Technical Note

Physeal-Sparing, All-Inside Anterior Cruciate Ligament Reconstruction Using Quadrupled Semitendinosus Autograft and Suture Tape Augmentation for Skeletally Immature Patients

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Abstract: The anterior cruciate ligament (ACL) is the primary soft-tissue structure for anterior stabilization of the knee and is one of the most frequently injured structures. The incidence of ACL injuries in children and adolescents ranges from 92 to 151 per 100,000 person-years. The choice of surgical treatment for this population group is controversial, with a widespread concern that adult reconstruction techniques may damage the epiphyseal plate, compromise growth, or cause deformity. In this article, we describe a physeal-sparing, all-inside ACL reconstruction technique for skeletally immature patients. This technique is supported by retrograde drilling of the femoral tunnel and retrograde drilling of the tibial tunnel, both of which are able to avoid the epiphyseal growth line. Fixation of the quadrupled semitendinosus autograft and suture tape augmentation are achieved by soft-tissue buttons on the femur and tibia. The surgical details of this reproducible reconstruction technique are elaborated.

Anterior cruciate ligament (ACL) rupture is one of the most common sports injuries. Between 1994 and 2013, the incidence of ACL tears was reported to range from 92 to 151 per 100,000 person-years among those aged 6 to 18 years.[1] In recent years, the incidence of ACL injuries has shown an increasing trend in skeletally immature patients,[2-5] and this greater injury rate may be associated with the growing participation of children in sports.[3,6]

Anterior cruciate ligament reconstruction (ACLR) is an effective treatment for patients with ACL injuries. The treatment of ACL rupture in skeletally immature patients remains controversial because of the potential for injury to the tibial or femoral epiphyseal plate.[3,4] Some authors recommended nonsurgical treatment based on functional bracing, physical therapy, and activity modification, or even delaying surgical treatment when necessary.[3,7] However, existing literature suggests that a delay of >6 to 12 weeks after injury is associated with recurrent instability and can increase the risk of meniscal (especially medial) and cartilage injury.[3,8] If treatment is delayed beyond 12 weeks, there is an 11-fold increase in the risk of lateral lesions and a 3-fold increase in the risk of chondral lesions of the patellar talus.[2,8]

At present, surgical treatment is considered the gold standard for ACL injuries, although there is little evidence comparing surgical and nonsurgical treatment of ACL injuries in children.[9] Early surgery and ACLR are now advocated for the purpose of reducing concomitant injuries, including meniscal and cartilage damage. Between 1994 and 2006, the number of ACLRs operated in children increased by 9-fold, probably due to the growing participation of this population in high-level sports, as well as improved surgical techniques and diagnostic capabilities.[10,11]

Several surgical techniques for ACLR in children have been described in the literature, and they can be divided

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Table 1. Step-by-Step Details

Patient positioning and arthroscopic exploration	1. Supine with limb at 90° flexion 2. General or regional anesthesia with femoral ischemia cuff 3. Anterolateral and anteromedial portals 4. ACL rupture identification
Graft preparation	1. Semitendinosus autologous tendons 2. The graft is prepared with the GraftLink technique
Femoral tunnel performance	1. Remnant cleaning 2. Footprint of ACL identification 3. Outside-in direction 4. 40° guide opening 5. Physeal-sparing: extra-articular end on distal to the femoral physis, and intra-articular end on the ACL femoral footprint 6. Radiographic control 7. FlipCutter, with the same diameter as the graft
Tibial tunnel performance	1. Remnant cleaning 2. Footprint of ACL identification 3. Outside-in direction 4. 40° guide opening 5. Physeal-sparing: extra-articular end on proximal to the tibial physis, and intra-articular end on the ACL tibial footprint 6. Radiographic control 7. FlipCutter, with the same diameter as the graft
Graft passage and fixation	1. The femoral adjustable loop is retrieved and is ready to flip 2. The graft is pulled hard into the femoral socket 3. The tibial adjustable loop is retrieved and the FiberTape strands are shuttled 4. The graft is pulled hard into the tibial socket 5. The FiberTape sutures are tied in full extension

ACL, anterior cruciate ligament.

into 4 different groups: physeal-sparing, partial transphyseal, transphyseal, and extraphyseal. There is no consensus on which method can best reconstruct the biomechanics of natural ACL.[4,12,13]

In this article, we described a physical-sparing, all-inside ACLR using quadruped semitendinosus autograft and suture tape augmentation (Table 1, Video 1), which is indicated for children and adolescents. This technique allows for better restoration of the intra-articular anatomy and can minimize the risk of epiphyseal injury compared with other techniques that preserve the epiphyseal plate.

