Technical Note

Medial Meniscus Allograft Transplantation: Bone Plug Technique With Anatomic Anterior and Posterior Horn Fixation

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Abstract: Meniscus preservation is crucial for avoiding cartilage degeneration after symptomatic meniscal tears. Despite efforts, meniscal repair procedures may fail, which requires a partial or total meniscectomy. Meniscus allograft transplantation (MAT) presents a viable solution, offering symptom alleviation, enhanced knee function, and potential osteoarthritis progression delay. Although MAT can address both lateral and medial compartments, medial MAT poses greater challenges as the result of its intricate attachments and limited mobility. The medial meniscus's unique anatomy, including attachments to the intermeniscal ligament, deep medial collateral ligament, capsule, and the anterior cruciate ligament, demands meticulous transplantation techniques. Refinements in surgical techniques are ongoing, emphasizing the importance of anatomical precision, particularly in positioning the anterior and posterior horns of the medial meniscus. Here, we present a bone plug technique for medial MAT, prioritizing the accurate anatomical attachment of the anterior horns of the allograft to improve surgical outcomes.

Meniscus preservation prevents cartilage degeneration after symptomatic tears.[1,2] However, repairs often fail, leading to partial or total meniscectomy.[3] Meniscus allograft transplantation (MAT) provides symptom relief and potential delay of osteoarthritis.[4,5] Medial MAT is more challenging than lateral MAT because of the multiple attachments and immobility of the medial meniscus (MM). The MM connects to the lateral meniscus via the intermeniscal ligament and to the deep medial collateral ligament (MCL) and capsule. The long distance between its anterior and posterior horns, with the anterior cruciate ligament insertion in between, requires separate fixation for each horn during transplantation, unlike the single bone-bridge technique used in lateral MAT.[6,7]

Although various surgical methods for medial MAT have been proposed, no gold standard exists, and the procedure often requires further interventions.[3,8] We believe accurate anatomic positioning of the anterior horn is crucial and often neglected. