Technical Note

Anatomic All-Inside Anterior Cruciate Ligament Reconstruction With a Modified Lemaire Extra-Articular Tenodesis: Quadruple-Bundle Semitendinosus Autograft and Surgery Tips

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Abstract: The past decade has seen changing trends in anterior cruciate ligament reconstruction surgery, with the hamstring becoming the most commonly used graft. Furthermore, the importance of extra-articular lateral tenodesis has been demonstrated to offer greater control of rotational laxity and a protective effect during cruciate ligament reconstruction. In this technical note, we describe a way to elaborate the graft with quadrupled semitendinosus tendon to obtain a compact and reliable graft. We provide tips and tricks to systematize and simplify the "all-inside" reconstruction technique and modified Lemaire's extra-articular tenodesis with femoral fixation in an independent bone tunnel under direct visualization to avoid confluence of the bone tunnels. This is a safe, reliable, and reproducible technique that causes less morbidity by removing a single hamstring tendon and preserving bone stock, with good clinical and functional results.

In recent decades, there has been a change in the preferred graft choice for anterior cruciate ligament (ACL) reconstruction. Historically, bone-tendon-bone was the gold standard graft. However, over the past 2 decades, the hamstring tendon (HT) graft has gained popularity and is now used in more than 50% of primary reconstructions.[1]

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Studies have demonstrated that the "all-inside" technique (AIT) can restore knee stability, presenting similar clinical and functional outcomes as other techniques using other types of grafts, such as bone-tendon-bone or HT (semitendinosus-gracilis).[2,3] In the past few years, with the results of the SANTI and STABILITY studies,[4,5] extra-articular procedures, such as lateral extra-articular tenodesis (LET), have been recommended for patients in whom hamstring repairs are performed, especially in patients under 20 years of age, those who participate in high-risk activities, or those with hyperlaxity.

This technical note describes the authors' preferred technique for preparing the quadrupled semitendinosus graft, along with tips and technical details for AIT and the modified Lemaire LET with femoral fixation in a separate bone tunnel.

Surgical Technique

This technical part of this study was performed at the Hospital General Universitario Reina Sofía (Murcia, Spain). The Research Ethics Committee assessed and approved the study (November 28, 2023) according to the requirements established by the legislation. The patient was given an information sheet

detailing the objectives and purpose of the study and signed an informed consent form for voluntary participation. Confidentiality of the clinical data were guaranteed. The information was used only for the purposes and objectives of this study, following the rules of data protection.

Operating Room Setup

The arthroscopy tower and saline-aspiration system are placed on the opposite side of the injured knee for greater comfort when approaching the lateral part of the knee during surgery. The electric scalpel terminal and the ischemia system are placed on the same side (Fig 1).

Patient Positioning and Examination

The patient is positioned supine on the operating table and examined under anesthesia. The arthroscopy clamp is used according to the surgeon's preference (Fig 1). The auxiliary table and working instruments are arranged so that they are not in the way when approaching the lateral part of the knee and to prevent entanglement between them (Fig 2).

Graft Harvest

Semitendinosus tendon (ST) autograft harvest is employed. This tendon is located at the most distal part of the tibial insertion of the pes anserine tendons, which requires a more distal approach than the standard collection of the 2 hamstrings (Fig 3). The ST tendon is isolated, its expansions to the inner calf are released, and the tendon is removed with a tenotome. Subsequently, the thickness of the quadrupled tendon is measured. If it is not of appropriate thickness

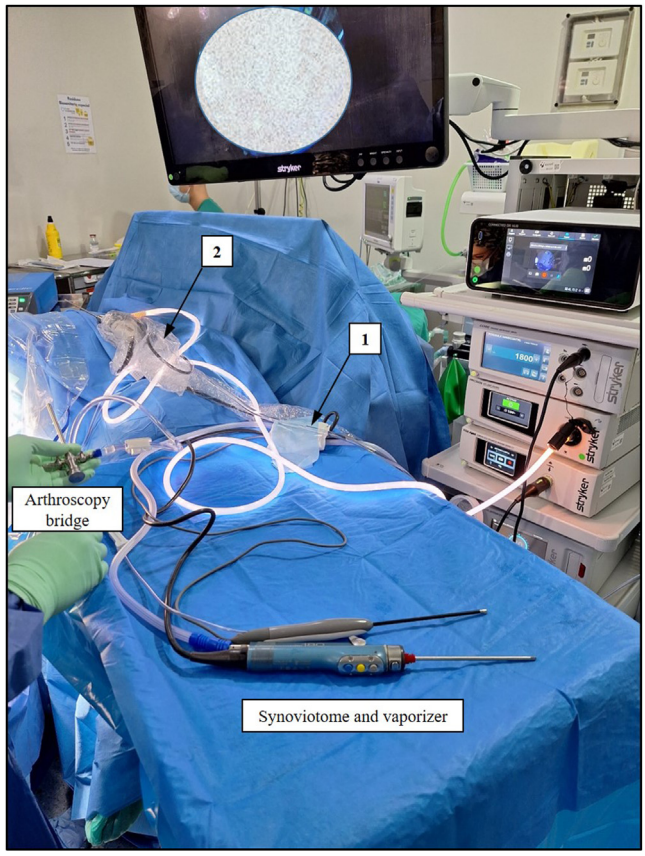

Fig 2. Auxiliary table and the working instruments. The synoviotome, vaporizer, and suction terminal are fixed on an auxiliary table with a compress and an adhesive band ("caneloning mode") (1) and placed on the opposite side of the right knee. The camera and the arthroscopy bridge should pass independently from the other instruments to allow better handling and avoid entanglement with the other terminals. This will be fixed to the sterile field in its straps (2).

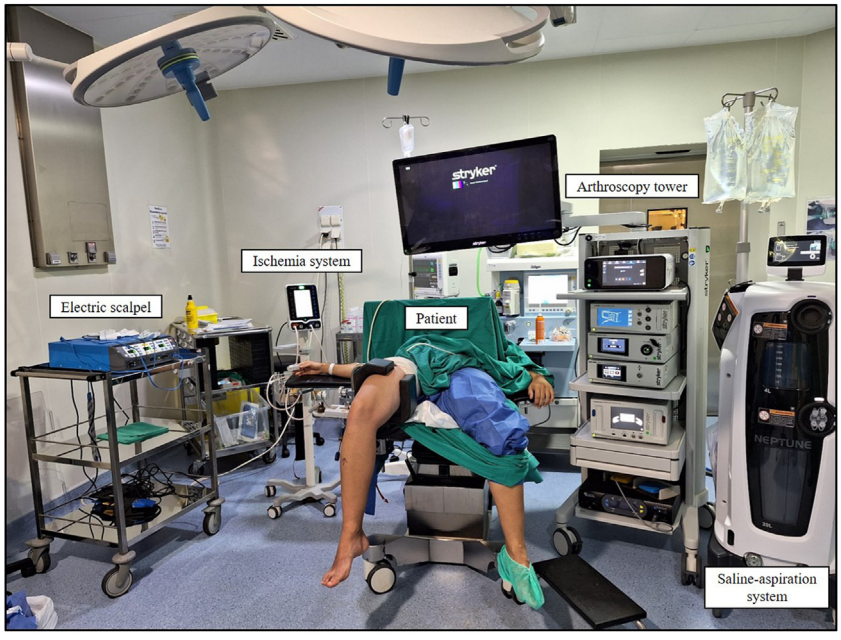

Fig 1. Position of the patient and the instruments required for right knee arthroscopy. Position: Supine position on the operating table and arthroscopy clamp. The arthroscopy tower and saline-aspiration system are placed on the opposite side (left side). On the same side (right side), the electric scalpel terminal and the ischemia system will be placed in the most posterior part of the operating room.

