tegner activity scores[19] and the occurrence of secondary meniscal lesions was noted (McMurray test). Comparative analyses were performed using the Student *t* test with subgroups depending on the type of fixation used, TLS or resorbable Milagro screws (Depuy, Warsaw).

RESULTS

X-Ray Analysis

The mean differences between the surgical and contralateral uninvolved leg were 0.5 degrees for the HKA angle, 0.2 degrees for the aLDFA, 0.5 degrees for the MPTA, 0.8 degrees for the PPTA, and 0.8 degrees for the PDFA. The difference in length of the legs was on average 0.3 mm, 0.1 mm for the femur, and 0.1 mm for the tibia, respectively (Table 2).

Differential Laxity

The mean difference in laxity at 134 N was 0.3 mm and the mean slope difference was 1.7 mm/N (Table 3).

At the latest follow-up no patient showed meniscus symptoms, and no x-ray indicated degenerative damage.

The Tegner activity score at the latest follow-up was a mean of 8.4; the Lysholm score was 95.4. Each patient returned to previous or higher activity levels.

There is a statistically significant difference between the 2 fixation systems with respect to the Tegner activity scores: 7.71 for TLS screws and 9 for the resorbable screws, and the Lysholm score: 92.1 (TLS) as versus 98.78,

FIGURE 3. Semitendinosus folded into 4 strands on polyethylene terephthale tapes put under tension on a table at 250 N.

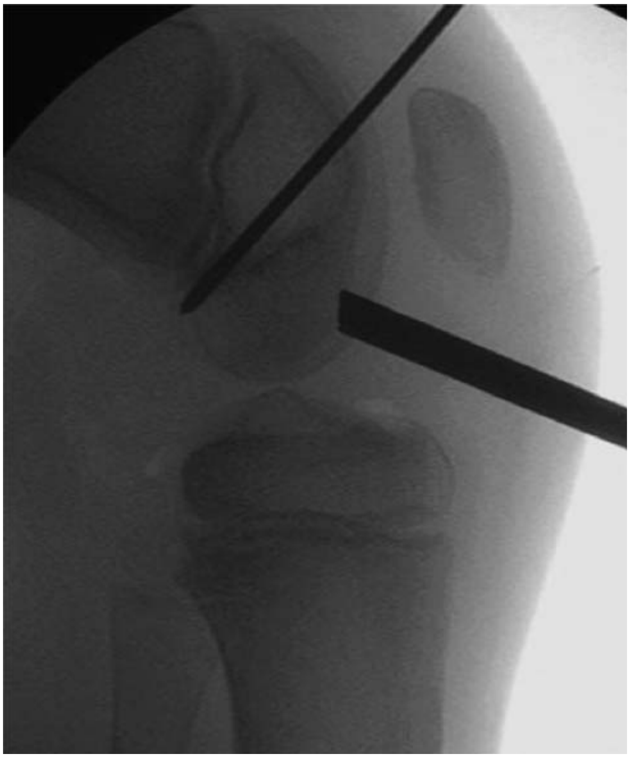

FIGURE 4. Fluoroscopic control of positioning of the femoral guide pin away from the epiphyseal plate.

respectively. No other statistically significant difference was found.

We studied 2 cases of new tears. One occurred early, 6 months after ligament reconstruction without further trauma. It was probably due to necrosis of the graft confirmed by MRI but we did not have confirmation from an anatomopathologist. The second case occurred 2 years after ligament reconstruction, during a sports accident (soccer); the patient had returned to his sport at an equivalent level.

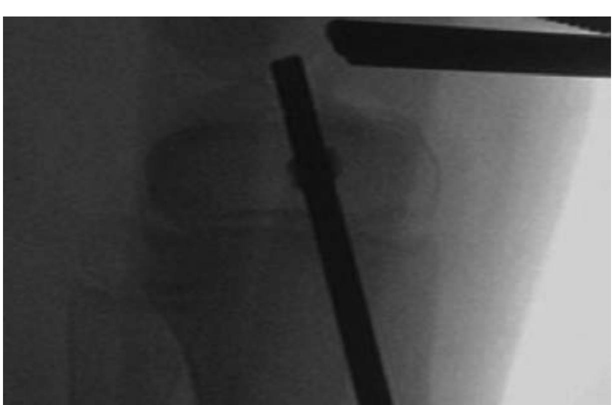

FIGURE 5. Fluoroscopic control of manual retrograde tapping of the tibial tunnel to avoid injury to the growth plate. The recess is only hollowed out in the epiphysis using a retrograde drill bit.

