Technical Note

Transphyseal Anterior Cruciate Ligament Reconstruction Using Hybrid Transtibial Femoral Drilling and a Quadriceps Tendon Autograft

Tyler Robert Johnston, M.D., M.S., Jessica Hu, B.S., Bonnie Gregory, M.D., Jordan Liles, M.D., and Jonathan Riboh, M.D.

Abstract: Significant controversy exists regarding the optimal surgical technique for anterior cruciate ligament (ACL) reconstruction in adolescents with 1 to 3 years of skeletal growth remaining. Graft choice and physeal injury remain primary concerns given significantly elevated rates of failure of hamstring autograft reconstructions in this population, as well as risks of leg-length discrepancy and growth axis deviation. Traditional (more vertical) transtibial drilling of the femoral tunnel can reduce risks of physeal injury but has been shown to have less accuracy restoring the native femoral ACL footprint and associated incomplete knee stabilization. On the other hand, anteromedial and outside-in drilling yields improvements in the tunnel location and biomechanics but at the cost of a more oblique trajectory and greater risk of physeal injury. A hybrid transtibial pin technique using a Pathfinder guide facilitates femoral drilling with the "best of both worlds," allowing for reproduction of the native ACL footprint and a more physeal-respecting femoral tunnel. When combined with an all—soft tissue quadriceps tendon autograft and suspensory fixation, the hybrid transtibial method yields a reliable, safe, and robust construct with promising results for the young athlete. We describe our preferred graft harvest, tunnel drilling, and fixation techniques to minimize physeal risks and optimize outcomes.

There is an increasing body of literature showing that nonoperative treatment of anterior cruciate ligament (ACL) tears in children and adolescents leads to low levels of return to sport, compromised patient-reported outcomes, and a dramatically increased risk of chondral and/or meniscal injury. As a result, growth-respecting ACL reconstruction (ACLR) is now considered by many surgeons to be the treatment of choice for ACL injury in the growing athlete.[1,2] However, the risk of physeal injury remains a primary concern with leg-length discrepancy and/or axis deviation rates of 1.8% to 2.6% reported in the literature.[3,4] Completely physeal-sparing techniques such as Micheli-Kocher iliotibial band or all-epiphyseal reconstruction have been advocated in the youngest, prepubertal patients, with good reported outcomes. Adult-type reconstructions can be performed in late adolescents with little to no growth remaining.[5,6] The most significant controversy exists for the "in-between" population, typically children with 1 to 3 years of growth remaining.

The most common technique in this population is transphyseal reconstruction, in which tibial and femoral tunnels are drilled across the growth plates but following a set of guidelines to minimize volumetric injury to the physis. One of the key principles is to maintain a drilling path as perpendicular as possible to the physis to minimize the surface area of injury.[7] Thus, most descriptions of the transphyseal technique use a transtibial femoral drilling strategy to minimize femoral tunnel obliquity. Unfortunately, this comes at the expense of femoral tunnel accuracy and recapitulation of knee stability, given that it is well documented that

From the Department of Orthopaedic Surgery, Duke University Medical Center, Durham, North Carolina, U.S.A.

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Address correspondence to Tyler Robert Johnston, M.D., M.S., Department of Orthopaedic Surgery, Duke University Medical Center, Box 3615 Durham, NC, 27701, U.S.A. E-mail: tyler.johnstonmd@gmail.com

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reaching the anatomic center of the femoral ACL footprint is difficult or sometimes impossible using a transtibial strategy.[8-10] Additionally, using outside-in or anteromedial (AM) portal femoral drilling techniques leads to significant coronal tunnel obliquity and increased concern for physeal injury.

Accordingly, as a surgeon considers transphyseal ACLR techniques, there exists an apparent trade-off between an anatomic location of the femoral tunnel and the risk of physeal disruption. The hybrid transtibial technique offers a unique solution to this dilemma because medial portal guidance of a transtibial guidewire has been shown to allow excellent reproduction of the anatomic ACL footprint while maintaining the more vertical orientation of a traditional transtibial tunnel, essentially accomplishing the "best of both worlds."[11]

We describe transphyseal ACLR using the hybrid transtibial technique, specifically using the Pathfinder femoral guide system (DanaMed, Chadds Ford, PA). In this unique population of adolescents, alarmingly high rates of graft failure have been reported (approximately 20%) using hamstring autograft.[4,12] Therefore, our preference in this population has been to use an all—soft tissue quadriceps tendon (QT) autograft with suspensory femoral and tibial fixation to avoid any hardware across the physes. The QT autograft continues to gain momentum as a safe and reliable option for ACLR with a potentially reduced incidence of graft retear (4%-8% reported in adolescents).[12-17]

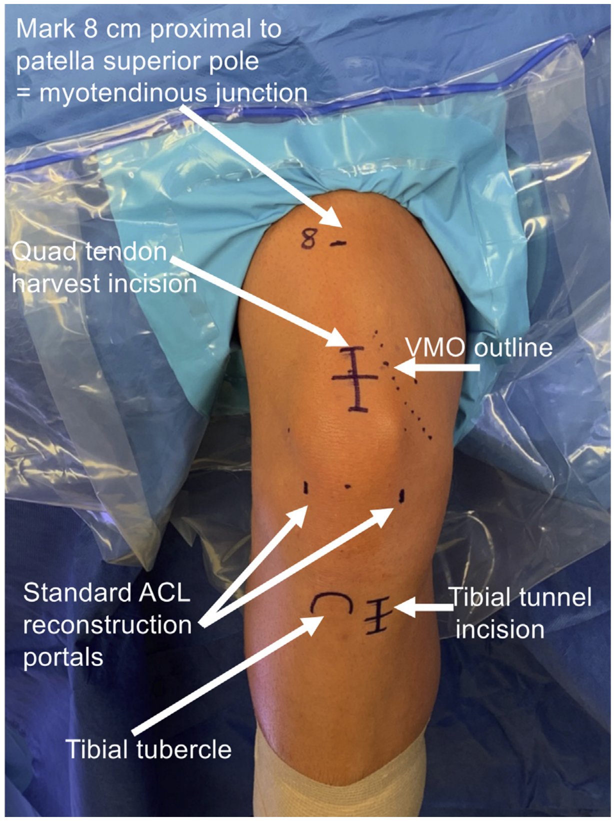

Fig 1. Planned surgical skin incisions for anterior cruciate ligament (ACL) reconstruction in a right knee (the right part of the image is medial, with the foot at the inferior part of the image). Standard arthroscopic ACL reconstruction incisions are used with a 2-cm longitudinal quadriceps (Quad) tendon harvest incision extending 2 cm proximally from the proximal pole of the patella, just lateral to the vastus medialis oblique (VMO) contour (dotted line).

