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OTSR-2105; No. of Pages 7
ARTICLE IN PRESS
Orthopaedics & Traumatology: Surgery & Research xxx (2018) xxx–xxx
Contents lists available at ScienceDirect
Orthopaedics & Traumatology: Surgery & Research
journal homepage: www.elsevier.com

Original article

MRI study of the ligamentization of ACL grafts in children with open growth plates

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A R T I C L E I N F O

Article history:
Received 27 July 2018
Accepted 6 September 2018
Available online xxx

Keywords:
ACL reconstruction
MRI
Ligamentization
Children
Open growth plates

A B S T R A C T

Introduction: There is little published information on the ligamentization of pediatric anterior cruciate ligament (ACL) grafts. The aims of our study were to compare the MRI appearance of ACL grafts performed in a population with open growth plates to normal ACLs in adolescents and to determine whether the MRI signal in the grafts at 6 months could predict a retear. We hypothesized that ligamentization was a slow, gradual process.
Material and methods: This was a prospective multicenter study of 100 ACL grafts (quadriceps tendon, hamstring tendon, fascia lata) in children 7 to 16 years of age. Of these, 65 intact grafts underwent one or more MRI examinations between 6 months and 2 years postoperative. MRI images were also analyzed in 7 patients who suffered a retear and in the intact ACL of 20 adolescents (15 to 18 years of age). The other 28 patients did not undergo an MRI during the postoperative phase. For each MRI, the signal-to-noise quotient (SNQ) was calculated in three different areas in the ACL (proximal, middle, distal) along with the Howell intra-articular and intra-tibial grades from I to IV. The Mantel-Haenszel Chi-square, Wilcoxon signed-rank test and Student's t-test were used to compare groups. The Lin concordance correlation coefficients were calculated for inter-rater consistency.
Results: There was a difference in the SNQ between the three zones of a normal ACL. Most were Howell grade III (55% Howell III, 25% Howell II and 20% Howell I). For intact grafts, the SNQ improved significantly between 6 and 12 months and between 6 and 24 months. There was no difference in the SNQ between the three zones independent of the postoperative time point. The intra-articular Howell grade improved significantly between 6 and 24 months and between 12 and 24 months. The intra-tibial Howell grade improved significantly between 12 and 24 months. There were no significant differences between patients with intact grafts and those who suffered a retear. There were no differences between the various types of grafts used.
Conclusion: Normal ACLs in adolescents have inhomogeneous SNQ and Howell grades. The SNQ and Howell grades in ACL grafts are more homogeneous and continue to improve out to 2 years, but do not reach that of a normal ACL. The signal and appearance of an ACL graft and normal ACL are very different, and the MRI signal at 6 months postoperative is not predictive of retear.
Level of evidence: III, prospective study.

1. Introduction

Anterior cruciate ligament (ACL) tears are a common injury that have increased in frequency in the past decades. There are now an estimated 2 million cases per year worldwide. In France, 35,000

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https://doi.org/10.1016/j.otsr.2018.09.003
1877-0568/© 2018 Published by Elsevier Masson SAS.

ACL ruptures were treated surgically in 2006 and more than 47,000 in 2016. This increase in the number of ACL tears is secondary to increasingly intense sports practices (especially pivot sports), more female participation and better detection of ligament injuries (wide use of MRI). Naturally, this injury also occurs in children [1].

For many years, ACL reconstruction has been performed in children to restore sufficient knee stability to allow resumption of sports and to prevent secondary lesions, particularly in the meniscus and cartilage [2]. These secondary lesions can lead to premature degeneration of the knee and can be highly disabling in the medium or long term.

The main challenge is to preserve the knee's growth plates when drilling the tunnels, since the residual growth potential may be several centimeters. Growth problems (misalignment, leg lengthening or shortening) in these young patients can occur if the growth plates are damaged [3].