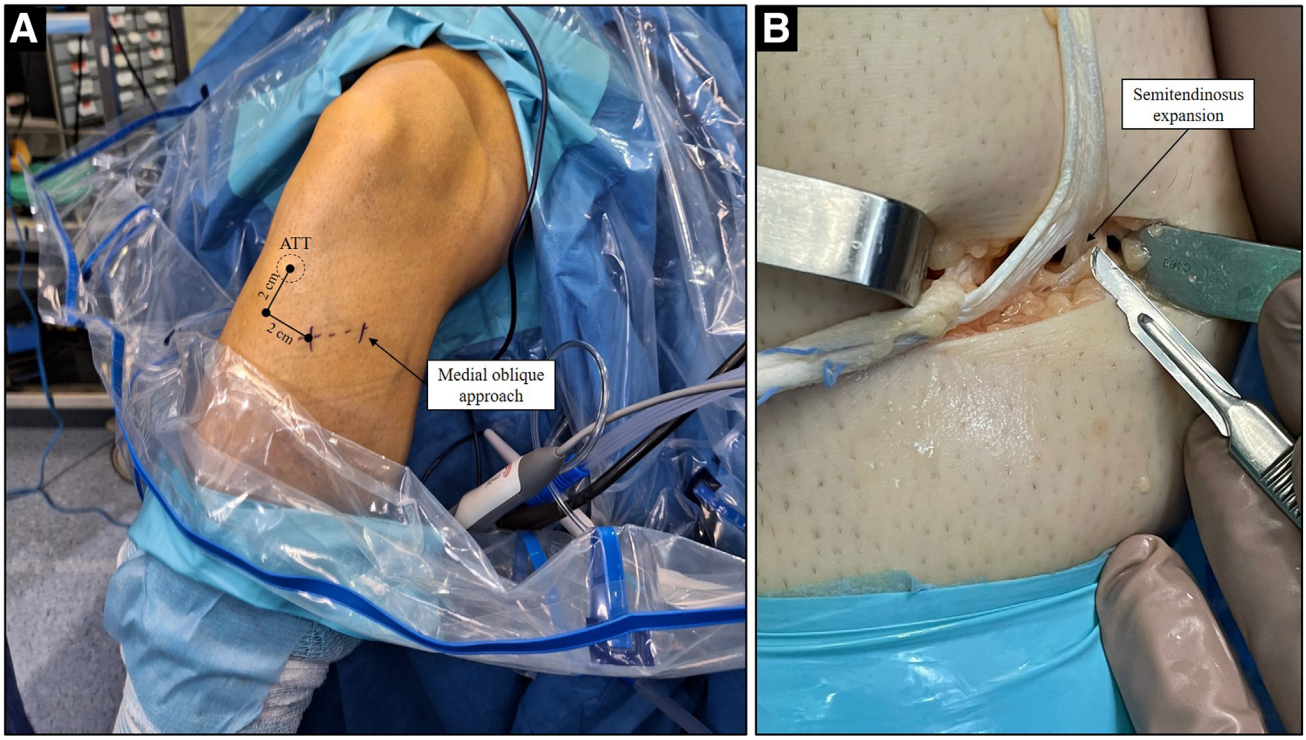

Fig 3. (A) Right knee approach for harvesting the semitendinosus tendon autograft. The medial oblique approach started 2 cm medial and 2 cm distal to the anterior tibial tuberosity (ATT). (B) The semitendinosus tendon is isolated, and its expansions to the inner calf are released.

(<8 mm), the gracilis tendon (GT) is harvested and added to the graft construct.

Graft Preparation

A quadrupled ST grafting is performed using the surgeon's preferred method and according to the GraftLink (Arthrex, Naples, FL) technique (Figs 4-9, Video 1).

Minimally Invasive Modified Lemaire Tenodesis

An external femoral epicondyle-centered approach of approximately 4 cm is used, and we indicate the length and width of the graft (8 × 1 cm) with a dermographic marker pen. We recommend performing the most posterior longitudinal cut first to prevent tension loss of the fascia, which might make the proximal cut and its extraction difficult. The graft is cut proximally, and a strip of iliotibial webbing is removed, preserving its tibial insertion on the Gerdy tubercle. The free edge of this graft is sutured with a FiberLoop (Arthrex, Naples, FL), which will be used for its transport and tunneling. To ensure that it does not flip over, especially when passing it medial to the lateral collateral ligament, its most superficial part is marked with a dermographic marker pen. The insertion point (8 mm proximal and 4 mm posterior to the lateral femoral epicondyle) is marked for subsequent bone tunneling, which will be performed later (Fig 10).

Portal Creation and Arthroscopic Examination

Standard anterior portals, anterolateral (AL) and anteromedial (AM), and global arthroscopic exploration of the joint are performed to diagnose associated injuries and confirm ACL injury. If ACL injury is doubted, diagnostic arthroscopy is performed before graft extraction.