Surgical Technique

Patient Setup

The patient is positioned supine with a nonsterile thigh tourniquet placed as proximally as possible on the operative thigh. The foot of the bed is dropped to allow easy knee hyperflexion while the operative leg is secured with a low-profile leg holder (Arthrex, Naples, FL). Great care is taken to prevent any pressure on the perineum. The contralateral leg is placed in a well-padded lithotomy stirrup allowing circumferential access to the operative leg, while the bed is placed in a slight Trendelenburg position with mild flexion to relax the lumbar spine.

Portals and Incisions

Preliminary skin markings are made with the knee flexed to 90° and include the distal contour of the vastus medialis oblique (VMO) muscle, the margins of the patella, and the tibial tubercle (Fig 1). The QT graft harvest incision is a 2-cm longitudinal midline incision centered over the tendon, just lateral to the VMO edge, with two-thirds above the superior patellar pole and one-third below. Along the same vector as the QT, a point 8 cm proximal to the superior patellar pole is measured and marked, demarcating the typical location of the myotendinous junction of the rectus femoris, which should be the most proximal aspect of the harvest to avoid rectus retraction and cosmetic deformity of the thigh. The planned skin incision for the tibial tunnel is longitudinal, 2 cm in length, just proximal to the superior border of the pes anserinus and midway between the anterior and posterior margins of the medial tibia (Fig 1, Video 1). Standard arthroscopic portals for arthroscopic ACLR are recommended, with a "high-and-tight" anterolateral portal and an AM portal localized with a spinal needle to optimize the angle of approach of the Pathfinder guide to the lateral wall of the notch.

Graft Harvest

The QT graft is harvested in similar fashion to the technique previously described by Slone et al.[18] In brief, the skin is incised sharply while an insulated-tip Bovie device (Bovie Medical, Clearwater, FL) is used to elliptically remove subcutaneous fat to improve

Table 1. Equipment

Quadriceps tendon graft harvest and preparation
Low-profile leg holder (Arthrex)
Medium vaginal speculum
Parallel-blade Quad Tendon Graft Cutting Guide (Arthrex), with 10-mm blade width recommended
0.5-inch straight osteotome
Cigar cutter (Quad Tendon Stripper Cutter; Arthrex)
Scorpion arthroscopic suture passer (Arthrex)
Hybrid transtibial femoral tunnel
Tibial guide and pin (elbow recommended)
Low-profile straight reamer for tibia
Cannulated tibial plug
Pathfinder ACL guide (DanaMed), left or right, sized with 5.5-, 7-, or 8-mm offset
Pathfinder guide pin with sheath (DanaMed), 2.4 mm
Flexible reamer sized to desired femoral tunnel size
4.5-mm flexible reamer for lateral femoral cortex perforation
Fixation
No. 2 FiberLoop with FiberTag (Arthrex)
TightRope RT (Arthrex)
ABS loop (Arthrex)
ABS concave button (Arthrex)

visualization (Video 1). A longitudinal paratenon incision is created and extended proximally and distally with dissecting scissors while blunt dissection with a Cobb elevator and sponge is performed to fully expose the QT to the 8-cm mark proximally and distally over the superior pole of the patella. One limb of a medium vaginal speculum is inserted and used to retract the anterior skin as the arthroscope is inserted to visualize QT exposure all the way to the myotendinous rectus margin. The proximal myotendinous margin should then be marked on the overlying skin, confirming the trajectory of planned QT harvest. A marking pen is also used to identify the superior pole of the patella on the QT and the medial border of the planned QT harvest, leaving a 1- to 2-mm cuff of tendon between the graft and the VMO. An Arthrex 9-, 10-, or 11-mm parallel quadriceps harvest blade (Table 1) is inserted at the level of the proximal patellar pole, with downward pressure applied to make sure the full depth (7 mm) of the blade is engaged. This allows for very consistent graft thickness. The blade is then advanced from distal to proximal, maintaining the 7-mm cutting depth, until the length markings on the blade read 70 mm at the proximal patellar pole (Fig 2, Video 1).

A No. 15 scalpel is used to create a transverse cut through the QT and periosteum on the patella at the distal extent of the graft. The graft is then carefully elevated off the patella, feathering it from the curved bony surface with the No. 15 blade. This dissection

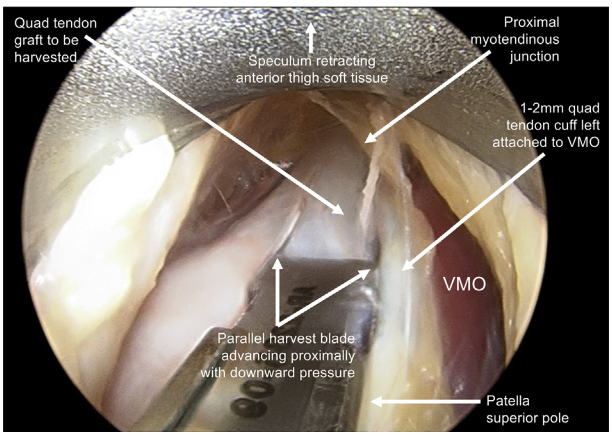

Fig 2. Dry arthroscopic view of quadriceps (Quad) tendon in a right knee as harvesting begins with a parallel blade (the right part of the image is medial, with the patella at the inferior part of the image); the speculum limb retracts the anterior thigh soft tissue (superior part of the image). A 1- to 2-mm cuff of tendon is retained at the lateral vastus medialis oblique (VMO) muscle margin and preserved for tendon integrity and closure (as necessary). A parallel blade is advanced proximally toward the myotendinous junction while downward pressure is applied for a target graft harvest thickness of 7 mm.

