Technical Note

Modified Anatomical Anterior Cruciate Ligament Reconstruction with Flat Semitendinosus Graft and C-shaped Tibial Canal

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Abstract: Every year, approximately 400,000 patients undergo anterior cruciate ligament (ACL) reconstruction surgery in the United States, accounting for almost 50% of all knee surgeries in the country. Recent studies have demonstrated that the ACL is a ribbon-like structure with a C-shaped tibial insertion and a flat femoral origin. This article introduces a modification of an ACL reconstruction technique. The modification renders the procedure easily reproducible with standard surgical instruments. We will describe a surgical technique modification that goes beyond the standard round bone tunnels and adopts a more anatomical approach using a C-shaped tibial canal and a flat femoral canal using a flat semitendinosus (semi-T) graft. The use of a semi-T graft better reproduces the ribbon-like ACL anatomy. The semi-T graft, a flat femoral canal, and a C-shaped tibial canal provide increased bone-tendon contact surface area and decreased diffusion length, resulting in improved tendon-bone healing. The modification proposed by our team makes the anatomical ribbon-like ACL graft, C-shaped tibial canal, and the flat femoral canal technique feasible in every orthopaedic operating room and mitigates costly specialized instrument.

Recent anatomical studies have described the anterior cruciate ligament (ACL) as a flat, ribbon-like structure with a flat femoral origin and a C-shaped tibial insertion.[1-4] In their anatomical cadaver study in 2015, Siebold et al.'s[3] findings negate the presence of 2 independent ACL bundles, anteromedial and posterolateral, as Buoncrisianti et al. proposed in 2006[5]. Siebold et al.[3] stated that the ACL bundles do not easily divide into two distinct bundles. Śmigielski et al.[4] showed that the appearance of 2 ACL bundles is an illusion because of the twisting nature of the flat, ribbon-like anatomy of the ACL.

ACL reconstruction techniques continuously evolve as our anatomical and technical knowledge expands.[6] Hence, Fink et al.6 designed an ACL reconstruction technique around the new findings of Śmigielski et al.[4] The Medacta-Anatomic Ribbon Surgery ACL reconstruction surgical technique goes beyond the standard round bone tunnels and adopts a more anatomical approach: a C-shaped tibial insertion and a flat femoral origin with a flat ribbon-like graft.

The technique proposed by Fink et al.,[7] M-ARS, requires specific surgical instrumentation. In this technical note, we describe a modification to the M-ARS ACL reconstruction technique using a flat, ribbon-like, semi-T graft with a flat femoral bone tunnel and a C-shaped tibial bone tunnel that does not rely on specialized equipment.

Technique

Patient Positioning

The patient is supine, with a proximal thigh tourniquet to be used if needed. Bumps are placed under the hip and at the end of the table near the patient's foot to

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aid knee flexion. Positioning should permit knee flexion between 0° and 120°.

Graft Harvesting and Preparation

The semi-T autograft is harvested according to the technique described by Vinagre et al.[8] Using a tendon stripper (Smith & Nephew, Andover, MA), the graft is harvested from the pes anserine area at the distal attachment site of the semi-T tendon. Then, the graft is cleaned from remaining muscle tissue (Fig 1 A and B, Video 1). We fold the semi-T graft on itself twice (Fig 1 C and D, Video 1). The graft is then prepared as a flat structure to mimic the flat, ribbon-like ACL (Fig 1, Video 1). The harvested semi-T graft is prepared according to the description of Fink et al.[7] The prepared graft is then attached with 2 UltraButton adjustable fixation devices (Smith & Nephew) at its ends (Fig 1 C and D, Video 1). Finally, we fixate the semi-T graft into its final flat shape by applying Krakow sutures (Fig 1E, Video 1). The prepared semi-T graft is then flattened using the back of any blunt tool (a bunt, flat structure) (Fig 1 E-G, Video 1). This method maintains the structural integrity of the harvested semi-T graft.[9]

Femoral Canal

Routine arthroscopic diagnostics are performed while the knee is positioned in 90° of flexion. ACL remnants and any surrounding synovitis or loose tissue are removed. With the knee in hyperflexion at 120°, a conventional guidewire is drilled into the femoral cortex from the middle portion of the femoral ACL insertion through the medial portal (Fig 2C, Video 1).

