



# Extraphyseal Anterior Cruciate Ligament Reconstruction and Lateral Tenodesis Using Hamstrings for Prepubescent Patients: The WHAT Technique (Without Hardware And Tunnels)

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**Abstract:** Anterior cruciate ligament injuries in prepubescent skeletally immature patients with significant remaining growth pose a serious challenge as surgeons must balance the desire to restore stability to the knee and prevent meniscal and chondral damage with the risk of iatrogenic injury to the open tibial and femoral physes. A physeal-sparing intra- and extra-articular reconstruction, which is a modification of a long-used “over-the-top and lateral extra-articular tenodesis” technique, is proposed as a safe approach to treat these patients. This article reports on the surgical details of this technique.

**A**nterior cruciate ligament (ACL) injuries in skeletally immature patients pose a difficult problem for treating surgeons. Delayed treatment and persistent instability are known to lead to increased chondral and meniscal injuries, which can be permanent. At the same time, restoring stability to the knee through surgery must be approached carefully so as not to cause damage to the open tibial or femoral physes. Damage to the physes can lead to coronal or sagittal plane deformity, as well as limb lengthening or shortening.<sup>1,2</sup> This risk is even greater in younger patients who have not experienced puberty yet and have more than 4 or 5 years of growth remaining.

In these patients, several surgical approaches have been proposed, but a consensus is not reached: transphyseal or partial transphyseal approaches are less technically demanding but can create physeal damage

in very young patients; all-epiphyseal techniques theoretically spare the growing physis but are technically demanding and have the risk of inadvertent physeal damage, especially in small knees; and extraphyseal techniques that avoid the tunnel drilling respect the growing bone but require the harvesting of a long strip of the iliotibial band (ITB), which can cause cosmetic issues and donor site complaints in some patients.

To treat this challenging population of skeletally immature prepubescent patients, the authors use an approach that is a modification of a long-used “over-the-top and lateral tenodesis” ACL reconstruction technique originally described by Marcacci et al.<sup>3</sup> in 1998. It utilizes both the gracilis and semitendinosus hamstring tendons, leaving them intact at their tibial attachment. They are then passed through the intercondylar notch without a femoral osseous tunnel and retrieved and fixed first on the lateral femur and then on the proximal anterolateral tibia to create both an intra-articular ACL graft and a lateral extra-articular tenodesis (LET) with a single graft. This technique has shown excellent results in adult patients, including high-level athletes, with more than a 25-year follow-up.<sup>4</sup> It is a minimally invasive technique with decreased morbidity and has the benefit of preserving the vascularity of the tendons, which may aid in quicker maturation of the graft. Most importantly, this technique provides surgeons with a reproducible approach to create an isometric ACL graft and lateral extra-articular augmentation.

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The modification proposed in this Technical Note is that the graft is passed anterior to the tibia and under the intermeniscal ligament to avoid affecting the tibial physis, rather than through a tibial tunnel. This is similar to the graft passage described by Kocher et al.<sup>5</sup> in their extraphyseal ACL reconstruction technique. For this reason, the present technique can be defined with the acronym WHAT: Without Hardware And Tunnels.

## Surgical Technique

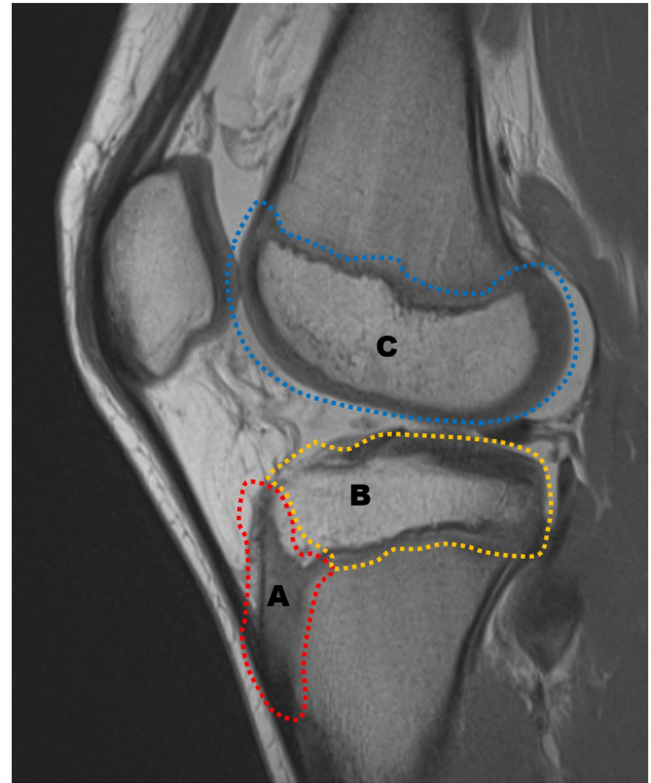
### Step 1: Preoperative Magnetic Resonance Imaging Assessment and Indications

This technique is indicated in skeletally immature “prepubescent” patients with ACL deficiency and 5 or more years of growth remaining: males with bone age less than 12 years and females with bone age less than 10 years.<sup>6</sup> It should also be considered in patients with 2 to 5 years of remaining growth where small dimensions of the tibial epiphysis can jeopardize the correct placement of all-epiphyseal tunnels and the integrity of physeal cartilage.

