Technical Note

Posterior Cruciate Ligament Reconstruction Using Flat Soft-Tissue Grafts

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Abstract: Isolated posterior cruciate ligament (PCL) ruptures are relatively rare, but they more commonly occur in multiligament knee injuries. To date, in isolated or combined injuries with grade III step-off, surgical treatment is recommended to restore joint stability and improve knee function. Several techniques for PCL reconstruction have been described. However, recent evidence has suggested that broad, flat soft-tissue grafts may more closely mimic the native PCL ribbonlike morphology in PCL reconstruction. Furthermore, a femoral rectangular bone tunnel may more accurately re-create the native PCL attachment, allowing grafts to simulate native PCL rotation during knee flexion and potentially improving biomechanics. Therefore, we have developed a PCL reconstruction technique using flat quadriceps or hamstring grafts. This technique can be performed using 2 types of surgical instruments that allow for the creation of a rectangular femoral bone tunnel.

Posterior cruciate ligament (PCL) tears represent 3% of acute knee injuries, most of which occur in the setting of multiligament injuries.[1] Owing to their intrinsic healing capability, isolated partial PCL tears can be addressed by nonoperative management. However, healing may occur in a lax or attenuated position.[2-4] On the contrary, in isolated or combined injuries with grade III step-off, surgical treatment is recommended to restore joint stability and improve knee function.[5-7] Several techniques for PCL reconstruction have been described, differing regarding tibial graft fixation (transtibial tunnel and tibial inlay techniques), the bundles addressed (single or double bundle), and the type of graft used.[8] Recent evidence has pointed out that the PCL at the midsubstance is flat, with a twisted ribbonlike appearance, without clearly separate bundles.[9-12] The femoral insertion of the PCL is flat and high in the notch. Moreover, at the level of the medial meniscus, the fiber layers of the PCL have an arc-like appearance and are attached to the tibial insertion site. These anatomic characteristics, in addition to the obliquely functional axis of the ribbon, produce a twisting effect during flexion and extension of the knee, acting as multiple bundles.[12,13] For these reasons, the use of round tunnels and tubular grafts as the optimum reconstruction technique has to be questioned. As previously reported for anterior cruciate ligament reconstruction, anatomically oriented rectangular bone tunnels may more closely replicate the anatomy and biomechanics of the native PCL, allowing a twisting effect of the graft during knee flexion.[14] One of the key technical downsides of a round tunnel on the femur in PCL reconstruction is the "dead space" that is created anteriorly to the graft owing to the angle and direction

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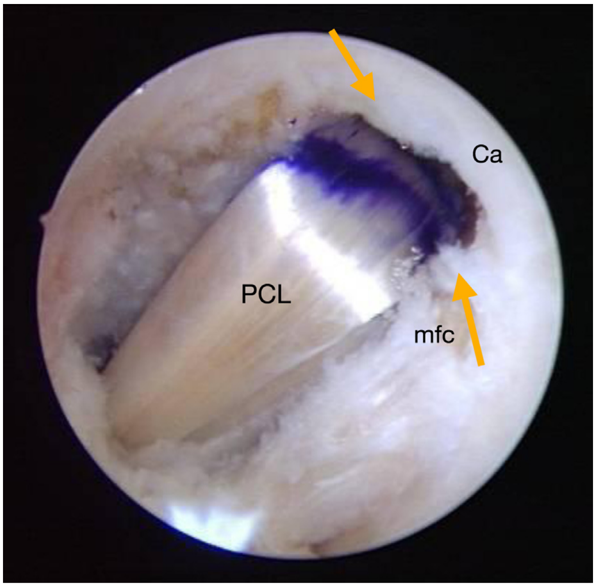

Fig 1. Arthroscopic view of the lateral wall of a medial femoral condyle of a right knee from a lateral standard portal in 90° of flexion. Dead space (arrows) anterior to posterior cruciate ligament (PCL) graft due to round tunnel on femur, owing to angle and direction of tensional forces. (Ca, cartilage; mfc, medial femoral condyle.)

of the tensional forces (Fig 1). Additionally, a round tunnel permits rotation of the graft within the tunnel when extracortical fixation is used.

Hence, we have developed a PCL reconstruction technique using flat soft-tissue grafts (Video 1). This technique can be performed using 2 types of surgical instruments that allow for the creation of a rectangular femoral bone tunnel.

Surgical Technique

Patient Positioning

The patient is positioned supine with placement of a thigh tourniquet. Knee motion between 0° and 120° should be possible. We prefer to use an electric leg holder (Maquet, Rastatt, Germany). For easy intraoperative access to the fluoroscope, the contralateral leg is placed in the lithotomy position (Fig 2).

Graft Harvesting

For the PCL reconstruction technique using flat soft-tissue grafts, we recommend the use of quadriceps tendon (QT) or hamstring tendon (HT) autografts. Soft-tissue allografts may alternatively be used in accordance with the surgeon's preference.

Soft-Tissue QT Graft

Minimally invasive QT graft harvesting is performed as described and illustrated by Fink et al.[15] using specialized instrumentation (either Medacta QTH [Medacta International, Castel San Pietro, Switzerland] or Karl Storz, Tuttlingen, Germany). In brief, with the knee at 90° of flexion, a 2- to 3-cm transverse skin incision is made over the superior pole of the patella. Subcutaneous dissection is performed, and the QT is exposed. A vertical cutter (Medacta International) with a width of 10, 12, or 14 mm is introduced, starting slightly lateral to the midline of the superior patellar border, and is pushed up to a minimum of 80 mm (Fig 3A). A horizontal cutter (4 or 6 mm) and subcutaneous cutter (Medacta International) are used to separate the tendon in the coronal plane and cut the proximal end (Fig 3 B and C). A strip of periosteum is harvested from the anterior face of the patella by gradual subperiosteal dissection, peeling back the graft under tension (Fig 4A).

Optionally, QT graft harvesting can be performed using QT harvesting instruments (Karl Storz). Similarly, this technique requires the use of 3 instruments: a double knife, a tendon separator, and a subcutaneous tendon cutter.

