The Knee 57 (2025) 60–67

Contents lists available at ScienceDirect

The Knee

journal homepage: www.elsevier.com/locate/thekne

Review

Growth disturbance in paediatric anterior cruciate ligament reconstruction ☆

Franck Accadbled [a,*], Marco Crippa [b,c,d], Marco Turati [b,c,d,e]

[a] Orthopaedic Department, Hôpital des Enfants, CHU de Toulouse, France
[b] Department of Orthopaedics and Trauma, Fondazione IRCCS San Gerardo dei Tintori, University of Milano-Bicocca, Monza, Italy
[c] Department of Medicine and Surgery, University of Milano-Bicocca, Monza, Italy
[d] Transalpine Center of Paediatric Sports Medicine and Surgery, University of Milano-Bicocca, Monza, Italy
[e] Department of Paediatric Orthopaedic Surgery, University Hospital Grenoble-Alpes, University Grenoble-Alpes, Grenoble, France

ARTICLE INFO

Article history:
Received 12 June 2025
Revised 8 July 2025
Accepted 29 July 2025

Keywords:
Paediatric ACL
Complication
Growth disturbance
Sports medicine
Arthroscopy

ABSTRACT

Anterior cruciate ligament (ACL) reconstruction in skeletally immature patients represents a significant challenge due to the risk of growth disturbance, including limb length discrepancy (LLD) and angular deformity (AD). Although rare, the consequences of such complications can be substantial. Contributing factors include inadequate clinical and radiological preoperative assessment and insufficient postoperative monitoring.

Methods: This review synthesizes the current understanding of growth disturbances after paediatric ACL reconstruction, examining their incidence, pathophysiology, and technical considerations. Growth anomalies, categorized as arrest (type A), overgrowth (type B), or tethering effect (type C), arise from physeal damage, periosteal disruption, or tunnel malposition, during autograft harvesting, bone tunnels placement or graft fixation.

Results: Surgical technique is crucial, with disturbances reported across transphyseal, all-epiphyseal, and extraosseous reconstructions, regardless of whether bone or soft tissue grafts are used. Meta-analyses indicate low overall rates of LLD and AD; however, reporting is complicated by heterogeneous definitions and follow up protocols.

Conclusions.

No single technique has demonstrated superiority in preventing growth disturbances, and most complications correlate with technical errors rather than the approach itself. Accurate assessment of growth potential – utilizing bone age, clinical markers, and radiographic tools – is paramount for surgical planning. Postoperative surveillance with clinical and full-length standing radiographs of the lower limbs is strongly recommended until skeletal maturity. While most growth disturbances are subclinical or self-limiting, significant anomalies may necessitate observation, guided growth procedures, or corrective osteotomy. Until high-level comparative studies are available, meticulous surgical technique and vigilant follow up are essential to minimize complications in this vulnerable population.

☆ This article is part of a special issue entitled: 'Paediatric knee' published in The Knee.

* Corresponding author at: Service de Chirurgie Orthopédique et Traumatologique, Hôpital des Enfants, 330 Avenue de Grande Bretagne, 31059 Toulouse Cedex 9, France.

E-mail address: faccadbled@gmail.com (F. Accadbled).

https://doi.org/10.1016/j.knee.2025.07.016
0968-0160/© 2025 The Author(s). Published by Elsevier B.V.

Contents

1. Introduction . . . 61
2. Knee growth . . . 61
3. Growth disturbances . . . 62
   3.1. Definition/assessment . . . 62
   3.2. Pathophysiology . . . 62
4. Technical considerations . . . 62
5. Is one technique safer? . . . 64
6. Management . . . 66
7. Conclusion . . . 66

CRediT authorship contribution statement . . . 66
Funding . . . 66
Declaration of competing interest . . . 66
References . . . 66

1. Introduction

Although early surgical reconstruction is often recommended for anterior cruciate ligament (ACL) rupture in children and adolescents, concerns remain about complications, specifically growth disturbance leading to limb length discrepancy (LLD) and angular deformity (AD) in the skeletally immature [1–3]. Extraosseous, all-epiphyseal and transphyseal techniques have been utilized depending on the patient's age and growth potential, and mostly the surgeon's preference [4]. The influence of ACL reconstruction (ACLR) techniques on bone growth has been actively studied, yet incidence of growth disturbance is inconsistent in the literature. Kocher clarified in his classic article from 2002 that the vast majority of growth disturbances are related to technical mistakes [5]. According to a systematic review, the incidence of LLD and AD after ACLR in skeletally immature patients appears low (2.1 % and 1.3 %, respectively), but the quality of preoperative evaluation and postoperative monitoring are insufficient for accurate assessment [6].

