

# Skeletally Immature Anterior Cruciate Ligament Reconstruction: Invited Perspectives of POSNA Member Experts

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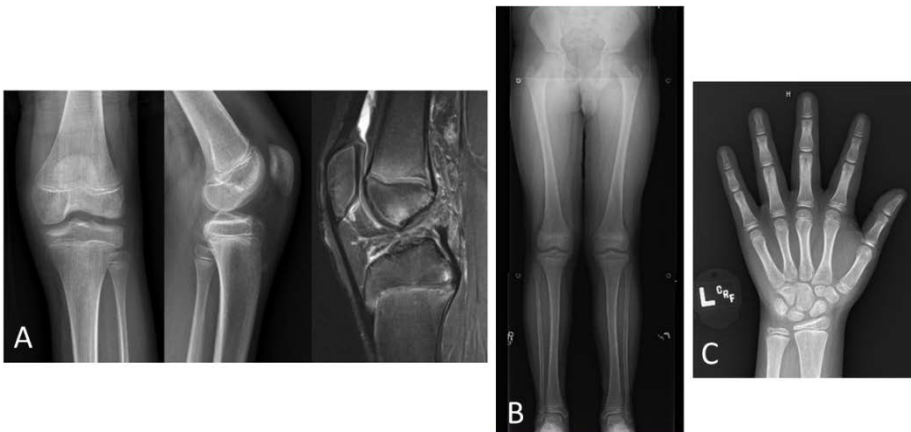
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## Introduction

Anterior cruciate ligament (ACL) tears account for a significant and increasing number of sports-related injuries in young athletes.<sup>1</sup> The incidence of ACL reconstruction in skeletally immature patients is also increasing, with the greatest number per capita increase in adolescents and teenagers.<sup>2,3</sup> Potential reasons for an increased incidence of ACL injury/reconstruction include intensive year-round training regimens, early sport specialization, limited time participating in free play, increased awareness of ACL injuries in children/adolescents, and concern for possible long-term consequences of ACL deficiency on meniscal and chondral health.<sup>4,5</sup> As a result, ACL reconstruction in the skeletally immature athlete has been advocated

because of the concern for further intra-articular injury in the ACL deficient knee.<sup>6-8</sup> Reconstruction techniques in this patient population, however, must take into account the distal femoral and proximal tibial physes and minimize the risk of growth disturbance.<sup>9,10</sup>

There are several described techniques for “physeal respecting” ACL reconstruction.<sup>5,11-17</sup> Each described technique distinguishes itself in a variety of ways, including graft selection, graft preparation, bone tunnel drilling, and method of fixation. The general principles of pediatric ACL reconstruction must take into account the goals providing a stable knee for chondral protection<sup>18,19</sup> and return to athletic activity<sup>20</sup> while minimizing the risk of iatrogenic injury to the rapidly growing physis. The goal of these invited perspectives is to discuss different approaches and rationale for preferred reconstruction



**Figure 1.** Anterior-posterior (AP), lateral radiographs, and sagittal plane magnetic resonance image (Panel A) of a patient with a mid-substance ACL tear. Long-leg standing alignment films (Panel B) and PA Hand radiograph (Panel C) showing alignment and Bone Age, respectively.

techniques when treating a skeletally immature patient with an ACL tear. Three prominent specialists in this area of expertise have been invited to contribute:

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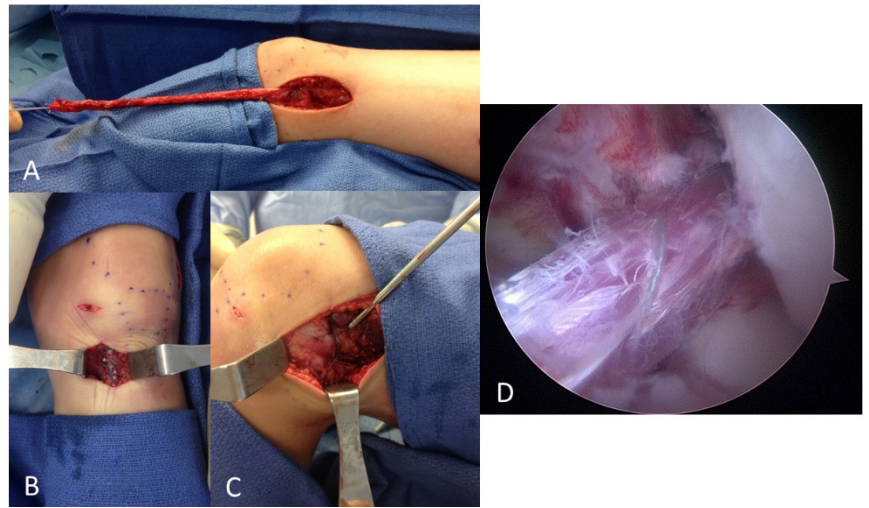
## Case

