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Outcomes, Including Graft Tears, Contralateral Anterior Cruciate Ligament Tears, and All-Cause Ipsilateral Knee Operations, are Similar for Adult-type, Transphyseal, and Partial Transphyseal Anterior Cruciate Ligament Reconstruction Using Hamstring A...

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# Outcomes, Including Graft Tears, Contralateral Anterior Cruciate Ligament Tears, and All-Cause Ipsilateral Knee Operations, are Similar for Adult-type, Transphyseal, and Partial Transphyseal Anterior Cruciate Ligament Reconstruction Using Hamstring Autograft in Pediatric and Adolescent Patients

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**Purpose:** To compare hamstring autograft primary anterior cruciate ligament reconstruction (ACLR) techniques including adult-type/anatomic, transphyseal, and transphyseal techniques by (1) ACL graft tear, (2) contralateral ACL tear, and (3) all-cause ipsilateral reoperation. **Methods:** A retrospective, single-surgeon review was performed including all ACLR with hamstring autograft in pediatric and adolescent patients from 2011 to 2019. Minimum 2-year follow-up was required for patients unless a tear or reoperation was sustained before that time point. Data collected included demographics and baseline surgical variables, type of reconstruction, sporting activity, and deviations from rehabilitation protocols. Comparisons were made among hamstring autograft reconstruction groups (adult-type/anatomic, transphyseal, and partial transphyseal) for primary outcomes of graft tear, contralateral ACL tears, and all-cause ipsilateral knee reoperations, including hardware removal. Secondary surgeries performed with different surgeons were noted. **Results:** In total, 214 patients of age  $15.2 \pm 2.0$  years with  $4.1 \pm 1.7$ -year follow-up were included. Overall graft tear rate was 11.7% (11.0% adult-type vs 19.1% transphyseal vs 5.6% partial transphyseal;  $P = .18$ ). On univariate analyses, all-cause ipsilateral reoperation did not differ by technique (21.3% vs 31.0% vs 33.3%;  $P = .20$ ), and neither did contralateral ACL tear (8.1% vs 9.5% vs 0%;  $P = .17$ ). 21.7% of ipsilateral revision ACLRs (all adult-type) and 16.7% of patients with any reoperations had subsequent procedures performed with a different surgeon. **Conclusions:** The graft tear rates in primary hamstring autograft ACLRs in the adolescent population did not significantly differ by technique (11.0% vs 19.1% vs 5.6% in adult-type, transphyseal, and partial transphyseal reconstructions, respectively). Furthermore, contralateral ACL tears (8.1% vs 9.5% vs 0%) and all-cause (including  $> 1/4$  hardware removal) ipsilateral knee reoperations (21.3% vs 31.0% vs 33.3%) did not statistically differ. Higher powered studies may detect statistical significance in the observed differences in this study. **Level of evidence:** Level IV, therapeutic case series.

Tears of the anterior cruciate ligament (ACL) are increasing in the general population but are progressing at likely a greater rate in pediatric and

adolescent patients relative to adults.<sup>1-6</sup> Greater rates of ACL tears in this population has been attributed to greater activity levels, single-sport specialization, and

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biologic factors, among others.<sup>1,7-9</sup> Anterior cruciate ligament reconstruction (ACLR) has become the gold standard of treatment for the young population seeking to return to sport, in part to mitigate risk of additional meniscal and chondral injuries in those with persistent instability from nonoperative or delayed operative treatment.<sup>10-14</sup>

ACLR in the skeletally immature patient, however, is not without risks. Concerns arise for angular deformity and growth disturbance, particularly in those with estimated greater than 5 years of growth remaining.<sup>15</sup> In the skeletally immature patient, therefore, the use of bone–patellar tendon–bone autograft is typically avoided, as it is thought that the bone plugs crossing the physis may additionally increase risk of growth disturbance.<sup>16-18</sup> Consequently, soft-tissue grafts are preferred in those with remaining growth, of which the most widely studied has been hamstring autograft, and in these circumstances it is advised to avoid any screws, whether made of biocomposite or metal, crossing the physis.<sup>17</sup> Allograft has frequently demonstrated higher failure rates in the adolescent population relative to autograft.<sup>19-22</sup>

In addition to graft selection, numerous other surgical factors may govern outcomes after ACLR in the pediatric and adolescent patient, of which reconstruction technique with respect to the physis is a critical consideration.<sup>17,23</sup> Reconstruction techniques vary based on drilling and fixation across the physis on the proximal tibia and distal femur and whether the reconstruction incorporates intra- or extra-articular techniques.<sup>17,24-26</sup> The estimated extent of growth remaining and the patient's goals, in addition to surgeon experience and comfort may dictate the specific soft-tissue graft technique utilized.