While many methods have been described for estimating remaining growth, the authors prefer the use of the technique described by Pennock et al.,<sup>7</sup> which assesses the appearance of the femoral physis and tibial physis and apophysis on a knee magnetic resonance imaging (MRI). The main benefit is that patients with ACL injuries will almost always already have a knee MRI, so no further imaging is necessary. In addition, knee surgeons are accustomed to reviewing knee MRIs. This technique has been shown to have reliability comparable to that of the Greulich and Pyle atlas, based on hand radiographs.<sup>7</sup> The primary MRI criterion to identify this specific “prepubescent” age group is the absence of the tibial tubercle apophyseal center, with both tibial and femoral physes completely visible (Fig 1). These patients are still 1 or more years away from puberty onset, with remaining growth at the knee exceeding 7.5 cm, mostly on the distal femur (5 cm). MRI is also used to assess the presence of an intermeniscal ligament and the anatomy of the medial meniscus anterior horn. Long-limb weightbearing radiographs are performed on all patients before surgery to evaluate and document possible pre-existing differences in limb lengths as well as to note the coronal alignment.

### Step 2: Patient Positioning and Diagnostic Arthroscopy

General anesthesia with or without a peripheral nerve block is administered. The patient is positioned supine on the operating room table with a foot post and a side support in place. All bony prominences are appropriately padded. A nonsterile tourniquet is



**Fig 1.** In this T2 fat-saturated sagittal image, the main indications for extraphyseal over-the-top anterior cruciate ligament reconstruction are prepubescent patients with a nonossified tibial tubercle (A) and the presence of open tibial (B) and femoral (C) growth cartilage on magnetic resonance imaging (right knee).

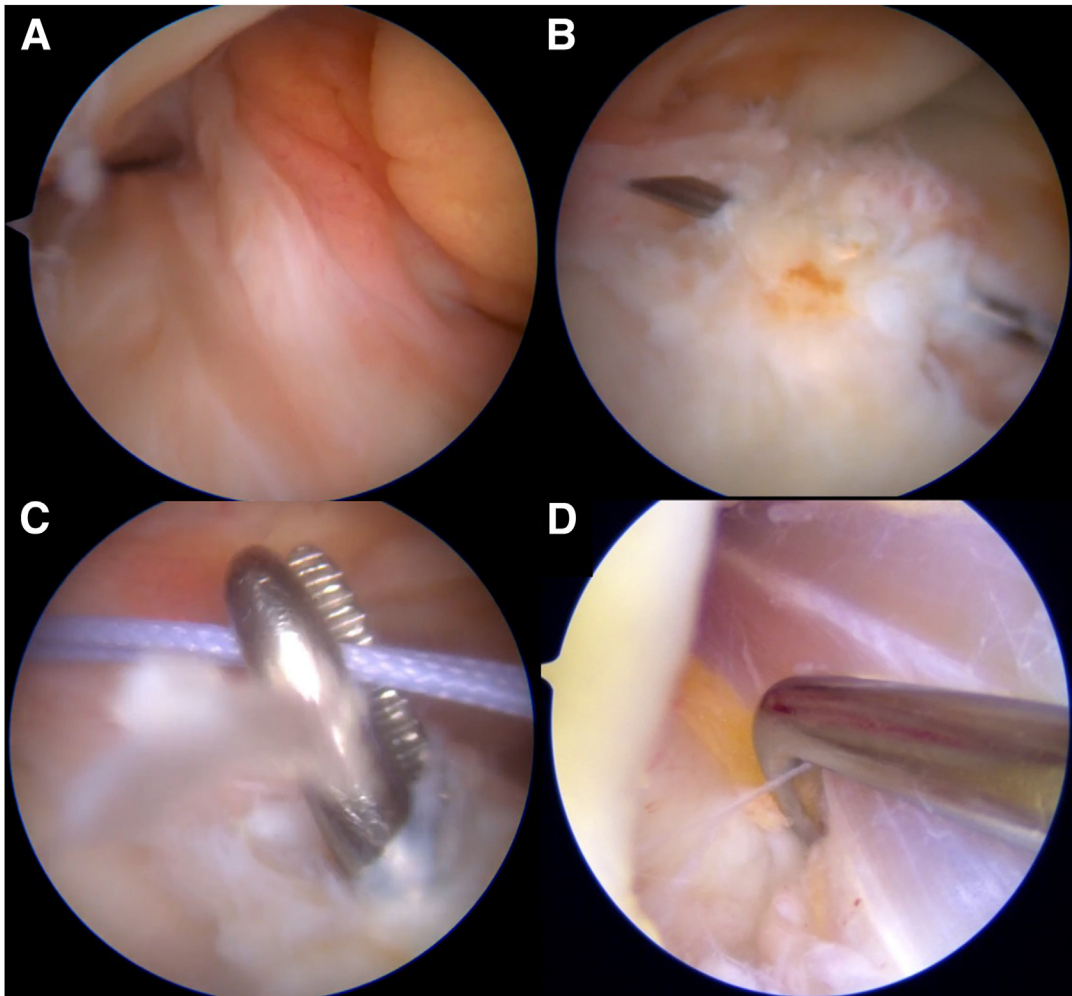
applied to the proximal thigh. Intravenous antibiotics are administered less than 30 minutes before incision.