Femoral Sockets Creation

The surgeon checks that the total thickness of the femoral metaphysis is sufficient (between 35 and 45 mm). The retrograde drill or Flipcutter (Arthrex) is placed in the anatomic footprint of the ACL and measured with a calibrated guide. If the tunnel is to be performed in an anterograde mode, the calibrated needle is introduced, which will also serve as a guide, from the AM portal and introduced to the metaphysis from the footprint of the ACL to the lateral cortex; this length is then measured. The femoral bone socket is created within the anatomic footprint of the ACL, with either retrograde or anterograde drilling based on the surgeon's preference, with a 25-mm length and thickness according to the graft. In a loop configuration, the socket is referenced with a shuttle suture or

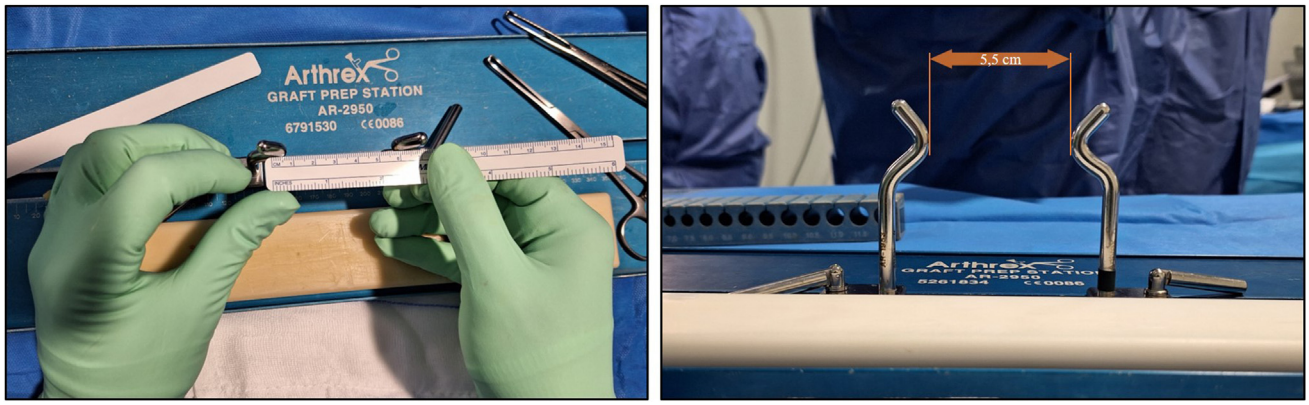

Fig 4. Auxiliary table for quadrupled semitendinosus graft preparation. Curved columns are used. The distance of the convex part of the two columns should be 5.5 cm to obtain a total graft length of 6.5 to 7.0 cm.

FiberStick (Arthrex) and retrieved through the AM portal (Fig 11). The AM portal is dilated with a scalpel before passing the suture through as the graft is introduced through this portal in the "all-inside" technique.

We place the biotenodesis needle at the previously marked point to perform the Lemaire bone tunnel. With optics in the AM portal and direct vision of the femoral socket of the ACL, non-confluence with this tunnel is verified (Fig 12). The surgeon determines arthroscopically that the needle does not affect the femoral trochlear notch, a potential risk to be considered. Then, a 30 to 40 mm bone tunnel is drilled, matching the size of the iliotibial band graft thickness. Finally, using the biotenodesis needle, the free edge of the Lemaire graft is introduced in the tunnel using the FiberLoop (Arthrex) that was previously sutured on it.

Tibial Socket Creation

The tibial metaphysis is determined to be of sufficient length (between 40 and 50 mm). A retrograde blind tibial bone socket is created with the Flipcutter with an anatomic footprint of 30 to 35 mm. Soft tissue at the tibial tunnel entrance is carefully removed to facilitate posterior graft entry. The tunnel is referenced with a single shuttle suture, leaving the proximal end longer than the distal end. Both the femoral (double) and tibial (single) shuttle sutures are removed simultaneously through the AM portal (Fig 13).

Graft Passage

The ACL graft is suspended in the femoral socket by inserting it from the AM portal and provisional cortical fixation with TightRope RT (Arthrex). Most of the reference suture is removed from the tibial socket through the AM portal, and a single knot is tied over

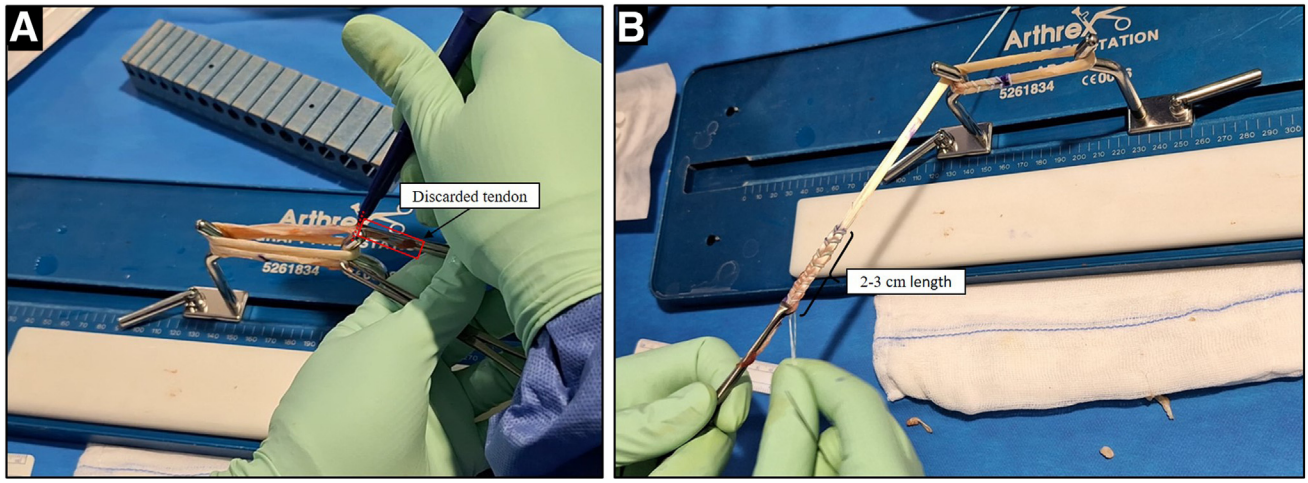

Fig 5. (A) Place Allis forceps on both ends of the tendon, fold it around the curved columns, mark the exact length of the tendon, and remove the excess. (B) Place a high-strength suture at both ends (2-3 cm length, previously marked) of the tendon using an Arthrex FiberLoop.

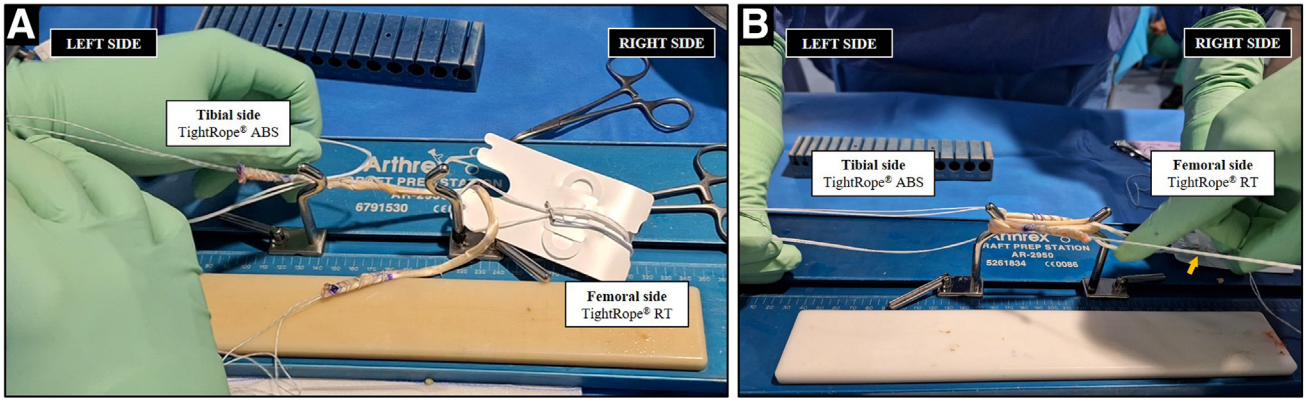

Fig 6. (A) Pass the tendon with the FiberLoop through the inside of both TightRope RT on the femoral side (table's right side) and TightRope Attachable Button System (TightRope ABS) on the tibial side (table's left side). (B) Result after passing the tendon through the TightRope and both columns. Both FiberLoop needles are oriented toward the femoral side (arrow).