It is well-known that graft failures in youth exceed those of the general population.<sup>19,27-30</sup> However, there are limited data comparing outcomes by type of hamstring autograft reconstruction technique, based on physeal status, within pediatric populations.<sup>25</sup> Much of the existing data report on outcomes of individual techniques. The purpose of this study was to compare hamstring autograft primary ACLR techniques including adult-type/anatomic, transphyseal, and transphyseal techniques by (1) ACL graft tear, (2) contralateral ACL tear, and (3) all-cause ipsilateral reoperation. We hypothesized that ACL graft tears, contralateral ACL tears, and all-cause ipsilateral reoperations would not differ based on techniques of hamstring autograft.

## Methods

This study was approved by the institutional review board of the University of California, San Francisco Benioff Children's Hospital Oakland (#170608). A retrospective review was performed at a single tertiary

referral center from 2011 to 2019 of all patients undergoing ACLR with the senior surgeon (N.K.P.). Patients were included in this study if they underwent surgical reconstruction with hamstring autograft with 1 of 3 techniques (adult-type, transphyseal, or partial transphyseal). Patients with less than 2-year minimum follow-up were excluded; however, if a patient was identified to have an outcome of interest (ie, graft tear, contralateral injury, reoperation) with less than 2-year follow-up, they were still included.

Patients were categorized as “adult-type” hamstring autograft reconstruction if their physes were closed. “Adult-type” refers to a standard anatomic reconstruction, and this term is utilized here within to denote the physeal status. “Transphyseal” reconstruction was offered to patients determined on preoperative radiographs to have less than 2 years of growth remaining, with both femoral and tibial tunnels drilled across the physis.<sup>31-34</sup> “Partial transphyseal” reconstructions were used in patients determined to have greater than 2 but less than 5 years of growth remaining,<sup>15</sup> with the femoral tunnel and fixation placed intraepiphyseal under fluoroscopic guidance and a transphyseal tibial tunnel.<sup>15,34,35</sup> Partial transphyseal techniques aim to minimize disruption of the distal femoral physis, which contributes more to growth potential than the proximal tibial physis.<sup>33</sup>

Hamstring autografts were harvested via a posterior hamstring harvest that has been previously described.<sup>36</sup> The femoral tunnel was drilled using an outside-in technique with the FlipCutter drill (Arthrex, Naples, FL). For the partial transphyseal group, care was taken to drill intraepiphyseal using small angle guides under fluoroscopic guidance. The tibial tunnel was drilled retrograde through an anteromedial incision on the tibia. A biocomposite screw was used in an interference fit fashion to secure the graft on the tibial side. In those with transphyseal-based techniques (transphyseal or partial transphyseal), the tibial tunnel was medialized away from the tibial tubercle, and graft fixation remained extraphyseal; care was taken to select an interference screw length that did not cross the proximal tibial physis. Additional care was taken in transphyseal and partial transphyseal techniques to avoid horizontal tunnel placement with a more centrally placed tunnel, minimize thermal damage with slow reaming, and minimize volumetric physeal disruption by tunnel diameter.<sup>15,17,23</sup> Adult-type reconstructions were performed in a standard reconstruction fashion without consideration of the physis, which was closed in these cases.