The guidewire is drilled through the cortex to make room to pass the Endobutton (Smith & Nephew) later on. Two additional guidewires are drilled laterally to the central guidewire already inserted, so the guidewires form a flat tunnel (Video 1). This step is "inside out," meaning the guidewires pierce the skin (Fig 2 C and D). The laterally inserted guidewires do not have to be drilled into the lateral femoral cortex, only to a depth of 30 mm (Video 1). Then the 2 lateral guidewires are overdrilled using a conventional 5 mm round drill to a depth of 30 mm (Fig 3, Video 1).

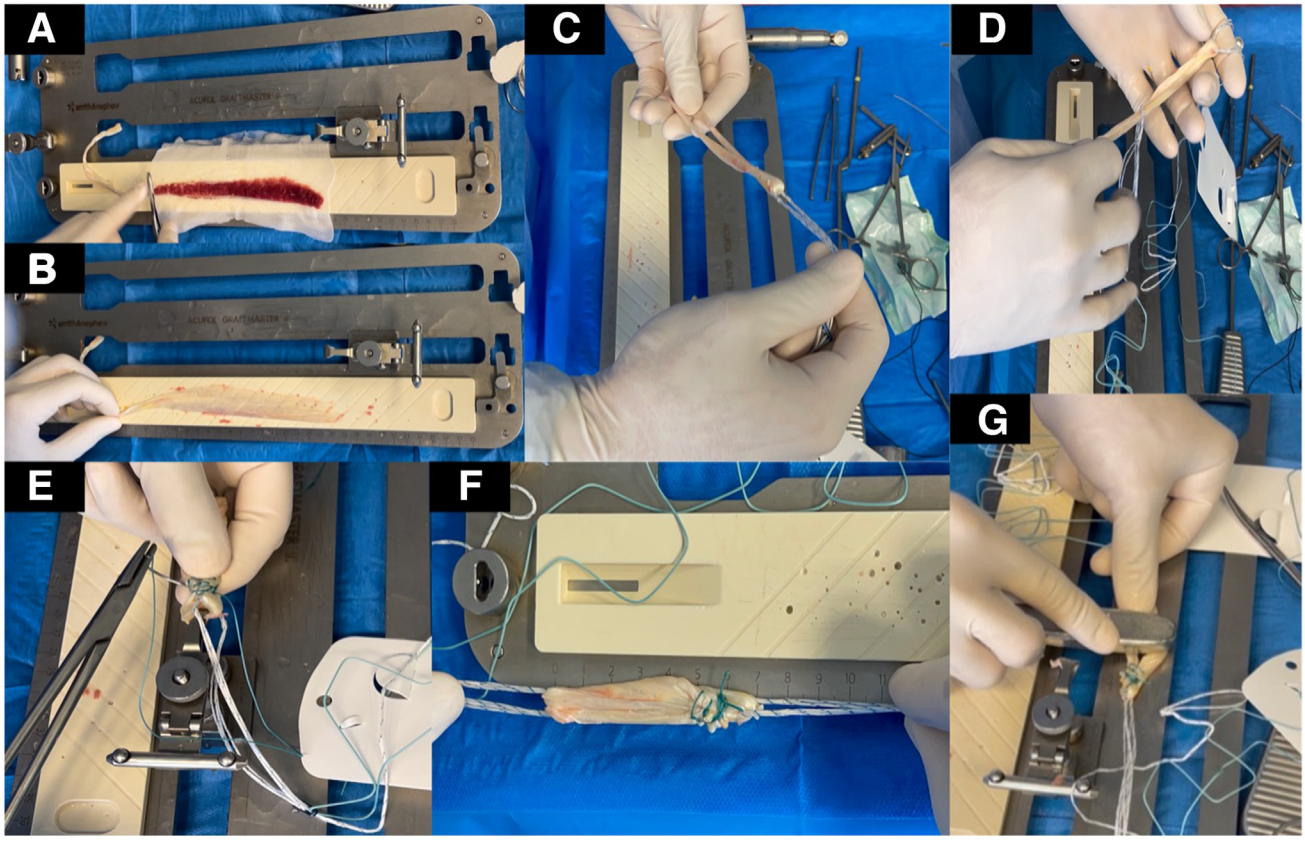

Fig 1. Preparing the harvested semitendinosus graft as a flat graft. (**A, B**) The harvested semitendinosus graft is placed on the preparation plate and debrided from muscle tissue. (**C**) Folding the graft on itself once and attaching an Endobutton (Smith & Nephew) using the Ultrastar (Smith & Nephew) technique. (**D**) Folding the graft on itself a second time