Patient Evaluation and Indications for Surgery

Most patients with ACL injuries have a history of acute injuries during sports or physical activity. Some patients may hear a tearing sound in the ACL during an ACL injury. When a patient arrives at the hospital, the first thing the doctor should do is ask the patient for detailed information about the onset and symptoms. This may include the cause of the injury, the level of pain at the time of onset, swelling, a feeling of instability in the knee, and the presence of specific symptoms during activity. The doctor will then perform a clinical examination of the knee, which will include examining the appearance of the injured knee, palpating the injured area, and performing a series of specialized tests, such as the anterior drawer test, Lachman test, and pivot shift test, to evaluate the stability of the ACL. The most common imaging test is magnetic resonance imaging, which can help determine the extent of the ACL tear and whether it is accompanied by damage to other structures.[14] Radiographs of the knee can be used to rule out other bone problems such as fractures. Arthroscopy is the gold standard for diagnosing ACL injuries, and in some cases, the patient's doctor may need to perform an arthroscopy to confirm the extent of ACL damage. Surgery is usually the treatment of choice when the ACL is completely torn, rather than partially torn. Surgery is also recommended for patients with multiple ligament injuries in the knee, combined meniscus injuries, or fractures.[15] Ligament reconstruction should be aggressively pursued surgically when joint instability and unsteady walking are still present after aggressive conservative treatment. Age and the overall health of the patient also can affect the indications for surgery. In general, younger, healthier patients are more likely to benefit from ACL reconstruction surgery. In this Technical Note, we aim to introduce the

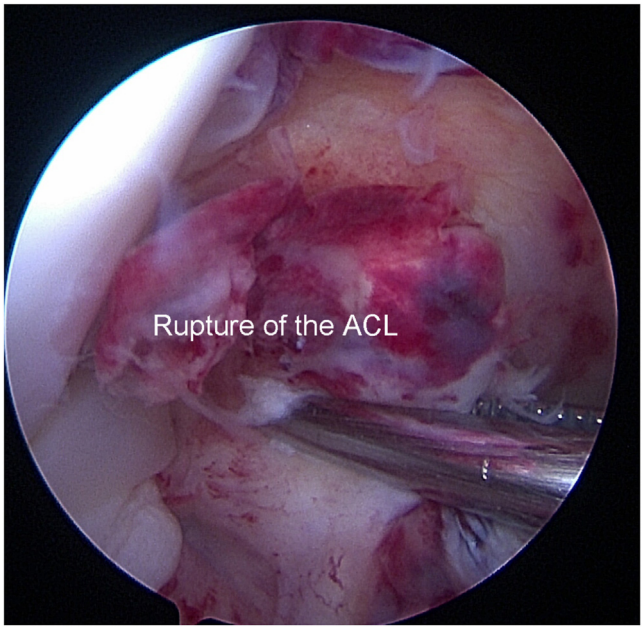

Fig 1. Arthroscopic view of the intercondylar notch of the right knee after the patient is placed in the supine position with the arthroscope set through the AL portal of the right knee. An ACL tear with tibial remnants can be seen. (ACL, anterior cruciate ligament; AL, anterolateral.)

detailed technical steps (Table 1, Video 1) of physeal-sparing, all-inside ACLR using quadrupled semitendinosus autograft and suture tape augmentation for skeletally immature patients.

Surgical Technique (With Video Illustration)

Surgical Position and Arthroscopic Exploration

The patient is administrated general anesthetic while being placed in the supine position. A tourniquet is placed around the thigh with the knee joint flexed at 90°. An anterolateral (AL) portal is created to explore the joint. Routine exploration of the knee includes anterior and posterior cruciate ligaments, medial and lateral meniscus, etc. After the ACL tear is identified (Fig 1), any associated injuries such as meniscal injuries (Fig 2) are addressed at this point with the aid of an anteromedial (AM) portal (if necessary, an additional AM portal can be used). In the meantime, some ACL remnants are removed using a shaver with an appropriate portion retained. If a meniscal injury is found, partial resection or suture can be chosen depending on the specific condition of injury (Fig 2).

