Technical Note

Physeal Sparing Anterior Cruciate Ligament Reconstruction in Skeletally Immature Patients Bridging the Tibial Physis With Two Divergent Tunnels

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Abstract: A technique for anterior cruciate ligament (ACL) reconstruction in patients with open physis is presented. The patient is positioned supine with the knee flexed 90°. After intraarticular injuries are addressed, an autologous hamstring graft is harvested and prepared using a suspension device attached in its expansion device. All-epiphyseal femoral and tibial tunnels of the same diameter of the graft are created; both of them are drilled in an outside-in direction, sparing the physis under radioscopic control. A second divergent tibial tunnel of the same diameter of the graft, distal to the physis, is created in an outside-in, mediolateral, and craniocaudal direction, leaving a 1-cm bone bridge between the 2 tibial tunnels. The graft is passed through the all-epiphyseal tunnels, from femoral to tibial, and pulled until the suspension device leans on the lateral femoral cortex. The graft is passed through the second divergent tibial tunnel and fixed in it with an interference screw to move the pressure away from the physis.

The number of anterior cruciate ligament (ACL) reconstructions in children and adolescents has tripled in the last 10 years.[1] This is probably due to the incremental participation of this population in high-level sports[1,2] and the improvement of surgical techniques.

The treatment of ACL rupture in skeletally immature patients remains controversial because of the possibility of harming the tibial or femoral physis.[3,4] Some authors have recommended nonoperative treatment based on functional bracing, physical therapy, and activity modification. They also recommend delaying the surgical treatment if necessary.[5] However, it has been shown that a delay >6 to 12 weeks after the injury is associated with recurrent instability and can increase the number of meniscal (especially on the medial side) and chondral lesions.[6,7]

Several surgical techniques have been described, and they can be classified into 3 different groups: transphyseal, physeal sparing, and hybrid techniques. Growth disturbances have been seen in all types of technique,[2-4] and many causes have been described. The most common cause of iatrogenic growth alterations is technical error.[2] Therefore the treatment of tears of the ACL in children and adolescents should be individualized and meticulously planned and performed.

The technique described in this article (Table 1) has the following features:

- Hamstring tendons are used as a graft.
- The tibial physis is bridged using a second divergent tibial tunnel, and fixation is achieved with an interference screw placed in a second divergent tunnel.

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Table 1. Step-by Step Details

1. Patient positioning and intraarticular exploration:
   a. Supine with limb in an L-shaped leg holder at 90° flexion
   b. General or regional anesthetic with femoral ischemia cuff
   c. Transtendinous and anteromedial portals
   d. Arthroscopic anterior cruciate ligament (ACL) rupture identification
2. Graft harvesting and preparation:
   a. Semitendinosus and gracilis autologous tendons
   b. Both tendons are doubled and both ends are sutured together
3. Intraarticular preparation
   a. Remnant cleaning
   b. Footprint of ACL identification
4. Femoral tunnel
   a. Outside-in direction
   b. 80° guide opening
   c. All-epiphyseal: extraarticular end more proximal, intraarticular end on the ACL footprint
   d. Same diameter of the graft (usually 8 to 9 mm)
   e. X-ray control
5. First epiphyseal tibial tunnel
   a. Outside-in direction
   b. Same diameter of the graft (usually 8 to 9 mm)
   c. 45° guide opening
   d. Intraarticular end in the center of the ACL footprint
   e. All epiphyseal
6. Second divergent tibial tunnel
   a. Starts 1 cm distal to the first all-epiphyseal tibial tunnel
   b. Craniocaudal and mediolateral direction
   c. Same diameter of the graft
7. Graft passage and fixation
   a. Outside-in direction, from femur to tibia
   b. After exiting the joint through the first tibial tunnel, femoral fixation is performed with a bioabsorbable interference screw 1 mm wider than the graft and the tunnel
   c. The graft is passed through the second tibial tunnel and fixed in it with a bioabsorbable interference screw 1 mm wider than the graft and the tunnel

Fig 1. Frontal extraarticular view of the preoperative setting, with the left knee flexed 90° while placed in an L-shaped leg holder with a lateral buttress.