The tendon defect is closed with absorbable sutures (No. 0 Vicryl; Ethicon, Somerville, NJ). It is important to place the stitches in the superficial aspect of the tendon to avoid shortening of the tendon ("fanlike closure"). The prepatellar bursa is carefully closed. A wet swab is inserted between the tendon and skin to limit leakage of arthroscopy fluid. Alternatively, the QT graft can be harvested using a conventional open

Fig 2. Patient position. The operated leg (left knee) is placed in an electric leg holder. For easy intraoperative use of the fluoroscope, the contralateral leg is placed in the lithotomy position.

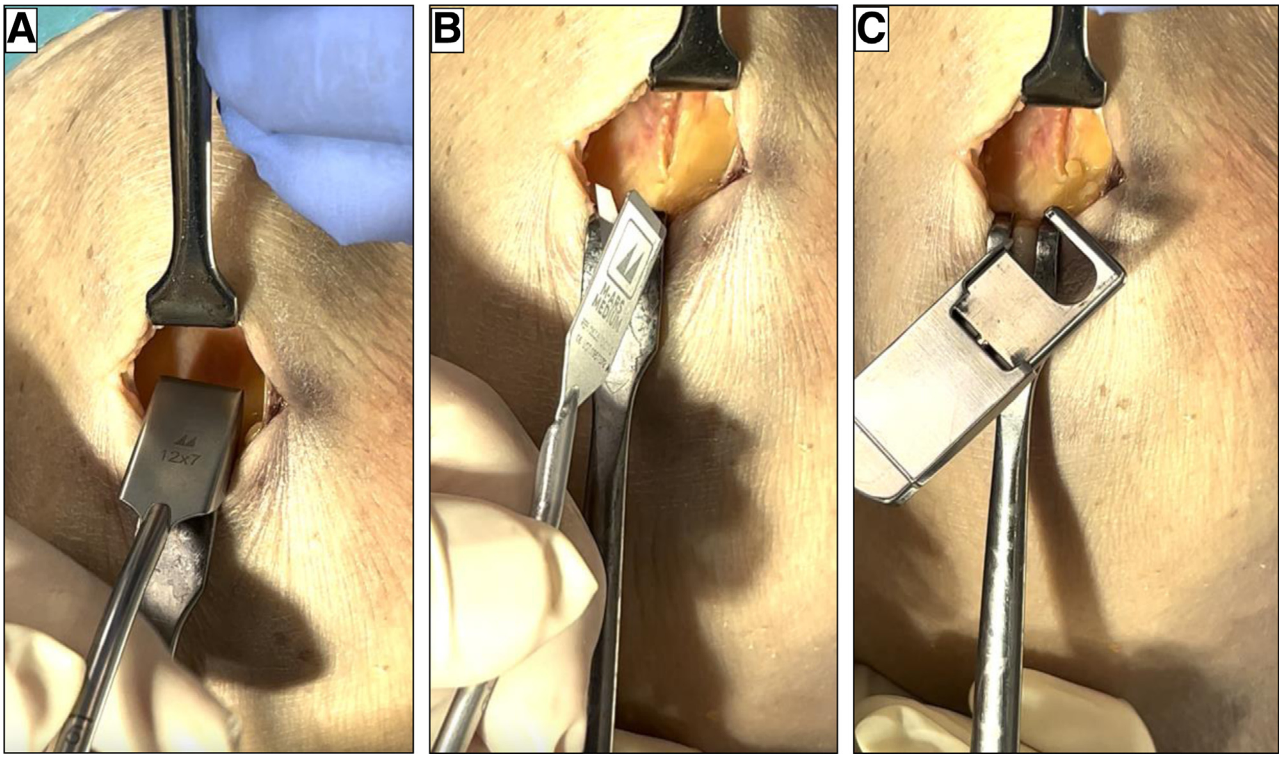

Fig 3. Quadriceps tendon (QT) graft harvesting with Medacta instruments. (A) A vertical cutter is used to create parallel subcutaneous incisions in the QT over a defined length for graft harvesting. (B) A horizontal cutter is used to create horizontal subcutaneous incisions in the QT over a defined length. (C) A subcutaneous cutter is used to create a proximal incision at a defined length.

approach with a longitudinal incision of about 6 cm in length without the use of special instrumentation.

Soft-Tissue HT Graft

For HT autografts, the semitendinosus (ST) and/or gracilis (GC) can be harvested from the surgical site or the contralateral side. Allografts may be considered according to the surgeon's preference. A vertical anteromedial incision at the level of the tibial tubercle is used to expose the sartorial fascia and pes anserine bursa, which covers the HTs. An incision in the sartorial fascia allows exposure of the tendons. The tendons are identified and then placed individually through an open tendon stripper and released from their muscular attachments proximally while the knee is flexed and the stripper is advanced in a proximal direction.

Graft Preparation

Soft-Tissue QT Graft

The periosteal part of the graft is folded over, and Krackow-stitch sutures are placed on each side of the graft using size 2 nonabsorbable sutures (FiberWire [Arthrex, Naples, FL] or Powerknot [Medacta International]) (Fig 4 B and C, Video 1). In this way, a smooth, round end of the graft is obtained. This allows easier graft passage and gains about 1 cm of additional graft length. Both aspects are a major point for using the QT for PCL reconstruction. The sutures are then passed through a flip button (e.g., Extracortical Femoral Button [Medacta International]) for later fixation. Alternatively, an adjustable-loop button (e.g., FairFix [Medacta International]) can be used for femoral fixation.

Soft-Tissue HT Graft

First, excess muscular tissue and unstable portions of the tendon are removed from the ST and GC grafts. The ST tendon is split from proximal to distal with a knife and smoothed into a flat shape by a blunt rasp at minimum pressure (Fig 5 A and B, Video 1). The length of the graft is measured.

The ST graft is folded in the middle, and Krackow-stitch sutures are placed on each side of the graft using size 2 nonabsorbable sutures (FiberWire or Powerknot) (Fig 5C). The ST graft can be triplicated if required. The graft is passed through a continuous-loop button (e.g., MedactaLoop [Medacta International]) or adjustable-loop button (e.g., FairFix). A minimum graft length of 80 mm is required to allow sufficient bone-tendon contact within the tunnels. The GC can be used additionally if the size of the graft is not adequate.