Most of the studies on ACL reconstruction in children describe the surgical techniques, postoperative outcomes, type of grafts or fixation methods, postoperative rehabilitation and time to return to sport, or expose the postoperative complications (growth disturbances are most common) or attempt to determine whether conservative or surgical treatment is better; however, very few address ligamentization of the graft [4–8]. The ligamentization process is a long, progressive histological change in the intra-articular and tunnel portions of the graft that can be monitored by successive MRI examinations [9–11]. The mechanical quality of grafts during ligamentization has been evaluated on various animal models; however these mechanical tests are not applicable in vivo [12,13]. The change in the MRI signal can be quantified and can be used in clinical research. The intensity of the MRI signal reflects histological remodeling of the graft. This is the only non-invasive in vivo method that can evaluate this process. To our knowledge, there is no MRI study analyzing the ligamentization of ACL grafts in children, despite the large number of studies in adults [14–16]. The studies in adults have looked at the intensity and distribution of the signal in the grafts and tunnels (signal-to-noise ratio, hyperintensity percentage, tendon-bone interface). Several studies have found a correlation between the MRI signal and the mechanical properties of ACL grafts [17–19]. Information from MRI analysis of grafts can be used in combination with clinical outcome scores, clinical tests and knee laxity measurements to determine the date of return to sports [19].

The primary objective of our study was to compare the MRI appearance of ACL grafts in children with open growth plates to normal ACLs. The secondary objective was to determine whether the MRI signal at 6 months postoperative was predictive of retear. This 6-month time point is used by many athletes for a clinical and radiological reassessment before resuming high-risk sports [20].

We hypothesized that graft maturation in children analyzed on MRI was a slow, gradual process.

2. Materials and methods

All patients agreed to provide their clinical information, undergo postoperative MRI examinations and participate in this study. The study was approved by a regional ethics committee.

2.1. Patients

This was a prospective, multicenter study (10 hospitals) performed under the umbrella of the Francophone Society of Arthroscopy (SFA) enrolling 100 patients with open growth plates who underwent primary ACL reconstruction between January and October 2015 and had 2 years' postoperative follow-up. The inclusion criteria were a bone age less than 15.5 years in boys and less than 13.5 years in girls at the time of the procedure. Excluded were patients with a bone age higher than listed above, multiple ligament injuries or revision ACL reconstruction. The cohort consisted of 75 boys (mean age 12.9 years) and 25 girls (mean age 12.2 years).

2.2. Surgical technique

All patients underwent arthroscopic ligament reconstruction, of which 33% were outpatient procedures. The techniques were specific to each participating site and performed by experienced surgeons. A semitendinosus + gracilis (STG) was used in 41 cases, a four-strand semitendinosus (ST4) in 35 cases, a quadriceps tendon (QT) in 17 cases and fascia lata in 7 cases. The tibial fixation was transphyseal in 95 cases and epiphyseal in 5 cases. The femoral fixation was transphyseal in 60 cases, epiphyseal in 35 cases and over-the-top in 5 cases. Anterolateral reconstruction was also performed in 12 cases. The average time elapsed between the injury and the surgery was 51 ± 8 days.

Meniscus injuries were also present in 30 patients (treated conservatively in 90%) with 47% in the medial meniscus, 43% in the lateral meniscus (mostly the posterior segment) and 10% in both menisci. Two patients had cartilage injuries; these occurred in patients who also suffered meniscus injuries and were treated by microfracture.

2.3. MRI analysis

Of the 100 patients initially enrolled in the study, 72 underwent one or several MRI examinations at 6, 12 and 24 months postoperative (MRI 1, MRI 2, MRI 3); the other 28 patients refused to undergo a follow-up MRI or were lost to follow-up.

Of the 72 available patients, the ACL graft was intact in 65 patients: 16 patients had three MRIs, 23 had two MRIs and 33 had a single MRI examination. Seven patients suffered a retear and had undergone at least one MRI before the retear (six had one MRI and one had three MRIs). These seven cases were used to analyze the graft's signal and appearance of MRI before the retear to detect any warning signs. We also analyzed the MRI images of 20 adolescents with an intact ACL to compare the appearance of the graft to a normal ACL; these examinations were done for indications unrelated to trauma. The patient characteristics are shown in Table 1.

The MRI examinations were performed with a standard 1.5 T machine. Sagittal and axial slices from proton-density fat-saturated sequences were used to evaluate the various parameters. Gadolinium injection was not performed.

Each MRI was analyzed twice by the same rater with a 10-day waiting period. The HOROS software (Horos Project TM) was used to evaluate the various parameters on the 3-mm thick axial and sagittal slices; no sagittal oblique or coronal oblique slices were analyzed. Sagittal slice(s) showing the entire graft was used for the

Table 1
Patient characteristics.