Graft Preparation

A 3-cm angled skin incision is made medial to the anterior tibial tuberosity to harvest the semitendinosus tendon using a standard tendon stripper. Preparation of the semitendinosus graft is performed on an assist table. First, the graft is folded and its width is measured with a caliper. Next, the graft is prepared by the GraftLink (Arthrex, Naples, FL) technique with 2 TightRope RT suture buttons (Arthrex) to be fixed on the tibia and femur. The graft length is between 50 and 55 mm, whereas the target graft diameter is between 7 and 9 mm. FiberTape (Arthrex) is shuttled through each hole of the button of the femoral TightRope fixation device. The strands of the FiberTape suture are then crossed and wrapped around the graft bundles, creating a self-reinforcing suture noose when tied.

Femoral Tunnel Performance

The arthroscope is placed into the AL approach, and the radiofrequency probe is entered from the AM approach to reveal and mark the ACL femoral stop. The arthroscope is entered from the AM approach for observation, and the ACL femoral locator (Arthrex) is placed into the joint cavity from the AL approach, with the locating point placed at the point marked previously (center of the femoral footprint). After a 1-cm incision is made at the level of lateral epicondyle, a guide pin is passed with the aid of a standard ACL guide set at 40° under radioscopic control, in an outside-in and slight craniocaudal direction (Fig 3), starting in a position distal to the femoral physis, with the needle tip exiting the femur in the center of the ACL footprint intra-articularly (Fig 3). Once the fluoroscopic position is satisfactory, the FlipCutter (Arthrex) of an appropriate size is used to drill from the lateral cortex to the guide on the footprint. The FlipCutter is then deployed and used to drill the femoral socket retrograde to approximately 25 mm. Subsequently, the FlipCutter is advanced into the joint, closed, and removed through the lateral cortex. Lastly, a polydioxanone (PDS) suture is advanced through the guide, delivered out the AM portal, and tagged for later graft passage.

Tibial Tunnel Performance

The arthroscope is viewed from the AM approach with the anterior tibial cruciate ligament guide set at approximately 40° and placed through the AM approach. The guide is placed approximately 2 cm medial to the tibial tuberosity. A guide pin is passed with the aid of the ACL guide under radioscopic control, starting in a position close to the tibial physis, with the needle tip exiting the tibial in the center of the ACL footprint intra-articularly (Fig 4). Once the fluoroscopic position is satisfactory, the FlipCutter (Arthrex) of an appropriate size is used to drill from the lateral cortex to the guide on the footprint. The FlipCutter is then deployed and used to drill the tibial socket retrograde to approximately 15 to 20 mm. Subsequently, the FlipCutter (Fig 4) is advanced into the joint, closed, and removed through the lateral cortex. Lastly, a PDS