A thorough examination under anesthesia is performed to evaluate the degree of laxity as well as to rule out any coronal plane or rotational instability due to collateral ligament injury that should be addressed in surgery.

A standard diagnostic arthroscopy is performed utilizing a superomedial portal for water inflow and anteromedial (AM) and anterolateral working portals. Chondral and meniscal pathology are treated as indicated. The femoral portion of the ACL remnant is then excised to create room for the ACL graft (Fig 2A). The shaver is inserted through the notch, and debridement is performed to allow the over-the-top extra-articular passage. Attention should be used to not damage the bone close to the proximal femur physis with the shaver or create excessive bleeding.

### Step 3: Graft Harvest and Preparation

Palpation is used to identify the pes tendons on the anteromedial tibia. An oblique skin incision is made overlying the pes tendon insertion on the tibia to reduce the risk of iatrogenic damage to the infrapatellar branch



**Fig 2.** (A) Arthroscopic views of this right knee show the anterior cruciate ligament rupture. (B) A spinal needle is inserted medial to the patellar tendon approximately 1 cm below the joint line and passed through the tibial stump to simulate the inclination of graft passage. (C) A curved Kelly clamp is inserted through a small arthrotomy and advanced through the tibial stump to retrieve the shuttle suture previously passed through the over-the-top. (D) Final probing of the anterior cruciate ligament, after graft passage and control of impingement.

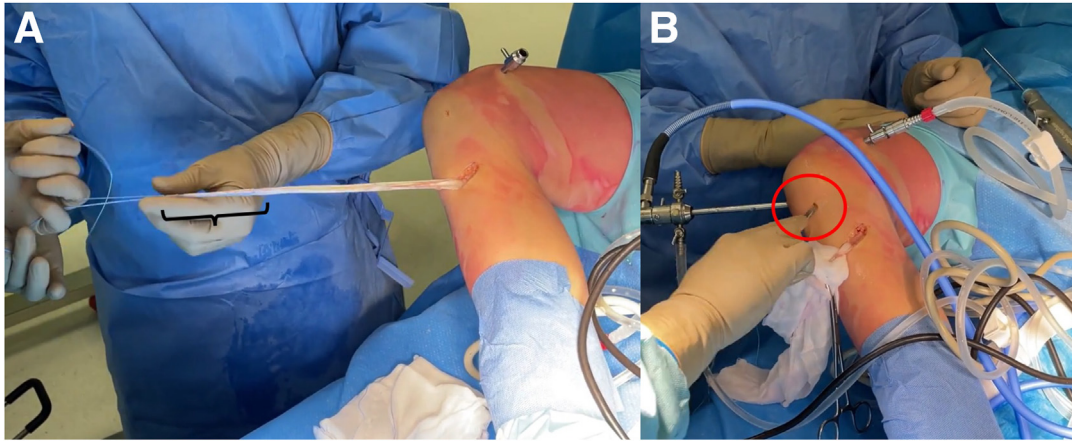
of the saphenous nerve. Dissection is carried down to the sartorius fascia, which is split in line with the underlying semitendinosus and gracilis, between the 2 tendons. The 2 tendons are harvested with an open tendon stripper, paying attention to not damage the tibial attachment and after releasing the fascial expansions to the medial gastrocnemius to maximize the graft length. After removing muscle tissue from the tendinous portion, 5 cm of the proximal tendon ends are whipstitched together with 2 No. 2 nonabsorbable sutures using Krackow stitches (Fig 3A). Attention should be given in suturing the 2 tendons with the same tension mimicking the proximal direction of the graft. The graft is then covered and protected in a sterile gauze.

#### Step 4: Preparation of Tibial Passage

The arthroscope is inserted into the knee, and the presence or lack of an intermeniscal ligament is noted.