	ACL graft (*n* = 65)	*p*	Retear	*p*	Normal ACL	*p*
Age	12.9 ± 2.3 (7–16)		14 ± 0.8 (12–15)		16.3 ± 1.1 (15–19)	
Boy/Girl	50/15	< 0.05	7/0	< 0.05	10/10	NS
Side (right/left)	35/30	NS	3/4	NS	10/10	NS

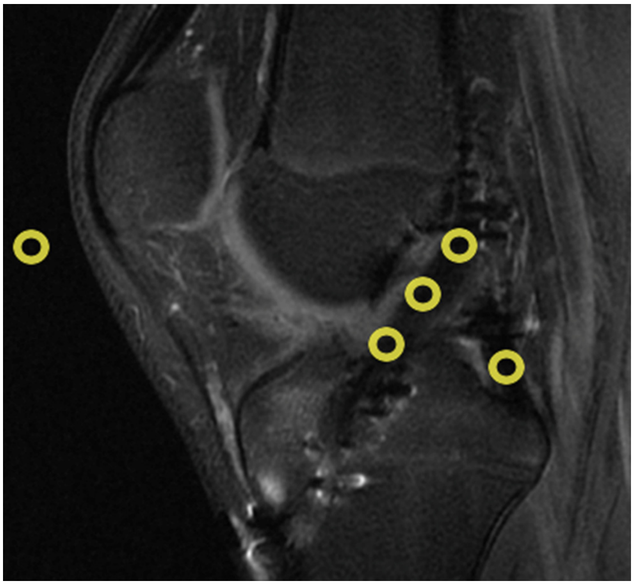

Fig. 1. Circular 16 mm2 regions of interest in five locations: proximal third, middle third, distal third of the ACL, PCL behind tibial spine and 1 cm in front of the pole of the patella.

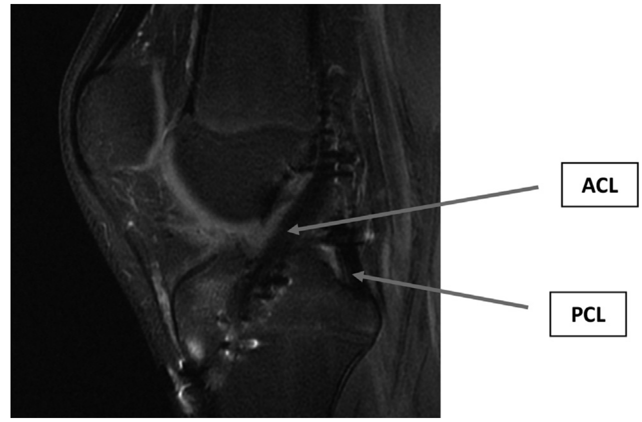

Fig. 2. Howell intra-articular grade I corresponding to a graft with full hypointense signal, like the signal in the PCL.

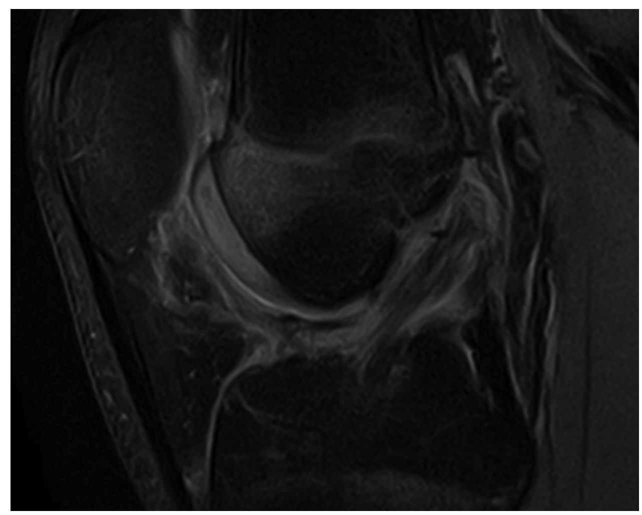

Fig. 3. Howell intra-articular grade III corresponding to a graft with more than 50% hyperintense signal.