A 12-year-old boy presents to the office after sustaining a non-contact knee injury during a soccer game. He is athletic and plays multiple sports (soccer, basketball, lacrosse) year-round. Plain radiographs of the knee, pertinent MRI images, standing alignment radiographs, and hand bone age are shown (Figure 1). According to the standards of Greulich & Pyle, the patient's bone age is 12 years 6 months.

### Mininder S. Kocher, MD, MPH

*What is your clinical rationale for surgical treatment of acute ACL tears in the skeletally immature patient?*

Although the initial treatment discussion with patients is nonsurgical vs. surgical, nonsurgical treatment has fallen out of favor because of high rates of subsequent instability with meniscal and articular cartilage injury<sup>8,21-23</sup>. Furthermore, it can be very challenging psychosocially to try to keep a young athlete out of sports and activities, and in fact, they may injure their knee just from recreational activities such as gym class or free play.



**Figure 2.** Iliotibial band (ITB) harvest (Panel A), tibial fixation (Panel B), and femoral fixation (Panel C), for modified Macintosh ACL reconstruction. Intra-articular appearance of ITB graft (Panel D).

*In what patient (if any) would you recommend nonoperative treatment?*

Nonoperative treatment is still advocated in some centers. At the Norwegian School for Sport Sciences in Oslo; Havarud Moksnes has performed a series of studies to try to identify pediatric copers of ACL injury<sup>24-27</sup>. I have been fortunate to serve on his PhD thesis committee consisting of several well-designed prospective studies. These studies found that although there may be some pediatric copers, most patients will go on to episodes of instability requiring reconstruction. In addition, many patients developed new meniscal tears. For me, I would consider nonoperative treatment in a patient who has low athletic demands and is risk-averse of surgery.

### Iliotibial (IT) Band ACL Reconstruction (modified MacIntosh technique)

[Link to surgical technique video](#)

*What are the major advantages of this technique?*

In this case, I would recommend the physal-sparing intra-articular, extra-articular reconstruction with IT Band (modified MacIntosh)<sup>28</sup> (Figure 2). This patient is

prepubescent, with much growth remaining. I would not drill across the physes at this age. Although growth disturbance is uncommon if it does occur, it has major implications in terms of leg length discrepancy or angular deformity. I think physal-sparing reconstruction with epiphyseal tunnels is a viable treatment alternative. However, there is a risk of skiving the growth plate or the subchondral bone. Also, overgrowth has been described with this technique<sup>10,29,30</sup>. The IT Band technique has not been associated with growth disturbances. The extra-articular component reconstructs the anterolateral ligament (ALL)<sup>31</sup>. This combined intra- and extra-articular technique has had high success rates in terms of return to sports and a low reinjury rate.

*What are the biomechanical implications of this technique's "non-anatomic" nature?*

The biomechanical implications of pediatric ACL reconstruction have been studied by Kennedy et al<sup>19</sup>. The authors found that the IT Band reconstruction technique was the procedure that most closely restored native biomechanics compared to other pediatric ACL reconstruction techniques. In fact, this technique can over constrain the knee if the ACL component is tightened with the foot in external rotation. I think this technique is fairly anatomic. We feel the tibial graft placement is anatomic as we place it in a groove in the epiphysis at the native ACL footprint. This avoids impingement in extension. On the femoral side, we are in the over-the-top position, but we are low on the notch where today's "anatomic" position is. With growth, the ACL lengthens and gets wider.

*In your experience, what are the most common complications associated with this technique?*

The most common complication is some prominence of the lateral thigh at the IT band harvest site due to protrusion of the underlying vastus lateralis muscle. To get a sufficiently large graft, a fairly wide portion of the IT Band must be taken; 1.6% of patients will mention

this spontaneously. If asked about it, 11% will say that it is present<sup>11</sup>. It does not cause functional limitations or pain. We have not had to go back and try to close the defect in any patients. Now, we place some stitches proximally to minimize this prominence.