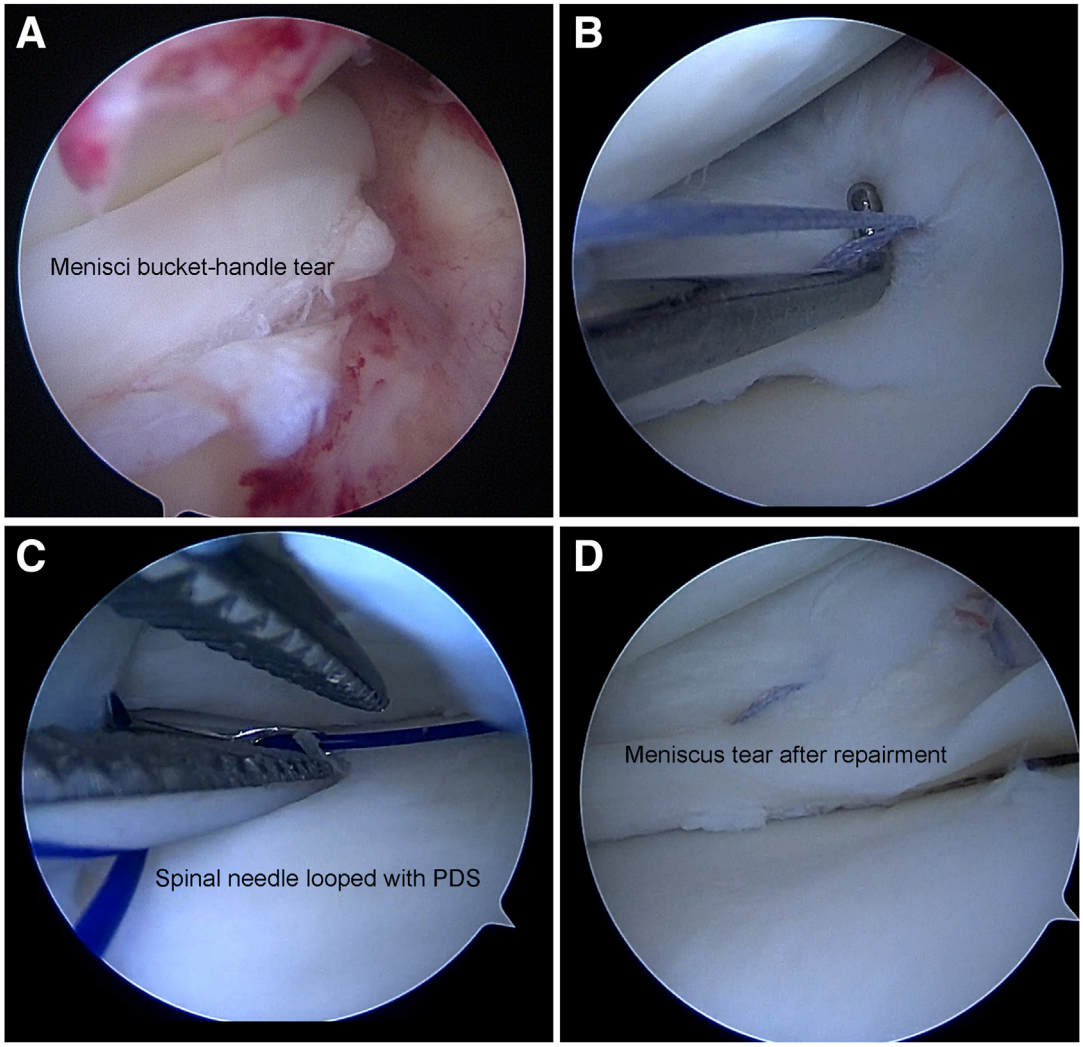

Fig 2. The patient is placed in the supine position with arthroscopic meniscal injury and management of the right knee. (A) Menisci bucket-handle tear of the lateral meniscus in a right knee is checked using a probe, with the arthroscope set through the AL portal of the right knee. (B) Posterior horn tear of the lateral meniscus of the right knee is sutured with a total internal suture technique as viewed from the AM portal of the right knee. (C) Lateral meniscus body tear of the right knee is sutured from the outside to the inside. The spinal needle is shown to loop with PDS as viewed from the AM portal of the right knee. (D) Lateral meniscus tear after repairment as viewed from the AL portal of the right knee. (AL, anterolateral; AM, anteromedial; PDS, polydioxanone.)

suture is advanced through the guide, delivered out the AM portal, and tagged for later graft passage.

Graft Passage and Fixation

The PDS threads of both the femoral and tibia are grasped out once from the AM approach to further ensure that the PDS sutures are not tangled (Fig 5). The femoral TightRope sutures are shuttled using PDS suture at the femoral end through the AM portal. The femoral adjustable loop is retrieved from the AM portal until the graft is seen at the tibial orifice intra-articularly, which indicates that the button has exited the femoral cortex proximally and is ready to flip. Once the button flips, the graft is then pulled hard into the femoral socket (Fig 5). Usually, only 20 to 25 mm of the graft should be pulled inside the femoral socket during femoral TightRope tensioning. The tibial TightRope and internal brace sutures are then retrieved using PDS suture at the tibial end through the tibial socket to the outside. Once the tibial TightRope and the internal brace sutures are outside the tibial cortex, the FiberTape strands are shuttled through the TightRope holes alongside the TightRope sutures. The graft is then pulled hard into the tibial socket. Similarly, only 15 to 20 mm of the graft should be pulled inside the tibial socket during tibial TightRope tensioning in usual cases. Subsequently, the FiberTape sutures are tied over the tibial TightRope in full extension (Fig 5). The knee