Another systematic review reported similar rates of the LLD and AD comparing transphyseal versus physeal-sparing techniques (0.81 % vs. 1.2 % and 0.61 % vs. 0 %, respectively) [7]. Some studies paradoxically report a lower incidence of growth disorders with transphyseal techniques than with physeal sparing techniques [8–10].

2. Knee growth

The knee is the joint with the highest potential for skeletal growth. It ensures an average growth of 2 cm per year (of which, 1.2 cm for the distal femur and 0.8 cm for the proximal tibia). It is therefore essential to determine the growth remaining around the knee in order to select a surgical technique [4]. The Anderson and Green prediction tables indicate the residual growth on each physis depending on bone age. The use of bone age (determined from an X-ray of the left hand or elbow according to the method of Greulich and Pyle [11] or Sauvegrain [12], respectively) is more accurate than chronological age. The growth of the lower limbs is completed on average at 13.5 years of bone age in a girl and 15.5 years in a boy. During the pubertal period, Dimeglio et al. found 50 % agreement between bone age and chronological age, 30 % ahead and 20 % behind [13]. The appearance of an ossification point on the iliac crest (stage 1 of the Risser score) signals the end of the growth of the lower limb [13]. The physiological closure of a physis is spread over time (about 2 years) and is centrifugal. Thus, it is possible to reconstruct an ACL without risk of epiphysiodesis as soon as the distal femoral physis is closed in its centre. Fusion of the anterior tibial tuberosity is the absolute criterion for complete bone maturation, but it is sometimes extremely late (on average 15–16 years for girls and 18 years for boys). In girls, the onset of menstruation is a good indicator of the end of growth in the knee [13]. In boys, pilosity of the lower limbs, axillary or pubis can be observed: adult stage (Tanner 4) also signals the end of knee growth [14]. It is recommended to combine all of these markers for optimal reliability.

Wester et al. developed a method for predicting length inequality and axial deviations caused by ACLR in a child [15]. For example, a ligament procedure performed 1 year before the end of growth can result in a shortening of 1 cm and a valgus of 5°. The earlier the iatrogenic epiphysiodesis, the greater the consequences. Paradoxically, the risk of epiphysiodesis is greater in adolescents [16]. Seil et al. showed experimentally on lambs' knees that filling a transphyseal bone tunnel with a tendon graft does not systematically prevent the formation of an epiphysiodesis bridge [17]. However, this epiphysiodesis has no clinical consequences if the residual growth is powerful enough to rupture the bone bridge [17]. Indeed, the growth cartilages of a human knee can produce a distraction force estimated at 500 N [18]. Growth decreases as bone maturity approaches, thus the risk of permanent epiphysiodesis is greater at this time [19]. As a matter of fact, the majority of growth disorders reported in the literature concern adolescents. Children undergoing ACL surgery routinely undergo magnetic resonance imaging (MRI), making the direct assessment of growth potential on MRI an attractive hypothesis. However, Fabricant et al. described low interrater reliability for physeal assessment, highlighting the need for more reliable MRI criteria [20].

Figure 1. Anteroposterior radiograph of a 9-year-old boy, 12 months after anterior cruciate ligament reconstruction. The presence of the Harris line parallel to the growth plate (arrows) implies the absence of growth arrest.

3. Growth disturbances

3.1. Definition/assessment

Monitoring of growth using standing full-length radiographs of the lower limbs until skeletal maturity is recommended. The use of long leg films will identify alterations in coronal limb alignment, whereas a deformity or LLD needs to be significant to be identified clinically, although does involve exposure to radiation [21]. It is helpful to observe the Harris growth lines on the distal femur and proximal tibia (Figure 1). Any clinically relevant deformation should be investigated with an MRI and/or a computed tomography (CT) scan to look for signs of growth issue [22].

There is a significant variability in the reporting and monitoring of growth-related complications after ACLR in skeletally immature patients [6]. A post-reconstruction growth disturbance is generally defined by an LLD of more than 10 mm and/or an angular asymmetry of more than 3° [23], 5° [8,10,24] or 10 mm of mechanical axis deviation [25] as compared with the contralateral extremity. Some of the reported infra-clinical growth anomalies may be physiological and simply unrelated to the procedure [23].

