ORIGINAL ARTICLE

Growth Arrest Following ACL Reconstruction With Hamstring Autograft in Skeletally Immature Patients: A Review of 4 Cases

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Background: Anterior cruciate ligament (ACL) tears are becoming more common in the skeletally immature population as participation in high-risk sports continues to grow. This presents a challenge for the treating surgeon as ACL reconstruction in this patient set has the added aim of preservation of the growth plate anatomy. The purpose of this investigation is to report on 4 patients who developed growth arrest following ACL reconstruction and offer a review of the available literature.

Methods: Four skeletally immature patients (2 male and 2 female) were identified who underwent ACL reconstruction at mean age of 14.2 years (range, 13.5 to 14.8 y) and developed growth arrests. Bone ages at the time of reconstruction were 14 and 16 years for the boys and 13 years 6 months and 14 years for the girls. All patients had a transphyseal reconstruction with a hamstring autograft. Standard postoperative care was provided including clinical and radiographic follow-up at regular intervals. Clinically significant postoperative physeal arrest was confirmed on MRI or CT scan. Detailed chart review examined demographics, operative variables, and postoperative subjective and objective clinical measures.

Results: Two patients developed tibial recurvatum; 2 patients developed genu valgum. Three patients required further surgery. One patient underwent distal femoral–guided growth procedure, 2 underwent proximal tibial epiphysiodesis, and 1 patient was skeletally mature at presentation and did not require deformity correction.

Conclusions: This report of 4 patients demonstrates that growth arrest following ACL reconstruction in skeletally immature patients is a real concern and highlights the importance of careful preoperative evaluation and discussion with patients and family members. We routinely obtain long-leg AP and lateral hip-to-ankle films on skeletally immature patients before performing an ACL reconstruction and then at 6 and 12 months postoperatively or every 6 months until the growth plates are closed to assess leg lengths and lower extremity alignment.

Level of Evidence: Level IV—therapeutic study, case series.

Key Words: transphyseal ACL reconstruction, growth arrest, deformity

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Injuries to the anterior cruciate ligament (ACL) are increasing in frequency among children and adolescents as a result of earlier and more active participation in high-risk sporting activities.[1,2] The treatment of ACL injuries in skeletally immature patients remains very controversial. The primary concern is injury to the growth plate during surgery, which may result in limb-length discrepancies and/or angular deformities.[3–10]

When approaching the pediatric patient with an ACL injury, options available to the treating surgeon include nonoperative management, primary ligament repair, extra-articular tenodesis procedures, partial transphyseal procedures, transphyseal reconstructions, physeal sparing all-epiphyseal procedures, or delayed reconstruction at skeletal maturity. Several recent studies have shown that transphyseal surgery has minimal risk of growth arrest.[11–18] However, many of these studies included patients with minimal growth remaining and therefore a lower likelihood of a resulting disturbance.[11,12,15] One study looked specifically at Tanner stage I and II patients, but in many cases patients were not followed to skeletal maturity.[13]

There is considerable literature regarding growth disturbances in animal models.[19–25] Moreover, a recent case report by Lawrence et al[26] described a skeletally immature patient with a transphyseal tibial and all-epiphyseal femoral ACL reconstruction who developed femoral valgus angulation postoperatively. Recent and ongoing research has thus been dedicated to understanding growth arrest following ACL reconstruction and possible methods of preventing it.[17,18,27–31] In our case series, we report the clinical outcomes of 4 patients who underwent transphyseal ACL reconstruction and subsequently developed either growth retardation or premature growth plate closure resulting in deformity.

METHODS

Between 2005 and 2013, 4 skeletally immature patients presented to the senior surgeons with growth arrests following ACL reconstruction (Table 1). We performed a

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TABLE 1. Patient Demographics

Case	Age at ACL Reconstruction	Bone Age at ACL Reconstruction	ACL Reconstruction	Sport Played	Time Until Presentation With Growth Arrest (mo)	Presenting Clinical Disturbance	Degree of Clinical Deformity (deg.)	Corrective Surgery Performed	Follow-up (mo)	Return to Sport
1	14 y 10 mo	14 y	Transphyseal with hamstring autograft	Soccer	7	Recurvatum	8.0	Proximal tibia epiphysiodesis	36	Yes
2	14 y 3 mo	14 y	Transphyseal with hamstring autograft	Football	8	Recurvatum	10	Proximal tibial epiphysiodesis	47	Yes
3	14 y 3 mo	16 y	Transphyseal with hamstring autograft	Soccer	12	Genu valgum	mild	None; skeletally mature	19	Yes
4	13 y 5 mo	13 y 6 mo	Transphyseal with hamstring autograft	Soccer	17	Genu valgum	mild	Medial distal femoral hemiepiphysiodesis	21	Yes

TABLE 2. Deformity Characteristics: Recurvatum Cases

	Recurvatum at Presentation (deg.)	Recurvatum at Final Follow-up (deg.)	aPPTA (Post-ACL) (deg.)	aPPTA (Final Follow-up) (deg.)	LLD Affected Extremity (Post-ACL) (cm)	LLD Affected Extremity (Final Follow-up) (cm)
Recurvatum cases						
Case 1	Unaffected = 2 Affected = 8	Unaffected = 3 Affected = 6	83.2	90.3	Not recorded	(–)1.4
Case 2	Unaffected = 3 Affected = 10	Unaffected = 0 Affected = 10	86.4	94.8	(+)0.1	(–)1.4

ACL indicates anterior cruciate ligament; aPPTA, anatomic proximal posterior tibial angle; LLD, leg-length discrepancy.

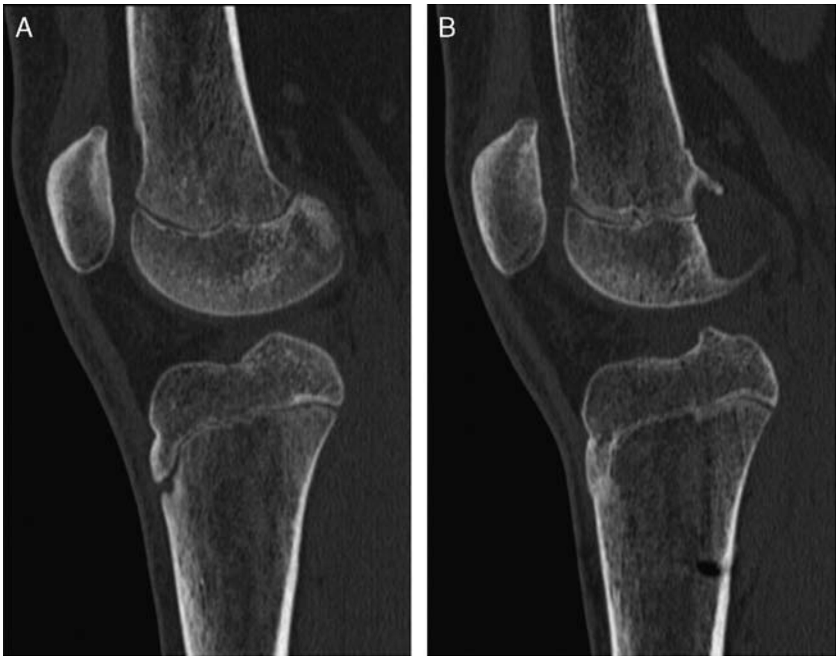

FIGURE 1. Computed tomography sagittal cut showing an open tibial tubercle apophysis in the unaffected extremity (A), compared with a completely fused tibial tubercle apophysis in the affected extremity (B).

retrospective review of data collected on these patients. Institutional review board approval was obtained before performance of this study.