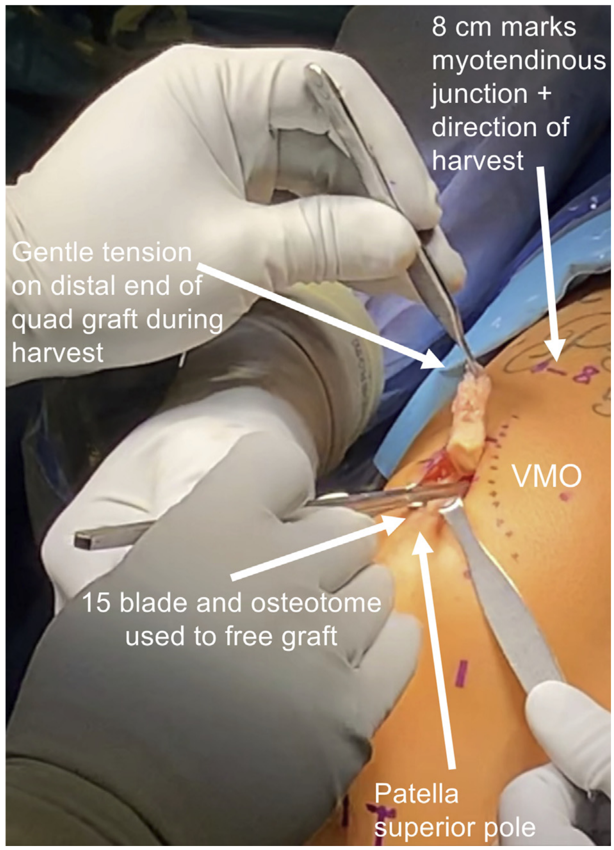

Fig 3. Quadriceps (quad) tendon graft liberation after incision with a parallel blade in a right knee (the right part of the image is medial, with the tibia at the inferior part of the image). The graft is gently tensioned with forceps in the non-dominant hand while a No. 15 blade and osteotome are used to proximally liberate the graft at the deep and medial-lateral tissue planes, until approximately 5 cm of graft is freed. (VMO, vastus medialis oblique.)

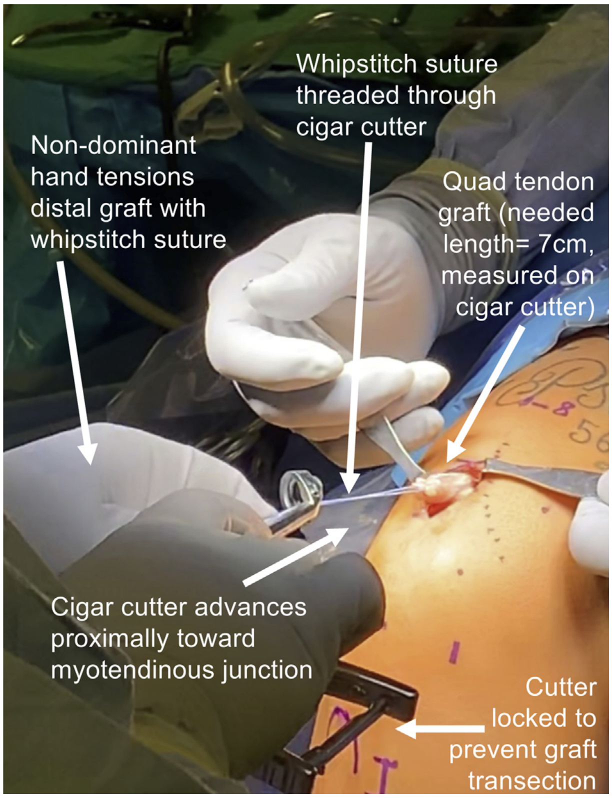

Fig 4. Quadriceps (Quad) tendon graft final harvest and transection with a cigar cutter in a right knee (the right part of the image is medial, with the tibia at the inferior part of the image). Distal graft whipstitch suture is threaded through the cutter and tensioned with the non-dominant hand while the cigar cutter is sequentially advanced proximally in the direction of the quadriceps myotendinous junction (previously marked on the skin). The cutter is kept locked until 7 cm of tendon is liberated (measured on the handle of the cutter), at which time it is unlocked and the graft is transected

plane on the undersurface of the graft is carried proximally 4 to 5 cm, or as far as possible based on incision length. If possible, a partial-thickness graft should be harvested, although in smaller patients, a full-thickness harvest may be required to achieve the desired 7 mm of graft thickness. If proper closure is achieved, we have not noted any ill effect of a full-thickness harvest. If needed, gentle proximally directed strokes with a 0.5-inch straight osteotome can be used to enhance and advance the graft-tendon harvest planes (Fig 3). Once the graft is clearly defined and approximately 5 cm is released, the distal end is whipstitched with nonlocking suture passes used for graft control. A locked cigar cutter (Quad Tendon Stripper Cutter; Arthrex) is inserted over the suture limbs and is passed superiorly, co-linearly with the QT, until 70 mm of graft is measured on the cutter (Fig 4, Video 1). The cigar cutter is unlocked, and the graft is transected at its proximal end. Any capsular defect should be closed with No. 0 absorbable braided suture with figure-of-8 stitches using an Arthrex Scorpion suture passer under dry arthroscopic visualization as needed (Fig 5). The skin incision must be left open during arthroscopy to allow fluid egress and prevent subcutaneous fluid accumulation and thigh compartment compression.

Graft Preparation

The graft is moved to the back table, length is confirmed, and each end is prepared using a No. 2 FiberLoop with FiberTag whipstitch (Arthrex), with the femoral end secured around a TightRope RT (Arthrex) and the tibial end secured around an ABS loop (Arthrex; Table 1, Video 1).[18] Twenty millimeters is measured and marked from the end of the femoral and tibial sides (planned length in each tunnel, Fig 6). Both femoral and tibial end diameters are measured (the femoral end should never be larger than the tibial end because this will inhibit graft passage). The graft is then tensioned to 20 lb and covered in moist gauze.

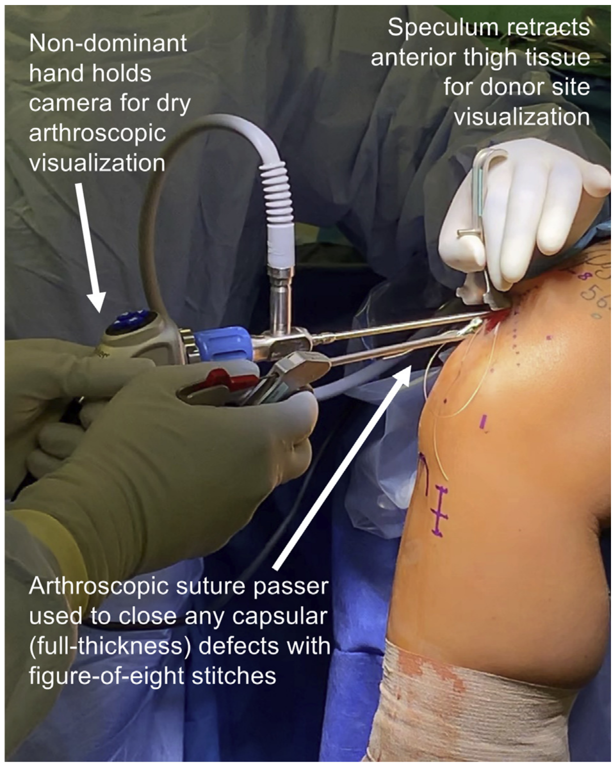

Fig 5. Visualization and repair of quadriceps tendon graft donor site with (dry) arthroscopic camera in a right knee (the right part of the image is medial, with the tibia at the inferior part of the image). The non-dominant hand holds the camera while the assistant retracts the anterior soft tissue with a speculum. Any full-thickness tendon defects (capsule violated) are closed with figure-of-8 stitches of No. 0 absorbable braided suture, using an arthroscopic suture passer as needed or desired. The harvest incision skin is left open (not closed) to allow for fluid egress for the remainder of the procedure.