Postoperative rehabilitation included a standardized protocol with discontinuation of brace and crutches at 2 weeks, straight line running at 4 months, agility at 6 months, and clearance for return to sport at 9 months postoperatively if patients had successful and safe physical therapy (PT) clearance including sport-specific

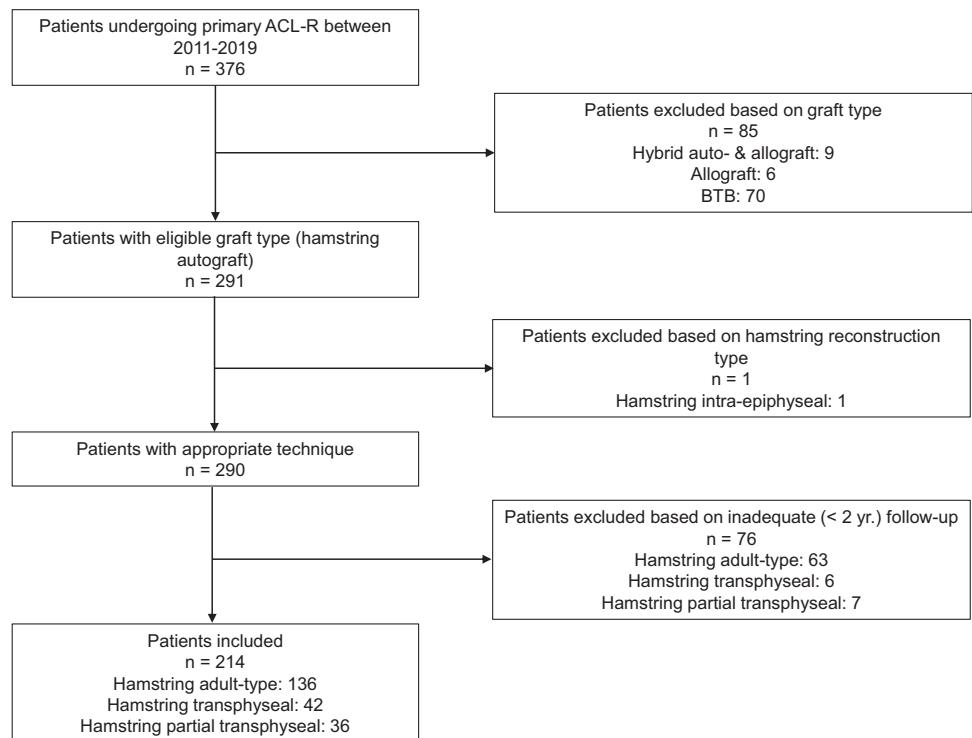
movement analysis. If patients had a concomitant meniscus repair, a similar protocol was followed but the patients remained toe-touch weight-bearing locked in extension in a hinge knee brace until week 6 post-operatively, allowing for unlocked range of motion from 0 to 90° when non-weight-bearing. No venous thromboembolism prophylaxis was administered.

Data collected included age at time of surgery, follow-up time, concomitant meniscal surgeries, graft size, reconstruction technique, graft retears, and contralateral ACL tears. Any operation to the ipsilateral knee after index ACLR was deemed an “all-cause ipsilateral knee reoperation,” which in this study included removal of hardware. When available, reoperations with a surgical provider who was not the primary index surgeon were noted. Medical records were searched in the Epic Care Everywhere network (Epic Systems Corporation, Verona, WI) to capture complications and patients that were not seen in the primary surgeon’s office. PT notes and clinical documentation were reviewed to identify deviations from PT protocols, including return to activities too early, frequent missing of PT appointments, or requiring additional PT appointments for slow progress resulting in delayed clearance to activities. The patient’s primary sport was recorded and classified whether it was considered a level I sport as previously described,<sup>37,38</sup>

including basketball, hockey (field or ice), football, rugby, lacrosse, soccer, and volleyball. All patients with remaining growth were monitored with lower extremity alignment radiographs pre- and post-operatively annually until skeletal maturity. Growth disturbances were defined as >1 cm of leg length discrepancy from baseline or >1 cm difference of mechanical axis deviation on full-length mechanical alignment radiographs as demonstrated in the paper by Chambers et al.<sup>15</sup>

Age and time comparisons by graft type were evaluated with analysis of variance and post-hoc analysis was performed with Tukey’s method.<sup>39</sup> Shapiro–Wilk test was performed to assess normality of graft size data; as graft size violated the normality assumption, it was evaluated with the Kruskal–Wallis nonparametric test. Rates of graft tears and contralateral ACL tears were compared with the Fisher exact test. All-cause reoperations were also noted and compared with the Fisher exact test. Subanalyses were performed to evaluate difference in rates based on deviation from PT protocols and engagement in high-risk sporting activity. Any factor found to be significantly different on univariate analyses were used in a logistic regression model. All statistical analyses were performed on STATA v16.1 (StataCorp, College Station, TX) with a 2-tailed level of significance of .05.