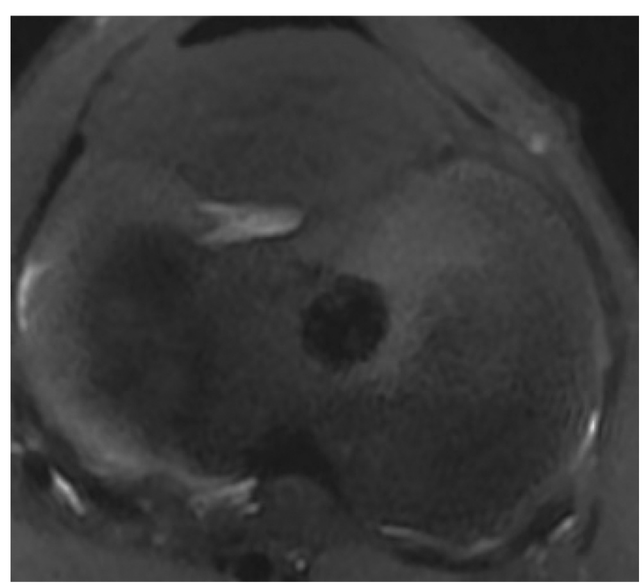

Fig. 4. Howell intratibial grade I corresponding to a graft with full hypointense signal.

analysis. The axial slices nearest the entry of the tibial tunnel were chosen, which was about 1 cm below the articular surface.

Four parameters were studied: SNQ ratio, intra-articular Howell grades, intratibial Howell grades and tendon-tibial tunnel interface. The signal intensity measurements were used to calculate the signal-to-noise quotient (SNQ) using the following formula: $SNQ = \frac{\text{ACL signal} - \text{PCL signal}}{\text{Background signal}}$ [18,21].

This standardized SNQ measurement was used to get around differences in the various MRI units used in this study. A SNQ close to 0 corresponded to a weak signal (low water content) with a “black” ACL theoretically showing ligamentization and a more mature graft. Conversely, a high SNQ corresponded to a high ACL signal (high water content), thus a “white” ACL [22].

The SNQ was measured on sagittal slices on five 16 mm2 circular regions of interest (ROI): proximal third, middle third, distal third of the ACL, on the posterior cruciate ligament (PCL) just behind the tibial spine and 1 cm in front the pole of the patella to measure the background noise (black reference). The intensity value of the ROI was an absolute value in pixels (at 2 decimals) that reflected the signal intensity, with a low value being evidence of a low signal and vice-versa. The mean of the two measurements performed by the rater was calculated for each of the five ROIs (Fig. 1).

The intra-articular Howell grade was determined on the sagittal slices: grade I corresponds to a graft with compete hypointense signal (Fig. 2) which is identical to the PCL or patellar tendon signal; grade II corresponds to a graft with more than 50% hypointense signal; grade III to a graft with more than 50% hyperintense signal (Fig. 3) and grade IV to a grade with full hyperintense signal with no normal ligament areas [23]. If the Howell grade differed between the two readings, the worse grade (higher Howell grade) was used.

The Howell grade in the tibial tunnel on axial slices was evaluated using the same criteria (Figs. 4 and 5) [23]. The tendon and tibial tunnel were analyzed as the percentage of hyperintense signal around the graft and was estimated at 0%, 25%, 50%, 75% or 100%. If the grades differed between the two readings, the worse grade (smallest %) was used. The presence of hyperintensity means that synovial fluid is present at the tendon-bone interface [24] or granulation tissue [10]. The graft volume was not evaluated as it is not predictive of the KOOS score or knee laxity measurements [19].

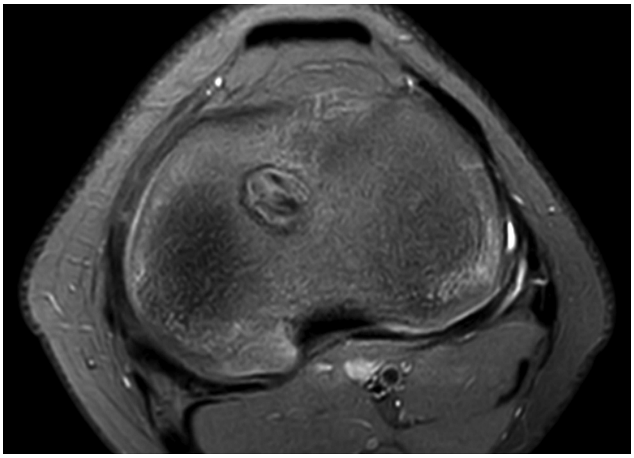

Fig. 5. Howell intratibial grade III corresponding to a graft with more than 50% hyperintense signal.