3.2. Pathophysiology

The growth disturbance can relate to the harvesting of an autograft, the placement of the bone tunnels or the graft fixation. Chotel reported three different types of growth disturbance after ACLR: type A (Arrest) is generated by a bone bridge across the physis, type B (Boost) is an overgrowth process due to local hypervascularization (Cozen like effect), type C (DeCelerate) is due to a tethering effect of the ligament graft [26]. Type A results from the violation of the physis when creating a bone tunnel or harvesting a bone–tendon–bone graft [27]. It is often located at the femur posterolaterally and therefore generates a valgus and flexion deformity (Figure 2). Harvesting a bone–tendon–bone graft in a skeletally immature individual may generate a growth arrest of the tibial tuberosity hence an inverted tibial slope and a genu recurvatum (Figure 3). The type B growth disturbance or overgrowth often occurs at the tibia and can be only transient (Figure 4).

4. Technical considerations

The most common technical errors include: (1) fixation implant or bone plug placed across the growth plate (Figure 5) [5]; (2) transphyseal tunnel incompletely filled with the tendon graft; (3) growth plate/perichondral ring damaged when drilling an all-epiphyseal tunnel; (4) overtightened lateral tenodesis (in theory).

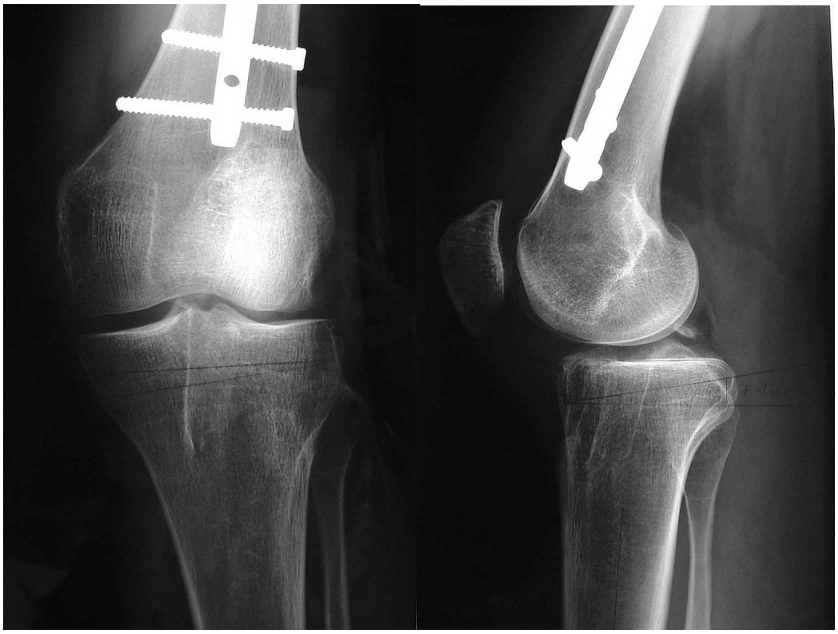

Figure 2. Type A growth disturbance 3 years after anterior cruciate ligament reconstruction in a 15-year-old boy. Posterolateral femoral growth arrest and tibial tuberosity growth arrest. Note the vertical Blumensaat line and the inverted tibial slope on the lateral view.