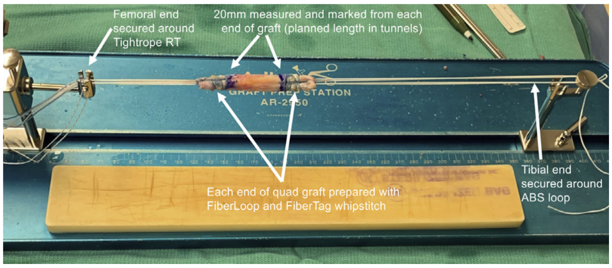

Fig 6. Quadriceps (quad) tendon graft preparation at graft station. Each end is prepared using a No. 2 FiberLoop with FiberTag whipstitch. The femoral end (left) is secured with a TightRope RT button, whereas the tibial end (right) is joined to an ABS loop. Twenty millimeters is measured and marked from each end (expected length of graft in the tibial and femoral tunnels), and each end is sized (the femoral end should never be larger than the tibial end because this will prevent graft passage). The graft is tensioned to 20 lb and covered with moist gauze until needed.

Compression tubes (Arthrex Graft Tubes) may be applied as desired.

ACL Tibial Tunnel Preparation

Diagnostic arthroscopy is performed via a standard high-and-tight anterolateral portal, with a superomedial outflow portal. Spinal needle localization of the AM portal is critical to ensure that the portal is sufficiently low and medial to allow perpendicular access of the Pathfinder guide to the lateral wall of the notch, allowing for proper pin trajectory and easy "hooking" onto the posterior aspect of the lateral femoral condyle (Fig 7, Video 1). With careful placement of the AM portal, we have eliminated the need for notchplasty in our practice. The extra-articular opening of the tibial tunnel is prepared by incising the skin over the proximal medial tibia halfway between the anterior and posterior tibial margins and completing this dissection down to bone using electrocautery (Video 1). Care must be taken not to stray too lateral with the deep dissection to avoid injury to the tibial tubercle apophysis. An elbow guide (Acufex Pinpoint Anatomic ACL Guide System; Smith & Nephew, Andover, MA) is inserted through the AM portal, set at 60° to provide a more vertical trajectory through the tibial physis, and positioned in the center of the ACL tibial footprint. The drill sleeve is advanced to bone, sufficient tunnel length is confirmed, and a 2.4-mm guide pin is advanced into the joint (Fig 8). The guide is removed, and the location of the tibial pin is verified relative to the native ACL footprint in flexion and then in full extension to confirm that no graft impingement will occur at the roof of the notch (Video 1). In resting flexion, the pin is advanced into the notch with a mallet; the pin is then over-reamed with the appropriately sized low-profile reamer, based on the tibial graft diameter. The tibial tunnel diameter should be slightly larger than the femoral side of the graft (0.5 mm) to facilitate graft passage. Electrocautery is used to clear soft tissue at the extra-articular tibial tunnel aperture, while a shaver is used to remove soft tissue obstructing the intra-articular aperture. The shaver is placed through the tibial tunnel and used in burr mode to smooth the posterior aspect of the tunnel to facilitate graft passage and prevent graft laceration. Finally, a cannulated plug is screwed into the tibial tunnel to maintain arthroscopic pressure.

Hybrid Transtibial Femoral Tunnel Preparation

A Pathfinder ACL guide (DanaMed; Table 1) with appropriate laterality is selected. This guide is available with a 5.5-, 7-, or 8-mm offset, depending on the planned femoral tunnel diameter and the size of the patient's femoral condyle. The guide is inserted through the AM portal, and the ability to hook the offset arm and center the guide on the femoral footprint is confirmed. The flexible guide pin and plastic sheath are then inserted through the tibial tunnel and captured in the guide within the joint (Fig 9).[19] Slight knee extension is often required to align the pin and the slot in the guide in the sagittal plane. Once the guide-pin complex is centered on the ACL footprint, the pin is advanced 1 to 2 mm to secure the starting point. Then, the guide hand must be dropped below the plane of the tibiofemoral joint, and knee flexion of at least 90° must be maintained (Fig 10A, Video 1). Higher degrees of flexion can be used to guide the tunnel trajectory as perpendicular as possible to the physis. This ensures an

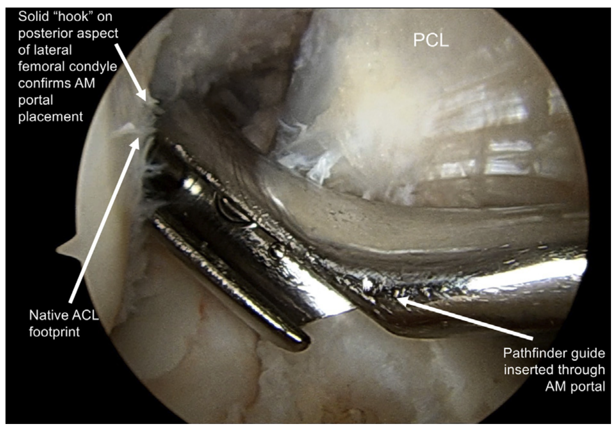

Fig 7. Confirmation of appropriate anteromedial (AM) portal placement in a right knee while viewing from the anterolateral portal (the right part of the image is medial, with the tibia in the inferior part of the image). After initial needle localization of the AM portal and diagnostic arthroscopy and/or debridement of the native ACL, the Pathfinder guide is inserted through the AM portal to confirm the ability to "hook" onto the posterior aspect of the femoral notch. This is essential so that the guide pin can be delivered to the native ACL femoral footprint and the native ligament trajectory may be re-created. (PCL, posterior cruciate ligament.)