The 4 patients underwent ACL reconstruction at a mean age of 14.2 years (range, 13.5 to 14.8 y). Three injuries were in soccer players and 1 was in a football player. Two patients were female and 2 were male. All patients had a transphyseal reconstruction with a hamstring autograft utilizing endobutton fixation on the femur and a biointerference screw in the tibial tunnel backed up with a cortical screw over a washer on the tibia. Clinically significant postoperative physeal arrest was identified on plain films and confirmed on MRI or CT scan. In addition, bone age was determined at the time of injury utilizing the standardized atlas of Greulich and Pyle.[32]

RESULTS

Average time from index procedure was 30.8 months (range, 19 to 47 mo). The mean time between the index surgery and presentation with growth arrest was 11 months (range, 7 to 17 mo). The average bone age at time of disturbance was 14.4 years (range, 13.5 to 16).

Two patients had asymptomatic tibial recurvatum (Table 2). In case 1, recurvatum of the affected extremity was 8 degrees compared with 2 degrees in the unaffected extremity. In case 2, the affected extremity had 10 degrees of recurvatum compared with 3 degrees in the unaffected extremity. Radiographs to evaluate the tibial apophysis were inconclusive. When there is a question of premature apophyseal closure it is our standard of care to obtain a bilateral CT scan to allow for a side-to-side comparison of the growth plates. CT scan obtained confirmed closure of the tibial apophysis in both cases (Fig. 1). Surgery was performed on both patients to prevent further progression. Deformity correction was not performed for 2 reasons: it would be technically difficult with a greater risk of potential complications than epiphysiodesis and the decreased tibial slope is protective for ACL-related instability.[33] One recurvatum case was treated with proximal tibial epiphysiodesis with crossed screws and the other underwent proximal tibial epiphysiodesis with H plates (Arthrex, Naples, FL). At final follow-up (36 and 47 mo, respectively) both patients were asymptomatic, demonstrated no progression of their deformity, and had returned to all sports activities.

Two patients developed painless genu valgum (Table 3). Clinically, valgus angulation was mildly apparent in both patients. Plain films, however, revealed 6.4 and 9.0 degrees of valgus, respectively. Valgus in the unaffected extremity measured 1 degree in both cases. Utilizing reformatted, 3-dimensional growth plate mapping MRI,[34] 1 case of genu valgus showed proximal tibial physis central fusion with posterocentral fusion of the distal femoral physis. The other genu valgus case showed growth arrest of 7.4% of the cross-sectional area of the growth plate primarily surrounding the ACL graft. One patient underwent distal medial hemiepiphysiodesis with a peanut plate (Biomet, Warsaw, IN). The other patient was skeletally mature and no surgery was indicated. Both patients had no symptoms, no progression of their deformity, and had fully returned to sports at the most recent follow-up (19 and 21 mo, respectively) (Fig. 2).

DISCUSSION

Management of the pediatric patient with open physes and an ACL rupture presents a complex clinical

TABLE 3. Deformity Characteristics: Genu Valgum Cases

	Extremity Mechanical Alignment (Post-ACL) (deg.)	Extremity Mechanical Alignment (Final Follow-up) (deg.)	mLDFA (Post-ACL) (deg.)	mLDFA (Final Follow-up) (deg.)	MPTA (Post-ACL) (deg.)	MPTA (Final Follow-up) (deg.)	LLD Affected Extremity (Post-ACL) (cm)	LLD Affected Extremity (Final Follow-up) (cm)
Genu valgum cases								
Case 3	Unaffected = 1.0 valgus Affected = 6.4 valgus	Unaffected = 0.4 valgus Affected = 3.5 valgus	82.0	83.3	92.0	90.2	(+)0.6	(+)0.9
Case 4	Unaffected = 1.0 valgus Affected = 9.0 valgus	Unaffected = 1.1 valgus Affected = 8.0 valgus	82.0	81.6	89.0	89.1	(−)0.5	(−)1.0

LLD indicates leg-length discrepancy; mLDFA, mechanical lateral distal femoral angle; MPTA, medial proximal tibial angle.