*Can you briefly discuss the recently published findings of your institution's experience with this technique?*

We recently published our results on 240 knees with an average 6.2 year follow-up in *JBJS* in 2018<sup>11</sup>. All patients were prepubescent (Tanner 1 or 2) with a mean age of 11.2 years. Interestingly, most were male (86%) compared to our adolescent ACL patients where most are female. There was a very low revision rate (7%) and no cases of growth disturbance as determined by physical examination and radiographs. The rate of arthrofibrosis was 2%, contralateral ACL injury was 10%, and subsequent meniscal or chondral surgery was 6%. The outcomes were excellent with return to sports rate of 97%, Pedi-IKDC 93, Lysholm 93, and Tegner 7.8. I think we will have better comparative prospective data from the PLUTO trial which is a major research initiative. PLUTO is a prospective multicenter cohort study. We are about to close enrollment after 3 years of data collection from approximately 700 patients. We will be able to compare outcomes for four different techniques (modified Macintosh, all-epiphyseal, "hybrid" partial transphyseal, and transphyseal reconstructions).

### **Nirav K. Pandya, MD**

*What is your clinical rationale for surgical treatment of acute ACL tears in the skeletally immature patient?*

In the skeletally immature patient, I believe ACL reconstruction is first a cartilage preserving surgery. Based on very high-quality data,<sup>21,23,32,33</sup> delays in ACL reconstruction have been shown to lead to increased meniscus/cartilage pathology as well as instability. In addition, it is very hard to keep young patients out of cutting and pivoting sport activity (and compliant with bracing) until greater degrees of skeletal maturity are

achieved. Furthermore, there are high activity demands placed on these youth athletes due to the current trend of single sport specialization<sup>34</sup> that require a stable knee to participate. Although we are beginning to change the high-demand youth sports culture, as clinicians, we are inevitably tasked with educating families about the benefits of multiple sports and rest from organized sporting activity while at the same time dealing with the plethora of patients who walk into our clinic daily who require intervention. Yet, we must continue to educate families that a return to high-risk sporting activity after ACL reconstruction increases the risk of re-tear at a much higher rate than the adult population.

*In what patient (if any) would you recommend nonoperative treatment?*

There is no age cutoff or degree of skeletal maturity for which I will not perform ACL reconstruction.

Based on a meta-analysis we recently published, the rate of growth disturbance was around 4%, of which only 27.6% required surgical intervention.<sup>9</sup> As a result, with the appropriate techniques, I believe the risk of clinically relevant growth disturbance is low. The risk of chondral injury and/or instability with delayed or nonoperative treatment is much greater in my eyes than the risk of growth disturbance. On the other hand, I will absolutely recommend nonoperative treatment for a child and/or family that is not emotionally and socially ready to handle activity restrictions, rehabilitation, and the seriousness of this type of intervention. Operating on a patient whose family is not ready and/or has unrealistic expectations for recovery is a disservice to them and will lead to failure.

### **“Hybrid” Partial Transphyseal ACL Reconstruction**

[Link to surgical technique video](#)

*What are the major advantages of this technique?*

The partial transphyseal technique,<sup>16</sup> allows for anatomic intra-articular placement of the femoral tunnel while minimizing the risk of growth disturbance via an intra-



**Figure 3.** AP (Panel A) and lateral (Panel B) radiographs of a patient who underwent hybrid/partial transphyseal ACL reconstruction. Relatively vertical tibial tunnel to minimize the cross-sectional area of physeal violation and all-epiphyseal femoral tunnel.

epiphyseal femoral tunnel (Figure 3). On the tibial side, the tibial tunnel (in my view) is technically easier to perform as you are not attempting to aim within the epiphysis, can more reliably be placed in the anatomic footprint of the ACL, allows for a longer tibial tunnel, and can be more easily utilized for revision surgery in this high-risk age group (in contrast to the all-epiphyseal technique). Special instrumentation is not required for this technique, and standard ACL equipment can be utilized. I believe it carries a low risk of clinically relevant growth disturbance while allowing a reconstruction that closely recreates an anatomic adult style reconstruction within the joint without violating the distal femoral physis.

*How do you reconcile the desire to place a graft of a certain minimum diameter with the potential injury to the proximal tibial physis?*

The majority of reports of growth disturbances in the literature with pediatric ACL reconstructions (when excluding outdated techniques which placed bone blocks or hardware across the physis) involve femoral sided deformity.<sup>9,10</sup> The utilization of a central tibial tunnel with a soft tissue graft stabilized via fixation placed distal to the proximal tibial physis should have a very low risk of growth disturbance. A tibial tunnel with a diameter of 7–8 mm will not be associated with a clinically relevant risk of growth disturbance; particularly in a centrally placed tunnel where angular deformity is unlikely to occur<sup>35</sup>.