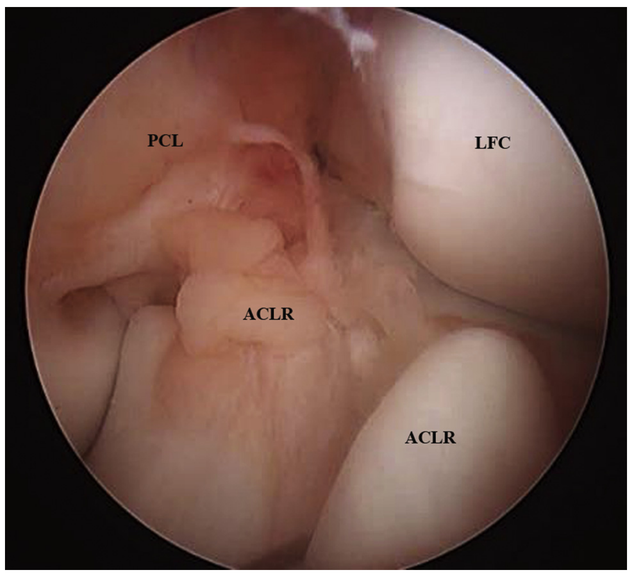

Fig 2. Arthroscopic view of the intercondylar notch of a left knee, with the arthroscope set through the central transtendinous portal. An anterior cruciate ligament tear with tibial remnants (ACLR) can be seen. LFC, lateral femoral condyle; PCL, posterior cruciate ligament.

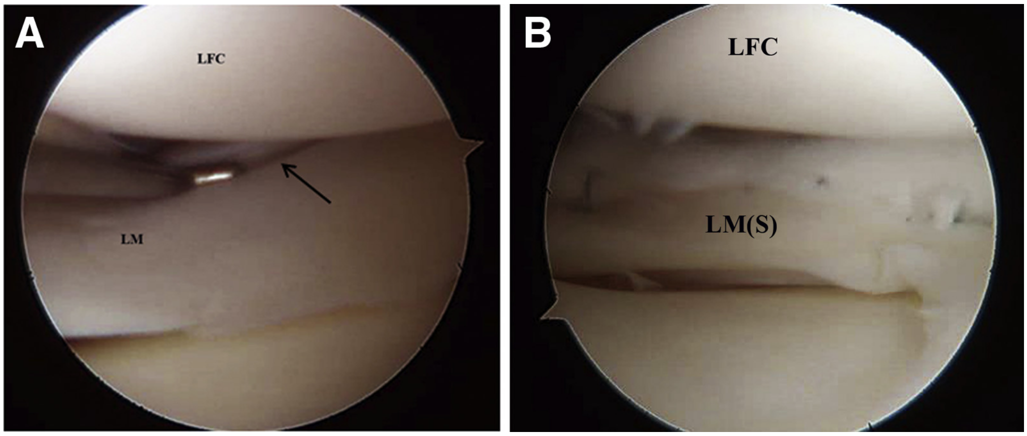

Fig 3. Other intraarticular injuries can be found in the setting of an anterior cruciate ligament (ACL) tear. (A) In this case, a longitudinal tear of the posterior horn of the lateral meniscus in a left knee (arrow) is checked with the aid of a probe (arthroscope through the central transtendinous portal). (B) Intraarticular lesions should be addressed before the ACL reconstruction: in this case, the meniscal tear was sutured (arthroscope through the anteromedial portal). LFC, lateral femoral condyle; LM, lateral meniscus; LM(S), lateral meniscus sutured.

- The femoral tunnel is all epiphyseal, and femoral fixation is achieved using a suspension device.
- X-rays are needed to check the correct position of the guide pins to avoid damaging the physis.

Technique

Patient Positioning

General anesthetic is used, and the patient is positioned supine. An ischemia cuff is placed around the thigh, and the limb is supported by an L-shaped leg holder and a lateral buttress with the knee placed at 90° flexion (Fig 1, Video).