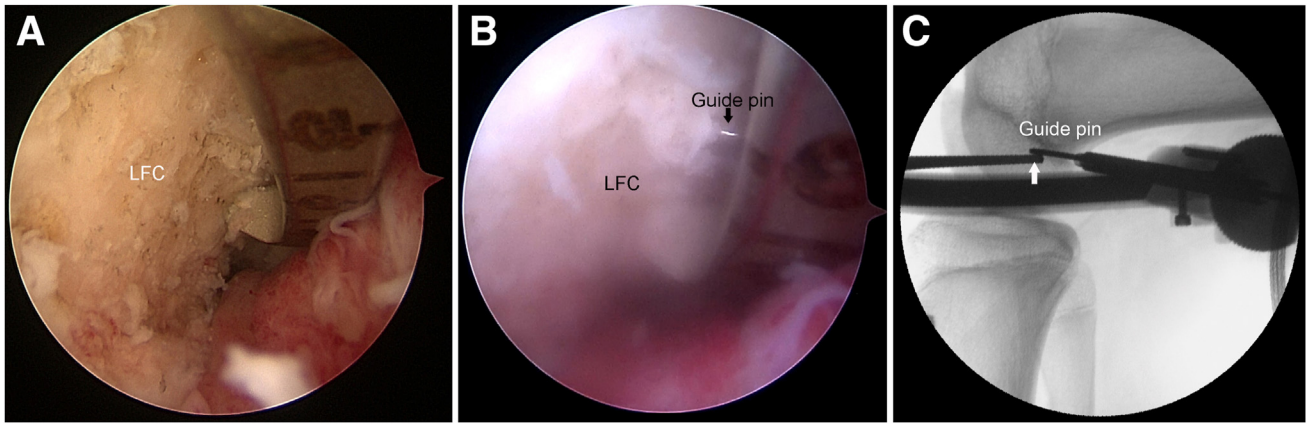

Fig 3. Femoral tunnel performance. (A) The right knee is flexed to 90° and the arthroscopic view of the right knee in the supine position is observed from the AM portal. The femoral aiming device is placed in the center of the ACL femoral footprint of the right knee. (B) Intra-articular view of the right knee, with the arthroscope set through the AM portal: in a 40° direction, in an outward and slightly craniolateral direction, the tip of the 2-mm guide pin is inserted through the lateral condyle and exits the femur at the center of the ACL footprint of the right knee. (C) Radioscopic lateral view of a 2-mm guide pin placement (arrow) during all-inside ACL reconstruction of the right knee. The guide pin is oriented in a 40° direction, outward and slightly craniolateral. (ACL, anterior cruciate ligament; AM, anteromedial; LFC, lateral femoral condyle.)

should be checked after internal brace tensioning to ensure that full range of motion is retained. Postoperative radiographs and computed tomography plain radiographs show excellent positions of hardware and tunnels (Fig 6).

Rehabilitation

The postoperative rehabilitation is similar to that of standard ACLR. Full weight-bearing and progressive range of motion exercises are encouraged. The postoperative program includes early mobilization and weight-bearing as tolerable. The child is allowed to remove or put on the brace if he/she wishes. Closed-chain exercises should be initiated early in the postoperative period, with emphasis on obtaining full extension and quadriceps movement. Routine postoperative physical therapy should continue for 6 weeks, followed by a guided exercise program. As rehabilitation progresses, physical activity can be gradually resumed.

Discussion

As common knee injuries, an increasing trend in the rate of ACL tears in adolescents has been reported in recent years.[1] Therefore, the ACLR technique aiming at this particular patient group has become a popular topic. Some scholars have advocated the preference of nonsurgical treatment for patients with epiphyseal