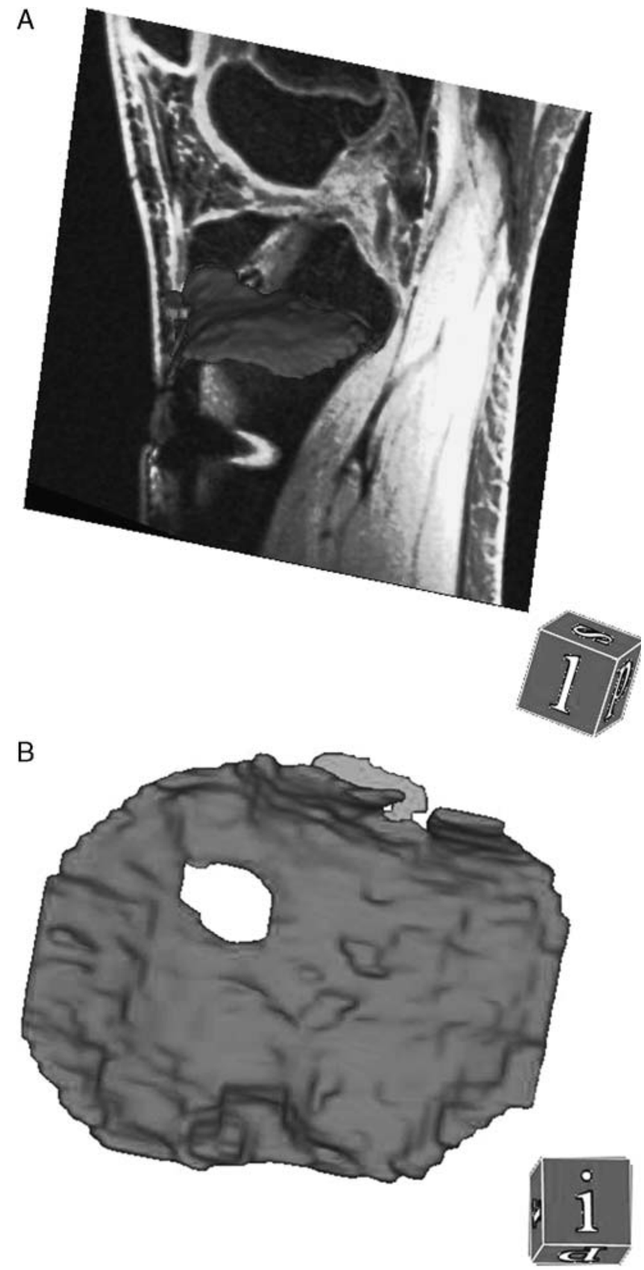

FIGURE 2. Sagittal 3D map of the proximal tibial physis superimposed on the anatomic source image (A). An isolated growth plate map (B) demonstrates bar formation (blue) at the tibial tubercle apophysis with an intact proximal tibial physis. The color defect posteriorly is from the ACL graft. ACL indicates anterior cruciate ligament.

challenge. Since the first report of transphyseal ACL reconstructions in pediatric patients by Lipscomb and Anderson[8] in 1986, the debate about how to manage these patients has been driven by the concern for postoperative growth disturbances (Table 4). In the years that followed, many authors reported clinical evidence that demonstrated the safety of transphyseal surgery in this patient population.[11,13–16] However, 2 large international meetings of

TABLE 4. Review of the Clinical Literature on Growth Arrests Following Pediatric ACL Reconstruction: Study Demographics and Complications