Arthroscopic Exploration

A central transtendinous portal is performed to explore the joint (Table 2). The ACL tear is identified (Fig 2), and any associated injuries are addressed at this point with the aid of an anteromedial portal (if necessary, an additional anterolateral portal can be used) (Fig 3). Meanwhile, ACL remnants are removed (Fig 4) using a shaver and a radiofrequency probe (Video).

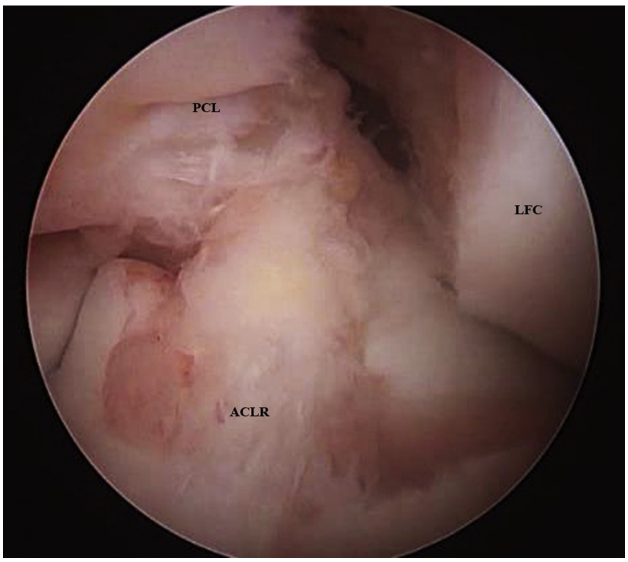

Fig 4. Arthroscopic view of the intercondylar notch of a left knee from the central transtendinous portal after cleaning the anterior cruciate ligament remnants (ACLR) and performing a synovectomy. Some ACLRs on the tibial footprint are conserved to serve as guide for ACL reconstruction. LFC, lateral femoral condyle; PCL, posterior cruciate ligament.

Fig 5. A hamstring graft is passed through the loop of a fixed-length suspension device, which is attached in its expansion piece (arrow). On the opposite side of the suspension device, all of the graft's ends are sutured together, leaving long traction threads.

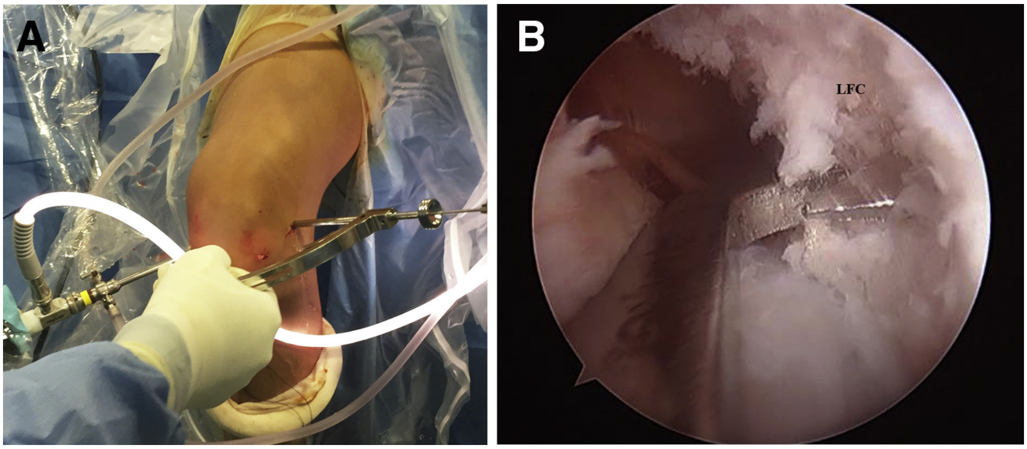

Fig 6. (A) Frontal extra-articular view of the left knee. An incision has been made over the lateral epicondyle. An anterior cruciate ligament (ACL) tibial guide opened to 80° is used to create the femoral tunnel in an outside-in manner, distal to the epiphysis and in slight craniocaudal direction. (B) Intraarticular view of the intercondylar notch of a left knee with the arthroscope through the central transtendinous portal: the tip of the guide pin is inserted through the lateral condyle and exits the femur on the center of the ACL footprint. LFC, lateral femoral condyle.