*In your experience, what are the most common complications associated with this technique?*

In individuals who have greater than 5 years of growth remaining, there is a higher rate of growth disturbance than those who are operated on with less than 5 years remaining<sup>16</sup>. Although these disturbances do not usually necessitate surgical intervention, in the very young patient, this may cause the clinician to perhaps chose a different surgical technique. Yet, it is important to note that even over-the-top and all-epiphyseal techniques can be associated with angular deformity and overgrowth, respectively.<sup>36</sup> Furthermore, intra-epiphyseal femoral drilling can be challenging for those who have not performed it frequently. Multiple fluoroscopic images should be taken to ensure anatomic tunnel placements that are truly intra-epiphyseal. Furthermore, there may not be enough room distal to the proximal tibial physis for interference screw fixation, so other techniques (i.e., screw/post, anchors) may need to be utilized. Finally, as many of these patients have limited soft tissue laterally, the suspensory fixation utilized may cause localized irritation.

*Can you briefly discuss any recent literature that supports the use of this technique?*

We recently published our series of patients who underwent partial transphyseal ACL reconstruction.<sup>16</sup> Twenty-four patients (mean  $\pm$  SD age,  $12.3 \pm 0.9$  years) with a mean follow-up of  $31.5 \pm 17.1$  months were reviewed. Our overall postoperative growth disturbance incidence was 16.7% (4 of 24), but for patients with  $>5$  years of growth remaining, the incidence of growth disturbance was 66.7% (2 of 3). Of note, none of these patients required re-operation for their growth disturbances. The graft failure rate was lower (8.3%) than what has been reported for this population of patients. In the subset of patients who completed a Pedi-IKDC questionnaire, the mean score was  $94.8 \pm 5.3$ . As a result, we feel that this technique, when performed appropriately, can restore knee function while minimizing the risk of growth disturbance, particularly when there is less than 5 years of growth remaining.

### **Theodore J. Ganley, MD**

*What is your clinical rationale for surgical treatment of acute ACL tears in the skeletally immature patient?*

The rationale for surgical treatment of acute ACL tears is to provide young patients with a stable, functional knee, which allows for healthy exercise and the absence of buckling, giving way, or early meniscal pathology. Non-surgical treatment had historically been the first line of treatment for pediatric patients. We analyzed 10 years of data from injured patients who were formally kept out of organized sports. We noted a 4- to 11-fold increase in the odds of irreparable meniscal tears and chondral injury for those patients treated nonoperatively relative to those who were treated with early surgical intervention within 3 months from the time of injury<sup>8</sup>. These findings which have been corroborated by the work of Allen Anderson and others, has created a paradigm shift in this country in terms of caring for these young athletes with early surgical intervention following ACL injury<sup>6,21–23,33,37</sup>.

*In what patient (if any) would you recommend nonoperative treatment?*

I would recommend nonoperative treatment for an ACL tear in any patient who is not physically, mentally, or emotionally capable of undergoing an ACL reconstruction or who will not follow an appropriate rehabilitation protocol. This is not limited to the patient because sometimes the patient may be prepared for surgery, but the family members are not. There are also patients with certain medical conditions that will prevent ability to fully cooperate and also for patients without sufficient support to attend physical therapy. For those who are not at all athletic, risk-averse families, or if the patient is sedentary at baseline, and everyone is comfortable that they are not going to do high-demand athletic activities, nonoperative treatment is reasonable while their growth plates are open.

I was fortunate to participate in the United States Olympic Committee's Delphi Method Analysis of pediatric ACL injuries<sup>38</sup>. Here, Lars Engebretsen and Havard Moksnes elegantly described a proportion of their patients who were considered copers who responded to their nonoperative physical therapy regimens. However, even a percentage of those patients later developed meniscal tears. We were not able to predict in our series of patients described above who would develop irreparable meniscal or chondral injuries. Therefore, I reserve nonoperative treatment in otherwise healthy young patients to very low-demand youngsters



**Figure 4.** Intra-operative fluoroscopy images (Panels A/B) of a patient undergoing all-epiphyseal ACL reconstruction to monitor drill tunnel placement and ensure epiphyseal location. Post-operative AP (Panel A) and lateral (Panel B) radiographs after all-epiphyseal ACL reconstruction.

in whom the patients and families are averse to surgical intervention.

### All-Epiphyseal ACL Reconstruction

[Link to surgical technique video](#)

*What are the major advantages of this technique?*

The main advantage of this method is that the new ACL graft is placed in the native footprint of the ACL that was ruptured. This technique allows for a variety of different graft sources and fixation methods. All-epiphyseal ACL reconstruction is not one single surgical technique, but a set of fundamental principles, in which the graft is placed in the native footprint of the ACL, tunnels are drilled in the epiphysis rather than across the

growth plate, and fixation is such that the graft and fixation construct is stronger than the native ACL.