References	No. Patients	Mean Age (y)	Mean Follow-Up (mo)	No. Arrests	Graft	Type of Arrest
Growth disturbance reported						
Lipscomb and Anderson[8]	24	15	35	1	Hamstring	Genu Valgum
Koman and Sanders[7]	1	14.4	35	1	Hamstring	Genu Valgum
Kocher et al[6]	NR	NR	NR	15	NR	8 distal femoral valgus, 3 tibial recurvatum, 2 genu valgum without arrest, 2 LLD
Chotel et al[3]	NR	NR	NR	8	NR	6 femoral valgus, 2 tibial recurvatum
Higuchi et al[35]	10	14.5	6	2	Hamstring	MRI narrowing in 8 patients, frank closure in 2
Chotel et al[4]	2	8.5	78	2	ITB	2 genu valgum
Lawrence et al[26]	1	12	42	1	Hamstring	Distal femoral valgus
Kumar et al[14]	32	11.3	72.3	1	Hamstring	Mild valgus deformity
Rozbruch et al[10]	1	12	72	1	Achilles allograft	Tibial varus/recurvatum, LLD
No growth disturbance reported						
McCarroll et all[36]	24	13.3	26	0	ITB, BTB, biceps transfer	None
McCarroll et al[16]	60	14.2	4.2	0	BTB, ITB	None
Lo et all[37]	5	12.9	88.8	0	Hamstring/quadriceps	None
Bisson et all[38]	9	12.9	39	0	Hamstring	None
Aichroth et al[11]	47	13	49	0	Hamstring	None
Edwards et al[19]	21	13.7	34	0	Hamstring, BTB	None
McIntosh et all[39]	16	13.5	41.1	0	Hamstring	None
Bollen et all[40]	5	13.4	34.6	0	Hamstring	None
Cho et all[41]	4	12.4	32.3	0	Tibialis anterior allograft	None
Hui et al[13]	16	12	24	0	Hamstring autograft/allograft	None

ACL indicates anterior cruciate ligament; BTB, bone-tendon bone; ITB, iliotibial band; LLD, limb-length discrepancy; NR, not reported.

experts in 2002 and 2007 reported a combined 23 cases of growth disturbances.[3,6] Further clinical, radiographic, and basic science research has corroborated these reports and underscored the significance of this clinical complication.[4,5,9,10,22,24,26,35]

Various mechanisms have been postulated to explain why growth arrests, angular deformities, and limb-length discrepancy occur following ACL reconstruction. There are many potential explanations depending on the specifics of each case. Hardware or bone plug placement across the physis has been reported to injure the physis and affect growth.[5–7] This was clearly not present in any of the cases reviewed. Lawrence et al[26] discussed a distal femoral growth arrest in an all-epiphyseal femoral tunnel suggesting that it was likely due to drilling close to the physis resulting in possible thermal injury, altered blood supply, or creation of abnormal mechanical forces once the graft was passed. The size of the drill holes traversing the physis also causes physeal injury.[5] Mäkelä et al[29] studied the cross-sectional area of the physis and the percentage of injury caused by drilling. They found that injury of $\geq 7\%$ of the area resulted in significant growth abnormalities; growth plate mapping performed in one of our patients corroborated these data (Fig. 3). During transphyseal reconstruction using an anteromedial portal, there can be a greater area of injury due to the obliquity of the femoral socket.[31] The femoral sockets in the 2 distal femoral growth arrests were created through an anteromedial portal with an oblique trajectory. This may have led to a greater volumetric injury of the physis and may explain the 2 cases of genu valgum reported. To the best of our knowledge this would be the first clinical report of growth arrest occurring secondary to this mechanism. When creating our femoral socket using an anteromedial portal, we locate the socket in the anatomic footprint, but create the tunnel in a more vertical manner (ie, less oblique) to minimize injury to the physis. We likewise caution surgeons when using a transphyseal femoral tunnel or socket to not only to be mindful of the size of the reamer used but to carefully observe the trajectory of the reamer as well. Indirect injury to the perichondrial or periosteal tissue directly abutting the physis may also result in aberrant growth.[5,22] Extensive periosteal stripping can occur during harvesting of the hamstring grafts and can directly injure the tibial apophysis or at least disturb the physeal blood supply resulting in physeal injury. While this is possible, we feel this etiology is unlikely in these cases of recurvatum. "Tenoepiphysiodesis" refers to the excessive tensioning of the graft across the physis and has been postulated as a potential source of both femoral-sided and tibial-sided arrests.[8,15,21] We believe that a rapid growth spurt in the 2 patients with tibial apophysis arrests led to the tenoepiphysiodesis due to graft tension across