Graft Harvesting and Preparation

A 3-cm oblique skin incision is made medial to the anterior tibial tuberosity to harvest the semitendinosus and the gracilis tendons (using a standard tendon stripper). The hamstring graft is prepared on an auxiliary table. First, the graft is folded, and its width is measured with a caliper. Next, the graft is passed through the loop of a suspension device attached in its expansion piece (G-Lok 15 mm plus XL piece; Stryker, Kalamazoo, MI) (Fig 5, Video), and both ends of the graft are sutured together, leaving long threads for traction.

Tunnel Performance

After a 1.5-cm incision is made at the level of the lateral epicondyle, a guide pin is passed with the aid of a standard ACL guide set at 80°, in an outside-in and slight craniocaudal direction (Fig 6A), starting in a position distal to the femoral physis, with the needle tip exiting the femur in the center of the ACL footprint intraarticularly (Fig 6B), under radioscopic control. Subsequently, a guide pin proximal to the tibial physis is inserted with the aid of an ACL guide set at 45°, in an outside-in, mediolateral direction (Fig 7A), exiting the tibia in the center of the ACL footprint intraarticularly

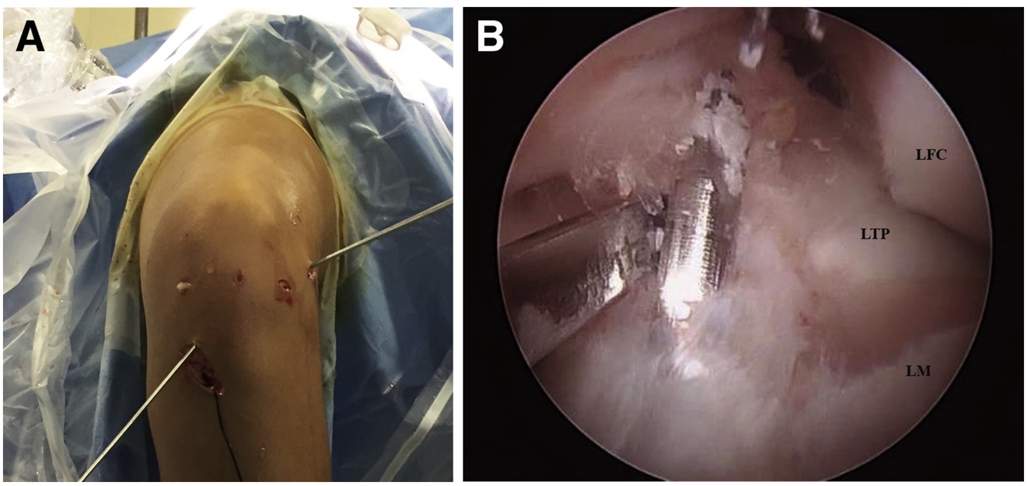

Fig 7. Femoral and tibial all-epiphyseal guide pins inserted on a left knee flexed 90°. (A) Outside frontal view with the needles inserted in an outside-in direction: the femoral guide pin is placed on the lateral side of the left knee and the tibial one on the medial side. (B) Intraarticular view of the intercondylar notch of a left knee with the arthroscope through the central transtendinous portal: the tip of the guide pin is inserted through the tibia and exits the tibia on the center of the anterior cruciate ligament (ACL) footprint. LFC, lateral femoral condyle; LM, lateral meniscus; LTP, lateral tibial plateau.