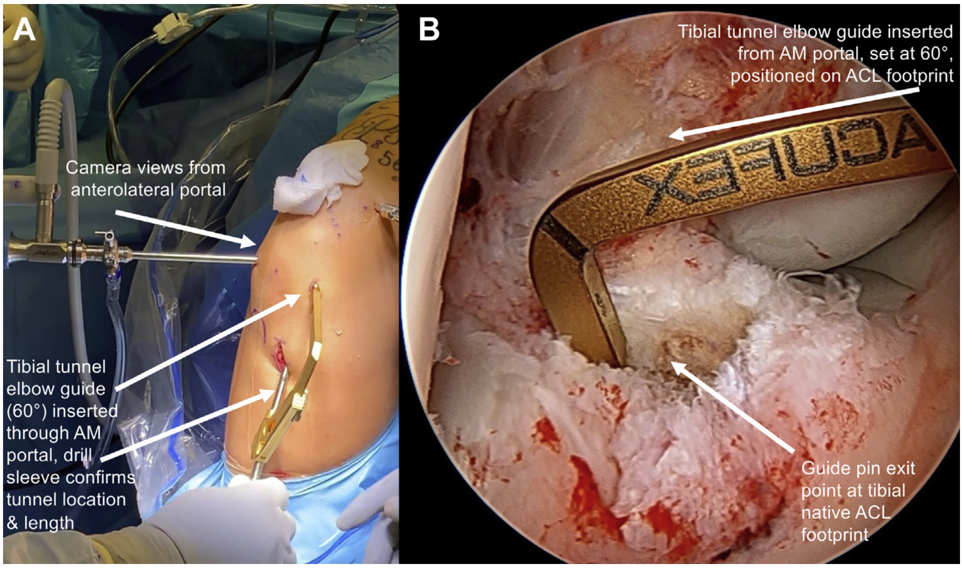

Fig 8. External (A) and arthroscopic (B) views during tibial tunnel preparation in a right knee. (A) An elbow guide is inserted through the anteromedial (AM) portal (the right part of the image is medial) and is set to 60° to maintain a vertical tunnel trajectory; the drill sleeve is advanced to the tibia to confirm an appropriate tunnel length and starting point. (B) Arthroscopic view from anterolateral portal looking across the knee at the medial condyle. The elbow guide (inserted from the AM portal) is positioned over the native anterior cruciate ligament (ACL) tibial footprint to receive the guide pin and re-create the anatomic ligament trajectory.

adequate pin trajectory away from the back wall (Table 2). The pin is then advanced through the femur and out the skin of the anterolateral thigh. A pin exiting anterior to the mid thigh confirms a safe distance from the back wall of the femur (Fig 10B). The pin is secured with a clamp at the lateral thigh; then, the silicone sleeve and Pathfinder guide are removed sequentially by pronating the guide hand. The arthroscope is

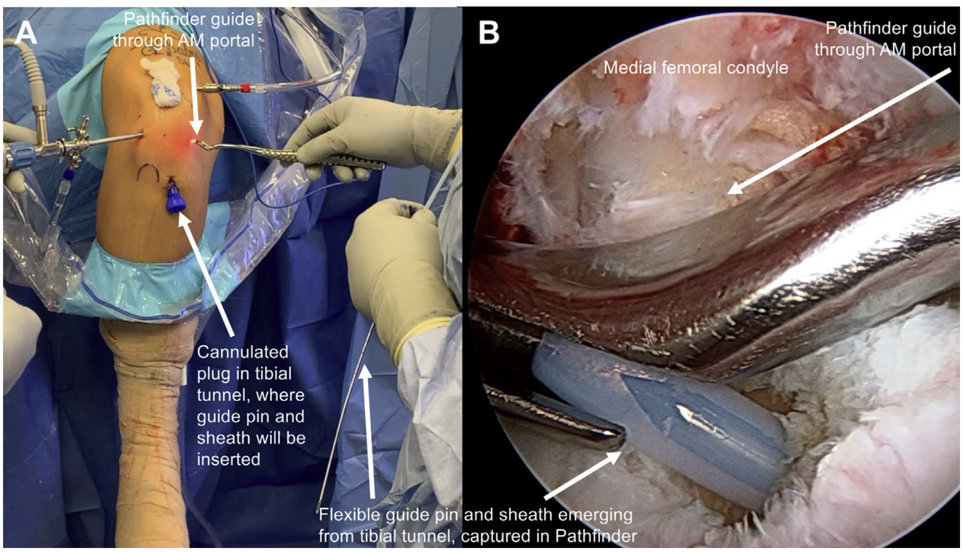

Fig 9. External (A) and arthroscopic (B) views of a right knee after tibial tunnel reaming and before femoral tunnel preparation. (A) A cannulated plug is placed in the tibial tunnel (the right part of the image is medial), and the Pathfinder guide is brought into the joint through the anteromedial (AM) portal. (B) Arthroscopic view from anterolateral portal. The flexible guide pin and sheath are inserted into the cannulated plug and captured in the Pathfinder guide with the knee in flexion (the angle of flexion may be varied to facilitate capture). The Pathfinder guide then hooks the posterolateral notch, delivering the flexible guide pin to the femoral anterior cruciate ligament footprint (Fig 7).

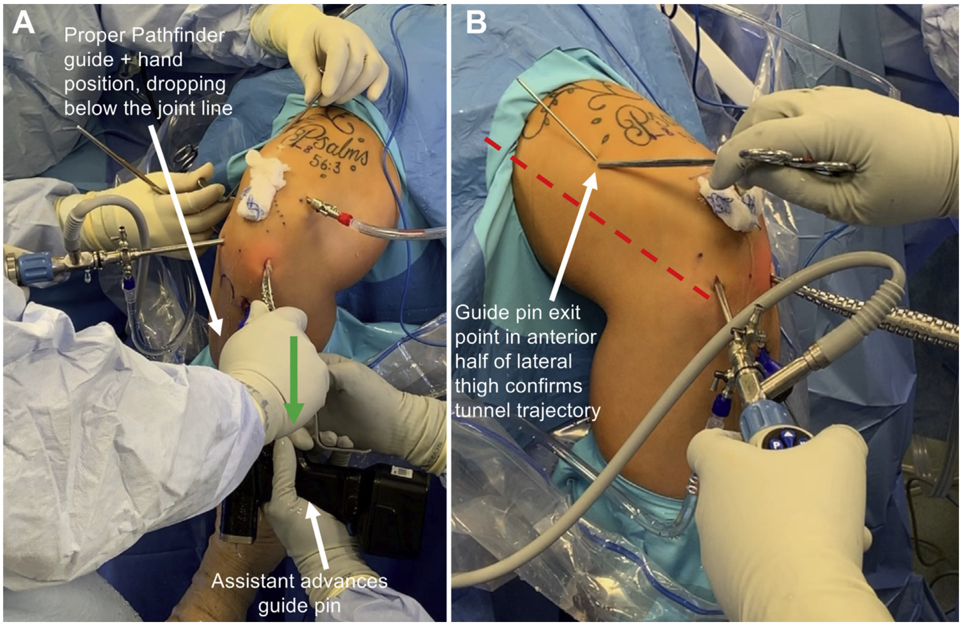

Fig 10. External medial (A) and lateral (B) views of a right knee during femoral tunnel preparation. (A) The Pathfinder guide is inserted through the anteromedial portal (the right part of the image is medial) and hooked on the posterior wall of the lateral notch. The surgeon's guide hand and the handle are dropped below the tibiofemoral joint line to ensure a proper tunnel trajectory. Once the femoral tunnel start site and trajectory are set and confirmed arthroscopically with the Pathfinder guide, the assistant advances the flexible guide pin under power. (B) The guide pin exits skin in the anterior half of the lateral thigh, confirming an appropriate femoral tunnel trajectory.