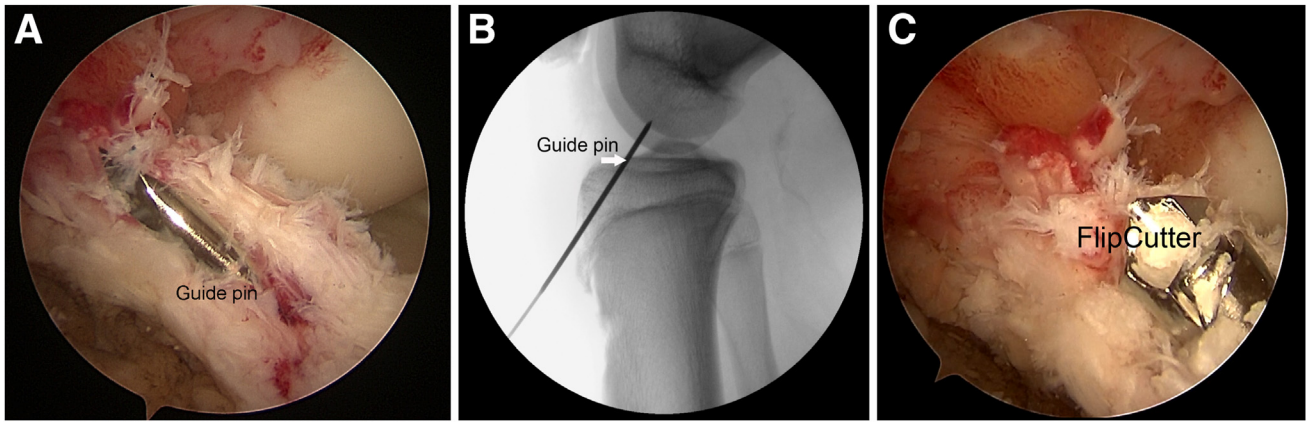

Fig 4. Tibial tunnel performance. (A) Intra-articular view of the right knee. The arthroscope is viewed from the AM approach with the anterior tibial cruciate ligament guide set at approximately 40° and placed through the AM approach. The guide is placed approximately 2 cm medial to the tibial tuberosity. The tip of the guide pin is inserted through the tibial and exits the tibial at the center of the ACL footprint in the right knee. (B) Radioscopic lateral view of intra-articular tibial pin (arrow) within the right knee. (C) Introduction of FlipCutter (Arthrex) into the right knee joint through the tibial insertion of ACL. (ACL, anterior cruciate ligament; AM, anteromedial.)