**Fig 1.** Patient selection flow diagram. (ACLR, anterior cruciate ligament reconstruction; BTB, bone–patellar tendon–bone.)



**Table 1.** Baseline and Follow-Up Data for Each Hamstring Reconstruction Type Group

	Adult-Type Reconstruction (n = 136)	Transphyseal Reconstruction (n = 42)	Partial Transphyseal Reconstruction (n = 36)	P Value
Age, y	16.3 ± 1.4	14.4 ± 0.9	12.1 ± 1.4	<b>.008</b>
Sex				
M	57 (41.9)	27 (64.3)	27 (75.0)	<b>&lt;.0001</b>
F	79 (58.1)	15 (35.7)	9 (25.0)	
Level I sport	113 (83.1)	36 (85.7)	20 (55.6)	<b>.002</b>
Concomitant index meniscal surgery				
MMR	30 (22.1)	6 (14.3)	1 (2.8)	<b>.013</b>
MMD	4 (2.9)	1 (2.4)	0 (0)	.83
LMR	21 (15.4)	5 (11.9)	5 (13.9)	.96
LMD	38 (27.9)	12 (28.6)	7 (19.4)	.60
Any meniscus procedure	74 (54.4)	20 (47.6)	13 (36.1)	.15
Graft size, mm	8.3	8.3	7.8	<b>.0001</b>
Rehabilitation deviation	42 (30.9)	17 (40.5)	8 (22.2)	.23
Follow-up, y	4.2 ± 1.6	4.3 ± 1.7	3.8 ± 1.7	.074

NOTE. Age and follow-up are reported as mean ± standard deviation. Other data are reported as number (percentage). Values in bold denote statistical significance.

F, female; LMD, lateral meniscus debridement; LMR, lateral meniscus repair; M, male; MMD, medial meniscus debridement; MMR, medial meniscus repair.

## Results

### Baseline and Follow-up Data

A total of 214 patients were included (Fig 1), including 111 (51.9%) male and 103 (48.1%) female (Table 1) patients. Total cohort average age was 15.2 ± 2.0 years (range, 8.6-19.5 years) with follow-up of 4.1 ± 1.7 years (range, 0.3-9.2 years). In total, 169 (79.0%) engaged in level I sports, 107 (50.0%) patients had a concomitant meniscal procedure, and 67 (31.3%) patients had documented deviations from the rehabilitation protocol throughout their course of follow-up. No patients with open physes (n = 78) had a documented growth disturbance in either overall length or angular deformity. Significant differences existed among groups in age, sex, level I sport, medial meniscus repair, and graft size (Table 1).

### Graft Tear Rates and All-Cause Ipsilateral Reoperations

A total of 25 (11.7%) patients sustained an ACL graft re-tear during the follow-up period (Table 2). Graft tear

rates did not significantly differ by reconstruction technique ( $P = .18$ ). In total, 54 (25.2%) patients underwent any all-cause reoperation on the same knee, and these all-cause ipsilateral reoperations did not significantly differ by graft technique ( $P = .20$ ). There were no significant differences in rates of contralateral ACL tears ( $P = .17$ ) (Table 2). On univariate analyses, graft tear (Table 3) or reoperation rates did not differ based on sex, high-risk sport, or rehabilitation protocol deviations ( $P > .05$ ). On logistic regression analyses, there were no significant factors identified that were predictive of ACL graft tear, all-cause ipsilateral reoperation, or contralateral ACL tear.