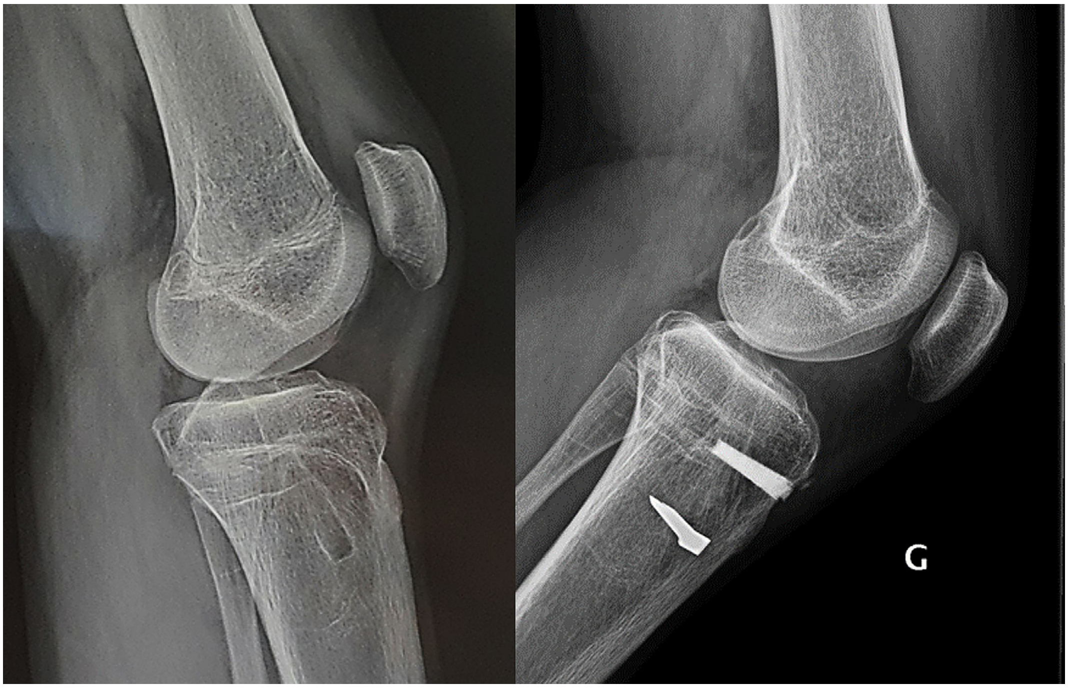

Figure 3. Left: inverted tibial slope as a result of tibial tuberosity growth arrest in a 15-year-old boy, 2 years after failed anterior cruciate ligament reconstruction (ACLR). Right: 12 month follow up after revision ACLR and anterior open-wedge high tibial osteotomy.

Regarding the transphyseal technique, great care should be taken not to insult the perichondral ring when preparing the femoral footprint. Bone tunnel diameter is limited to 9 mm [5,28], and the tendon graft should match the diameter of the tunnel or socket and fill it completely. It is also recommended to drill the tunnels at low speed to avoid heat necrosis. All epiphyseal techniques require intraoperative image intensifier monitoring, despite the use of intraoperative three-dimensional fluoroscopy reducing the incidence of physeal violations during all-epiphyseal ACLR, the risk is not eliminated,