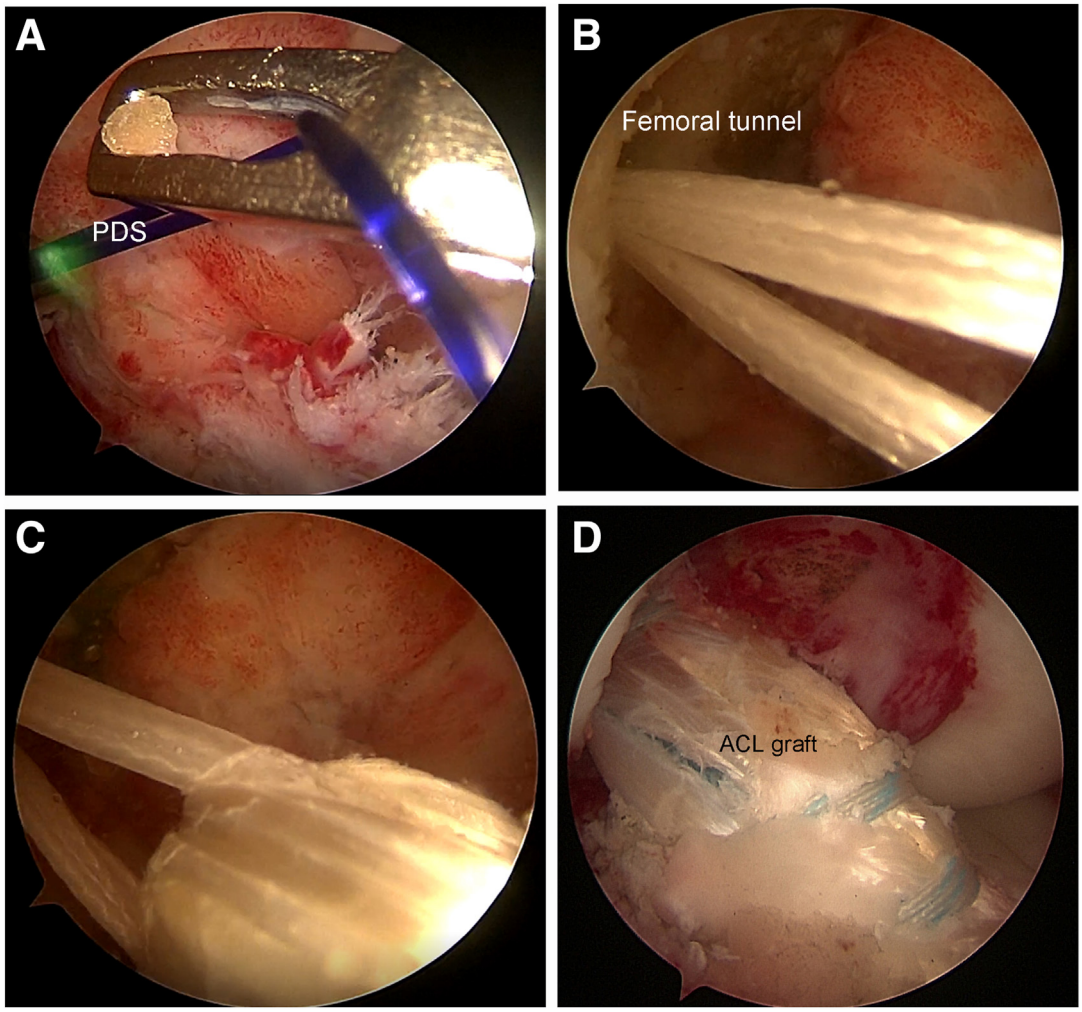

Fig 5. Graft passage for all-inside ACL reconstruction and internal bracing of the right knee. (A) The PDS of the femoral and tibial is grasped with wire graspers from the AM approach of the right knee as viewed from the AL portal of the right knee. (B) Femoral tunnel of the right knee. (C) The ACL graft is passed through the femoral socket of the right knee first, and then the shortening strands of the TightRope are alternately pulled to seat the graft in the femoral socket of the right knee. (D) New ACL as viewed from the AL portal of the right knee. The femoral and tibial parts of the graft are tensioned until tight when the right knee is flexed 20°. (ACL, anterior cruciate ligament; AL, anterolateral; AM, anteromedial; PDS, polydioxanone.)

immature ACL injuries in order to avoid causing growth disturbances in adolescents, which is the main cause of controversy in the treatment modalities of ACL injuries in children and adolescents.[16,17] However, there are also relevant studies that suggest that delaying surgery may lead to further damage to the cartilage and meniscus.[2,8,18] Previous data showed that 21% to 100% of the pediatric patients suffered meniscal injury in conjunction with ACL injury.[19] Several studies have also reported that surgical reconstruction provided better outcomes.[20]

Regarding the choice of surgical approach for ACLR, epiphyseal extracorporeal ACLR has been demonstrated to be a technique characterized by the advantage of a low rate of reported growth disturbances. In 1997, Stähelin and Weiler[21] published an all-inside technique in which the tibial socket is fabricated from the inside out and the graft is fixed at both ends with interference screws. The all-epiphyseal technique, which is most often performed using a “total internal” arthroscope, allows for anatomic ACLR without the need to drill a tunnel across the epiphyseal plate. This technique is most useful for those with significant remaining bone. However, there are also some disadvantages: (1) a long learning curve, which is technically challenging; (2) the potential risk of "bottoming out" the graft, which can result in insufficient tension; and (3) high cost due to the fact that a disposable retrograde drill targeting device is required for each tunnel. Further, several studies have shown that the all-medial technique has similar or superior biomechanical properties and clinical outcomes compared with the more traditional all-tunnel cruciate ligament reconstruction technique.[22] Moreover, the partial transepiphyseal lateral cruciate ligament is