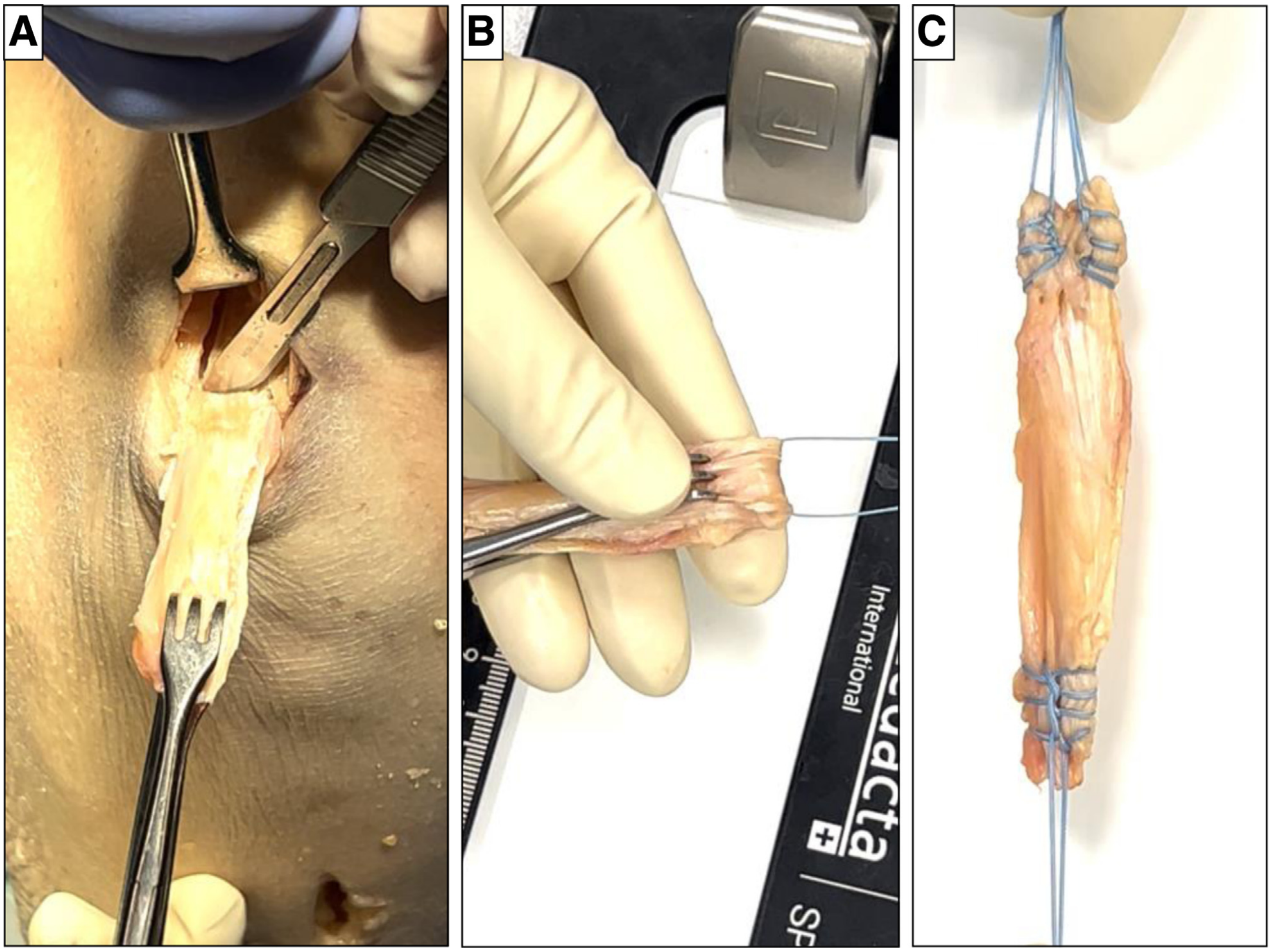

Fig 4. Quadriceps tendon graft harvesting and preparation. (A) A strip of periosteum is harvested from the anterior face of the patella by gradual subperiosteal dissection, peeling back the graft under tension. (B) The periosteal part of the graft is folded over a suture to the tendon insertion. (C) Krackow-stitch sutures are placed on each side of the graft using size 2 nonabsorbable sutures (FiberWire).

Tibial Tunnel

After routine diagnostic arthroscopy, the PCL remnant is debrided with a shaver and/or radiofrequency device, leaving a small amount of remnant on the femoral condyle for footprint visualization (Fig 6 A and B, Video 1). At this point, an accessory posteromedial portal is established under arthroscopic visualization with a spinal needle, followed by a stab incision and blunt intra-articular dissection.

The tibial PCL footprint is identified with careful subperiosteal dissection using a radiofrequency ablation device and shaver placed through the posteromedial portal while visualizing through the trans-notch view (Fig 6C). With the knee at 90° of flexion, a PCL tibial guide (e.g., Medacta PCL guide [Medacta International]) set at 55° is inserted through the medial portal and placed about 10 to 15 mm distal to the joint line to precisely locate the tibial PCL footprint for guidewire placement and tunnel drilling (Fig 6D). A guidewire is advanced into the tibial guide under direct fluoroscopic control, maintaining arthroscopic visualization of the tibial PCL footprint. Subsequently, the tibial socket is reamed according to the graft size under direct fluoroscopic control.