and attaching a second Endobutton (Smith & Nephew). (**E**) Stabilizing the graft in place with Krakow sutures and final tightening of the 2 Endobuttons (Smith & Nephew) into place. (**F**) The prepared semitendinosus anterior cruciate ligament graft ready for being flattened out. (**G**) Flattening the prepared Semi-T graft with any blunt tool.

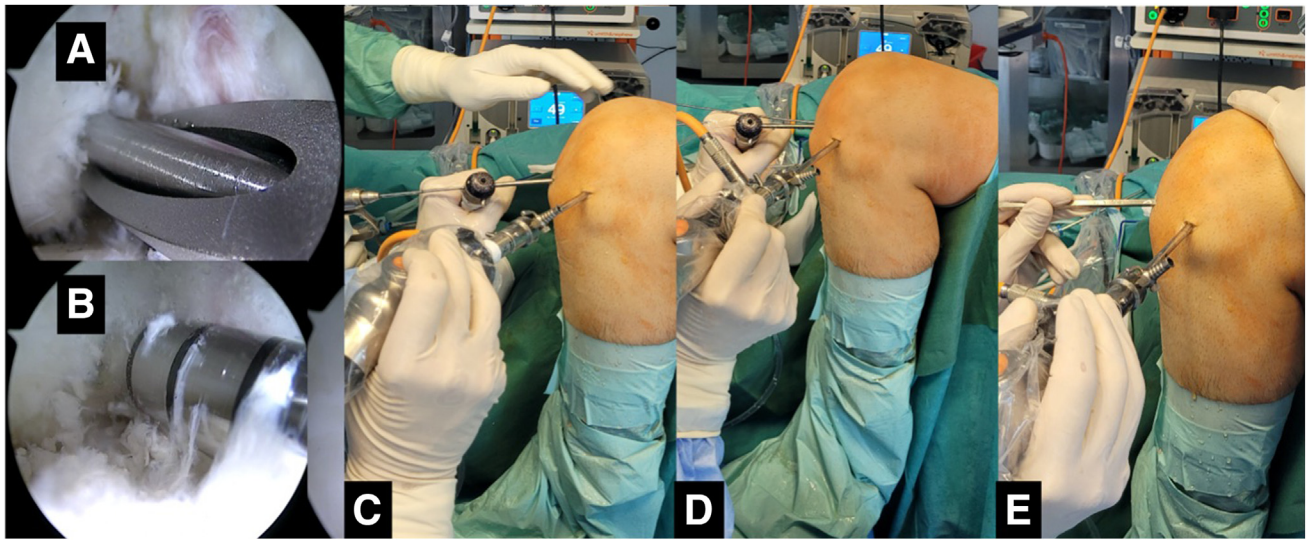

Fig 2. Femoral canal preparation. (**A**) Drilling with a guidewire, marking the beginning, middle, and end of the flat femoral anterior cruciate ligament origin site. (**B**) Drilling with a cannulated 5 mm drill on a directional wire so that the depth of the canal at the lateral drill site is 3 cm and the middle drill site goes beyond the cortex of the condyle. (**C**) Drilling in the first guidewire. (**D**) Drilling in the second guidewire. (**E**) Flattening and smoothening out of the flat femoral canal with a bone chisel (medial standard portal view of arthroscope; Smith & Nephew).