the shuttle suture, referencing the TightRope Attachable Button System (ABS) (Arthrex) so that after graft passage to the tibial socket (Fig 14), part of the shuttle suture remains in the AM portal and passes through the bone tunnel with the graft. This is helpful if it is necessary to retrieve the graft back to the AM portal if graft length is greater than the sockets and is not taut enough (Video 1). Correct graft tensioning is checked

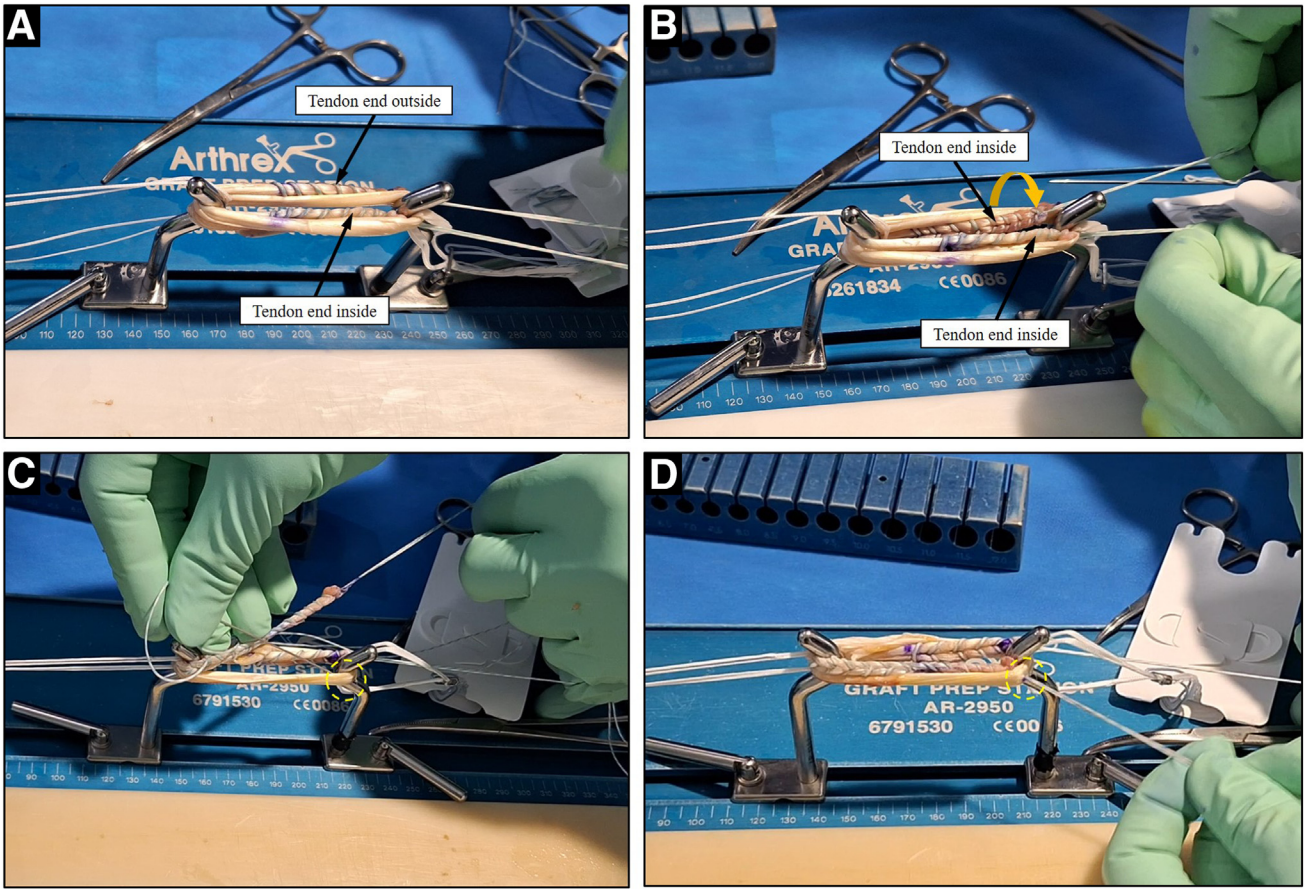

Fig 7. (A) Quadruplicate tendon. One tendon end is on the inside of the loop, and the other is on the outside. (B) The outside end of the tendon is introduced into the loop so that both ends, with their respective FiberLoop, are inside the graft. (C and D) The FiberLoop needle is passed through the tendon's thickness on both sides (circles).