Three possible scenarios are possible: if an intermeniscal ligament is present (which can be evaluated on pre-operative MRI), careful debridement is performed anteriorly to create a passage underneath. If the ligament is not present and the anterior horn of the medial meniscus has a type I insertion (on the flat intercondylar area lateral to the medial tibial spine), according to Berlet and Fowler,<sup>8</sup> a small aperture and passage is created beneath the anterior horn of the medial meniscus. In the case of type II insertion (on the downward slope from the medial articular plateau, medial to the medial tibial spine), the passage is created through the tibial ACL stump. Type III and IV insertions are usually correlated to the presence of the intermeniscal ligament or could be approached as a type I insertion.

A spinal needle is inserted medial to the patellar tendon approximately 1 cm below the joint line. If the



**Fig 3.** (A) Medial view of the right knee showing the gracilis and semitendinosus tendons being harvested through an oblique incision, preserving the tibial insertion, and are whipstitched with nonabsorbable suture for at least 5 cm in their proximal ends (black line) after being cleaned of muscle tissue. (B) After protecting the graft in a sterile gauze, a small 1-cm arthrotomy (red circle) is performed medially to the patellar tendon after checking the proper position with a spinal needle.

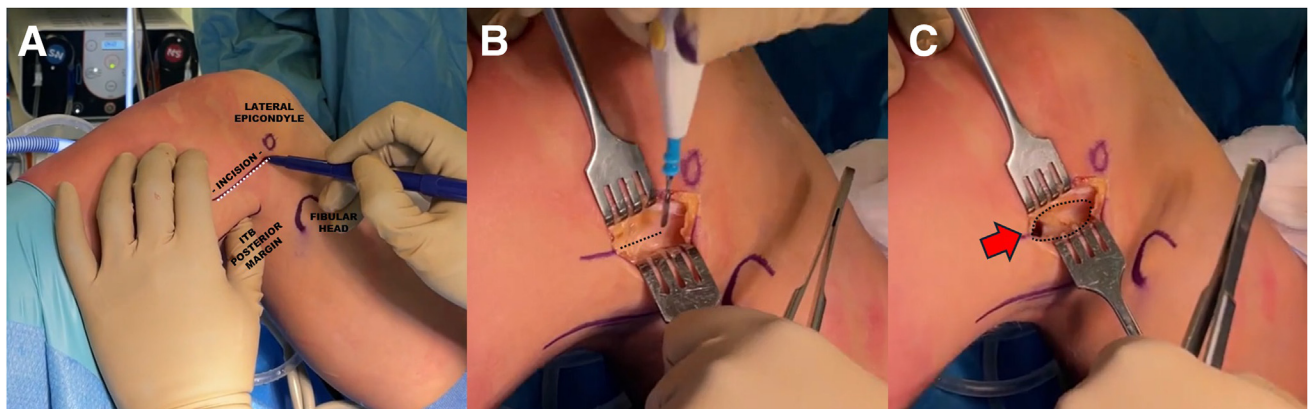
inclination of the needle is satisfactory to reach the intermeniscal ligament, tibial stump (Fig 2B), or anterior root of the medial meniscus, a small 1-cm arthrotomy is performed, and the shaver is used to create a small trough on the central tibial plateau (Fig 3B).

#### Step 5: Preparation of Over-the-Top and Graft Passage

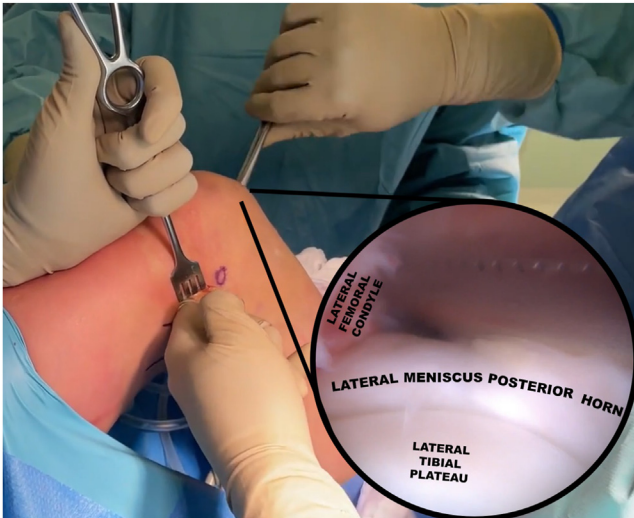
A 4-cm longitudinal incision is made on the lateral thigh, proximal and posterior to the lateral epicondyle and in line with the ITB course. The ITB is split in line with its fibers, 1 to 1.5 cm from its posterior margin (Fig 4A). After placing 2 retractors (Fig 4B), a small opening in the intermuscular septum is performed with electrocautery, creating communication with the space posterior to the joint capsule (Fig 4C). The index finger of the opposite hand with respect to the patient's limb

side is inserted through this space to perform a blunt dissection and reach the posterior capsule, feeling the posterior lateral femoral condyle. Usually, extensive release is not required to reach the posterior capsule if the ITB split is not performed too anteriorly.