This depth of the femoral canal will be sufficient to accommodate the 70 mm graft length. The middle canal is then drilled beyond the femoral cortex to an additional depth of 7 mm to adjust for proper Endobutton (Smith & Nephew) fixation. The guidewires are then removed. Three side-by-side canals are drilled at

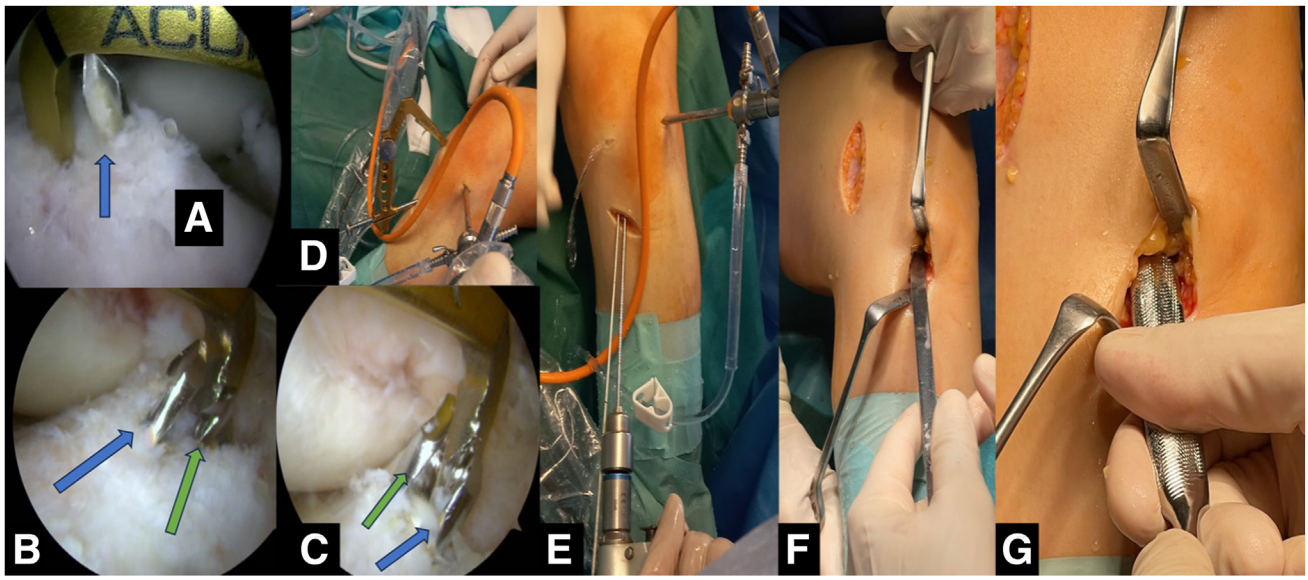

Fig 3. Tibial canal preparation. (**A**) With the knee still in 90° of flexion, a tibial aimer (Smith & Nephew) is inserted and set on the line of the anatomic tibial anterior cruciate ligament insertion, close but sparring, the anterior horn of the lateral meniscus, medial standard portal view. The first most anterior guidewire (demarcated by the blue arrow) is drilled visible under arthroscopy in contact with tibial aimer (Smith & Nephew). (**B**) Medial standard portal view of the first lateral guidewire (demarcated by the green arrow) being drilled lateral and posterior to the middle wire (demarcated by the blue arrow). (**C**) Medial standard portal view of the second lateral guidewire (demarcated by the green arrow) being drilled lateral and posterior to the middle guide wire(demarcated by the blue arrow) the tibial aimer (Smith & Nephew) is repositioned for every guidewire drilling. For reference, the middle guidewire(demarcated by the blue arrow) is kept in place as a landmark to easily overdrill the lateral posterior canals to guarantee a C-shaped tibial canal. (**D**) External view of knee in 90° of flexion and adjusting the tibial aimer into place, drilling the first guidewire. (**E**) Overdrilling of guidewires to achieve the C-shaped tibial canal. (**F, G**) Bone chisel (Smith & Nephew) is used to seamlessly even out and smoothen the walls of the C-shaped tibial canal to avoid any damage to the flat semitendinosus graft during insertion.