Average time to ipsilateral revision ACLR was 2.5 ± 1.7 years (range, 0.7-5.5 years), 2.1 ± 1.3 years (range, 0.8-4.3 years), and 1.7 ± 0.1 years (range, 1.6-1.7 years) in the adult-type, transphyseal, and partial transphyseal groups, respectively ( $P = .71$ ). Average time to ipsilateral non-ACLR reoperation was 1.9 ± 1.9 years (range, 0.1-7.9 years), 1.6 ± 1.4 years (range, 0.1-3.7 years), and 2.3 ± 1.7 years (range,

**Table 2.** Graft Tear and Contralateral ACLR by Initial Reconstruction Type

	Adult-Type Reconstruction (n = 136)	Transphyseal Reconstruction (n = 42)	Partial Transphyseal Reconstruction (n = 36)	P Value
Graft tear	15 (11.0)	8 (19.1)	2 (5.6)	.18
Ipsilateral all-cause reoperation	29 (21.3)	13 (31.0)	12 (33.3)	.20
Contralateral ACLR	11 (8.1)	4 (9.5)	0 (0.0)	.17

NOTE. Data are reported as number (percentage). ACLR, anterior cruciate ligament reconstruction.

**Table 3.** Evaluation of Graft Tears by Sex, Rehabilitation Deviations, and Level I Sport

	Adult-Type Reconstruction (n = 136)	Transphyseal Reconstruction (n = 42)	Partial Transphyseal Reconstruction (n = 36)	Overall (n = 214)
<b>Sex</b>				
Male (n = 111)	6/57 (10.5%)	7/27 (25.9%)	1/27 (3.7%)	14/111 (12.6%)
Female (n = 103)	9/79 (11.4%)	1/15 (6.7%)	1/9 (11.1%)	11/103 (10.7%)
	<i>P</i> = 1.0	<i>P</i> = .22	<i>P</i> = .44	<i>P</i> = .68
<b>Rehabilitation deviation</b>				
Yes (n = 67)	7/42 (16.7%)	4/17 (23.5%)	0/8 (0%)	11/67 (16.4%)
No (n = 147)	8/94 (8.5%)	4/25 (16.0%)	2/28 (7.1%)	14/147 (9.5%)
	<i>P</i> = .23	<i>P</i> = .69	<i>P</i> = 1.0	<i>P</i> = .17
<b>Level I sport</b>				
Yes (n = 169)	12/113 (10.6%)	6/36 (16.7%)	1/20 (5%)	19/169 (11.2%)
No (n = 45)	3/23 (13.0%)	2/6 (33.3%)	1/16 (6.3%)	6/45 (13.3%)
	<i>P</i> = .72	<i>P</i> = .32	<i>P</i> = 1.0	<i>P</i> = .79

NOTE. Graft tears are reported as n / total of subcategory (%). *P* values are reported within each comparison.

0.1-4.9 years) in the adult-type, transphyseal, and partial transphyseal groups, respectively (*P* = .73).

Types of all-cause ipsilateral knee reoperations are noted in Table 4. In total, 23 of 25 (92.0%) patients with graft tears had an ipsilateral revision ACL-R procedure (one with concomitant meniscal repair), 5 of whom (21.7%) had this procedure done with a different surgeon (all 5 adult-type at index operation). 15 (7.0%) patients were noted to have a contralateral knee ACL-R during the follow-up period (11 adult-type, 4 transphyseal). Therefore, the total ACL tears (ipsilateral graft or contralateral ACL tear) after index procedure were 40 (18.7%). Including all patients with ipsilateral and/or contralateral total all-cause reoperations, 11 (16.7%) of 66 patients sought surgical care with another surgeon (10 adult-type, 1 partial transphyseal). Three of the 15 (20.0%) with contralateral ACL surgeries were with a different surgeon, all of whom underwent adult-type hamstring autograft reconstruction in this cohort. Of the 15 contralateral ACLRs, 13 (86.7%) participated

in a level I sport. Average time to contralateral ACLR was 2.6 ± 1.4 years (range, 1.3-5.5 years) and 3.5 ± 1.5 years (range, 2.1-5.4 years) in the adult-type and transphyseal groups, respectively (*P* = .31).

### Discussion

In this minimum 2-year follow-up study, we identified ACL graft retear rates of 11.0%, 19.0%, and 5.6% in adult-type, transphyseal, and partial transphyseal hamstring autograft reconstruction groups per patient, respectively. No statistical differences in graft tears, all-cause ipsilateral reoperations, or contralateral ACL tears existed by hamstring technique type, although observed differences may be underpowered. Outcomes in this cohort also did not differ based on participation in level I sports or deviations from rehabilitation protocols.