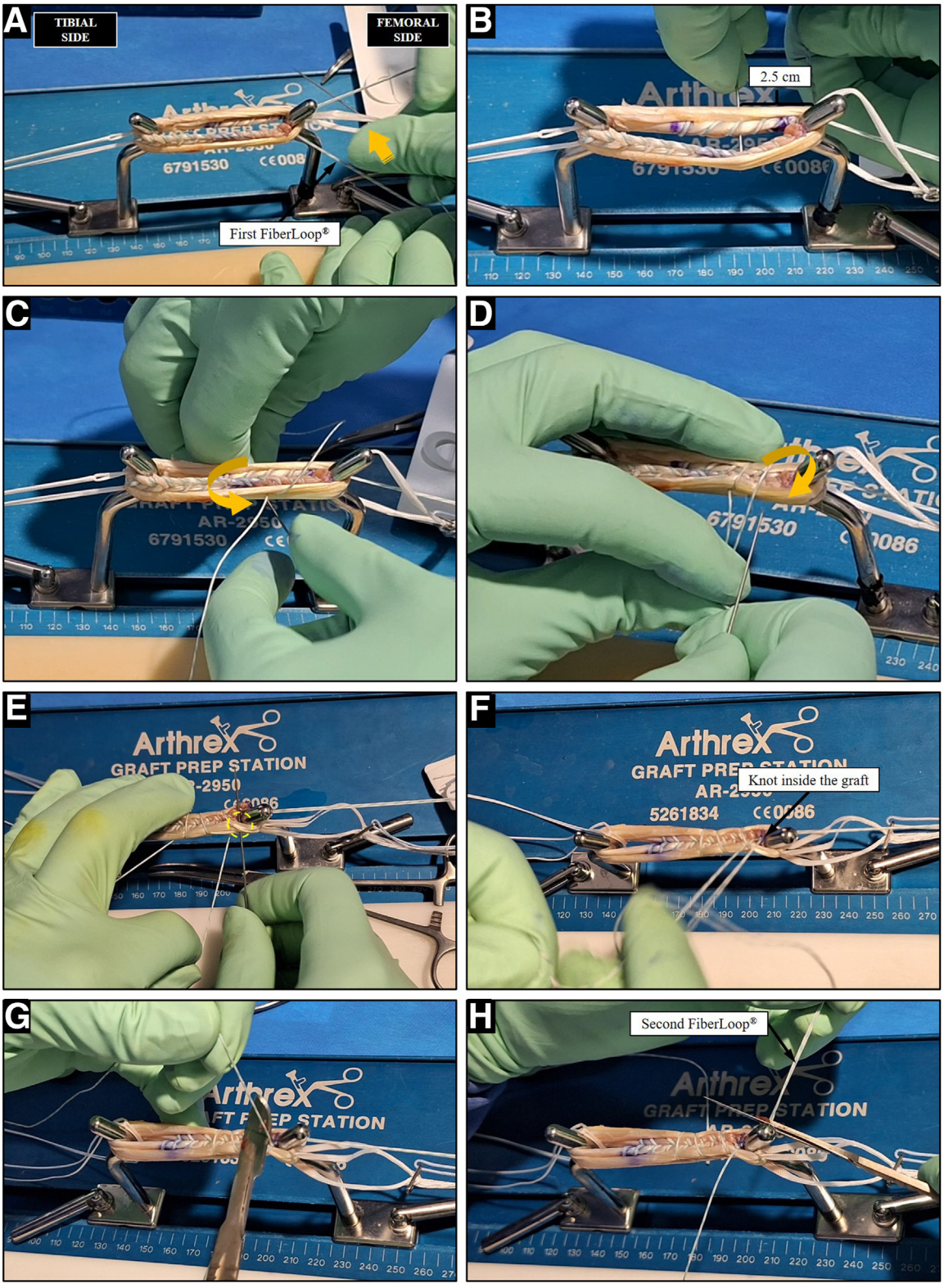

Fig 8. (A) Introduction of the FiberLoop through the TightRope RT to take it to the other side of the graft. (B) First transfixing suture approximately 2.5 cm from the end of the graft, passing through the 4 fascicles. (C and D) Cut the FiberLoop loop to obtain 2 single threads, which are used to create transfixing stitches, alternating their direction (up-down) until reaching the end of the graft where the TightRope RT is located. (E and F). Both sutures are inside the graft so that the knot is placed in this position and does not hinder the passage of the graft through the sockets. (G) The excess suture is cut. (H) Use the other FiberLoop and to perform the transfixing fixation on the tibial side of the graft in the same way as described in the previous steps.

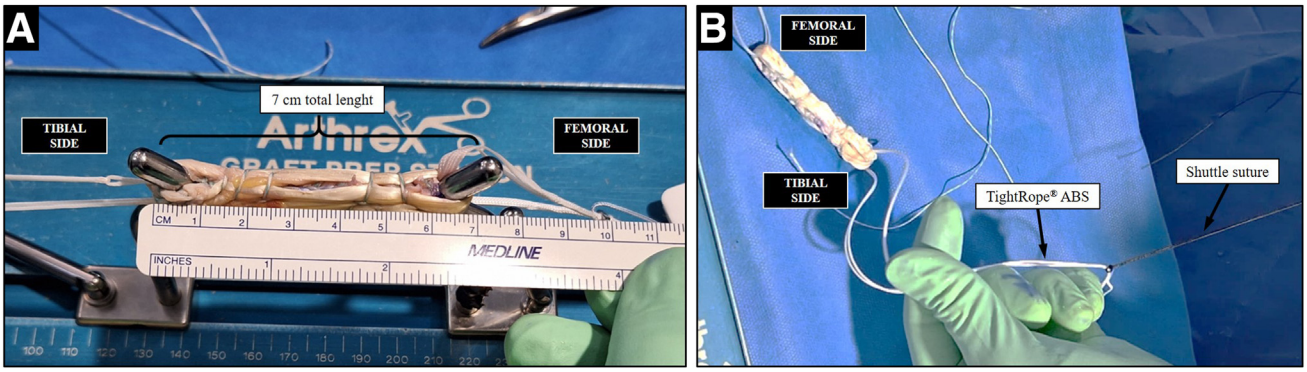

Fig 9. (A) Final result of the 7-cm quadrupled semitendinosus graft using the Arthrex GraftLink technique. (B) Placement of the shuttle suture around the TightRope Attachable Button System.