The change in all these parameters (SNQ, intra-articular Howell grade, intratunnel Howell grade, tibial interface) was determined during the postoperative period in patients who underwent at least two MRI examinations (41 patients).

2.4. Statistical analysis

The statistical analysis was performed with SAS software, version 9.4 (SAS Institute). The Wilcoxon signed-rank test was used to compare changes in the SNQ over time and perform comparisons on the same MRI; the Mantel-Haenszel Chi^2 was used to determine the change over time of the Howell intratibial and intra-articular grades; the Kruskal-Wallis test was used to compare the various types of grafts used. An α value of 0.05 was considered as significantly different.

Lin concordance correlation coefficients (CCC) were calculated to determine the agreement and consistency between the two measurements of each parameter on all the MRI images [25]. A coefficient of > 0.81 is considered good, > 0.91 is considered very good and > 0.95 is excellent.

3. Results

3.1. Normal ACL

In the 20 normal ACLs, the mean SNQ was 2.3 ± 1.7 in the proximal third, 3.5 ± 2.5 in the middle third and 5.8 ± 3.2 in the distal third; thus the normal ACL has an increasingly hyperintense signal from proximal to distal. These differences between zones were significant, especially the proximal to distal ones (Fig. 6).

The majority of normal ACLs had an intra-articular Howe grade of II (55%) while 20% were grade I and 25% were grade III; there were no grade IV ligaments. Thus a small number of ACLs have a complete hypointense signal and have proximal to distal differences (Fig. 7).

Table 2: Change in the intra-articular Howell grades over time in the intact grafts

Howell grade	MRI 1 (n = 33)	MRI 2 (n = 33)	MRI 3 (n = 35)
I	0 (0%)	1 (3%)	7 (20%)
II	10 (30%)	18 (54.5%)	21 (60%)
III	21 (63.6%)	12 (36.4%)	5 (14.3%)
IV	2 (6.1%)	2 (6.1%)	2 (5.7%)

MRI 2 vs MRI 3: p < 0.05

MRI 1 vs MRI 3: p < 0.05

Fig. 6. SNQ in normal ACL.

	Normal ACL (n = 20)
Proximal SNQ	2,3 ± 1,7
Middle SNQ	3,5 ± 2,5
Distal SNQ	5,8 ± 3,2

Proximal vs Middle: p < 0,05; Middle vs Distal: p < 0,05; Proximal vs Distal: p < 0,05

Fig. 7. MRI of a normal ACL is characterized by a hypointense band corresponding to the anteromedial (AM) bundle and a posterior hyperintense band corresponding to the posterolateral (PL) bundle, with no separation.

	Intacts grafts
Proximal SNQ – MRI 1 (n = 33)	33,6 ± 112,7
Proximal SNQ – MRI 2 (n = 33)	9 ± 14,7
Proximal SNQ – MRI 3 (n = 35)	8,4 ± 15,6
Middle SNQ – MRI 1 (n = 33)	31,4 ± 93,8
Middle SNQ – MRI 2 (n = 33)	10,4 ± 11,8
Middle SNQ – MRI 3 (n = 35)	10,2 ± 16,4
Distal SNQ – MRI 1 (n = 33)	31 ± 106,8
Distal SNQ – MRI 2 (n = 33)	8,3 ± 13,6
Distal SNQ – MRI 3 (n = 35)	8,9 ± 13,5

Proximal: MRI 1 vs MRI 2: p < 0,05; MRI 1 vs MRI 3: p < 0,05
Middle: MRI 1 vs MRI 2: p < 0,05; MRI 1 vs MRI 3: p < 0,05
Distal: MRI 1 vs MRI 2: p < 0,05; MRI 1 vs MRI 3: p < 0,05

Fig. 8. Change in the SNQ over time for intact grafts.

The CCCs were always > 0.91 for these measurements, thus very good.

3.2. Intact ACL grafts

The SNQ and Howell grades for all the MRI examinations performed are shown in Fig. 8 and Fig. 9. The SNQ in all three zones was significantly lower between months 6 and 12 and between months 6 and 24; there was no significant difference between months 12 and 24 (Fig. 8). Over time, the proportion of Howell grades II and III decreased while the proportion of grade I increased (Fig. 9). There was no difference in the SNQ of the three zones (proximal, middle, distal) of the grafts at any point in the postoperative time frame. The CCCs were always > 0.91 for these measurements, thus very good.