This study identified an overall rate of 11.7% graft tear in those undergoing hamstring autograft reconstruction at average 4.1 years follow-up. More specifically, 11.0% of adult-type, 19.0% of transphyseal, and

**Table 4.** Ipsilateral Knee Reoperation Procedures by Technique

Ipsilateral Knee Reoperation Type	Total n – Subgroup n (Overall n = 54)
Cyclops debridement	3:2 adult-type, 1 transphyseal
Cyclops debridement + meniscectomy	1:1 partial
Irrigation and debridement, gunshot wound	1:1 adult-type
Irrigation and debridement, knee	2:2 adult-type
Irrigation and debridement, knee + removal of hardware	1:1 adult-type
Meniscus repair	4:2 adult-type, 2 partial transphyseal
Meniscus repair + debridement	1:1 adult-type
Manipulation under anesthesia	3:2 adult-type, 1 partial transphyseal
Manipulation under anesthesia + removal of hardware	1:1 partial transphyseal
Notch microfracture	1:1 adult-type
Removal of hardware	13:4 adult-type, 4 transphyseal, 5 partial transphyseal
Revision ACLR	22:12 adult-type, 8 transphyseal, 2 partial transphyseal
Revision ACLR + meniscus repair	1:1 adult-type

ACLR, anterior cruciate ligament reconstruction.

5.6% of partial transphyseal patients had a graft tear. Although the rate of transphyseal graft tears trended greater, this was not statistically significant. The transphyseal retear rate in the present study is within the range of previously reported data demonstrating reports of 0% to 25%.<sup>40</sup> Barber-Westin et al.<sup>41</sup> found in a recent systematic review of 1,239 patients undergoing transphyseal reconstruction a hamstring autograft failure rate of 15% and Pennock et al.<sup>42</sup> found a failure rate of 21%. A large case series by DeFrancesco et al.<sup>43</sup> including 504 transphyseal surgeries in patients <16 years and 331 patients ≥16 years found graft rupture rates in these 2 groups of 21.6% and 16.4%, respectively. There is less data currently available on the partial or hybrid transphyseal technique available on reinjury rates; one prospective evaluation by Cordasco et al.<sup>34</sup> identified ACLR revision rate of 20% in 66 patients undergoing partial or complete transphyseal techniques, which was significantly greater than their all-epiphyseal (6%) and bone–tendon–bone autograft (6%) groups. In that study, there were no differences in other ipsilateral knee surgery or contralateral ACL tear rates among their groups.<sup>34</sup> In contrast, although the comparison groups differ between Cordasco et al.'s study and the present study, we did not identify statistical differences in ipsilateral revision ACLR or contralateral ACLR between our cohorts of all-hamstring reconstructions among adult-type, transphyseal, and partial transphyseal techniques. By comparing only hamstring-based techniques in the present study, the authors feel that differences are less confounded by potential variation that some studies have shown with different outcomes in adult-type hamstring versus bone–tendon–bone autograft use in the skeletally mature young, active population.<sup>23,44</sup> Although the observed differences in this study did not meet statistical significance, it is likely with greater-powered studies differences would be detected in the graft failure rates.

The present study's contralateral ACL tear rate was 7.0%, which is lower than other reports in the pediatric and adolescent literature.<sup>27,41</sup> Some data demonstrate that in an active, young population, the contralateral injury risk is not only similar, but may be even greater than the index surgical side.<sup>45</sup> In contrast, in the study by DeFrancesco et al.,<sup>43</sup> there was a 4-year cumulative rate of contralateral ACL rupture of 15.7% and 8.1% in those with transphyseal reconstructions <16 and ≥16 years, respectively, which is lower than their ipsilateral graft rupture rates. There were no significant differences identified in contralateral ACLR in our cohort, and Cordasco et al.<sup>34</sup> also did not find a difference in contralateral ACLRs comparing their all-epiphyseal, partial or complete transphyseal, and bone–patellar tendon–bone autograft groups. With a larger sample size, however, we may have found statistical differences