A large curved Kelly clamp is inserted through the AM portal, driven through the intercondylar notch and brought into the posterolateral aspect of the knee (Fig 5). The scope can be used to check arthroscopically the clamp positioning if desired. The clamp is pushed against the capsule to create a small aperture, using the index finger to protect the surrounding structures (Fig 6A). Alternatively, a small posterior arthrotomy can be performed to aid the passage. The loop end of a No. 2 nonabsorbable passing suture is placed into the clamp, shuttled back through the knee, and pulled out of the AM portal (Fig 6B).



**Fig 4.** (A) On the lateral aspect of this right knee, landmarks for the lateral femur skin incision are the lateral epicondyle, the posterior margin of the ITB, and the fibular head; a 4-cm longitudinal incision (white dotted line) is performed proximal and posterior to the lateral epicondyle and parallel with the ITB course. (B) After splitting the ITB in line with its fibers, 1 to 1.5 cm from its posterior margin, the intermuscular septum is opened (black dotted line) with electrocautery. (C) In this way, it is possible to create a communication with the space posterior to the joint capsule (red arrow). (ITB, iliotibial band.)



**Fig 5.** On the lateral side of a right knee, the index finger of the opposite hand with respect to the patient's limb side is inserted through the lateral incision to perform a blunt dissection and reach the posterior capsule, feeling the posterior lateral femoral condyle, and a large curved Kelly clamp is inserted through the anteromedial portal. Arthroscopic view of the lateral compartment shows the clamp being driven through the intercondylar notch between the posterior cruciate ligament, lateral meniscus, and lateral femoral condyle and pushed against the capsule and finger.

A curved Kelly clamp is inserted through the medial joint line incision and advanced through the passage created beneath the intermeniscal ligament, meniscal root, or ACL stump and used to retrieve the suture loop (Fig 2C). At times, it is helpful to use a grasper or probe to pass the suture into the Kelly clamp. Using the index finger, blunt dissection is performed to create a subcutaneous communication between the incision over the pes anserinus and the arthrotomy. A Kelly clamp is passed through this space and used to retrieve the shuttle suture from the arthrotomy to the harvest site (Fig 6C). The passing suture is used to shuttle the graft into the joint through the intercondylar notch and out the posterolateral arthrotomy.

### Step 6: Graft Fixation and Lateral Extra-articular Tenodesis

Once the graft has been retrieved through the arthrotomy, tension is held on the graft, and the knee is cycled with the arthroscope visualizing the graft in the knee (Fig 2D). If the posterolateral arthrotomy is too large or too distal, the graft could sublux into the lateral compartment with knee range of motion. In these cases, closure of the distal portion of the arthrotomy is performed, and then the graft position throughout the range of motion is rechecked. Moreover, a small notchplasty is considered in small notches to smooth graft movement.

Once an appropriate intra-articular graft position has been confirmed, a small 1-cm oblique incision is then made overlying Gerdy's tubercle on the tibia. A curved Kelly clamp is inserted through this incision and advanced toward the lateral femoral incision beneath the ITB (Fig 6D). The distal portion of the graft is loaded on the Kelly clamp and pulled deep to the ITB and retrieved through the tibial incision overlying Gerdy's tubercle. By pulling the graft distally, the knee is flexed and extended to check graft mobility and adjust the graft on the lateral condyle. If the graft tends to slide posteriorly with knee flexion, the passage beneath the ITB is repeated.