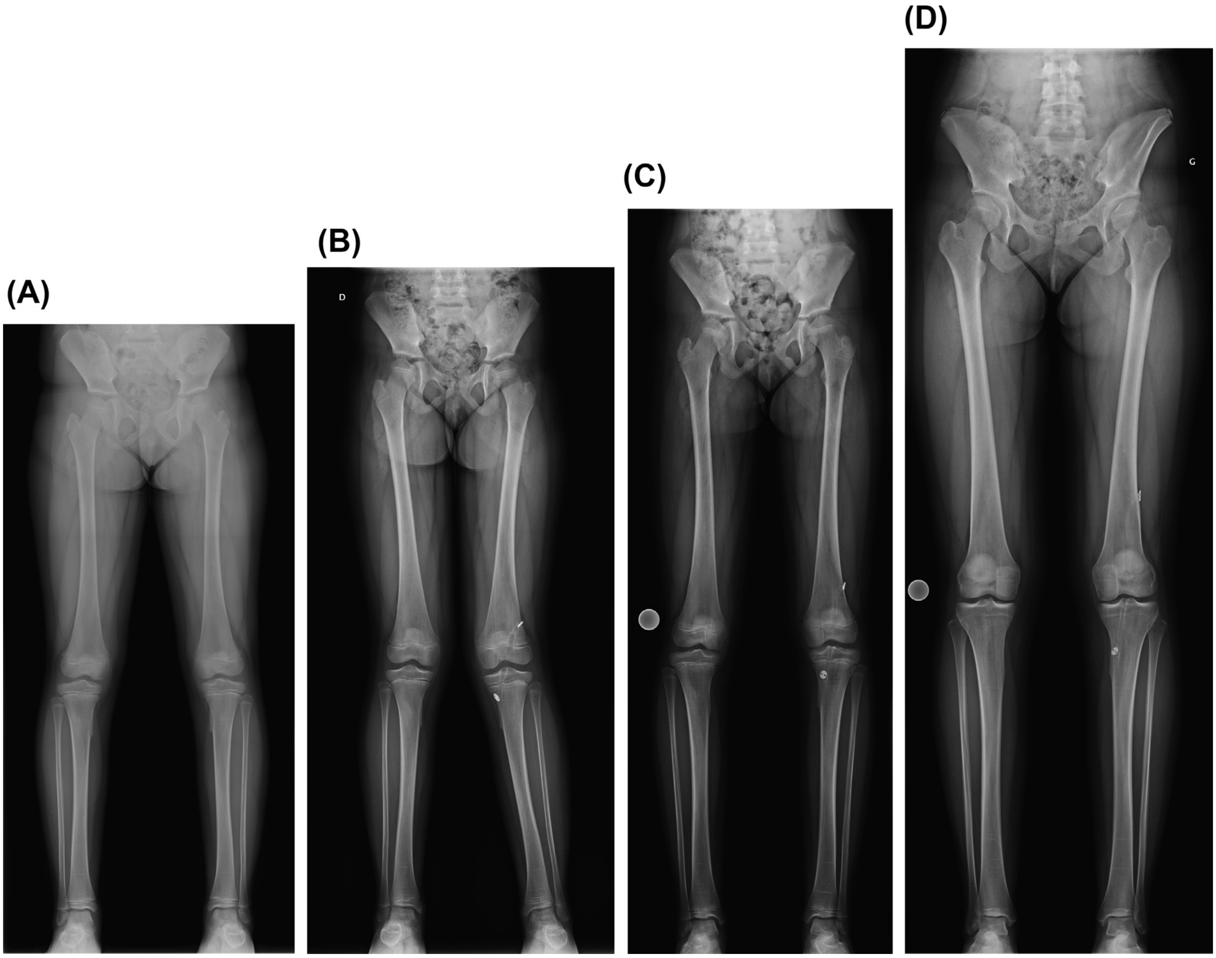

Figure 4. Type B growth disturbance 6 months after anterior cruciate ligament reconstruction in a 6-year-old girl (hamstring autograft). (a) Preoperative. (b) Tibial valgus 6 months postoperative. (c) Complete resolution 12 months postoperative. (d) Final follow up at skeletal maturity.

with residual rates of 11 % at the distal femoral physis and 17 % at the proximal tibial physis [29]. The anteromedial portal for femoral drilling is advocated to place a more anatomic femoral tunnel [30]. However, this leads to a more oblique and more peripherally located drill tunnel through the distal femoral epiphysis; consequently, the anteromedial (AM) portal technique tends to create more laterally positioned and larger physeal violations compared with the transtibial (TT) approach [31]. This represents a higher risk of growth disturbance compared with more centrally placed tunnels as it involves a larger volume of physis and may damage the perichondral ring [17]. Notably, the AM approach is more likely to exceed 8 % of physeal volume removal, a threshold associated with an increased risk of growth disturbances [32]. As a general principle, it is recommended to adjust the drill angle to the most vertical (50–60° for the transphyseal tibial tunnel), to reduce the damaged surface area of the physis.

5. Is one technique safer?

Induced growth disturbances may occur with any reconstruction technique, in an EPOS and POSNA survey, 5.5 % of respondents reported growth disturbances after ACLR [2]. In a *meta*-analysis from Wong et al. of 1392 ACLRs (640 transphyseal) in patients aged 8.7–16.4 years, there were 58 growth disturbances of which 16 required corrective surgery (37 cases of LLD, 18 cases of single plane AD, three cases of multiplanar AD) [10]. Among the 18 knees which developed AD, 10 had transphyseal reconstruction, three had physeal sparing, though the specific technique was not further clarified, and two had partial physeal sparing reconstruction (crossing the tibial physis). The most frequent deformity was valgus in 14 cases, and among those, transphyseal ACLR was the most common technique used. Of the 37 patients with at least 10 mm LLD, 19 had shortening (14 cases of transphyseal, four cases of partial transphyseal, one case of physeal sparing reconstruction) and 14 had overgrowth (nine cases of physeal sparing, three cases of partial transphyseal, and two cases of transphyseal reconstruction).

Figure 5. Bioabsorbable interference screw wrongly placed across the tibial physis.

Collins et al. conducted a systematic literature review including 21 studies reporting on 39 patients with growth anomalies [8]. The most common angular deformation was genu valgum (81 %, $N = 13$; mean of 6.5°). They noted that physeal-sparing techniques were performed in 25 % of the cases of AD and 47 % cases of LLD, despite the belief that this technique mitigates the risks of growth disturbance by not violating the physis. In another systematic review, Pierce et al. demonstrated similar incidence rates of LLD and AD in transphyseal and physeal-sparing cohorts [7]. In their *meta*-analysis, Wong et al. emphasized that all cases of AD that required surgical correction presented technical issues, regardless of the reconstruction techniques used [10].

The systematic review by Fury et al. represents the most extensive to date concerning skeletally immature patients undergoing ACLR and exhibiting growth discrepancies [6]. Their findings indicated an incidence of LLD exceeding 10 mm and AD surpassing 5° of 2.1 % and 1.3 %, respectively. These rates are lower than those reported previously by Wong (2.8 %) and Collins (9.3 %).

Consistent with previous literature, Fury et al. also reported that limb shortening was the most frequent form of length discrepancy, while valgus deformity was the most prevalent angular anomaly. Interestingly, they were the first to identify a subgroup of patients with ≥ 20 mm discrepancies and highlighted a potential association between overgrowth and all-epiphyseal reconstructions [6].

Faunø et al. reported on 33 patients (age 9 to 14 years, mean 11.7) treated with transphyseal ACLR with postoperative MRI. Eight patients (24 %) had more than 10 mm shortening of the operated leg, and one (3 %) had a 10-mm overgrowth. Twenty-seven patients (82 %), had a femoral valgus > 2° of the operative leg compared with the contralateral [33].