in contralateral ACL tears, which were 8.1%, 9.5%, and 0% in adult-type, transphyseal, and partial transphyseal reconstructions, respectively, in this study. The all-cause ipsilateral reoperation rates were 21.3%, 31.0%, and 33.3%, respectively, and demonstrate an observed trend that younger patients may have a greater likelihood of having subsequent surgery. These rates are high in part due to the liberal definition of reoperation in this study, including ¼ of these all-cause reoperations including hardware removal of the tibial interference screw due to local skin irritation. While the authors do not have patient-reported outcome measures available, there were no notable concerns on chart review with any of these patients returning to sports or activity unless they had a reoperation for ACLR or meniscus procedure. Moreover, by using the CareEverywhere network we may have captured more additional procedures being performed than if we had looked at our institution alone, further contributing to a high all-cause ipsilateral reoperation rate.

Surgical technique selection in the pediatric and adolescent population is dictated in large part by estimated growth remaining. Although growth abnormalities are legitimate concerns of transphyseal drilling and fixation that may be under-reported,<sup>46</sup> many studies demonstrate that in the appropriate patient, minimal clinically relevant growth abnormalities may be noted using appropriate transphyseal techniques.<sup>15,40,47-50</sup> A magnetic resonance imaging study demonstrated physeal violations with transphyseal techniques on both the femoral and tibial sides to be less than 4%, suggesting low likelihood of noticeable abnormality.<sup>51</sup> In those with more substantial growth remaining, partial transphyseal and intraepiphyseal techniques also may have minimal impact on growth.<sup>15,52</sup> Some data may also suggest that perhaps the patients with less growth remaining have a greater incidence of growth disturbance due to less ability to respond to physeal injury.<sup>53</sup> Using the senior author's protocol in skeletally immature patients to utilize partial transphyseal techniques in those with 2 to 5 years of estimated growth remaining and transphyseal techniques in those with less than 2 years of growth remaining,<sup>15</sup> no clinically significant growth disturbances in either length or angular deformity were noted in the cohort of 78 patients with open physes.

It has been well-published that primary ACLR graft tear rates in younger populations exceed those of the general, adult population. Although age and technique selection may be intimately related, we did not identify differences in failure rates between techniques despite the significantly different ages in each technique cohort. This finding is not consistent with other data supporting age as a primary contributor to graft failure.<sup>19,27-30,54</sup> Too small graft size (typically <8 mm)<sup>55</sup> has been previously shown to be predictive of failure,

but despite subtle differences between groups (7.8 mm vs 8.3 mm in each of adult and transphyseal groups;  $P = .0001$ ) there remained no differences in measured failures. However, caution must be taken in evaluating this study that was likely underpowered to detect differences if one were to exist.

Return to high-risk sporting activity is thought to compound the risk of subsequent injury after ACLR.<sup>27,45,56</sup> Considering the level I sports of basketball, hockey (field or ice), football, rugby, lacrosse, soccer, and volleyball,<sup>37,38</sup> these greater-risk level I sports did not seem to alter the rates of failure either. Webster et al.<sup>27</sup> demonstrated the risks of ipsilateral and contralateral rupture to be compounded by factors of 3.9 and 5, respectively, in those younger than age 20 years returning to cutting and pivoting sports. One explanation why the present study may not have identified a similar risk is due to the high proportion (79.0%) of the studied population engaging in high risk, level I sports, making the comparison group small and therefore less likely to detect differences.

Little has been reported on patient compliance to rehabilitation in the pediatric population after ACLR. In the present study, we defined a deviation from rehabilitation as returning to sport/activities earlier than recommended, missing frequent PT appointments, or requiring additional therapy for slow progress; however, no differences in rehabilitation deviations between groups were identified. Although more studies are still needed to understand the extent of ACL graft maturation<sup>57,58</sup> and its role in permitting return to sport, early greater-level activity before graft remodeling may increase the risk of re-tear. Dekker et al. evaluated 112 pediatric patients with autograft ACL-R and found that earlier time to return to sport was associated with secondary ACL injury, with a slower return hazard ratio of 0.87 (95% confidence interval 0.73-0.99;  $P = .04$ ).<sup>56</sup> Deviations from rehabilitation may lead to return to activities with poor kinematics; altered mechanics such as knee abduction moment and dynamic valgus have been shown to increase risk of ACL injury and programs targeting these have been effective in reducing ACL tears.<sup>59-62</sup> Rugg et al.<sup>8</sup> found that after revision ACLR procedures, those with poor compliance had a trend towards repeat tears, though this was not statistically significant. Understanding the extent of deviations from rehabilitation and their individual impacts is challenging to characterize, but more data in this realm may be helpful in understanding the most crucial aspects of rehabilitation and to quantify risks to patients during counseling.