Femoral Tunnel

Femoral tunnel preparation can be performed using M-ARS instrumentation (Medacta International). The following steps are described in Figure 7 and Video 1:

1. With knee flexion of 90°, a 2.4-mm guidewire is drilled into the native femoral PCL insertion through a low anterolateral portal. The tunnel length is measured extra-articularly over the guidewire,

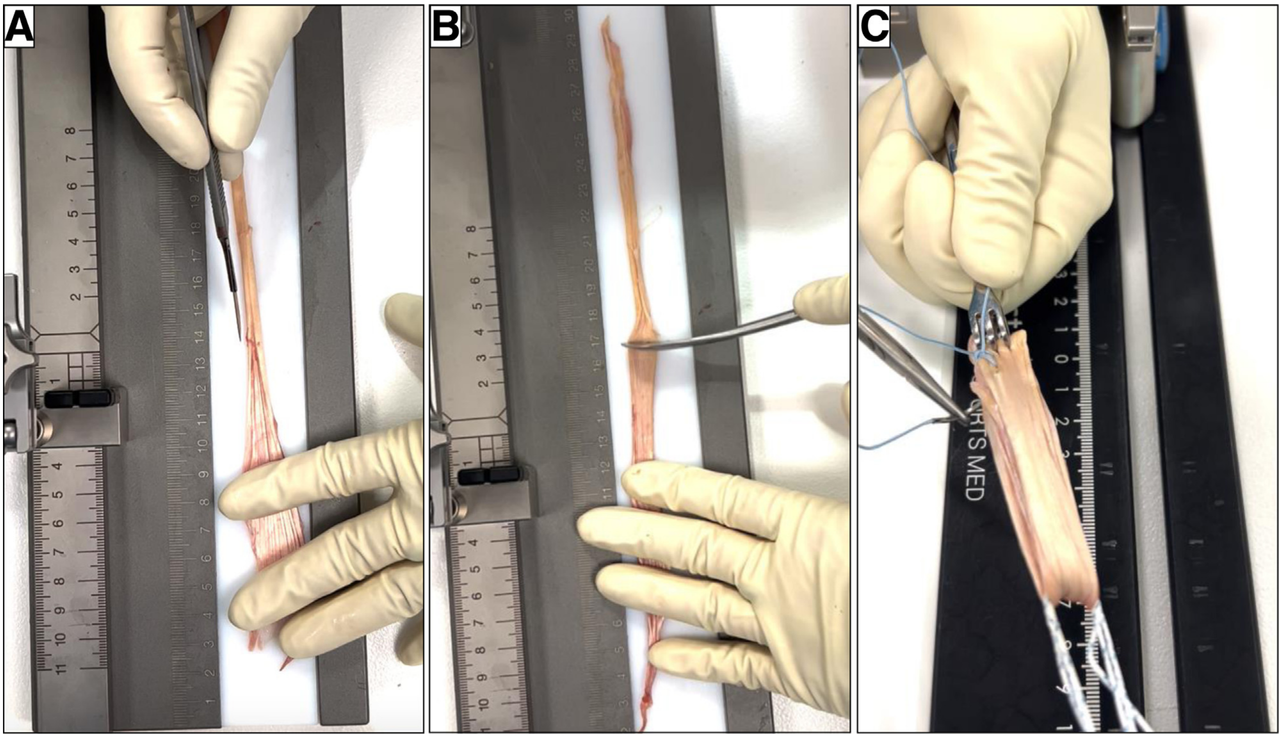

Fig 5. Hamstring tendon graft preparation. (A) The semitendinosus tendon is split to half its diameter from proximal to distal in the round part of the tendon with a knife. (B) The graft is smoothed into a flat shape by a blunt rasp at minimum pressure. (C) Krackow-stitch sutures are placed on each side of the graft using size 2 nonabsorbable sutures (FiberWire).

referencing from the medial femoral cortex and the laser marking on the wire.

2. The tunnel position should be checked through the high lateral viewing portal.
3. A femoral aimer (Medacta International) is inserted through the low anterolateral portal (Fig 8B). The aimer presents 3 holes for guidewires. The 2.4-mm guidewire (used for tunnel length) is inserted within the central hole of the aimer (Fig 7 A-D).
4. With knee flexion of 90° and visualization through the high lateral viewing portal, the aimer should be aligned with the margin of the articular cartilage of the medial femoral condyle within the PCL footprint. Next, 2.4-mm guidewires are inserted into the anterior and posterior hole of the aimer. The aimer is removed (Fig 7E).
5. A 4.5-mm drill bit is used to over-drill the anterior and posterior guidewires to a depth of 25 to 30 mm (Fig 7B). Subsequently, the same drill is used to over-drill the central wire in a bicortical manner. The anterior and posterior guidewires are removed.
6. According to the femoral graft size (small, medium, or large), a dilator (Medacta International) is inserted over the central guidewire intra-articularly and advanced to a depth of 25 to 30 mm (Figs 7 C-F and 8A). Any rough edges and debris can be removed with a shaver (Fig 8C).

Alternatively, femoral tunnel preparation can be performed using Karl Storz instrumentation. The following steps are described in Figure 9 and Video 1:

1. Similarly to the previous femoral tunnel preparation, a 2.4-mm guidewire is drilled into the native femoral PCL insertion through a low anterolateral portal. The tunnel length is measured extra-articularly over the guidewire, referencing from the medial femoral cortex and the laser marking on the wire (Fig 9A).
2. A 4.5-mm drill is used to over-drill the guidewire in a bicortical manner (Fig 9B).
3. A rectangular rasp (Karl Storz) matching the graft diameter (8 or 10 mm) is inserted over the guidewire intra-articularly. Under visualization through a high lateral viewing portal, the rasp should be aligned with the margin of the articular cartilage of the medial femoral condyle within the PCL footprint (Fig 9 C and D).
4. The tunnel is rasped to a depth of 25 to 30 mm (Fig 9E).
5. In the case of 9- and 12-mm grafts, a dilator (Karl Storz) of the same size as the graft is inserted after rasping.

The finished tunnel is shown in Figure 9F, viewed arthroscopically from the lateral portal.