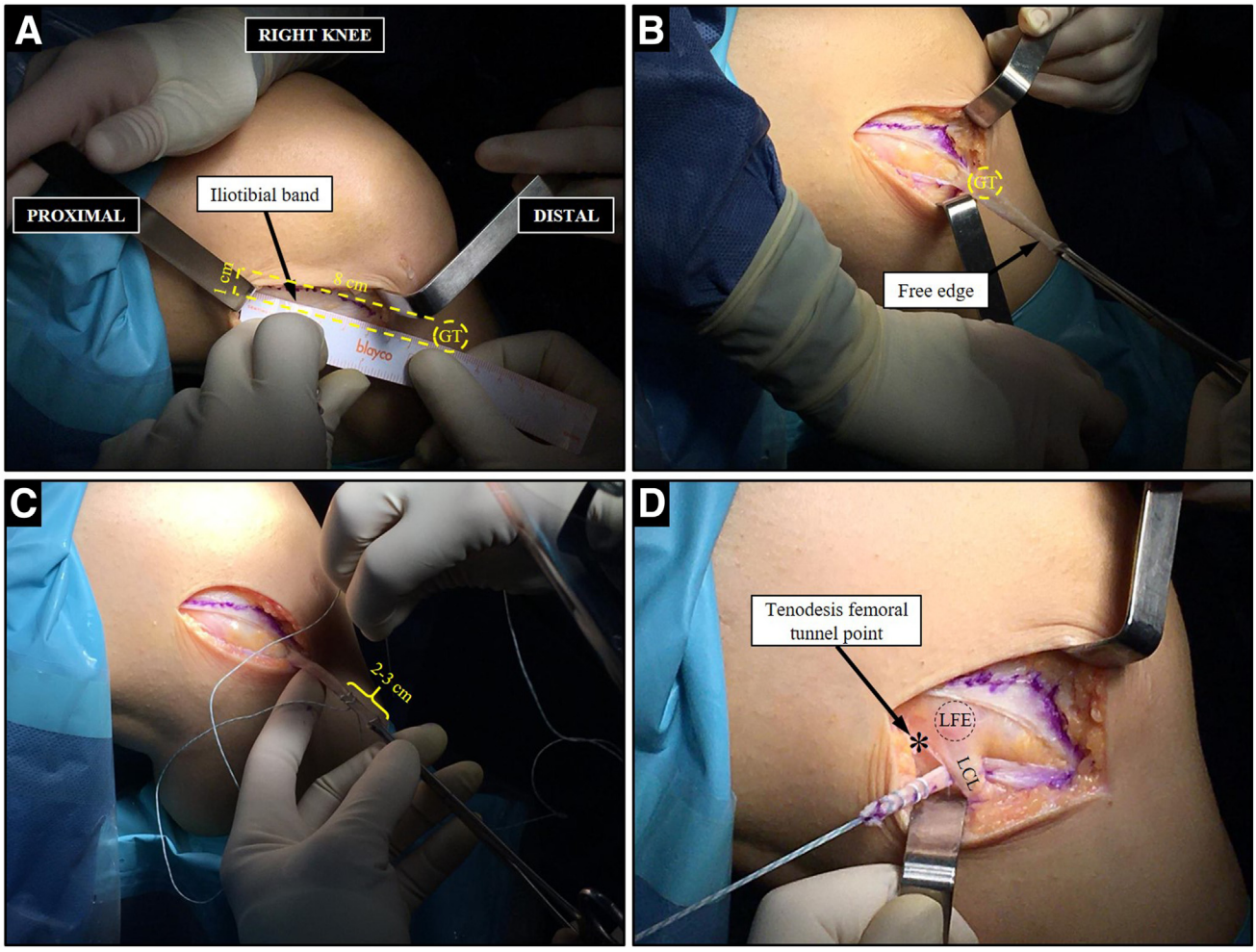

Fig 10. Right knee modified Lemaire tenodesis. (A) A lateral femoral epicondyle (LFE)-centered approach of approximately 4 cm is used to expose the iliotibial band, and we indicate the length and width of the graft (8 × 1 cm) with a ruler and a dermographic marker pen. The LFE is palpated, and there we mark the thickness of 1 cm of the graft. The Gerdy tubercle (GT) is located, and the 8 cm graft length is marked proximally, following the fibers of the iliotibial band. (B) With a scalpel or Metzenbaum scissors, both longitudinal cuts of the graft are made for its extraction. The graft is cut proximally, and a band of iliotibial webbing is removed, preserving its tibial insertion on the GT. (C) The free edge is sutured with a FiberLoop. (D) Dissect and reference the lateral collateral ligament (LCL) and pass the graft medially to this ligament. Mark the tenodesis femoral tunnel point (8 mm proximal and 4 mm posterior to the LFE) with an electric scalpel.

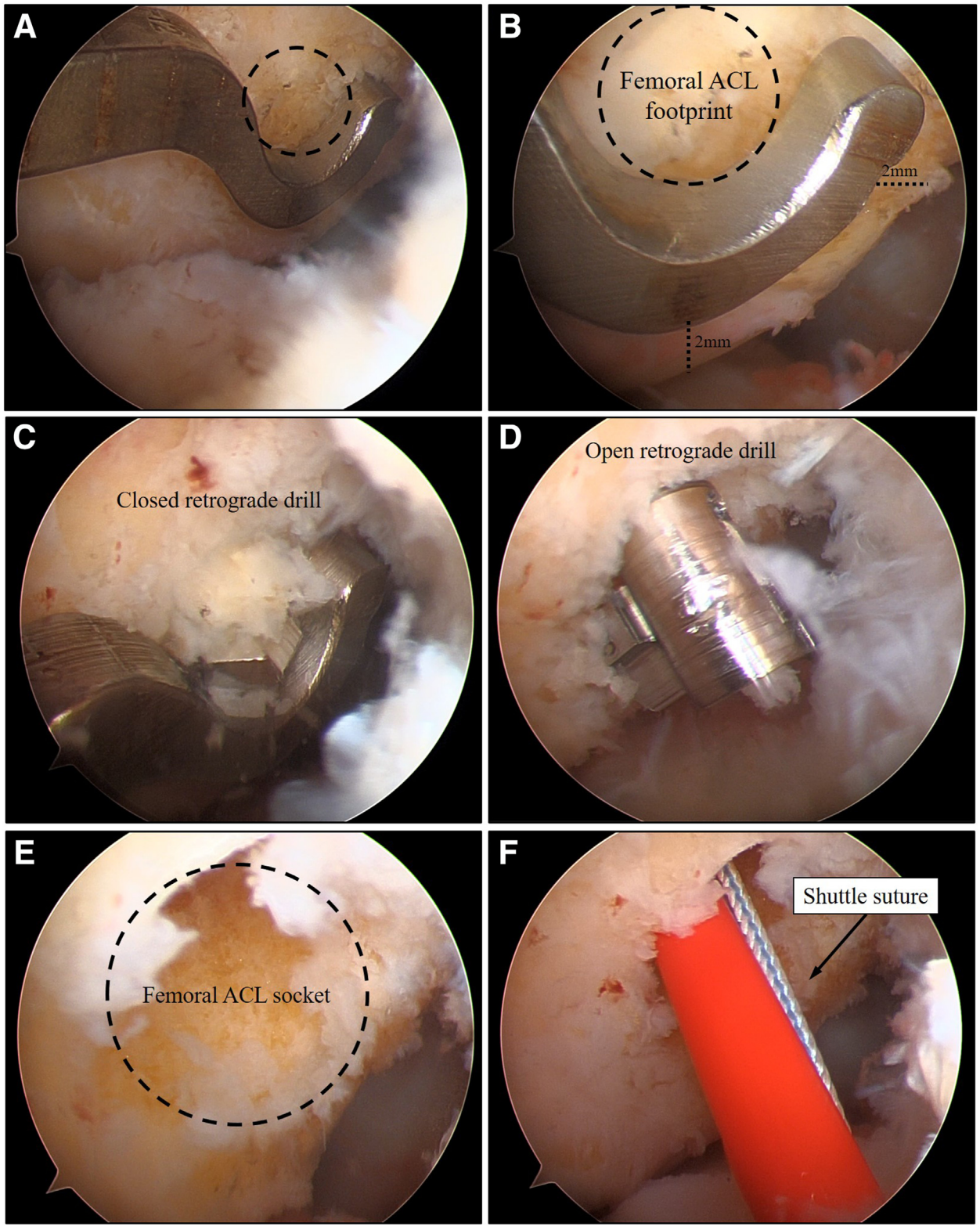

Fig 11. Right knee anterior cruciate ligament (ACL) femoral socket. Anteromedial (AM) portal view. (A and B) Retrograde drill guide (Flipcutter) position in the anatomic femoral footprint of the ACL from the anterolateral portal, keeping a bony septum of approximately 2 mm at the posterior and inferior aspect of the femoral condyle. (C and D) Introduction of the retrograde drill and opening at the desired width. (E) Perform an incomplete bone socket of 25 mm and thickness according to the graft. (F) Femoral socket referencing with a shuttle suture or FiberStick as a loop and retrieve it through the AM portal.