Another challenge with accurately reporting on outcomes in the pediatric and adolescent population is that many patients seek care from different surgeons for new injuries, particularly as they transition to adulthood. We attempted to capture patients

seen for re-injuries and re-operations outside of the senior author's primary institution using the Epic Care Everywhere network (Epic Systems). Using this system, the authors were able to identify 16.7% of total re-operations were with a new surgeon. The proportion of patients undergoing surgery with a new surgeon is not frequently reported in the pediatric and adolescent ACLR literature. However, one study by Sutherland et al.<sup>63</sup> notes that 75.0% of patients requiring revision ACLR who saw low-volume ACL surgeons ( $\leq 10$  primary ACL-R/year) surgeons changed surgeons for revisions compared with 21.5% of those who saw high-volume ACL surgeons ( $> 50$  primary ACLR/year). The senior surgeon who performed the surgeries on this cohort exceeds this high-volume measure, and the proportions who changed surgeons for revision ipsilateral ACLR of 21.7%, total reoperations of 16.7%, and contralateral surgeries of 20% are similar. Interestingly, all of the ipsilateral revisions and contralateral ACLRs performed with different surgeons were in patients undergoing adult-type reconstruction. Overall, only one reoperation in a nonadult-type reconstruction patient was performed by a different surgeon. Perhaps an older age group patient is more likely to undergo reoperation with a different surgeon as they transition care from pediatric to adult providers. It is ultimately challenging to capture the reasons for a change; another contribution to the present cohort may be the setting in a large metropolitan city area with numerous pediatric and sports medicine orthopaedic specialists. Delineating factors influential to switching surgeons may help guide patient-physician interactions.

### Limitations

This study has several limitations. The study was retrospective and from a single surgeon at a single institution, and outcomes may vary in different centers. Rates of graft tear, contralateral ACL tear, and all-cause ipsilateral re-operation may be underestimated by patients not captured in our institution or the Epic Care Everywhere network (Epic Systems). In contrast, by excluding patients with less than 2-year follow-up, the rates of tears and subsequent surgeries may be falsely elevated if those with shorter-term follow-up are doing well and do not feel the need to return to a surgeon. Furthermore, the follow-up average of approximately 4 years may not accurately represent longer-term retears and reoperations. Although in the spectrum of data on ACLR in pediatric and adolescent patients the patient numbers in the present study are similar to other studies, the numbers are still likely underpowered to detect true differences in rates. Therefore, there is a potential for type II (beta) error in this study, and it is likely larger sample sizes



would be needed to detect differences among groups for the primary outcome of graft tear or reoperation, particularly when analyzing subgroups. Power analyses and sample size estimates, depending on estimated effect sizes, range to more than 500 patients, indicating that multicenter studies may be beneficial to evaluate outcomes in the pediatric and adolescent age groups. This study also did not include postoperative return-to-sport rates, times, or performance level, which are important factors in evaluating the ability of the knee to withstand greater activity-related stress. Function of the knee and muscular strength were not assessed, although data suggests function may differ by age group.<sup>64</sup> In addition, without patient reported outcomes or satisfaction scores, it is unclear how patients perceived their function.

### Conclusions

The graft tear rates in primary hamstring autograft ACLRs in the adolescent population did not significantly differ by technique (11.0% vs 19.1% vs 5.6% in adult-type, transphyseal, and partial transphyseal reconstructions, respectively). Furthermore, contralateral ACL tears (8.1% vs 9.5% vs 0%) and all-cause (including > ¼ hardware removal) ipsilateral knee reoperations (21.3% vs 31.0% vs 33.3%) did not statistically differ. Higher powered studies may detect statistical significance in the observed differences in this study.

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