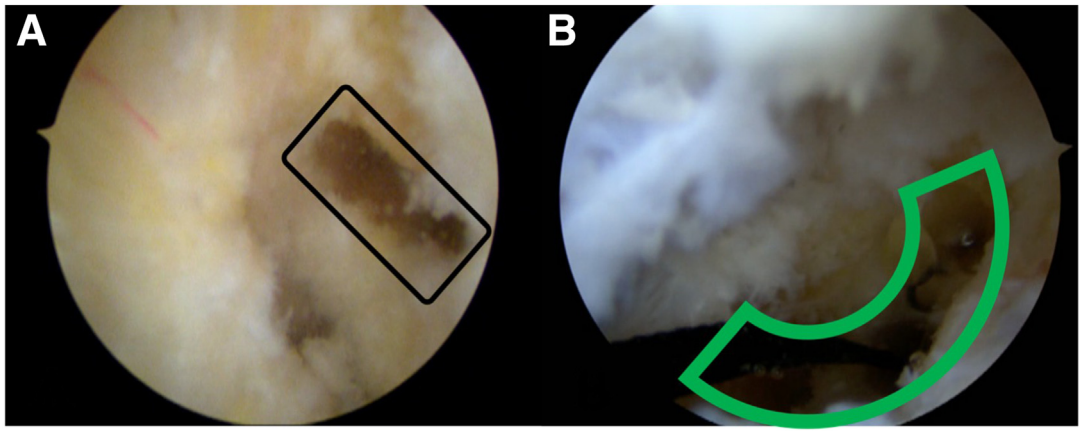

Fig 4. Medial standard portal Arthroscopic view of the prepared canals. (**A**) Flat femoral canal demarked within the black rectangle. (**B**) C-shaped tibial canal highlighted in green.

the level of the native femoral ACL insertion (Video 1). A bone chisel and a shaver (Smith & Nephew) are used to remove any bony irregularities and smoothen the flat femoral canal (Fig 2E, Video 1). Figure 4A shows a medial standard portal view of the flat femoral canal.