Two cases of femoral valgus (Chotel type A, 4° each) were reported by Lemaitre et al. after transphyseal ACLR in 14 skeletally immature knees and 15 months mean follow up [34].

Bolzinger et al. reported transphyseal ACLR had generated a LLD in 13 % of cases (range 10–14 mm), a mechanical axis deviation in 34 % of cases at the femoral level, and in 53 % of cases at the tibial level (range 3–8°). No clinically relevant growth disturbance was reported at 2 years follow up [23]. The most frequent angular deformation was proximal tibial varus (16 cases), likely due to either a growth arrest (Chotel type A) or tethering effect (Chotel type C). The second most frequent was proximal tibia valgus (nine cases), presumably because of a Cozen effect in relation to periosteal stripping at the pes anserinus during tendon graft harvest, and/or the medial metaphyseal 4.5-mm-diameter bone tunnel [35]. Regarding induced LLD encountered in six cases (13 %), all three Chotel types were found. One case involved the tibia only, five involved both femur and tibia. An angular deformation was associated in four cases (66 %). Interestingly, age at surgery and Tanner stage did not influence the occurrence of a growth disturbance, AD or LLD.

A recent systematic review by Zakharia et al. directly compared the outcomes and complication profiles of two different physeal sparing techniques: all-epiphyseal and modified-Kocher ACLRs [36]. Although no significant differences were found in clinical or functional outcomes, all-epiphyseal reconstruction may carry a higher risk of postoperative complications. Specifically, the all-epiphyseal technique was associated with higher rates of growth disturbances (1.5 %) and AD (1.3 %) compared to the modified-Kocher technique, which reported rates of 0.0 %.

The fact that growth disturbance occurs with all techniques of ACLR in the skeletally immature leaves surgeons unsure of which technique is optimal. Physeal sparing techniques are more technically demanding, which can be problematic when performed only occasionally, and can lead to periosteal disruption and increased vascularity in the physis [26]. There continues to be no prospective randomised studies comparing transphyseal reconstruction with physeal sparing methods.

6. Management

Early diagnosis is of utmost importance to allow timely management. We recommend growth monitoring with full-length standing radiographs of the lower limbs every 6 months for the first 2 years postoperative then yearly until skeletal maturity. The management of a growth disturbance depends on its type, location, severity and the remaining growth. Therefore, it is mostly a case-by-case discussion. However, we can use the following recommendations as general guidelines: (1) Check the graft positioning as an incorrect tunnel placement can both generate a growth arrest and a failed ACLR (Figure 3). (2) Any growth disorder in a prebuscent patient should be observed 12 months before operative treatment is undertaken as it could correct spontaneously (Figure 4). (3) In case of a growth arrest, contralateral epiphysiodesis is only considered for predicted LLDs exceeding 2 cm. (4) In case of a growth arrest, asymmetrical epiphysiodesis is only considered for predicted angulation exceeding 5°. (5) For patients already at or close to skeletal maturity, corrective osteotomy or bone lengthening are indicated for LLDs exceeding 2 cm or angulation exceeding 5° (Figure 3).

7. Conclusion

Growth disturbances after paediatric ACLR are rare yet require attention. Based on our experience and the literature, we recommend a guarded approach with careful attention to the surgical technique and the follow up. Monitoring of growth using standing full-length radiographs of the lower limbs until skeletal maturity is recommended.