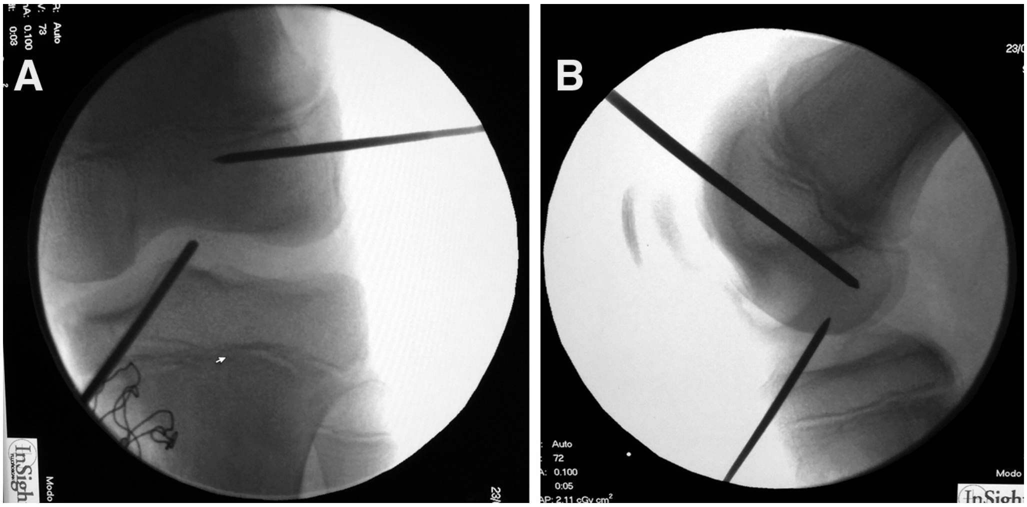

Fig 8. (A) Radioscopic anteroposterior view of the intraarticular guide pins. (B) Radioscopic lateral view of both intraarticular femoral and tibial pins.

(Fig 7B). After the correct location of the guide is confirmed using X-rays (Fig 8, Table 2), a tunnel of the same diameter of the graft is drilled through each pin using a cannulated drill bit. After the graft is passed through, another guide pin is set distal to the tibial physis (1 cm distal to the extraarticular exit of the all-epiphyseal tunnel) in divergent direction, in a craniocaudal and mediolateral direction (Fig 9), and the second tibial tunnel is made with a drill bit of the same diameter of the graft.

Graft Passage and Fixation

The graft is passed in an outside-in direction, inserting the traction threads of the distal end of the graft in the joint with the aid of a grasper. The traction threads are recovered inside the joint with the aid of a clamp inserted through the anteromedial portal. Next, those threads are inserted through the all-epiphyseal tibial tunnel with the aid of a grasper. Finally, traction is applied from the distal threads, and the graft is pulled from the extraarticular end of the tibial tunnel (Fig 10), until the suspensory device leans on the lateral femoral cortex (Fig 11). Subsequently, after the second divergent tibial tunnel is performed, the distal traction threads are inserted through the tunnel using a guide pin (Fig 12), and traction is applied in a craniocaudal direction. The graft should lean on the bony bridge between the 2 tibial tunnels (Fig 13). At the end, tibial fixation is performed by inserting an interference screw on the second tibial tunnel from proximal to distal and from medial to lateral with 30° of knee flexion and neutral rotation (Fig 14). The definitive outcome of ACL fixation is checked arthroscopically (Fig 15).

Table 2. Tips, Pearls, and Pitfalls

Tips and Pearls
- A central portal should be used to ensure a clear view of the intercondylar notch.
- Femoral anteroposterior and tibial lateral X-rays should be obtained intraoperatively to check the correct position of the guide pin.
- The femoral guide pin should follow a slight craniocaudal direction to diverge from the femoral physis.
- Both ends of the graft should be sutured together, and both threads should be tied together to facilitate their management inside the joint (both threads can be caught by pulling just 1 of them).
- Femoral fixation should be achieved before passing the graft through the second tunnel, to avoid slippage of the graft.
Pitfalls
- It should be checked that the graft can be passed with ease through the diameter calibrator. If not possible, enlargement of the tunnel's diameter is recommended by passing 1 or 2 more times the drill bit through the tunnel or by using a drill bit 0.5 mm wider than the graft.