Graft Insertion

Graft insertion is performed as follows:

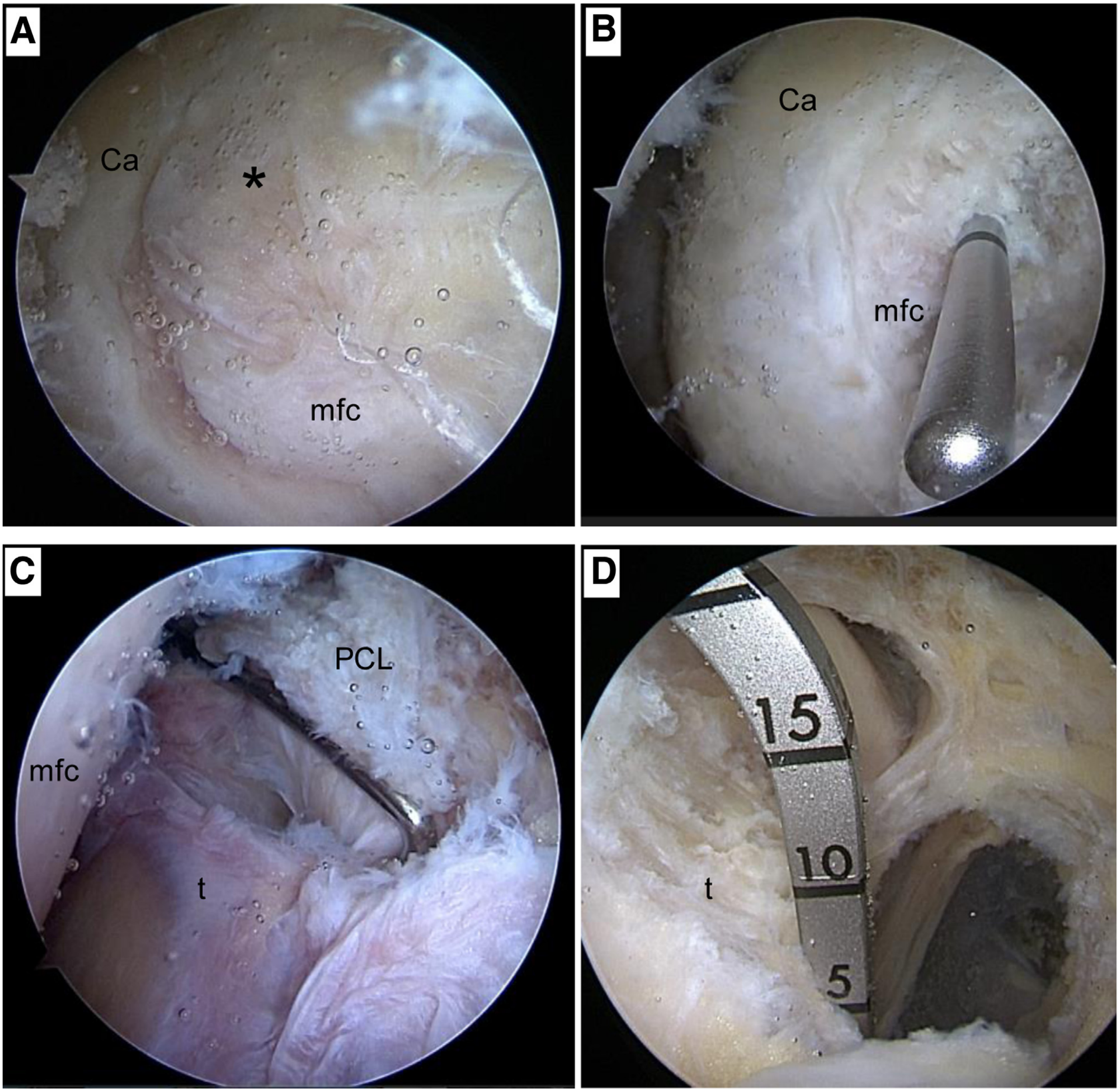

Fig 6. (A, B) Femoral footprint on arthroscopic view through low anterolateral portal. (C) Tibial posterior cruciate ligament (PCL) footprint on arthroscopic trans-notch view with hook in posteromedial portal. (D) Arthroscopic view from posteromedial portal. With the knee at 90° of flexion, a PCL tibial guide (M-ARS) set at 55° is inserted through the medial portal and placed about 10 to 15 mm distal to the joint line to precisely locate the tibial PCL footprint for guidewire placement and tunnel drilling. The asterisk indicates the PCL footprint. (Ca, cartilage; mfc, medial femoral condyle; t, tibia.)

1. A Beath pin is introduced through the low anterolateral portal and used to pass a No. 2 suture through the femoral tunnel. The suture loop is grasped intra-articularly and pulled out through the anteromedial portal.
2. To place the tibial shuttle suture, a Magellan suture retriever (Zimmer Biomet, Warsaw, IN) is inserted through the tibial tunnel, and the nitinol wire loop is advanced into the joint space and then retrieved through the anteromedial portal. The shuttle suture is inserted into the loop and pulled out through the tibial tunnel.
3. The loop of the No. 2 suture is inserted into the loop of the Magellan suture retriever; a soft-tissue bridge should be avoided. The instrument is retrieved from the tibial tunnel.
4. A key maneuver is to introduce a PCL elevator (Karl Storz or Medacta International) through the