switched to the AM portal to confirm the planned femoral tunnel for location, trajectory, and available posterior wall (Fig 11).

The arthroscope is returned to the anterolateral portal, and the appropriately sized flexible reamer is introduced over the guide pin distally and passed through the tibial tunnel into the notch (Video 1). This results in no risk of injury to the medial femoral condyle during reaming. The reamer is then advanced to a depth of 25 to 30 mm (leaving ≥7 mm of intact lateral femoral cortex for button fixation, Fig 12A). The larger reamer is exchanged for a 4.5-mm flexible reamer that is carefully advanced under power to create a hole in the lateral cortex to allow cortical button passage (Fig 12B). Owing to the biplanar bending of the 4.5-mm reamer, there is a risk of reamer breakage if excessive axial force is applied (Table 2). The shaver is used to clear bony debris, and the flexible guide pin is used to place shuttle suture through both tunnels.

Graft Passage and Femoral Fixation

The transtibial plug is removed, and the sutures from the femoral TightRope are shuttled through both tunnels, with care taken that the button and graft do not yet enter the tibial tunnel. While the femoral socket is viewed through the AM portal, the TightRope is slowly advanced until the button is visualized flipping on the lateral cortex of the femur (Fig 13A, Video 1). Correct button position is confirmed fluoroscopically and adjusted as necessary (Fig 13B). The reverse tensioning sutures are then alternately pulled, bringing the graft into the femoral tunnel until at least 20 mm of graft is present in both the tibial and femoral sockets (Fig 14A).

Tibial ACL Fixation

Prior to tibial fixation, one must ensure that an adequate distance is present between the distal end of the graft and the extra-articular metaphyseal tunnel

Table 2. Technical Pearls and Pitfalls

Pearls
A medialized anteromedial portal should be used to allow proper perpendicular access of the Pathfinder guide to the posterior lateral condyle and hook.
The knee should be extended to facilitate silicone guide and guide pin passage into the Pathfinder guide.
The Pathfinder guide hand should be dropped below the level of the tibiofemoral joint such that the pin exit point is anterior to the mid IT band (this ensures a more vertical trajectory with respect to the physis).
Knee hyperflexion can be useful to improve the femoral tunnel trajectory.
Femoral reaming should be performed under "wet" conditions to minimize thermal insult to the physis.
Reaming should always be performed on full speed with fresh and/or sharp reamers to minimize insult to the femoral physis.
The femoral socket should be viewed through the AM portal to confirm the distance from the tunnel back wall and during button passage to allow easy visualization of deployment on the lateral cortex.
Pitfalls
Insufficient posterior femoral condyle hooking with pronation of the Pathfinder guide hand results in an oblique femoral tunnel exiting the posterolateral femur (increased physeal risk and increased risk of posterior wall blowout).
When a leg holder is used, the knee usually rests at 70°-80° of flexion; reaming the femoral tunnel in this position puts the posterior wall at risk.
Excessive forceful reaming with a 4.5-mm flexible reamer at the lateral femoral wall risks reamer breakage.

AM, anteromedial; IT, iliotibial.

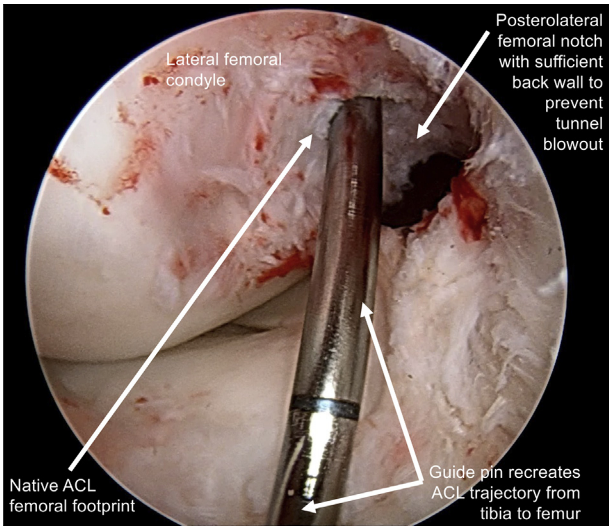

Fig 11. Arthroscopic view of a right knee from the anteromedial portal (the right part of the image is medial). Taking time to switch viewing from the anterolateral to anteromedial portal is an essential step to confirm an appropriate trajectory of the flexible guide pin before femoral tunnel reaming. The pin obliquely traverses the tibial and femoral anatomic anterior cruciate ligament (ACL) footprints with sufficient posterior femoral wall to prevent tunnel blowout during femoral reaming.

aperture because the ABS loop has a minimal length of 7 mm. If there is less than 7 mm between the end of the graft and the tunnel aperture, adequate tensioning will not be possible. Then, an appropriately sized ABS concave button (Arthrex) is loaded over the ABS loop, and the loop is shortened by pulling the tensioning suture limbs alternately until the button is flush with the tibial cortex (Figs 14B and 15B). Tibial fixation is performed in full extension with a mild posterior drawer load applied to the tibia. The knee is then repeatedly cycled through full flexion-extension, and both the femoral and tibial buttons are sequentially tightened again with the knee in full extension. The arthroscope is reintroduced into the knee, confirming the position and tension of the ACL graft, absence of lateral wall or roof impingement, and maintenance of native hyperextension (Fig 15A). The tourniquet is released, and the tibial-sided tensioning suture limbs are tied over the ABS concave button. Wounds are irrigated with inspection for adequate hemostasis, particularly at the QT donor site, to minimize the risk of hematoma formation. Buried No. 2-0 absorbable suture is used to close the deep dermal layer of the QT and tibial incisions, followed by No. 4-0 running absorbable suture for the subcutaneous layer. Arthroscopy portals are closed with nonabsorbable suture.