Fig 12. Tunneling the modified Lemaire tenodesis with a direct view of the femoral socket of the anterior cruciate ligament from the anteromedial portal to check for bone tunnel confluence.

in full extension and by manually pulling on the TightRope ABS, without the plate. Once the graft is correctly tensioned, the tibial reference wire is removed.

Graft Tension and Fixation

The LET is tensioned and fixed with the knee at 20° of flexion and neutral rotation using an Invibio PEEK-OPTIM biotenodesis screw (Invibio, Lancashire, UK) that is 1 mm larger than the bone tunnel. The ACL graft is fixed to the tibia with the knee in full extension and neutral rotation using an 11 mm concave plate on the TightRope ABS. Finally, the graft is checked to ensure correct tension.

Postoperative Protocol

Early mobilization with a range from 0° to 90° of flexion and unloaded ambulation with crutches begins during the first month. Muscle-strengthening exercises are begun immediately. At 3 months postsurgery, the patient may begin running on level ground. At 6 months, the patient may begin exercises for changes in rhythm and direction. Patients may return to previous competitive activity at 9 months postsurgery.

Tables 1 and 2 describe pearls/pitfalls and advantages/disadvantages of the procedure, respectively.

Discussion

The AIT was popularized by Lubowitz in 2006 and enhanced in 2011 with the GraftLink technique, which allows ACL reconstruction by creating incomplete bone sockets independently in both the femur and tibia, using cortical suspension systems for graft fixation at both ends.[6]

Incomplete bone tunnels enable a shorter graft length, allowing an autograft with a single tri or quadruple HT (semitendinosus), which preserves hamstring strength by preserving the gracilis muscle.[7,8] This technique is associated with reduced postoperative pain and swelling, appropriate graft tensioning and re-tensioning, better integration of the graft, circumferential graft to bone healing, lower tunnel widening rates, and greater bone stock preservation.[9-11]

The quadruple ST graft is usually thicker than the GT-ST standard graft. Various preparation techniques have been described for this graft, with none found to be

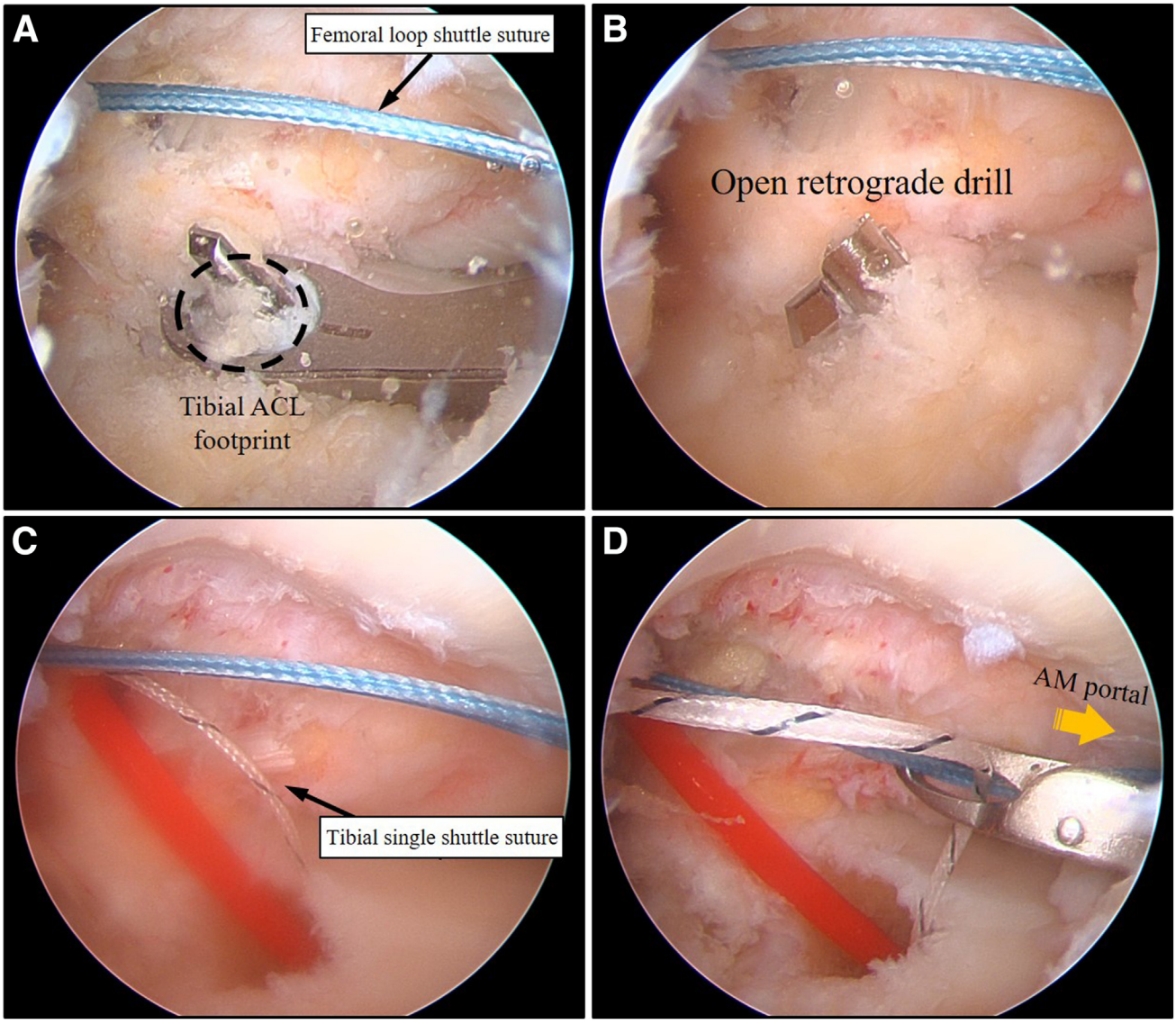

Fig 13. Right knee anterior cruciate ligament (ACL) tibial socket. Anterolateral portal view. (A) Positioning the guide and retrograde drill bit (Flipcutter) in the anatomic tibial footprint of the ACL from the anteromedial (AM) portal. (B) Opening of the retrograde drill bit to the desired width and creation of an incomplete bone socket of 30 to 35 mm long (same thickness as the graft). (C and D) Socket referencing with single shuttle suture or FiberStick and retrieval through the AM portal simultaneously with the femoral loop socket reference.

superior to the others.[12] The configuration described in this technical note allows the creation of a compact and homogeneous graft by connecting its strands with transfixing stitches along most of its length, ensuring consistent thickness at both ends.