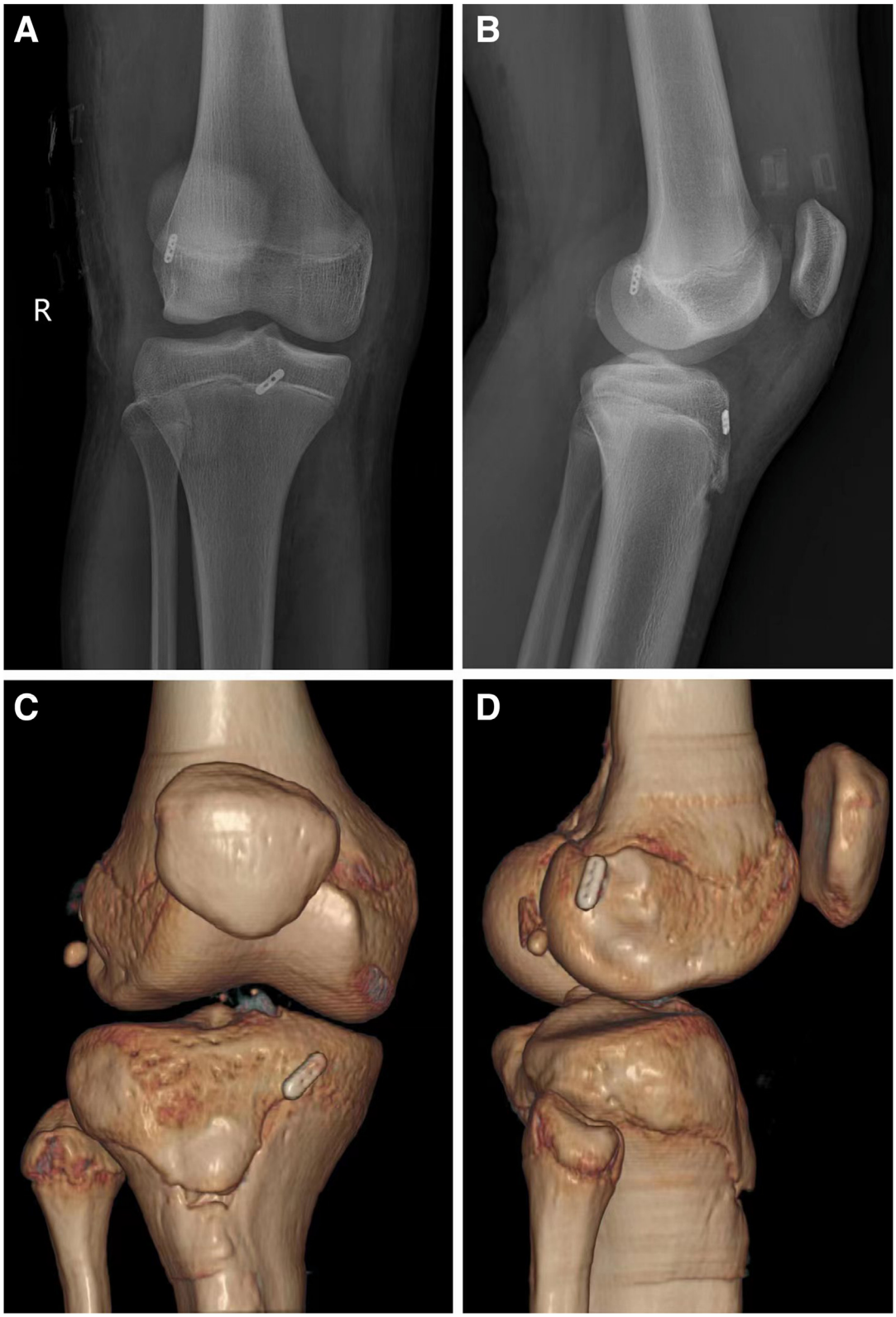

Fig 6. (A) Orthostatic radiography of the right knee with physeal-sparing, all-inside ACL reconstruction and fixation with TightRope RT suture buttons. (B) Right lateral radiography of the right knee with physeal-sparing, all-inside ACL reconstruction and fixation with TightRope RT suture buttons. (C) Orthopantomographic CT plain film of the right knee with physeal-sparing, all-inside ACL reconstruction and fixation with TightRope RT suture buttons. (D) Right lateral CT plain film of the right knee with physeal-sparing, all-inside ACL reconstruction and fixation with TightRope RT suture buttons. (ACL, anterior cruciate ligament; CT, computed tomography.)

advocated for those approaching puberty, whereas the transepiphyseal ACL, which is the most traditional technique used in ACLR, is most commonly used in those approaching skeletal maturity.

Graft selection for ACLR in patients with immature bone is also an important consideration for surgeons. The bone−patella tendon−bone autograft is the gold standard for ACLR in adults, with advantages of rapid tissue integration and low potential re-rupture rate.[23] However, it is not recommended for skeletally immature patients due to concerns about epiphyseal adhesions and bone rod formation within the epiphyseal plate. The use of quadriceps as a graft is less invasive and carries a lower risk of patellar fracture, but there is a lack of literature regarding its efficacy and safety in the pediatric population. The advantages of hamstring grafts include easy harvesting, no risk to the body, and no risk of patellar fracture, whereas disadvantages include a potentially greater rate of re-rupture, reduced sprint velocity, and variable graft size.[24] In a relevant study, the clinical results of primary ACLR using the 4-chain hamstring technique were reported to be comparable with the patellar tendon technique, with significantly fewer postoperative complications. Therefore, we chose to use the semitendinosus autograft as a graft in our technique, which is in line with the latest trend of preferring the use of popliteal autograft.[25]

Intraoperative suture tapes are used as reinforcement. In a retrospective study, the safety and complications, graft failure, and reoperation rates were reported to be lower for popliteal autografts with independent suture tape reinforcement compared with ACLR with popliteal autografts without reinforced suture tapes in at least 2 years of follow-up.[26] Children and adolescents may require more time to recover than adults, and a more careful postoperative protocol, as well as resumption of exercise no earlier than 9 months postoperatively, has been shown to reduce the risk of reoperation and revision in children.[27]

Disclosures

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