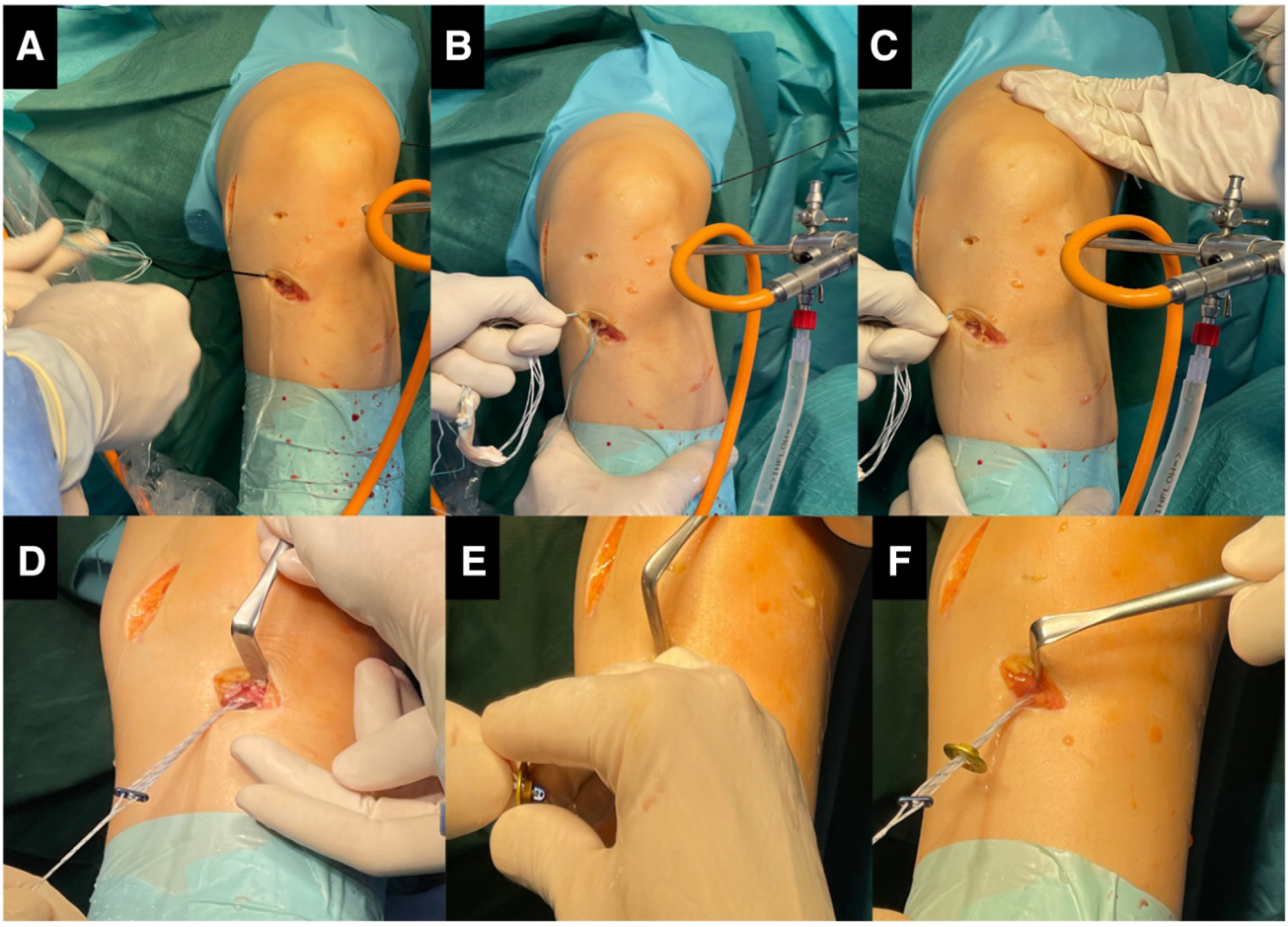

Fig 5. Graft insertion (lateral side). (**A**) A guide thread is attached to the prepared flat semitendinosus anterior cruciate ligament (ACL) graft for ease of retrograde passage through the tibial and femoral canals. (**B-D**) A hook is used to pull the flat semitendinosus ACL graft retrograde through from the C-shaped tibial canal into the flat femoral canal. (**E, F**) Attaching the XTEndobutton (Smith & Nephew) to the flat ACL semitendinosus graft in preparation for final graft fixation.

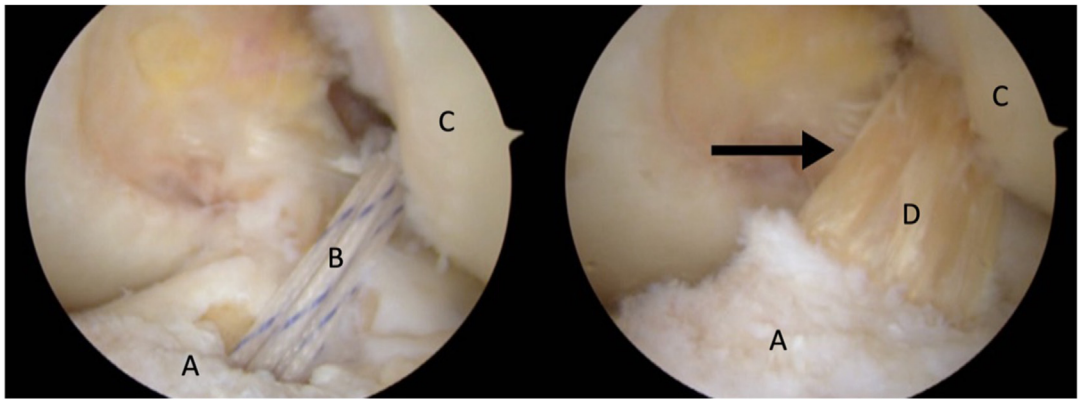

Fig 6. Medial standard portal view of the stabilized semitendinosus graft in the femoral and tibial canals. (**A**) C-shaped tibial anterior cruciate ligament (ACL) insertion site. (**B**) Guide thread of ACL graft being pulled retrograde into the flat femoral from the C-shaped tibial canal. (**C**) Flat femoral ACL origin site. (**D**) Flat ACL semitendinosus graft fixated in its final position.

Tibial Canal

Routine arthroscopic diagnostics are performed while the knee is positioned in 90° of flexion. ACL remnants and any surrounding synovitis or loose tissue are removed. With the knee still in 90° of flexion, a tibial aimer (Smith & Nephew) is inserted through the medial portal and set on the line of the anatomic tibial ACL insertion, close to the anterior horn of the lateral meniscus (Fig 3 A-D, Video 1).