CRediT authorship contribution statement

Franck Accadbled: Writing – review & editing, Writing – original draft, Validation, Software, Conceptualization. **Marco Crippa:** Writing – review & editing, Investigation. **Marco Turati:** Writing – review & editing, Investigation, Conceptualization.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Ramski DE, Kanj WW, Franklin CC, Baldwin KD, Ganley TJ. Anterior cruciate ligament tears in children and adolescents: a meta-analysis of nonoperative versus operative treatment. Am J Sports Med 2014;42:2769–76. doi: https://doi.org/10.1177/0363546513510889.
[2] Accadbled F, Gracia G, Laumonerie P, Thevenin-Lemoine C, Heyworth BE, Kocher MS. Paediatric anterior cruciate ligament tears: management and growth disturbances. A survey of EPOS and POSNA membership. J Child Orthop 2019;13:522–8. doi: https://doi.org/10.1302/1863-2548.13.190074.
[3] Brophy RH, Silverman RM, Lowry KJ. American academy of orthopaedic surgeons clinical practice guideline case study: management of anterior cruciate ligament injuries. J Am Acad Orthop Surg 2023;31:538–48. doi: https://doi.org/10.5435/JAAOS-D-23-00088.
[4] Tang C, Kwaees TA, Accadbled F, Turati M, Green DW, Nicolaou N. Surgical techniques in the management of pediatric anterior cruciate ligament tears: current concepts. J Child Orthop 2023;17:12–21. doi: https://doi.org/10.1177/18632521221149059.
[5] Kocher MS, Saxon HS, Hovis WD, Hawkins RJ. Management and complications of anterior cruciate ligament injuries in skeletally immature patients: survey of the herodicus society and the ACL study group. J Pediatr Orthop 2002;22:452–7. , http://www.ncbi.nlm.nih.gov/pubmed/12131440.
[6] Fury MS, Paschos NK, Fabricant PD, Group PS, Anderson CN, Busch MT, et al. Assessment of skeletal maturity and postoperative growth disturbance after anterior cruciate ligament reconstruction in skeletally immature patients: a systematic review. Am J Sports Med 2021:3635465211008656. doi: https://doi.org/10.1177/03635465211008656.
[7] 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;45:488–94. doi: https://doi.org/10.1177/0363546516638079.
[8] Collins MJ, Arns TA, Leroux T, Black A, Mascarenhas R, Bach Jr BR, et al. Growth abnormalities following anterior cruciate ligament reconstruction in the skeletally immature patient: a systematic review. Arthroscopy 2016;32:1714–23. doi: https://doi.org/10.1016/j.arthro.2016.02.025.
[9] Frosch KH, Stengel D, Brodhun T, Stietencron I, Holsten D, Jung C, et al. Outcomes and risks of operative treatment of rupture of the anterior cruciate ligament in children and adolescents. Arthroscopy 2010;26:1539–50. doi: https://doi.org/10.1016/j.arthro.2010.04.077.
[10] Wong SE, Feeley BT, Pandya NK. Complications after pediatric ACL reconstruction: a meta-analysis. J Pediatr Orthop 2019;39:e566–71. doi: https://doi.org/10.1097/BPO.0000000000001075.