Extra-articular procedures complement ACL reconstruction by controlling residual rotational laxity and reducing early graft rupture rates in young, who perform high-demand activities or sports.[4,5] To obtain optimal knee rotational stability after ACL injury, ACL + extra-articular produces was found to be the preferred technique.[13] Many anterolateral ligament reconstruction and extra-articular tenodesis techniques, including the modified Lemaire LET, show similar functional results.[14] However, they have the potential complication of tunnel confluence with the ACL femoral tunnel, potentially compromising graft integrity. Therefore, we recommend creating the bone tunnel after the ACL femoral socket but before suspending the ACL graft to have a direct view during the

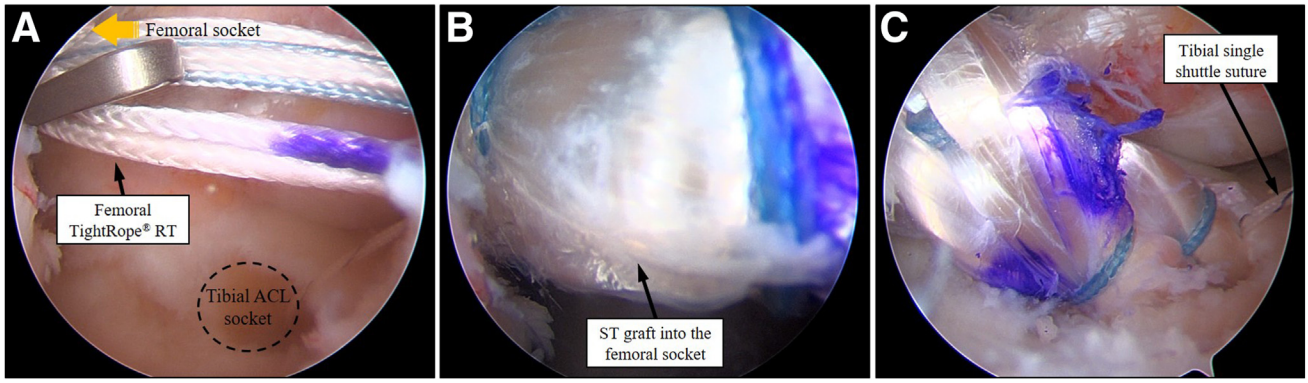

Fig 14. Graft passage. Right knee, anterolateral portal view. (A) Introduce the TightRope RT through the femoral socket with a loop shuttle suture. (B) Suspend the anterior cruciate ligament graft in the femoral socket with the TightRope RT system by inserting it from the anteromedial (AM) portal and provisional cortical fixation. (C) Introduce the Tightrope ABS through the tibial tunnel with the single shuttle suture from the AM portal. Insert the rest of the semitendinosus tendon graft into the tibial tunnel by pulling on this Tightrope and check the correct graft tensioning with a feeler from the AM portal in full knee extension.

procedure, reducing the risk of tunnel convergence and graft damage.

In conclusion, our quadrupled semitendinosus graft design provides a homogenous, compact, and resistant graft. The systematized AIT procedure with modified Lemaire LET and femoral fixation in an independent bone tunnel simplifies and enhances the technique's reproducibility.

Disclosures

The authors (J.J-O., S.A-J., V.J.L-M., F.S-M., F.L-M.) declare that they have no known competing financial

Table 1. Pearls and Pitfalls

Pearls	Pitfalls
Place the arthroscopy tower, saline bags, and suction system on the side opposite the injured knee to be operated on.	Do not perform a graft >7 cm. The tibial metaphyseal size may not be sufficient to achieve a bone socket longer than 35 mm. The graft will bottom out in the tibial cavity, and adequate graft tension will not be achieved.
Harvest the ST, and measure its quadrupled diameter. The GT can be harvested and added to the graft if the thickness is inappropriate (<8 mm).	The ST should be precisely identified. Accidental harvesting of the GT will lead to unnecessary removal of both hamstrings.
To obtain a quadrupled graft between 6.5 and 7.0 cm in length, the distance between the convex part of the preparation columns should be 5.5 cm.	
To facilitate the tendon's passage through the bone sockets, place 2 ends of the tendon with the FiberLoop strands on the inside of the loop formed after the graft's quadruplication.	
Make the most posterior longitudinal cut of the modified Lemaire graft to facilitate its removal, and mark the most superficial part with a dermographic marker pen to control its correct orientation and prevent it from turning over.	
Arthroscopic verification from the AM portal shows that Lemaire's tunnel does not confluence with the femoral socket of the ACL and that the femoral trochlea is unaffected.	
Clean the tibial socket on the intra-articular side to facilitate the graft passage.	
Referencing the tibial socket of the ACL with a simple shuttle suture and leaving the proximal end longer than the distal end allows the graft to be retrieved easily and without manipulation through the AM portal if the tibial socket does not have the necessary length.	
Enlargement of the AM portal and meticulous removal of soft tissue at the tibial socket entrance facilitates graft passage.	

ACL, anterior cruciate ligament; AM, anteromedial; GT, gracilis tendon; ST, semitendinosus tendon.

Table 2. Advantages and Disadvantages

Advantages	Disadvantages
Less morbidity at the donor site by removing only the ST tendon and greater preservation of bone stock	Need for cortical suspensory fixation systems; not suitable for interferential screw fixation
Thicker grafts than those obtained with the 4-strand ST-GT technique	Meticulous preparation of the quadrupled ST graft with adequate length; accurate measurement of the metaphyseal bone stock before tunneling, modifying the angulation of the drill bit if the metaphyseal length is too short (<30 in femur or <40 in tibia) to allow 25 mm in the femoral socket and 35 mm in the tibial socket
Ability to increase the thickness of the graft, if necessary, by adding GT tendon	Increased technical difficulty and, generally, surgical time, compared with the standard hamstrings tendon technique with complete tibial tunnel without associated Lemaire
Preparation of a compact quadrupled graft, resistant and homogeneous at both ends, without knots or too many suture threads on its surface	
Adjustable suspensory fixation systems that allow re-tensioning of the graft once tunneled	
Associated LET protects intra-articular reconstruction and improves cosmetic appearance when performing mini-incision graft removal.	

AM, anteromedial; GT, gracilis tendon; LED, lateral extra-articular tenodesis; ST, semitendinosus tendon.

interests or personal relationships that could have appeared to influence the work reported in this paper. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

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