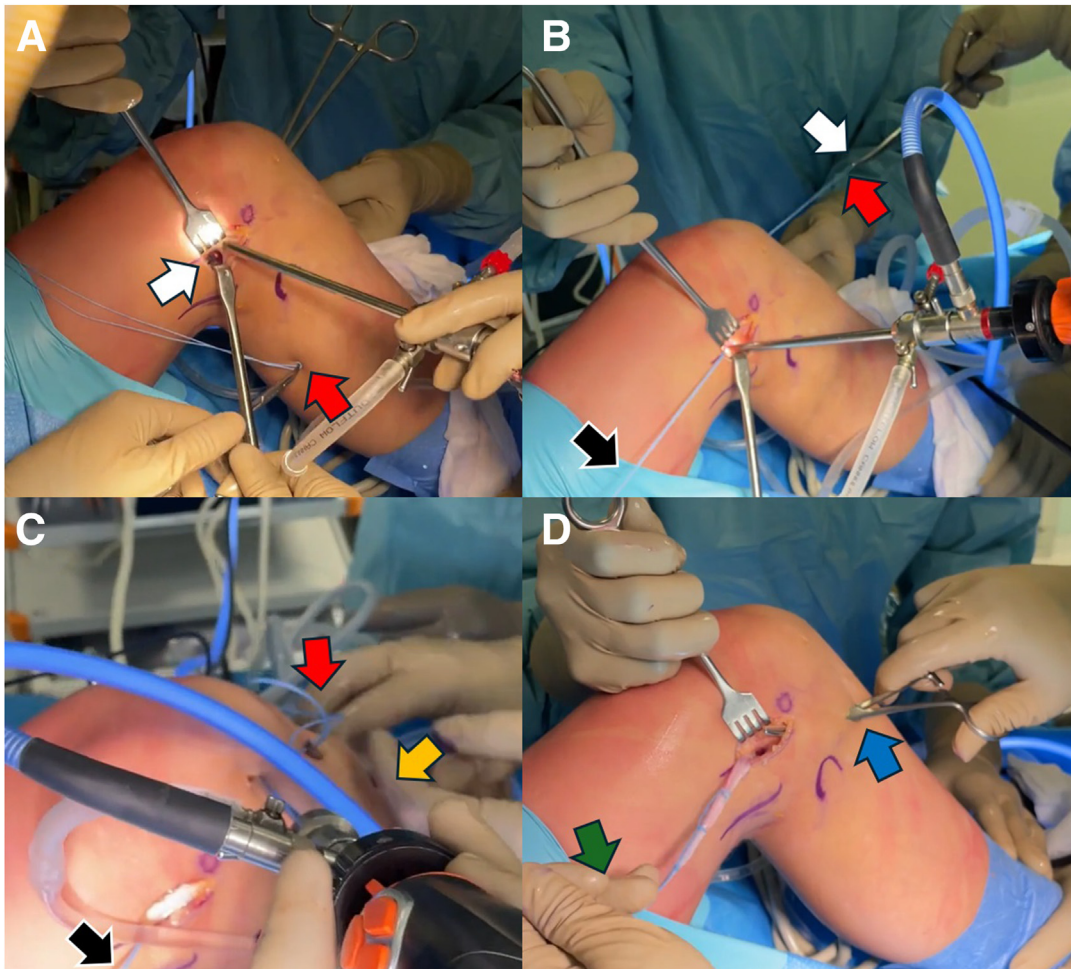
Once the graft is stable and the knee can reach full extension, 2 or 3 stitches with a No. 2 nonabsorbable suture are used to fix the graft to the lateral condyle periosteum, proximal to the lateral epicondyle and distal to the physal cartilage (Fig 7A). Fixation is performed with the knee at 70° of flexion and neutral tibial rotation. Stability and full extension are checked after this is done.

Finally, the graft is secured to the tibia, sewing it into the periosteum overlying Gerdy's tubercle with 2 No. 2 nonabsorbable sutures, with the knee at 30° of flexion and neutral tibial rotation (Fig 7B). The remainder of the graft is then excised. The knee is again brought through full flexion and extension to make sure there is no block to full range of motion. A Lachman and pivot-shift test are then gently performed to confirm restoration of stability to the knee. The wounds are closed in standard subcutaneous fashion, and staples are used to close the skin.

### Postoperative Rehabilitation

For isolated ACL reconstructions, patients are not placed in a brace and are allowed to weight-bear as tolerated with the use of crutches for support. It is important to train the patient to fully extend the knee from the first postoperative days and not to walk with a flexed knee. However, in very young kids with possible concerns related to compliance, an extension brace or cast can be used for the first 15 days to avoid a flexion contracture. Restoration of full active and passive extension should be the primary focus in the immediate postoperative period, with no restrictions on flexion. Should there have been meniscal, chondral, or collateral ligament pathology that required surgery, weight-bearing and flexion restrictions may be indicated. Physiotherapy can begin as early as the day after surgery. Patients are seen in the clinic for follow-up at 2 weeks, 6 weeks, and 3 months postoperatively, and when they have passed functional return-to-play testing, they are ready to return to sport.

A control MRI could be performed after 3 months, if needed (Fig 8). Long-limb weightbearing radiographs are repeated after 6 months and then annually until



**Fig 6.** (A) Viewing the lateral aspect of the right knee, the tip of the Kelly clamp (white arrow) is inserted in the anteromedial portal is pushed against the capsule to create a small aperture, where a suture loop (red arrow) should be passed. (B) The suture loop (red arrow) is grabbed with the tip of the Kelly clamp (white arrow) and retrieved from the anteromedial portal, maintaining the free end of the suture (black arrow) outside the lateral incision. (C) After passing the suture under the tibial stump and outside the small arthrotomy, the suture loop (red arrow) is retrieved from the harvest site incision (yellow arrow). (D) Finally the curved Kelly clamp is inserted through a small incision at the level of Gerdy's tubercle (blue arrow), advanced toward the lateral femoral incision beneath the iliotibial band, to retrieve the proximal portion of the graft (green arrow).