[11] Greulich W, Pyle S. Radiographic Atlas of Skeletal Development of the Hand and wrist. 2nd ed. Stanford: Stanford University Press; 1959.
[12] Sauvegrain J, Nahum H, Bronstein H. Study of bone maturation of the elbow. Ann Radiol (Paris) 1962;5:542–50. In French.
[13] Dimeglio A. Growth in pediatric orthopaedics. J Pediatr Orthop 2001;21:549–55. , http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11433174.
[14] Tanner JM. Growth at adolescence. Oxford: Blackwell; 1962.
[15] Wester W, Canale ST, Dutkowsky JP, Warner WC, Beaty JH. Prediction of angular deformity and leg-length discrepancy after anterior cruciate ligament reconstruction in skeletally immature patients. J Pediatr Orthop 1994;14:516–21. , http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=8077439.
[16] Chotel F, Seil R. Growth disturbances after transphyseal ACL reconstruction in skeletally immature patients: who is more at risk? Young child or adolescent? J Pediatr Orthop 2013;33:585–6. doi: https://doi.org/10.1097/BPO.0b013e318286c161.
[17] Seil R, Pape D, Kohn D. The risk of growth changes during transphyseal drilling in sheep with open physes. Arthroscopy 2008;24:824–33. doi: https://doi.org/10.1016/j.arthro.2008.02.007.
[18] Bylski-Austrow DI, Wall EJ, Rupert MP, Roy DR, Crawford AH. Growth plate forces in the adolescent human knee: a radiographic and mechanical study of epiphyseal staples. J Pediatr Orthop 2001;21(6):817–23. , http://www.ncbi.nlm.nih.gov/pubmed/11675562.
[19] Anderson M, Green WT, Messner MB. Growth and predictions of growth in the lower extremities. J Bone Joint Surg Am 1963;45-A:1–14. , http://www.ncbi.nlm.nih.gov/pubmed/14040773.
[20] Fabricant PD, Heath MR, Veerkamp M, Gruber S, Green DW, Strickland SM, et al. Reliability of radiologic assessments of clinically relevant growth remaining in knee MRI of children and adolescents with patellofemoral instability: data from the JUPITER cohort. Orthop J Sports Med 2021;9:2325967121991110. doi: https://doi.org/10.1177/2325967121991110.
[21] Bayomy AF, Bompadre V, Schmale GA. The impact of transphyseal anterior cruciate ligament reconstruction on lower extremity growth and alignment. Arthroscopy 2019;35:940–9. doi: https://doi.org/10.1016/j.arthro.2018.10.132.
[22] Yoo WJ, Kocher MS, Micheli LJ. Growth plate disturbance after transphyseal reconstruction of the anterior cruciate ligament in skeletally immature adolescent patients: an MR imaging study. J Pediatr Orthop 2011;31:691–6. doi: https://doi.org/10.1097/BPO.0b013e3182210952.
[23] Bolzinger M, Thevenin Lemoine C, Flumian C, Nicolaou N, Sales de Gauzy J, Accadbled F. Analysis of growth after transphyseal anterior cruciate ligament reconstruction in children. J Pediatr Orthop 2023;43:537–42. doi: https://doi.org/10.1097/BPO.0000000000002484.
[24] Fauno PZ, Boge Steinmeier Larsen J, Nielsen MM, Hellfritzsch M, Nielsen TG, Lind M. The risk of growth disturbance is low after pediatric anterior cruciate ligament reconstruction with a femoral growth plate sparing technique. Arthrosc Sports Med Rehabil 2023;5:100793. doi: https://doi.org/10.1016/j.asmr.2023.100793.
[25] Seeto AH, Carty CP, Bradford K, Maine S, Bade D, Johnson L, et al. Leg-length and alignment changes in children and adolescents after transphyseal anterior cruciate ligament reconstruction with soft tissue graft: results at 1-year follow-up. Orthop J Sports Med 2023;11:23259671231180874. doi: https://doi.org/10.1177/23259671231180874.
[26] Chotel F, Henry J, Seil R, Chouteau J, Moyen B, Berard J. Growth disturbances without growth arrest after ACL reconstruction in children. Knee Surg Sports Traumatol Arthrosc 2010;18:1496–500. doi: https://doi.org/10.1007/s00167-010-1069-5.
[27] Turati M, Caliandro M, Gaddi D, Piatti M, Rigamonti L, Zanchi N, et al. Clinical outcomes and complications after anterior cruciate ligament reconstruction with bone-patellar tendon-bone in patient Tanner 3 and 4: a systematic review. Eur J Orthop Surg Traumatol 2023;33:2191–9. doi: https://doi.org/10.1007/s00590-022-03402-z.
[28] Shea KG, Belzer J, Apel PJ, Nilsson K, Grimm NL, Pfeiffer RP. Volumetric injury of the physis during single-bundle anterior cruciate ligament reconstruction in children: a 3-dimensional study using magnetic resonance imaging. Arthroscopy 2009;25:1415–22. doi: https://doi.org/10.1016/j.arthro.2009.06.023.
[29] Aitchison AH, Perea SH, Cordasco FA, Green DW. Improved epiphyseal socket placement with intraoperative 3D fluoroscopy: a consecutive series of pediatric all-epiphyseal anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 2022;30:1858–64. doi: https://doi.org/10.1007/s00167-021-06809-z.
[30] Marchant BG, Noyes FR, Barber-Westin SD, Fleckenstein C. Prevalence of nonanatomical graft placement in a series of failed anterior cruciate ligament reconstructions. Am J Sports Med 2010;38:1987–96. doi: https://doi.org/10.1177/0363546510372797.
[31] Kachmar M, Piazza SJ, Bader DA. Comparison of growth plate violations for transtibial and anteromedial surgical techniques in simulated adolescent anterior cruciate ligament reconstruction. Am J Sports Med 2016;44:417–24. doi: https://doi.org/10.1177/0363546515619624.
[32] Janarv PM, Wikstrom B, Hirsch G. The influence of transphyseal drilling and tendon grafting on bone growth: an experimental study in the rabbit. J Pediatr Orthop 1998;18:149–54. , https://www.ncbi.nlm.nih.gov/pubmed/9531394.
[33] Fauno P, Romer L, Nielsen T, Lind M. The risk of transphyseal drilling in skeletally immature patients with anterior cruciate ligament injury. Orthop J Sports Med 2016;4:2325967116664685. doi: https://doi.org/10.1177/2325967116664685.
[34] Lemaitre G, Salle de Chou E, Pineau V, Rochcongar G, Delforge S, Bronfen C, et al. ACL reconstruction in children: a transphyseal technique. Orthop Traumatol Surg Res 2014;100(4 Suppl):S261–5. doi: https://doi.org/10.1016/j.otsr.2014.03.001.
[35] Cozen L. Fracture of the proximal portion of the tibia in children followed by valgus deformity. Surg Gynecol Obstet 1953;97:183–8. , https://www.ncbi.nlm.nih.gov/pubmed/13077157.
[36] Zakharia A, Al Katanani F, Hatem A, Dhillon S, Vivekanantha P, Cohen D, et al. All-epiphyseal versus Micheli–Kocher anterior cruciate ligament reconstruction in skeletally immature patients: a systematic review. J Pediatr Orthop 2025;45:316–26. doi: https://doi.org/10.1097/BPO.0000000000002953.