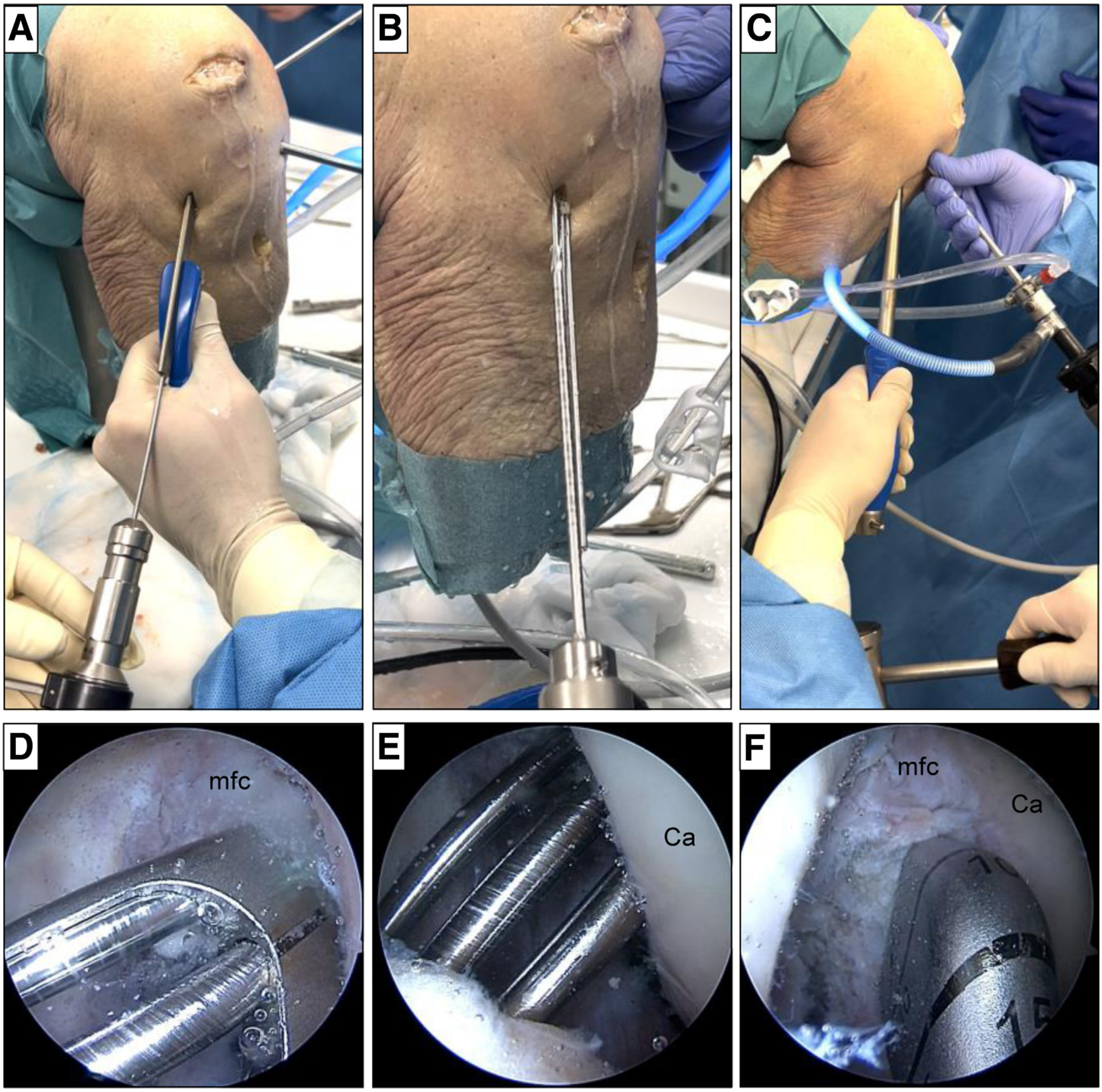

Fig 7. Femoral tunnel preparation with M-ARS instrumentation. (A-C) External view of femoral preparation steps. (D-F) Arthroscopic view of femoral preparation steps through high anterolateral portal. A 2.4-mm guidewire (used for tunnel length) is inserted over the femoral footprint of the anterolateral bundle of the posterior cruciate ligament. (A) The femoral aimer is introduced through a low anterolateral portal over the guidewire. (D) The aimer should be aligned with the margin of the articular cartilage of the medial femoral condyle (mfc). (B, E) Guidewires measuring 2.4 mm are inserted into the anterior and posterior holes of the aimer. The aimer is removed. A 4.5-mm drill bit is used to over-drill the anterior and posterior guidewires to a depth of 25 to 30 mm. The central guidewire is over-drilled in a bicortical manner. (C, F) According to the size of the graft, a dilator (small, medium, or large) is inserted over the central guidewire intra-articularly through a low anterolateral portal. (Ca, cartilage.)

posteromedial tunnel placed underneath the shuttle suture to facilitate graft passage through the tibial tunnel and over the tibial ridge by changing the force orientation to minimize graft abrasion over the "killer curve."

5. The loop is used to pull the lead sutures for the extracortical femoral fixation device (continuous- or adjustable-loop button) through the knee and out through the femoral tunnel aperture.
6. The graft is introduced by pulling on the lead sutures and the PCL elevator alternately (Video 1). Free flipping of the Extracortical Femoral Button device is confirmed under arthroscopic vision to ensure that there is no entanglement of the lead sutures.