The intra-articular Howell grade improved significantly between 6 and 24 months and between 12 and 24 months, meaning that the proportion of Howell grades II and III decreased while the proportion of grade I increased over time. Note that the two grade IV grafts did not change between months 6 and 24 (Fig. 9). The CCCs were always > 0.81 for these measurements, thus good.

There was a significant difference in the intra-tibial Howell grades only between 12 and 24 months postoperative (Fig. 10. The CCCs were always > 0.91 for these measurements, thus very good.

At the tendon-tibial tunnel interface, the contact area at the interface increased progressively and there were no signs of deterioration. The mean area was 53% at 6 months, 63% at 12 months and 82% at 24 months (Fig. 11). The interface was unchanged between the first and last MRI in 11 grafts, while it improved in all the other grafts. The CCCs were always > 0.81 for these measurements.

The Howell intra-articular and intra-tunnel grades were identical in 10 cases at 6 months, 15 cases at 12 months and 18 cases at 24 months.

3.3. Retears

We found no differences in the SNQ, Howell intra-articular or intra-tibial grades at any postoperative time point between intact grafts and those that suffered a retear. Among the seven retears, there was one case with Howell I, two with Howell II, three with Howell III and one that was grade III at 6 and 12 months and then grade IV at 24 months before the retear.

Howell grade	MRI 1 (n = 33)	MRI 2 (n = 33)	MRI 3 (n = 35)
I	0 (0%)	1 (3%)	7 (20%)
II	10 (30%)	18 (54,5%)	21 (60%)
III	21 (63,6%)	12 (36,4%)	5 (14,3%)
IV	2 (6,1%)	2 (6,1%)	2 (5,7%)

p < 0,05

p < 0,05

Fig. 9. Change in the intra-articular Howell grades over time in the intacts grafts.

Howell grade	MRI 1 (n = 33)	MRI 2 (n = 33)	MRI 3 (n =35)
I	2 (6,1%)	1 (3%)	10 (26,8%)
II	18 (54,5%)	24 (72,7%)	20 (57,1%)
III	13 (39,4%)	8 (24,2%)	4 (11,4%)
IV	0 (0%)	0 (0%)	1 (2,9%)

p < 0,05

Fig. 10. Change in the intratibial Howell grades over time in the intacts grafts.

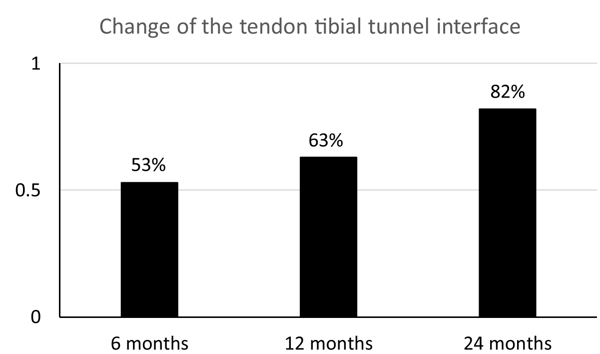

Fig. 11. Change of the tendon tibial tunnel interface over time.

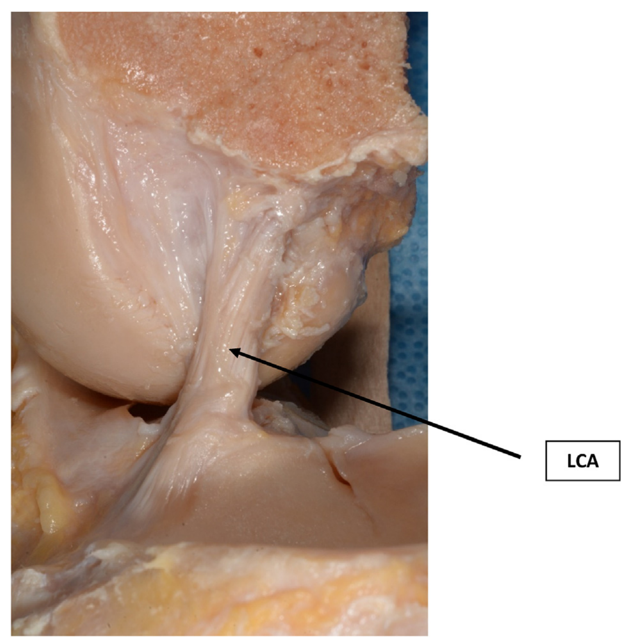

Fig. 12. Anatomy of the ACL on a sagittal view with the knee extended (medial condyle has been removed). Dissection of the ACL showing the pes anserinus tibial insertion.