Discussion

The main feature of the technique presented here is that ACL reconstruction in skeletally immature patients is achieved while preserving the femoral and the tibial physis (Table 3). This issue has been addressed previously by different researchers[8,9]; however, to the authors' knowledge, this is the first technique to propose a second tibial tunnel to achieve physeal preservation. Tibial location of the ACL graft varies according to different techniques: some authors suggest extraarticular tibial fixation without a bone tunnel, passing the graft under the intermeniscal ligament to the anteromedial aspect of the tibia,[2] but this option does not reproduce the anatomy of the ACL faithfully. Other colleagues have proposed an all-epiphyseal tunnel[9]: the fixation of the ACL could be performed with a

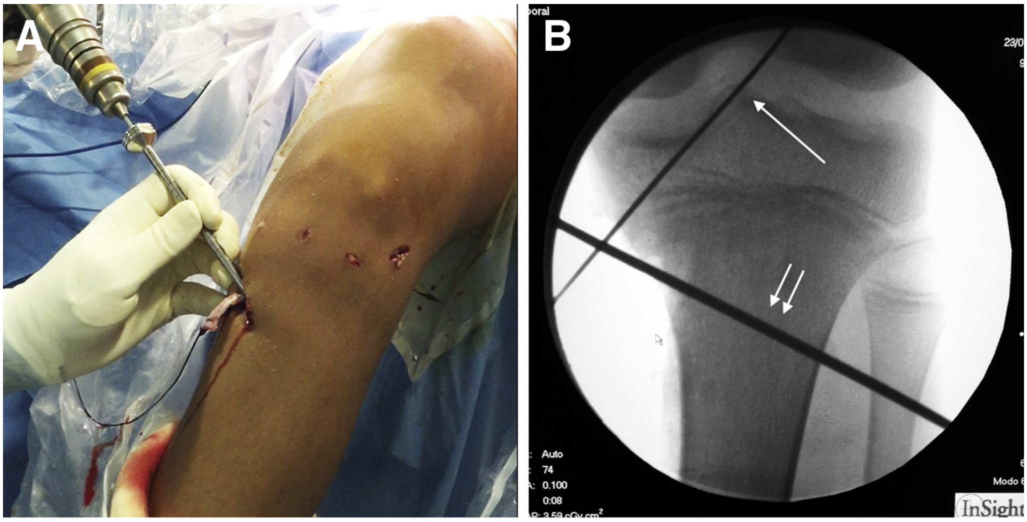

Fig 9. Left knee flexed 90°. (A) Insertion of the guide pin used to perform the second divergent tibial tunnel using the same anteromedial approach used to harvest the hamstring graft and to set the first tibial needle. (B) Radioscopic view of both tibial needles avoiding physeal violation. Arrow, nitinol flexible needle inserted through the all-epiphyseal tibial tunnel; double arrow, second divergent tibial guide pin.

suspension device or a screw. The authors have previously used this technique and believe that, because of the small area available, the resultant tunnel is too shallow and horizontal, and fixation of the ACL in such a tunnel could damage the articular cartilage. The main reason for drilling a second divergent tunnel is to move the pressure of the tibial fixation away from the cartilage and the physis (Table 3). This feature is also helpful in cases in which the bone is softer than expected and the tunnels performed are wider than originally measured, a scenario not unusual in young sedentary women.

Regarding femoral fixation, the authors believe that there is usually sufficient area in the femoral epiphysis