Guidewires are then drilled into the tibia and through the joint until they are visible under arthroscopy, in contact with the tibial aimer (Fig 3 A-E, Video 1). Three guidewires are inserted side by side so that the middle wire is most anterior, resembling a C-shape (Fig 3 A-C, Video 1). With a cannulated 5 mm round drill, we proceed to overdrill each guidewire into the joint until the drill is visible under arthroscopy (Fig 3E, Video 1).

The tibial aimer (Smith & Nephew) is repositioned for every guidewire (Fig 3, Video 1). After successfully overdrilling 3 canals side by side, with the middle canal being the most anterior, we realize a C-shaped tibial canal (Fig 3, Video 1). The order of canal drilling is not essential. The guidewires are removed. A bone chisel and shaver (Smith & Nephew) are used to remove bony irregularities and smooth the C-shaped tibial canal (Fig 3 F and G, Video 1). It is important to note that the entrance of the tibial tunnel should be dilated and smoothed out for proper fixation by UltraButton(Smith

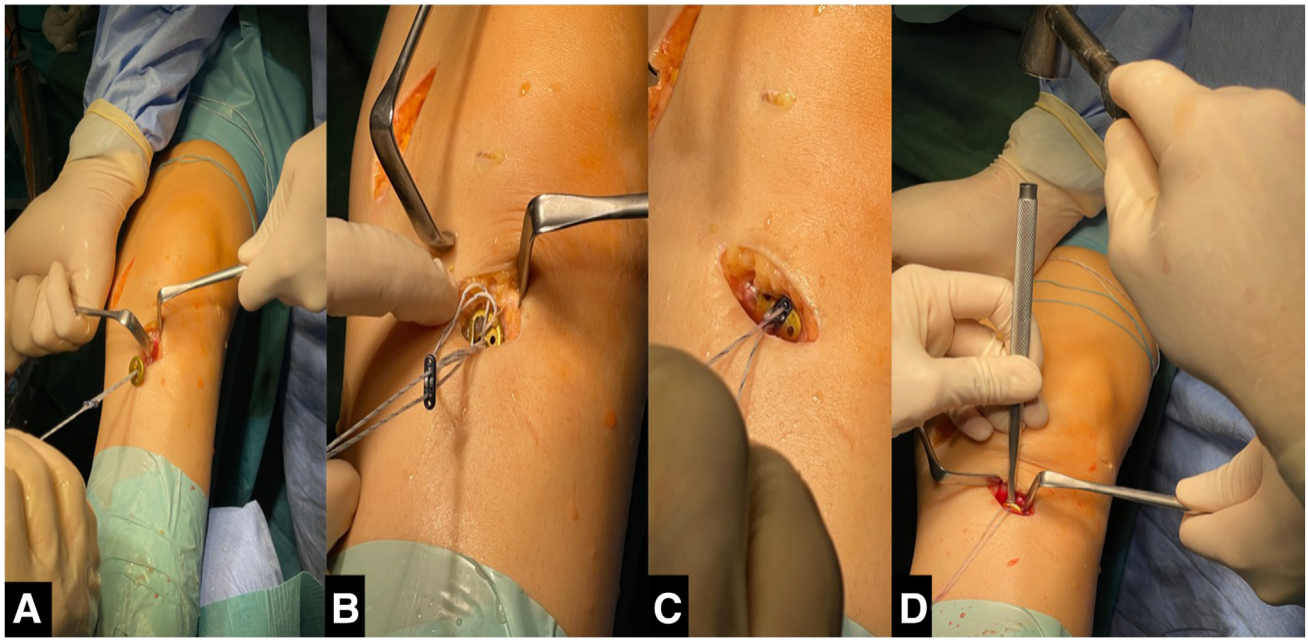

Fig 7. Final flat semitendinosus anterior cruciate ligament graft fixation and tightening (lateral side). (**A-C**) Tightening the Semi-T graft into place by tensioning the Endobuttons (Smith & Nephew). (**D**) Graft fixation by locking UltraButton (Smith & Nephew) into place by using a light mallet.

Table 1. Pearls and Pitfalls

Correct guidewire positioning on the ACL tibial insertion site is crucial to recreate a C-shape canal, make sure the middle drill site is most anterior to the other two lateral drill sites.
Canal debridement with a bone chisel is vital to ensure proper graft insertion
The semitendinosus graft should be properly flattened by any blunt instrument to ensure proper graft insertion
It is crucial to dilate and smooth out the entrance of the tibial canal for proper UltraButton(Smith & Nephew) fixation
It is crucial to identify the ACL origin and insertion sites to properly orient the tools for canal drilling and not miss proper canal positioning.