3.4. *Effect of graft type*

The only differences found between the three types of grafts used were that the SNQ in the middle and distal zones at 24 months postoperative was significantly lower for the STG than the QT.

4. Discussion

The main finding of this study was that ligamentization of ACL grafts in children with open growth plates is a very slow process with changes seen on postoperative MRI up to 2 years out.

MRI of a normal ACL shows a hypointense band corresponding to the anteromedial bundle and a hyperintense band corresponding to the posterolateral bundle, with no separation [26]. This physiological appearance must not be confused with an ACL tear. The SNQ measurements on three ROIs of 20 normal ACLs found this structure to be inhomogeneous from proximal to distal and mostly Howell grades II and III (80%).

Despite the 2-year follow-up, maturation of the graft does not result in an MRI signal like that of a normal ACL. Our hypothesis that graft maturation is slow and gradual is confirmed. The ACL grafts had a homogeneous signal over their entire length and had a slightly higher signal overall than a normal ACL. Conversely, the signal in a normal ACL is uneven with the distal third being hyperintense. This inhomogeneity has already been documented by Ng et al. [26]. The distal hyperintense signal may be attributed to the pes anserinus tibial insertion. This insertion groups direct ligament fibers and fan-like extension fibers (Fig. 12) [27].

When comparing our findings with those of similar studies in adults, the SNQ values at 6 months were higher than in adults [11,15,16,22,28,29]. For example, at 6 months, Ma et al. reported SNQ values of 3.3 ± 1, 2.4 ± 0.5 and 1.5 ± 0.6 in the upper, middle and lower third of 14 hamstring grafts [22]. Colombet et al. found SNQ values below 1 at 6 months' follow-up, no matter the type of tibial fixation used [28]. At 1 year, our results are similar to those of Cavaignac et al. [14] who reported SNQ of 5.2 ± 4.5 for an STG graft and 5.9 ± 3.7 for a ST4 graft. Our findings of changes in the hyperintense signal are consistent with those reported in several studies in adults. According to Murakami et al., all grafts have a full hyperintense signal up to 1 year and 31% continue to have it after 19 months [16]. Ntoulia et al. found a weak but homogeneous signal in grafts starting at 2 years postoperative [15]. Decrease in the signal was reported by Muramatsu et al. up to 60 months postoperative [11].

After a graft is implanted, it undergoes ligamentization in three successive phases: early (decrease in cell count, graft covered by synovial membrane), remodeling (revascularization, repopulation by fibroblasts), and then maturation [30]. Several clinical studies have found that the minimal duration of the ligamentization phase is 1 year and can take up to 2 or 3 years [31]. The duration of these phases depends on the micro-environment, conditions of ligamentization near the tunnel, tendon stumps and Hoffa fat pad. Since the middle portion has less favorable mechanical conditions and environment, ligamentization occurs later in this zone. According to Murakami et al., the hyperintensity in and around a hamstring tendon graft corresponds to vascular and synovial infiltration that gradually disappears after 1 year [16]. In an animal study, Weiler et al. showed a hyperintense signal in the grafts during the initial phase and then a signal decrease that parallels improvement in mechanical properties [18]. They also showed a negative correlation between SNQ intensity and the graft's mechanical properties. We also found a gradual decrease in the hyperintensity of the grafts after 6 months. The benefits of injecting platelet-rich plasma in the joint or tunnels are controversial. There was no benefit according to Figueroa et al. [24], while Radice et al. and Orrego et al. [32,33] found that ligamentization on MRI was accelerated. MRI could be an evaluation tool for graft quality and a decision tool for rehabilitation and return to certain sports [30].

The intra-tibial Howell grade improved between 6 months and 2 years; however less than 10% are Howell grade I at 2 years, while Colombet et al. found 25% grade I with screw fixation and 97% with suspensory fixation at 6 months postoperative [28]. According to Murakami et al. who studied 75 STG grafts on MRI, 65% of grafts had a Howell intra-tibial grade of I at 1-year minimum follow-up [10].