Discussion

An ideal transphyseal ACLR should re-create the native ACL anatomy and normalize knee kinematics while minimizing the risks of growth disturbance and graft retear. Traditional transtibial drilling of the femoral tunnel for ACLR results in longer and more vertical tunnel trajectories in the coronal plane versus

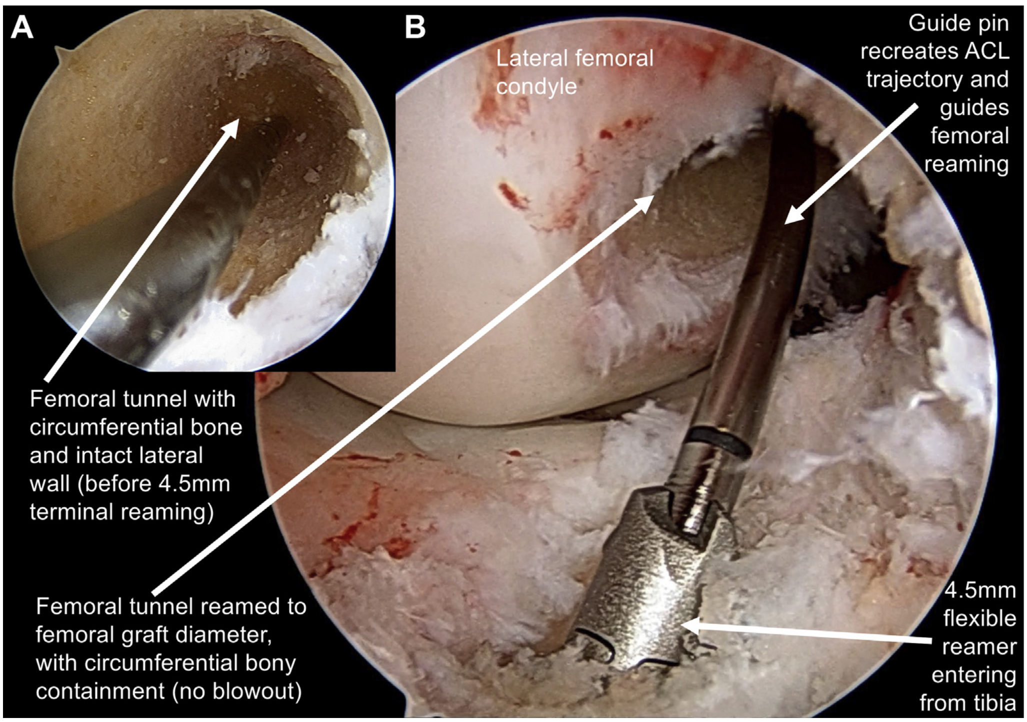

Fig 12. Arthroscopic views of a right knee from the anteromedial portal (the right part of the image is medial). (A) Looking up into the reamed tunnel (25-30 mm in length) confirms circumferential bony containment of the tunnel (no blowout), as well as an intact lateral wall (necessary for button fixation). (B) After initial reaming with a larger reamer sized to the femoral graft diameter, a 4.5-mm reamer is advanced over the flexible guide pin and used to perforate the lateral femoral cortex to enable button passage. (ACL, anterior cruciate ligament.)

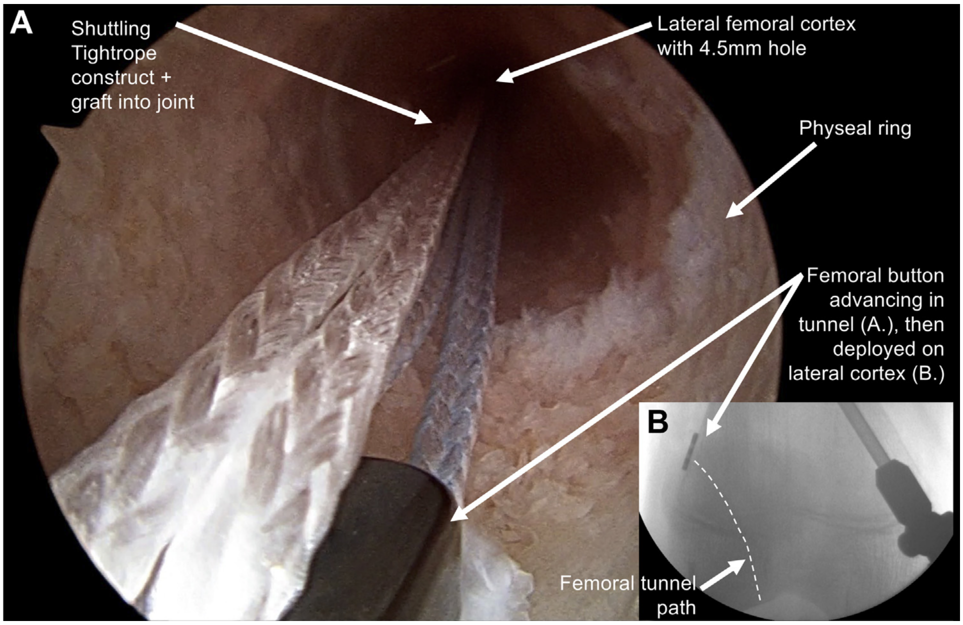

Fig 13. Arthroscopic (A) and fluoroscopic (B) views of the femoral tunnel in a right knee during suture shuttling and TightRope button deployment. (A) The shuttling suture and femoral button are advanced in the femoral tunnel so that the button can be flipped onto the lateral femoral cortex. The cartilaginous physeal ring is visible arthroscopically and on radiography, confirming a vertical tunnel trajectory. (B) Fluoroscopy (anteroposterior view) is used to confirm appropriate femoral button deployment on the lateral cortex.