For these 2 patients the fixation of the tapes was with Milagro screws. There was no case of infection.

DISCUSSION

The modified pediatric TLS technique with an intraepiphyseal socket in the femur and the tibia seems to be suited to the pediatric condition. In our series, we did not find any pathological values thus agreeing with acknowledged thresholds. Frosch et al[14] fixed the limit at 1 cm for inequality in length of the limbs according to the findings of Rush et al[20] who found inequality in 77% of cases in a population sample. Seil et al[21] fixed the pathological limit at an angular deviation greater than 3 degrees. Few series have analyzed the angles measured on profile x-ray images of the knee.

In the present study, the time between the accident and the surgery was particularly long (14.8 mo). This was due to late presentation of the patients. We decided not to wait before performing this surgery; in fact, we believed that we should treat these patients as soon as possible.

The included population had a mean age of 13 years overall, with the girls having a mean age of 12.8 years and the boys 13.2 years. This population comprised individuals who were still growing, and a lesion of the growth cartilage could have led to deformity or leg-length inequality.

In their respective meta-analyses Frosch et al[14] and Kaeding et al[15] found that tolerance of the growth plate cartilage was better with transphyseal techniques. Similarly, it seems that distant fixation using hamstring tendons is the most suitable for the pediatric population. Indeed the presence of tendon tissues in contact with the growth plate in the tunnel may counteract the occurrence of growth arrest.

Frosch et al[14] in their meta-analysis of 941 cases found growth abnormalities after ACL reconstruction in 2.1%, for all techniques considered together. The cases most often described are those in which the operated limb is shortened,[22–24] but cases of hyperelongation by stimulating the growth plate have also been found.[25,26] Abnormal angles are essentially described in valgus, as by Koman et al,[27] as well as in genu recurvatum of tibial origin.[8,28]

The 4.5 mm femoral tunnel produced independently of the tibial tunnel means being nearer to the isometric position without damaging the growth plate, since the risk of growth arrest is greater in the lateral part of the distal epiphyseal plate of the femur.[29] Manual retrograde excavation avoids epiphyseal plate lesions due to heat.[30]

Only a small diameter (4.5 mm) central, vertical tunnel is made through the tibial growth plate. Ford and Key[31] demonstrated that a central tunnel reduces the risk of growth arrest. The more vertical and smaller the tunnel the smaller the volume of epiphyseal damage[32]; the smaller the volume of damaged epiphyseal plate the less the risk to growth.[33]

Shea et al[32] demonstrated the need to make a tunnel with a medial entry point on the tibial cortex to avoid the anterior tibial tuberosity and limit the risk of genu recurvatum.