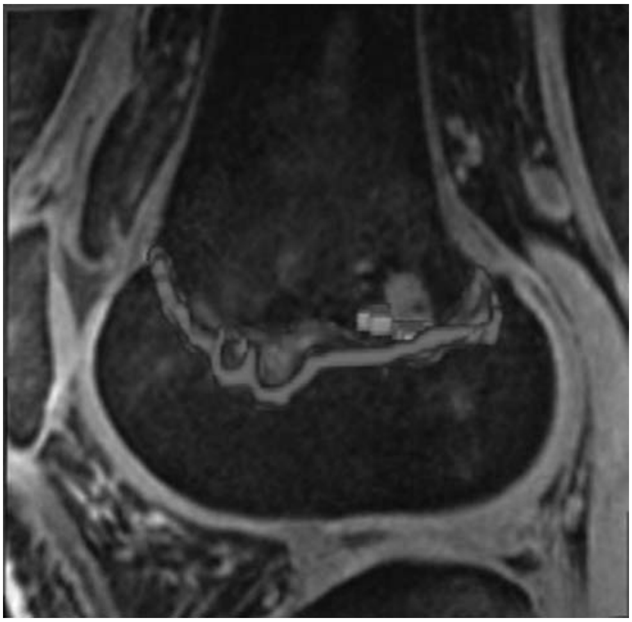

FIGURE 3. Sagittal 3D map of the distal femoral physis superimposed onto the anatomic source image in a 14-year-old girl demonstrates the physeal bar (blue) around the graft. The area of the physis was found to be 2585 mm^2 and the area of the bar was 190.2 mm^2 (7.4% of the total area).

the physis, although this is impossible to state with certainty. Indeed, this would be the first clinical report of this mechanism in the literature to our knowledge. If this is correct, however, it may theoretically be unavoidable with a transphyseal approach on the tibia. We postulate, though, that utilizing a more vertical tunnel that is not too anterior on the ACL footprint might mitigate the eccentric forces experienced by the physis and limit this tensioning effect. Given this risk, we recommend careful physical examination to detect knee hyperextension on the operative leg at 6 to 12 months following transphyseal ACL reconstruction in skeletally immature patients. This evaluation may identify the growth arrest early and allow prompt treatment as was seen in the cases presented.

Unfortunately, ACL ruptures in the skeletally immature patient are on the rise.[1,2] Reconstructive options need to be weighed heavily and postoperative care must allow for identification of possible growth disturbances. The absence of symptoms and the wide variation in time until presentation in the 4 cases presented is an alarming combination. The progression of deformity can be missed by clinicians, patients, and family members. Given the possibility of this potentially serious complication, physicians must remain vigilant. The importance of a thorough physical examination including evaluation of knee hyperextension cannot be overstated. To aid in early diagnosis, we routinely obtain EOS (EOS Imaging, Cambridge, MA) long leg AP and lateral hip-to-ankle films before performing an ACL reconstruction and then at 6 and 12 months postoperatively or every 6 months until the growth plates are closed. Hand and wrist films for bone age are obtained at the same intervals. Taken together, this will allow the treating surgeon to assess for subtle angular deformities and limb-length inequalities.

Growth arrest following ACL reconstruction in skeletally immature patients must be a part of every preoperative discussion with patients being considered for surgery. It remains unclear precisely what leads to this complication and further investigations into patient-specific variables as well as surgical technique are indicated to better understand the pathophysiology of this problem.

There are certainly limitations to this study. Despite being the largest series of patients reviewed with this complication, this study still has a small sample size with retrospectively reviewed data. Therefore, it is more challenging to generalize for all pediatric patients with this injury. In addition, no pre-ACL reconstruction hip-to-ankle films were available to assess for preoperative subtle deformities, which may have influenced postoperative care. Another limitation is that we were unable to quantify a true incidence in our report. Future studies could overcome these shortfalls if directed at evaluating large sample sizes, identifying the incidence of this complication, and better elucidating which factors place patients at risk for developing growth arrest.

This report of 4 patients demonstrates that growth arrest following ACL reconstruction in skeletally immature patients is a real concern and highlights the importance of careful preoperative and postoperative evaluation and discussion with patients and family members.

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