*Can you provide pearls for intra-operative imaging techniques to minimize potential physeal injury?*

The imaging used to minimize potential physeal injury can be standard fluoroscopic imaging (Figure 4). On the tibial side, the angle for drilling should be 25-30° rather than customary drilling angle. A small guide pin is placed, the location is confirmed on fluoroscopic imaging and the lateral image is most critical for that analysis. For the femoral side, a pin placed parallel and distal to the physis can be confirmed using fluoroscopic imaging. The angle of the femoral guide is typically 90° and the femoral guide at the intercondylar notch is placed at the anatomic footprint of the ACL. When performing drilling for the femoral tunnel, it is also helpful to use a sterile pen to outline the bony landmarks of the distal lateral femur. This allows the surgeon to note the position of the central aspect of the distal lateral femoral condyle, which is an appropriate starting point for drilling distal and parallel to the physis.

*In your experience, what are the most common complications associated with this technique?*

Complications include recurrent instability following reinjury, recurrent meniscus injury, and superficial infection. In our analysis of a series of patients who required a return trip to the operating room following pediatric ACL reconstruction, 40% had returned back to activities against the recommendations written in our post-operative rehab protocol<sup>39</sup>. Care must be taken, therefore, to counsel young athletes following ACL surgery, such that they and their parents, coaches, and physical therapists fully understand the rehab protocol. Having a written protocol for the physical therapist and a separate written description (which is in layman's terms for the patient and the family) can be extremely helpful in this process. Other complications include arthrofibrosis, which, while rare, can be challenging to

treat<sup>40</sup>. Therefore, stable fixation followed by early post-operative range of motion can help minimize this complication.

The family should also be counseled that there is a risk of contralateral ACL injury<sup>41</sup>. LLD and angular deformity have been described on rare occasions despite the fact that the procedure, by definition, consists of drilling within the epiphysis rather than across the physis. Patients and families should also be aware that there have been reports of slight overgrowth in the affected limb<sup>10,29,30</sup>.

*Can you briefly discuss any recent literature that supports the use of this technique?*

In 2017 and 2018, a group of us worked with Dr. Kevin Shea to carefully analyze pediatric cadaveric knees to demonstrate a consistent relationship between the origin of the ACL and LCL as well as the anterolateral ligament and popliteus using 3D-CT studies<sup>42</sup>. A sequential MRI study of graft integrity following all-epiphyseal ACL reconstruction revealed that grafts maintain stable intensity signaling at long term MRI follow-up<sup>29</sup>. Dr. Eric Wall also noted excellent functional outcomes despite significant rates of secondary procedures and complications in a highly active cohort with an incidence of graft failure that was similar to standard ACL reconstruction in patients younger than 20 years<sup>43</sup>.

In a follow-up study of 1001 patients published in 2019; after adjusting for age and other confounders, there was no difference in range of motion, strength, or increased risk of graft rupture or new meniscal tears in young patients treated with all-epiphyseal surgery compared with older adolescents treated with transphyseal ACL reconstruction<sup>44</sup>.

## Conclusions

Rates of ACL reconstruction in children and adolescents continue to increase<sup>2,45,46</sup>. Historically, the recommended treatment for ACL ruptures in this population was initial nonoperative treatment followed by delayed

reconstruction once they reached skeletal maturity. Recent evidence, however, has shown that this strategy may be suboptimal because of the potential for further irreparable intraarticular damage due to either micro or macro instability<sup>6,8,21,22</sup>. Additionally, pediatric patients with ACL injuries may have difficulty returning to their pre-injury level of activity with nonoperative treatment alone<sup>20,37,47,48</sup>. Recurrent instability due to ACL deficiency has been shown to lead to a high rate of sport dropout, and up to 50% of children treated nonoperatively do not return to athletic activity<sup>49</sup>.

Because of the potential for irreparable intra-articular injury in the ACL deficient knee and the desire to return pediatric athletes to their pre-injury level of function, there is an increasing interest in performing ACL reconstruction in the skeletally immature athlete. There are a number of described techniques for ACL reconstruction in this population, including, 3 of which were discussed above. Each technique has its associated risks and technical nuances, yet all have been shown to have favorable clinical outcomes. Given the high rates of ACL injury in the skeletally immature pediatric population, “physeal respecting” ACL reconstruction will continue to play an important role in the treatment of this highly active and athletic population.

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