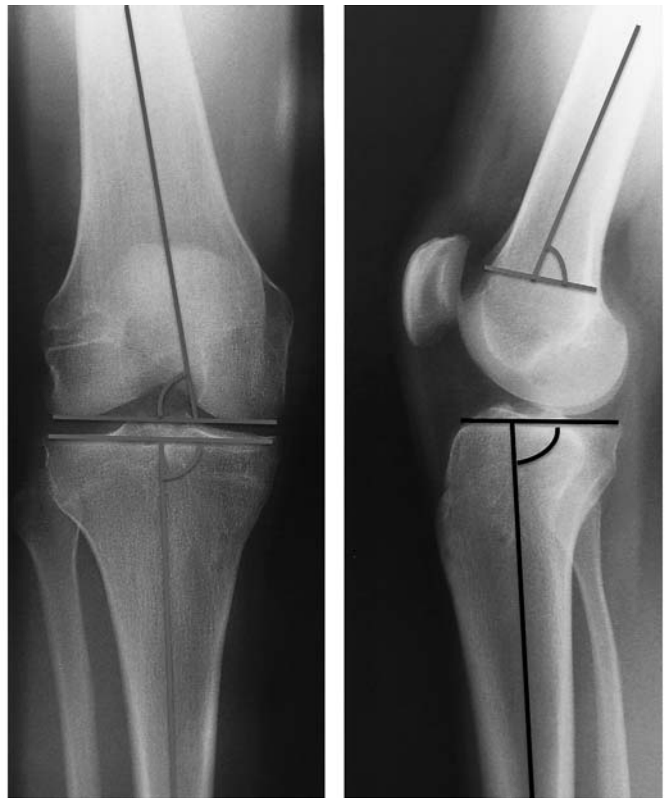

FIGURE 6. Summary of angle measurements made according to Paley and Tetsworth.[17] aLDFA indicates anatomic lateral distal femur angle; MPTA, mechanic proximal tibial angle; PDFA, posterior distal femur angle; PPTA, proximal posterior tibial angle.

Moreover tunnels close to the growth plates are not empty (the graft or polyethylene terephthalate tape is present) nor are they filled by the osteosynthesis device or bone tissue following the recommendations in the literature.[26,34,35]

Finally McConkey et al[36] insist that excessive graft tension can cause growth disorders; here the graft is prestressed before implantation and then fixed into the femoral and tibial sockets.

Claes et al[37] have shown that the ligamentization process of a graft is linked to the neovascularization of the graft by the synovial capsule and Hoffa's fat pad. Furthermore, Yamasaki et al[38] and Zantop et al[39] have shown that the length of graft tunnels does not affect the incorporation of the graft.

We had 2 cases in our series where a second tear occurred. One occurred early without further trauma. We believed that was due to biological failure of the graft[40] viewed on MRI as a necrosis of the graft. It may be that excessive pretension of the graft, modifying the organization of the collagen fibers, was the cause of this failure.[41] The other one occurred 2 years after surgery and 1 year after returning to soccer again. The patient had presented a new collision injury. These figures are

TABLE 2. Summary of Criteria Concerning the Impact on Growth

	HKA	aLDFA	MPTA	PPTA	PDFA	Limb Length
Mean	0.5	0.2	0.5	0.8	0.8	0.3
Median	0	0	0	0	0	0.2
SD	1.3	1.3	0.8	1	1.4	0.6
Minimum	−3	−2	−2	−2	−1	−0.8
Maximum	3	2.2	1	2	2.5	1

The operated limb is the reference, the – sign indicates that the value for operated limb is less, for example the minimum difference in length of −0.8 indicates that the operated limb was 0.8 mm shorter.

aLDFA indicates anatomic lateral distal femur angle; HKA indicates hip-knee-ankle; MPTA, mechanic proximal tibial angle; PDFA, posterior distal femur angle; PPTA, proximal posterior tibial angle.

TABLE 3. Summary of the Efficacy Criteria

	Tegner Activity	Lysholm Score	Differential Laxity (mm)	GNRB Difference in Slope
Mean	8.4	95.4	0.3	1.7
Median	9	95	0	0
SD	1.1	4.5	1.2	3.2
Minimum	6	85	−2.5	0
Maximum	9	100	2	6

The differential laxity was evaluated at 134 N. The difference in slope is expressed in mm/N.

comparable with other pediatric series with a similar number of patients and similar follow-up.[14,42] These 2 patients had revision ligament reconstruction using the patellar tendon in the tunnels made for the first ligament reconstruction.

No patient presented secondary meniscal lesions. The Lysholm score was close to that of a population with healthy knees.[43] The difference in activity score between the 2 types of fixation is probably explained by the longer follow-up time. Resorbable Milagro screws were used at the beginning of the series and the patients had had more time to regain confidence and increase their activity. No other statistically significant difference was found between the TLS and the Milagro screw groups.

Laxity figures were close to those for the contralateral knee; no patient had a difference of more than 3 mm at 134 N, or a difference in slope of more than 9 mm/N, which are the accepted rupture thresholds for GNRB analysis.[18] This surgical technique uses only one tendon and smaller bone tunnels than a classic technique, which means considerable economy in bone and tendon resources in a pediatric population.

This study presents preliminary results for the first patients who have undergone this technique, which is innovative in children. Longer follow-up and a comparative prospective study with another recognized technique would confirm these.

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