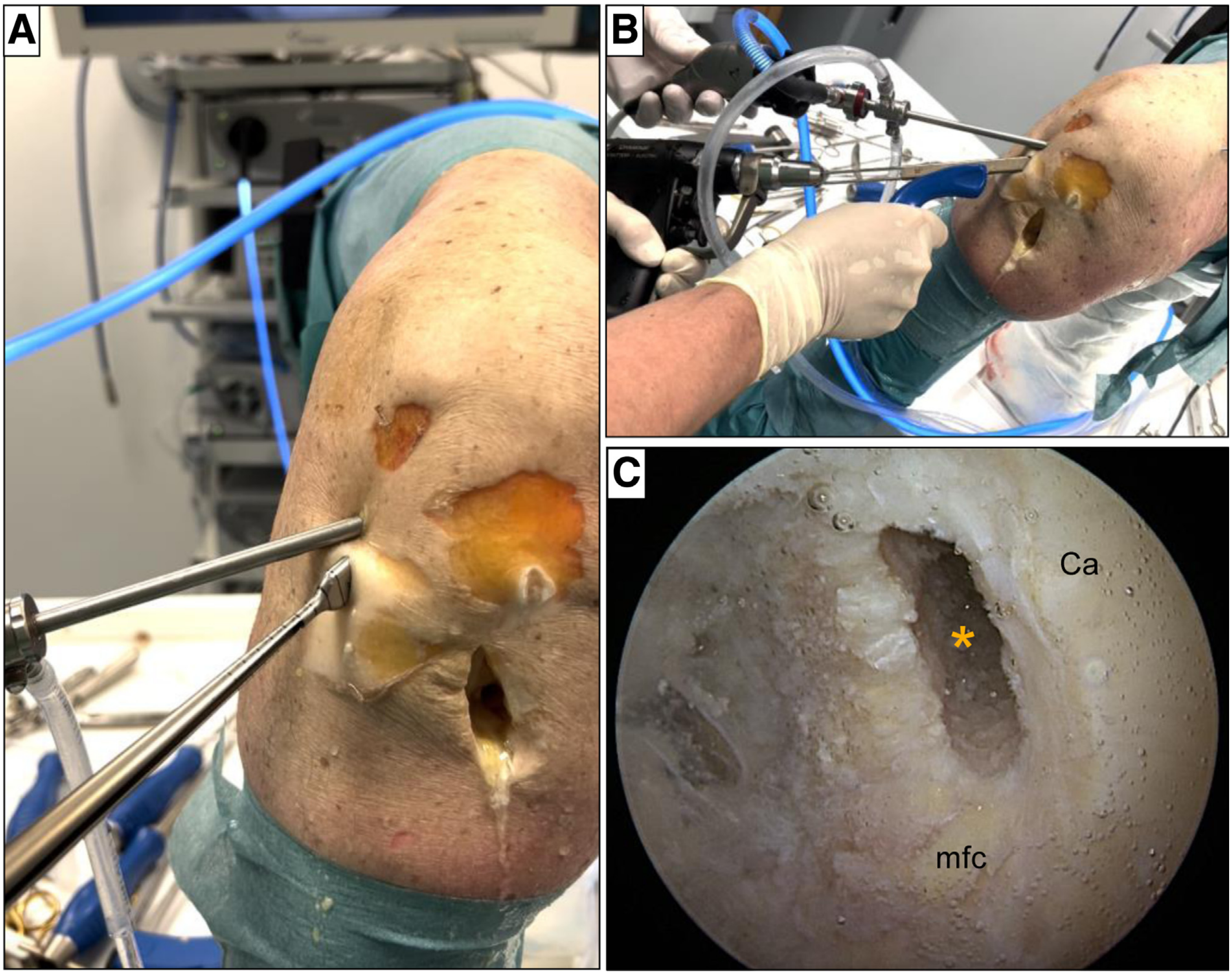

Fig 8. Surgical trick for femoral tunnel preparation in right knee. (A, B) The surgeon should hold the scope in a high anterolateral portal looking medially while inserting the aimer and dilator for femoral tunnel preparation through a low anteromedial portal. (C) Right knee viewed from high lateral portal looking medially toward lateral wall of medial femoral condyle (mfc). The asterisk indicates the prepared flat femoral tunnel. (Ca, cartilage.)

7. Before insertion into the femoral tunnel, the soft-tissue graft is guided and correctly rotated intra-articularly with the aid of a standard arthroscopic palpation hook.
8. When the graft is in correct rotation, it is pulled completely into the rectangular bone tunnel until the femoral fixation button is flipped. Depending on the device, the graft is pulled into the tunnel at least 15 mm (adjustable-loop button) or the graft is pulled back after the button is flipped (fixed-loop button).
9. Hybrid fixation is used distally. A fully threaded, cannulated bioabsorbable interference screw matching the tunnel diameter and 25 to 30 mm long is inserted over a guidewire. Additionally, the sutures are tied over a bone bridge.[14]

The final PCL graft orientation is shown in Figure 10 and Video 1.

Postoperative Care

A PTS brace (PTS Medi, Bayreuth, Germany) is used for the first 2 postoperative days. Afterward, a dynamic PCL knee brace limiting flexion to 90° is used for 8 weeks. Passive range-of-motion exercises are initiated immediately and performed only in the prone position for the first 4 weeks to prevent hamstring activation and posterior sag of the tibia due to gravity. Quadriceps activation exercises are started immediately after surgery. The patient is mobilized with partial weight bearing (20 kg) for 2 weeks and then gradually increases to full weight bearing. Physical therapy 2 to 3 times per week for at least 8 to 12 weeks is recommended.

Discussion

We describe a versatile PCL reconstruction technique using flat soft-tissue grafts (QT or HT graft)