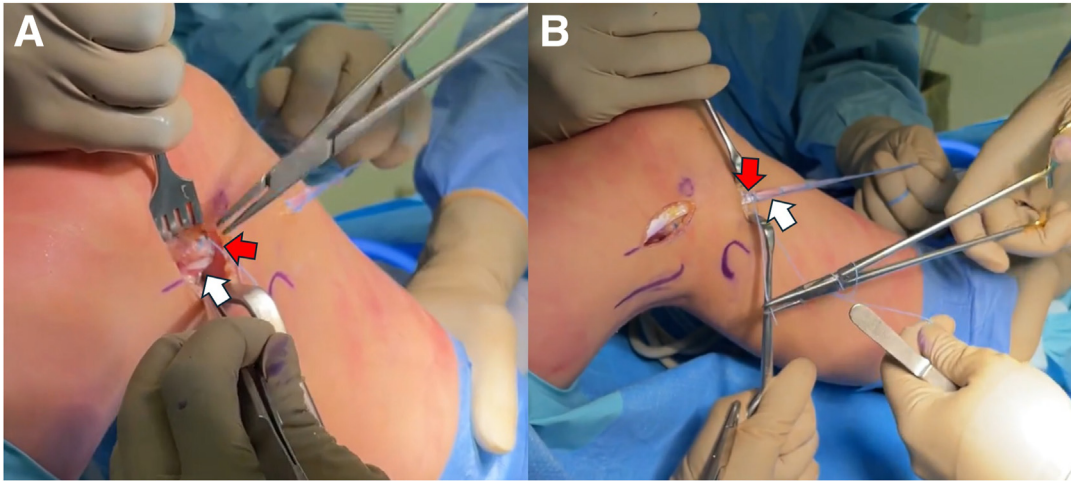
skeletal maturity is reached to allow early identification and treatment of any growth disturbance. In the case of growth abnormalities visible clinically, the interval between radiographs could be shorter, to allow for planning of potential guided growth procedures.

### Discussion

ACL injuries are becoming more common in young athletes, potentially due to early sport specialization and the increased number of games and tournaments being played.<sup>9,10</sup> When these injuries occur in skeletally immature individuals with significant growth remaining, they pose a significant challenge to the treating surgeon. Historically, young patients with ACL tears were treated with activity avoidance and delayed reconstruction, but this approach comes with the risk of increased meniscal and chondral injuries.<sup>11,12</sup> In

addition, early surgery may be indicated for many reasons, including concomitant unstable meniscal or chondral injuries in the multiligament injured knee or even in patients unwilling to avoid the activities and sports that place their knee at risk for further damage. In these patients, the goal is to restore stability to the knee to prevent further injury while also avoiding iatrogenic injury to the open physes.

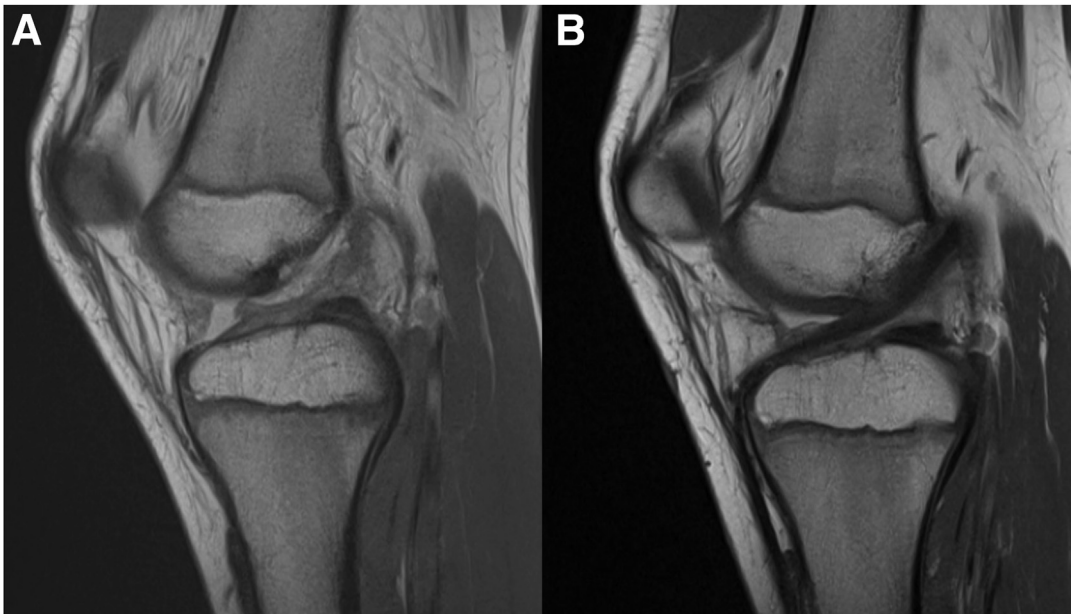
To accomplish this, the authors propose the use of the WHAT technique, which is a modification of a long-used "over-the-top and LET" technique originally described by Marcacci et al.<sup>3</sup> This technique utilizes a 2-strand hamstring autograft to restore anterior-posterior as well as rotational stability with the use of both an intra-articular and an extra-articular limb. The addition of an anterolateral procedure, such as an LET, has been shown to decrease the rerupture rate in