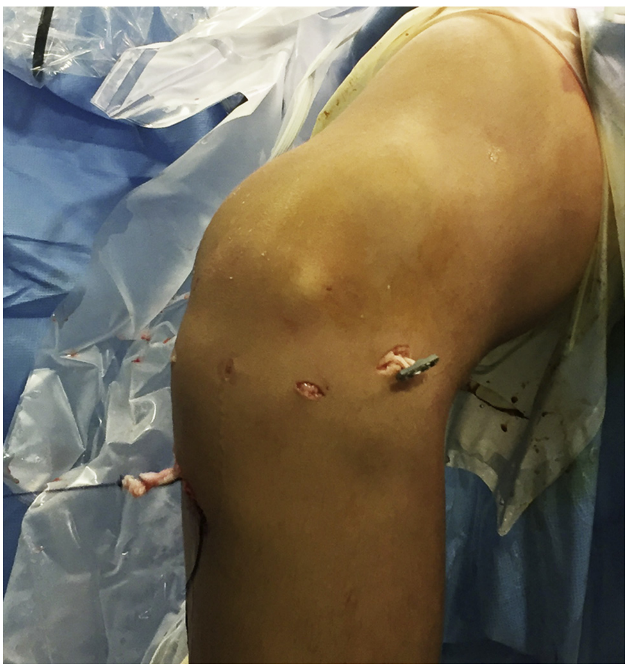

Fig 10. View of the hamstring graft inserted through the femoral and tibial all-epiphyseal tunnels in a left knee flexed 90°, with the suspension device located on the femoral side of the reconstruction and the tibial end of the graft still free.

Fig 11. Frontal view of the left knee with the hamstring graft exiting the all-epiphyseal tibial tunnel after it is pulled in a craniocaudal direction.

Fig 12. Passage of the traction threads of the graft through the second divergent tibial tunnel with the aid of a guide pin, from medial to lateral and from cranial to caudal in a left knee flexed 90°.

Fig 14. Fixation of the graft in the second divergent tibial tunnel in a left knee flexed 30° and neutrally rotated, distal to the physis, using an interference screw, in craniocaudal and mediolateral direction while traction from the graft is applied.

for an all-epiphyseal tunnel, as other authors defend.[8,9] An over-the-top fixation could be justified in these cases of skeletally immature patients,[10] but it would not be an anatomic approach, and the length needed for the second tibial tunnel might limit this option. Another limitation for this technique is that an additional tunnel is required, compromising bone stock, so it should not be used in multiligament knee injuries. There is also a potential risk for soft tissue tethering of the growth plate (Table 3) that may cause growth arrest[2]; to date, however, no growth disturbances or abnormalities have been documented for this reason, to the author's knowledge.

Fig 13. Detail of the part of the hamstring graft between tibial tunnels, leaning on the resultant anteromedial bony bridge (arrow) in a left knee flexed 90°.

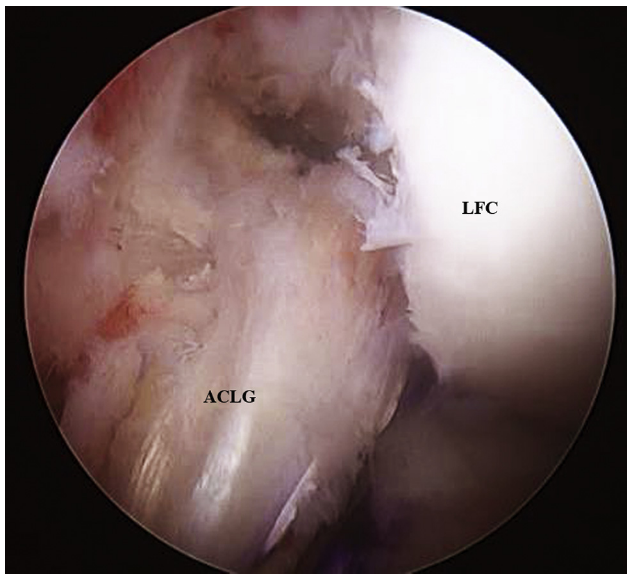

Fig 15. Arthroscopic view of the intercondylar notch with the arthroscope through the central portal: the final status of the anterior cruciate ligament graft (ACLG) is checked arthroscopically. LFC, lateral femoral condyle.

Table 3. Advantages and Disadvantages

Advantages
- Very simple technique, with single diameter drilling of tunnels in outside-in direction
- Physis is spared in skeletally immature patients
- Anatomical insertions of the anterior cruciate ligament (ACL) can be reproduced
- Pressure is moved away from the articular cartilage and the physis
Disadvantages
- Tunnels are performed in outside-in direction, so 2 incisions (1 femoral and 1 tibial) are needed
- Two tibial tunnels are needed, compromising bone stock (the surgeon should be aware of this, especially in multiligament knee injuries)
- A long graft might be needed to fit the second tibial tunnel
- Potential risk for soft tissue tethering of the growth plate

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