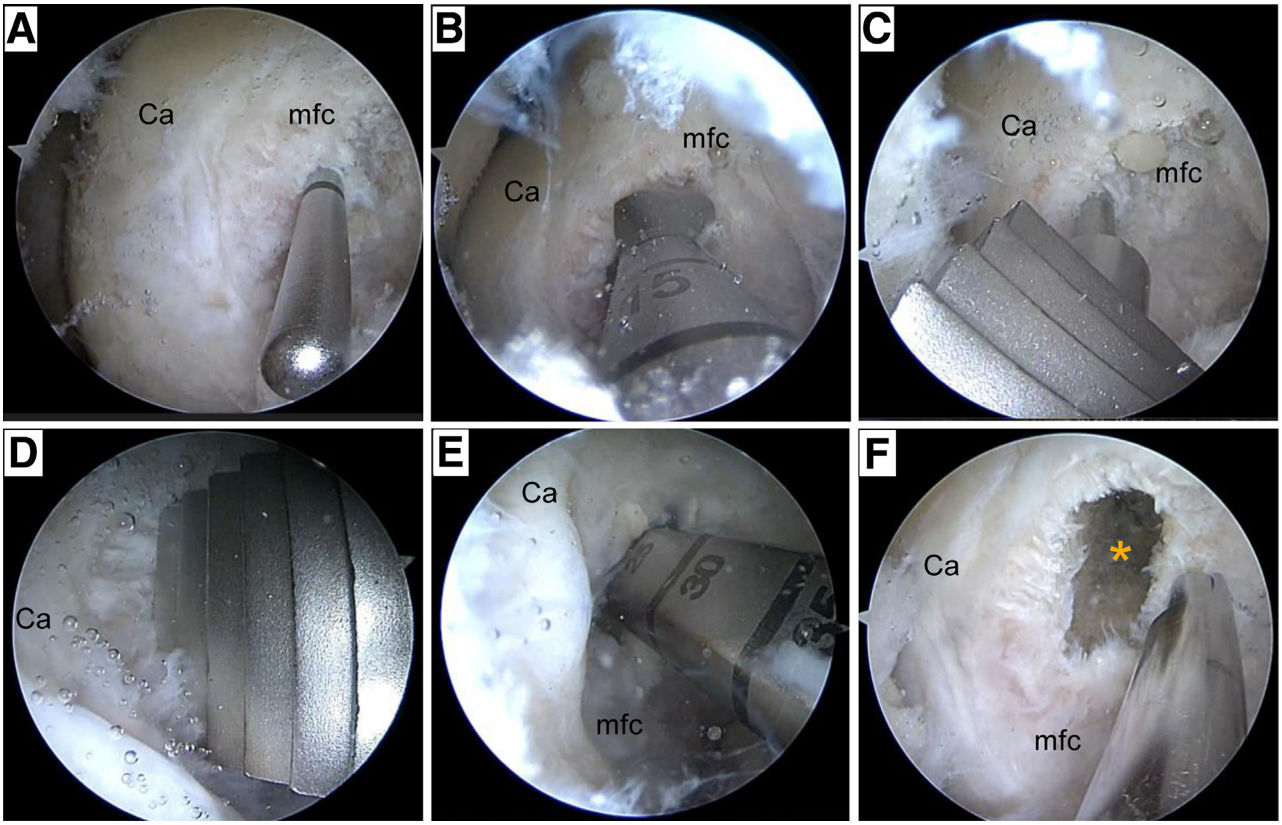

Fig 9. Femoral tunnel preparation with Karl Storz instrumentation: arthroscopic view of femoral preparation steps through high anterolateral portal. (A) A 2.4-mm guidewire is drilled into the footprint of the anterolateral bundle of the posterior cruciate ligament through a low anterolateral portal. (B) A 4.5-mm drill bit is used to over-drill the guidewire in a bicortical manner through a low anterolateral portal. (C, D) A rectangular rasp matching the graft diameter is inserted over the guidewire intra-articularly through a low anterolateral portal. (E) The tunnel is rasped to a depth of 25 to 30 mm. (F) The finished tunnel (asterisk) is viewed arthroscopically. Debris can be removed with an arthroscopic shaver. (Ca, cartilage; mfc, medial femoral condyle.)

characterized by a rectangular femoral tunnel and a round tibial tunnel (Video 1). Pearls and pitfalls are shown in Table 1. Similar to rectangular anterior cruciate ligament reconstruction, the use of a flat graft combined with a rectangular femoral tunnel mimics the native PCL insertion and biomechanics, facilitating graft twisting during knee flexion.[12,13] Moreover, a rectangular footprint on the femur created by a rasp or dilator covers the anatomic insertional area more efficiently than a conventional round footprint created by a reamer,[14,16] whereas on the tibial side, a round bone tunnel seems appropriate. Siebold et al.[17] reported that interference screw compression of a flat graft against the rim of a round tunnel may achieve aperture fixation similar to the anatomic C shape, which comes close to the tibial insertion of the PCL.

To our knowledge, Kim et al.[18] are the only authors who have compared the clinical outcomes of conventional round tunnels versus rectangular tunnels in PCL reconstruction. They reported satisfactory clinical results and stability as compared with PCL reconstruction using a conventional round reamer. However, it was difficult to draw a solid conclusion because most of the patients (91%) underwent additional posterolateral corner reconstruction and round HT was used as a graft.

Our technique has risks and limitations that need to be considered. On the femoral side, extra care must be

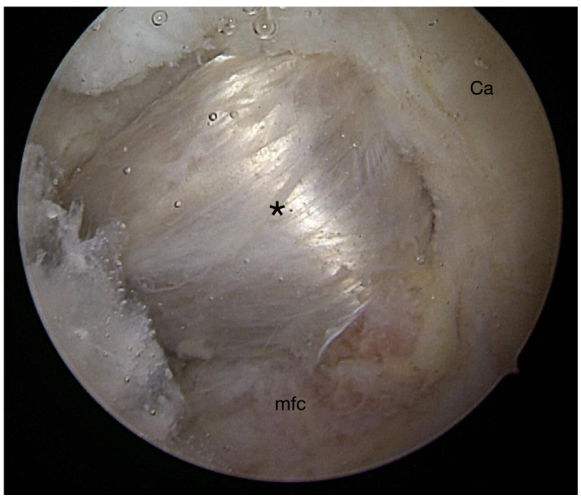

Fig 10. Arthroscopic view of reconstructed flat posterior cruciate ligament graft (asterisk) through high anterolateral portal. (Ca, cartilage; mfc, medial femoral condyle.)

Table 1. Pearls and Pitfalls

Surgical Step	Pearls and Pitfalls
Graft harvesting	Regarding QT graft, the surgeon should start harvesting the graft slightly lateral to the center of the proximal border of the patella to obtain an adequate length of graft.
	Regarding HT graft, the surgeon should locate the ST and GC. At the beginning of the procedure, we advise harvesting only the ST. The GC can be used if the size of the graft is not adequate.
Graft preparation	Pull strands should be placed in every portion of the proximal graft end; otherwise, the surgeon will struggle to position the midportion in the femoral tunnel.
Portal placement	A high lateral portal, just lateral to the patellar tendon, should be used to maximize notch and posterior-compartment visualization. A low accessory lateral portal is mandatory to insert the guidewire, reamer, and rasp for the femoral tunnel (Fig 8 A and B)
	A 5.0 mm cannula or a half pipe cannula can be used to maintain the posteromedial portal for easy instrumentation use.
Femoral footprint	The meniscofemoral ligaments should be preserved if they are intact and do not impede surgical exposure or visualization to improve the healing of the graft.
Tibial tunnel	The surgeon should use the posteromedial portal as a viewing portal. Fluoroscopy can be used to supervise guidewire placement and reaming. The knee should be flexed during reaming to locate the neurovascular structures posteriorly.
	The surgeon should contour the anterior aperture of the tibial footprint with a shaver or rasp to minimize any sharp edges to facilitate graft passage and minimize graft abrasion once the graft is passed.
Femoral tunnel	We advise visualizing the femoral footprint from a high lateral portal while inserting the femoral aimer through a low lateral portal to minimize the risk of malposition.

GC, gracilis; HT, hamstring tendon; QT, quadriceps tendon; ST, semitendinosus.

taken regarding the correct orientation of the aimer and guidewires. More surgical steps are required for tunnel preparation, and graft rotation must be controlled before pulling the graft into the femoral tunnel.

In conclusion, we describe a PCL reconstruction technique with a rectangular femoral tunnel using flat soft-tissue grafts. This technique better reproduces the native anatomy and avoids graft rotation within the tunnel. Further clinical studies are mandatory to understand whether the theoretical anatomic advantage corresponds to better clinical results compared with conventional round tunnels.

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