ACL, anterior cruciate ligament.

Table 2. Advantages and Disadvantages

Advantages
Dismisses the use of costly equipment
Anatomically reconstructs the bone canals, the flat femoral anterior cruciate ligament origin, and C-shaped tibial insertion
Spares the anterior horn of the lateral meniscus
Semitendinosus tendon is easily manipulated into the desired shape
The anatomical flat femoral and C-shaped tibial canals offer a decreased healing time because of increased bone tendon surface area
Disadvantages
Multiple drill sites needed to recreate the anatomical canals, flat femoral origin, and C-shaped tibial insertion
Learning curve for graft preparation and canal drilling
More time spent on surgery

& Nephew). Figure 4B shows a medial standard portal view of the C-shaped tibial canal.

Graft Insertion

The graft is inserted retrograde from the tibial canal (Figs 5, 6, Video 1). It is pulled into position with the previously attached UltraButton (Smith & Nephew) exiting the femoral condyle and tightened to set it in place (Fig 5, Video 1). Then, with the knee in flexion, final graft tightening is performed, and the graft is fixed in place at the distal aspect of the tibial canal using an XTEndobutton (Smith & Nephew) after achieving the desired tension (Figs 5, 7, Video 1).

Discussion

The modified anatomical flat, ribbon-like ACL graft with a flat femoral canal and a C-shaped tibial canal approach hopes to revolutionize how the orthopaedic community reconstructs the ACL (Figs 1-5, Video 1). Table 1 presents the pearls and pitfalls of the surgery described above, whereas Table 2 presents the advantages and disadvantages when compared to the conventional round bone tunnel single bundle ACL reconstruction surgery.

Furthermore, the flat femoral and C-shaped tibial canals play a dual role in this surgical technique. The first role of the flat bone canal is to mimic the anatomic attachments of an intact ACL to the femoral and tibial bones, and the second is to provide a larger surface area for bone-tendon contact, which enhances healing after ACL reconstruction.[10] Furthermore, a study examining the radiological and clinical differences between rectangular (flat) bone canals and round bone tunnels concluded that there are no striking differences between both canals; hence, adopting a rectangular canal approach during ACL reconstruction is as valid.[11] Moreover, the C-shaped canal prevents iatrogenic injury to the anterior horn of the lateral meniscus, a common complication in standard bone canal drilling.[3,7,12] A cadaveric biomechanical study in 2022 demonstrated that the flat tunnel technique is superior in terms of reproducing innate kinematics and rotational stability during ACL reconstruction as opposed to the round bone tunnel technique.[13]

In addition, the flat, ribbon-like semi-T graft allows a personalized approach to fit the size of the patient's native ACL before being damaged[8] (Fig 1, Video 1). ACL structural differences exist between patients, thus prompting a more individualized approach for ACL reconstruction.[14] This improves the function and stability of the knee and provides a personalized surgical procedure that guarantees a better outcome.[15] The semi-T graft was shown to promise more definite positive outcomes in patients after ACL reconstruction.[16] Also, using a semi-T graft provides increased bone-tendon contact and decreased blood diffusion length across the ACL graft, improving tendon-bone healing.[7,8] In addition, the use of 2 adjustable Endobutton fixation devices (Smith & Nephew) offers a speedy muscle recovery, faster return to sports, and decreased failure rate when compared to graft fixation with a femoral Endobutton and tibial and femoral interference screws as reported by a 2022 study done on military personnel in Marseille, France.[17]

Finally, our work has limitations, such as training surgeons to prepare the graft as a flat graft and to master the tunnel drilling techniques. However, these issues are usually encountered when learning a new surgical procedure.

Conclusions

Accordingly, the modified anatomical ACL reconstruction technique is an exciting and promising approach that modernizes how the orthopaedic community manages ACL reconstruction. Following this

modification, any orthopaedic surgeon can deliver optimal ACL reconstruction management concerning the new ACL and knee anatomy findings. One must still see if this modified technique delivers better long-term results than the gold standard procedures.

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