Experimentally, the hypervascular tendon-bone interface is replaced by Sharpey fibers that ensure complete graft fixation at 6 months in rabbits and at 1 year in rhesus monkeys [34,35]. During the revision of two ACL reconstruction cases by Pinczewski et al., Sharpey fibers were found at 12 weeks postoperative [36]. Femoral tunnel biopsy has found mature tendon anchoring starting at 10 months' postoperative [37]. Murakami et al. showed gradual reduction of the hyperintense signal at the interface and concluded that complete maturation of the interface requires 6 to 12 months; reduction of the hyperintense signal at the interface corresponded to maturation of the granulation tissue into collagen fibers and was faster than maturation of the intra-tibial portion of the graft [10].

Our analysis of MRI examinations at 6 months postoperative did not identify any variables that could identify patients at risk for a retear. One patient actually had Howell grade I. Li et al. also found no factors that were predictive of the clinical outcome at 1 year postoperative [29]. Biercevicz et al. found no predictive value of volume or MRI signal at 3 years postoperative for the KOOS score or knee laxity measurements, but a predictive value at 5 years [19]. Most retears occur following a new injury event, as evidenced by the 13.2 months elapsed in our study, which is suggestive of a new injury event on an operated but stable knee or to incorrect tunnel positioning instead of a ligamentization problem. Several recent studies have shown that major retear risk factors are a young age and suffering additional injuries after the return to sports [38].

There was no evidence that the type of graft made a difference. Biercevicz et al. found no difference in the MRI signal between hamstring and patellar tendon grafts [19]. Ma et al. found significantly lower SNQ in QT grafts than in hamstring grafts [22]. This SNQ reduction may be explained by the better-quality bone fixation achieved with QT than STG or ST4 grafts.

Our study has several limitations. The 2-year follow-up is not long enough for the grafts to mature [31]. Other authors have shown that ligamentization make take 3 years or more in humans [19,39,40]. The lack of retear predictive factors at 6 months can be explained by the differences in group sizes (7 retear vs 39 intact). We would need to compare similar-sized groups of future tears to intact grafts at 6 months. Also, for the graft type comparison, it may have been possible to detect signal differences between graft types if the groups sizes were more even. Given that this was a multicenter study, certain technical aspects likely varied between surgeons: amount of pretension on the graft, anatomical sites of graft implantation, postoperative immobilization and rehabilitation. The type of graft is not the only factor that comes into play during graft remodeling. Acquisition of MRI images on units from different manufacturers is a limiting factor that was controlled by using the SNQ measurement.

Despite these limitations, our study has three strengths: the large number of MRI examinations evaluated (126) allowed us to analyze ligamentization in a reliable manner up to 2 years' postoperative; the time points were consistent (6 months, 1 year, 2 years); the double reading by the rater improved the consistency of the various parameters as evidenced by the very good CCC.

5. Conclusion

The change in the MRI signal corresponding to ACL graft maturation continues up to 2 years' postoperative in children with open growth plates. However, ligamentization of the graft does not lead to a normal ACL with the graft continuing to be homogeneous, unlike a normal ACL. Contrary to current thinking, the maturation of ACL grafts in children seems to take longer than in adults. Consequently, we must be particularly vigilant to ensure the return to sports is not done too quickly. The MRI signal of the graft at 6 months' postoperative does not predict the risk of retear.

Disclosure of interest

N. Lefèvre is consultant for developing logicielwebsurvey. fr® software.

The authors declare that they have no competing interest.

Funding

None.

Authors' contribution

Pauvert Adrien, Robert Henri: data collection and analysis, writing of the article.

Gicquel Philippe, Graveleau Nicolas, Pujol Nicolas: data collection.

Chotel Franck, Lefevre Nicolas: data collection and analysis, reading of the article.

Acknowledgement

We are thankful to all the research sites that participated in this study: CHRU of Strasbourg, Hôpital Mère Enfant (Hospices Civils de Lyon), Centre Hospitalier Nord Mayenne, CHU of Nantes, Clinique du Sport Bordeaux–Mérignac, Centre Orthopédique Santy (Lyon),

CHU of Toulouse, CHU of Tours, Clinique du Sport Institut Nollet (Paris), Centre Hospitalier of Versailles.

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