**Fig 7.** (A) Lateral view of a right knee where 2 or 3 stitches with nonabsorbable sutures (red arrow) are used to fix the graft (white arrow) to the periosteum of the lateral femoral condyle distal to the physal cartilage. (B) Two to three stitches (red arrow) are used to suture the tenodesis (white arrow) to the periosteum at the level of Gerdy's tubercle.

young high-risk patients, and thus the authors feel it should be included in very young patients who are known to have some of the highest rates of graft failure.<sup>13,14</sup> The adult version of this technique, as described by Marcacci et al.,<sup>3</sup> has shown excellent results out to a 25-year follow-up, with failure rates of 14% and a return-to-activity rate of 90%. More reassuring, this technique has performed well in another high-risk patient cohort, professional soccer players.<sup>15</sup> The modification proposed by the authors in the WHAT technique is to pass the graft under the intermeniscal ligament rather than drilling a tibial tunnel to avoid the risk of iatrogenic injury to the

proximal tibial physis; moreover, the suture fixation to the periosteum avoids problems of graft irritation or migration. These technique is similar to what has been described by Kocher et al.,<sup>5,16</sup> although using a different graft which, has yielded very low rates of physal injury and reruptures. Moreover, similar techniques but with a complete arthrotomy and without tenodesis were used in a small case series,<sup>17,18</sup> confirming the safety of an ACL reconstruction without a tibial tunnel. Recently, other Italian authors have described a surgical technique with features similar to the present procedure<sup>19</sup>, which could therefore be considered the "Italian Kocher-Micheli".



**Fig 8.** (A) Preoperative sagittal magnetic resonance imaging view shows complete absence of the anterior cruciate ligament. (B) The postoperative magnetic resonance imaging performed after 3 months shows isointense signal of the graft, with physiologic oblique course and no impingement at the level of the anterior tibia (right knee).

**Table 1.** Pearls and Pitfalls

Pearls	Pitfalls
<b>Preoperative</b>	
<ul style="list-style-type: none"> <li>- Skeletal age, not chronological age, should be used to estimate the amount of remaining growth.</li> <li>- The authors prefer using the technique described by Pennock et al.<sup>7</sup> to evaluate bone age. Prepubescent patients will have an absence of the tibial tubercle apophyseal center, with both tibial and femoral physes completely visible on their knee MRI.</li> <li>- Evaluate for the presence of the intermeniscal ligament on MRI and the anatomic variant of anterior horn of the medial meniscus.</li> </ul>	<ul style="list-style-type: none"> <li>- Failing to detect the proper skeletal age could affect the decision-making process.</li> </ul>
<b>Intraoperative</b>	
<ul style="list-style-type: none"> <li>- During graft harvest, it is important to release the fascial connections to the medial gastrocnemius to avoid truncating the graft.</li> <li>- Graft positioning must be assessed arthroscopically throughout range of motion before fixing it on the femur.</li> </ul>	<ul style="list-style-type: none"> <li>- Truncation of the graft during harvest can lead to a short graft, which is unable to reach all the way to the tibia.</li> <li>- Too anterior split of the ITB could make it difficult to access the posterior space of the knee.</li> <li>- A posterolateral arthrotomy that is too large or too distal will result in the graft subluxing into the lateral compartment during knee range of motion. Should this occur, perform a repair of the arthrotomy and recheck graft position.</li> <li>- Extensive dissection in the posterolateral aspect of the knee can lead to damage of the physeal ring and possible deformity.</li> <li>- Overtension of the graft or fixation at &gt;90° of flexion could produce a flexion contracture.</li> </ul>
<b>Postoperative</b>	
<ul style="list-style-type: none"> <li>- Consider extension bracing or casting in extremely young patients after surgery to decrease the risk of developing a flexion contracture.</li> <li>- Long-limb radiographs should be performed at 6 months post-operatively and then annually until skeletal maturity.</li> </ul>	<ul style="list-style-type: none"> <li>- Failing to correct immediate flexion contracture could lead to lack of extension and risk of a second surgery.</li> </ul>

ITB, iliotibial band; MRI, magnetic resonance imaging.

This evidence suggests the use of the WHAT technique as an option for extraphyseal ACL reconstruction and lateral tenodesis in prepubescent skeletally immature patients with more than 5 years of growth remaining, or older, to restore knee stability and minimize the risk of growth disturbances from physeal injury. Pearls and pitfalls of our technique are described in Table 1.

## Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: A.G. is a consultant or advisor for DePuy Orthopaedics and Smith & Nephew. S.Z. receives speaking and lecture fees from Depuy Orthopaedics and Smith & Nephew and is a board member of the International Society of Arthroscopy Knee Surgery and Orthopaedic Sports Medicine. K.B. is a consultant or advisor for Xiros Ltd, DePuy Synthes Mitek Sports Medicine, and CONMED Corporation and receives speaking and lecture fees from Xiros Ltd.

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