AM or outside-in techniques, implying increased safety in the context of open physes.[7,19] However, transtibial drilling has been shown to consistently result in less accurate positioning of the femoral tunnel with respect to the native ACL footprint, as well as reduced knee rotational stability compared with the tibial-independent drilling technique.[20,21] Thus, a hybrid transtibial technique appears to offer the best of both worlds, consistently reproducing the native ACL trajectory and footprint while reducing tunnel obliquity

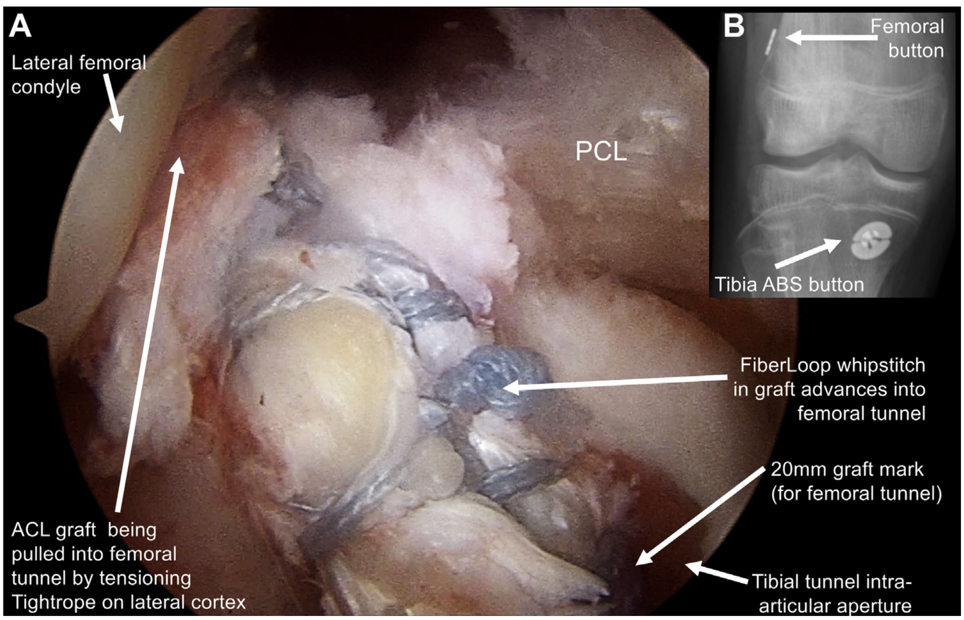

Fig 14. Arthroscopic (A) and anteroposterior radiographic (B) views of a right knee during anterior cruciate ligament (ACL) reconstruction with quadriceps tendon graft. (A) Arthroscopic view from anterolateral portal (the right part of the image is medial). The quadriceps tendon graft is advanced into the femoral tunnel from the tibial tunnel until the 20-mm mark on graft is visible at the entrance to the femoral tunnel (all whipstitch suture is contained in the tunnel). (B) The final anteroposterior radiographic view of a right knee shows appropriate femoral button deployment, tibial ABS button location and fixation, and hybrid transtibial ACL reconstruction tunnels obtained with the described technique. (PCL, posterior cruciate ligament.)

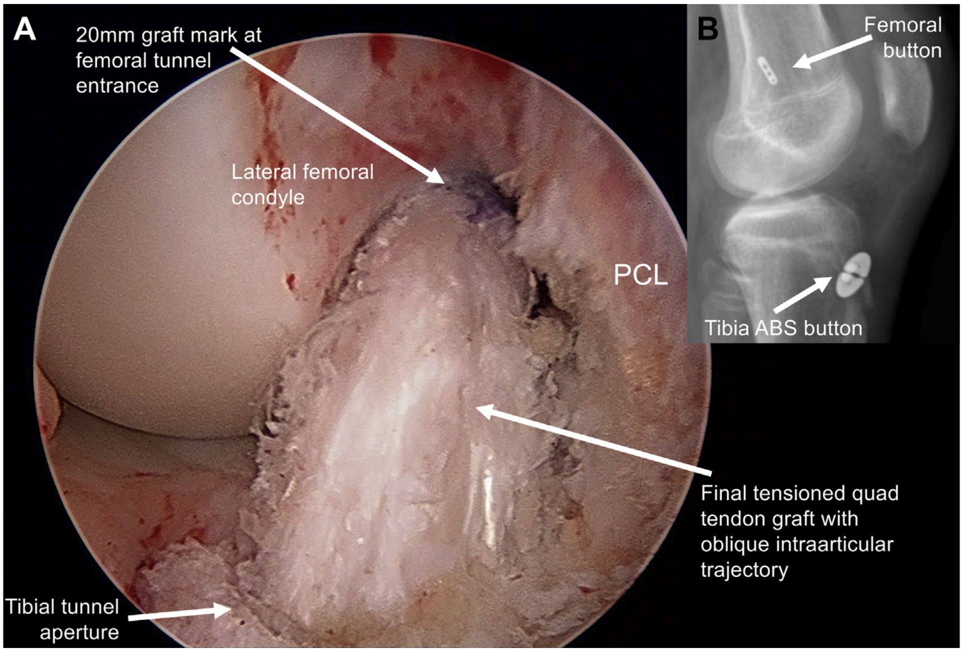

Fig 15. Final arthroscopic (A) and lateral radiographic (B) views of a right knee after anterior cruciate ligament reconstruction with quadriceps (quad) tendon autograft using the hybrid transtibial technique. (A) Viewing from anteromedial portal (the right part of the image is medial), the quadriceps tendon graft replicates the native oblique anterior cruciate ligament trajectory and is well tensioned after knee cycling and sequential tightening of the femoral and tibial buttons. (B) A lateral radiograph shows proper femoral and tibial button fixation of the graft, as well as graft tunnel trajectories. (PCL, posterior cruciate ligament.)

(and the associated risk of physeal injury) and maintaining the technical advantages of traditional transtibial ACLR.[11] The described hybrid technique, combined with the safety profile of an all—soft tissue QT autograft harvest and fixation, may afford improved outcomes and decrease rates of ACLR revision in this high-risk population.[4,15]

Nonetheless, this hybrid QT transtibial technique is not without its risks and limitations. Primarily, these involve risks stemming from QT graft diameter and/or length constraints including QT injury and potential rectus femoris tendon retraction after harvest. By sizing down the parallel blade harvester to 9 mm and proceeding carefully with superior harvest, we have not encountered these complications or the need for alternate graft harvest. This experience has also been corroborated by cadaveric study of QT in skeletally immature patients, which showed sufficient graft width parameters even in young patients (median deep QT width, 15 mm at its narrowest); however, this study did note the theoretical risk of rectus tendon retraction if the proximal myotendinous junction is violated and not repaired.[22]

Limitations also include an associated theoretical reduction in QT strength, although this has not been quantified and may be minimized by appropriate side-to-side tendon closure after harvest, as well as postoperative rehabilitation. Additionally, although this technique is physeal respecting regarding more vertical tunnel trajectories, it still involves physeal drilling and thus is not recommended in patients with greater than 3 years of growth remaining; this subgroup should instead be treated with true physeal-sparing techniques. Finally, the long-term data on failures after ACLR with QT graft continue to evolve, and although most recent reports remain promising,[17] it is important that these outcomes be followed to confirm the graft safety profile in this patient population.

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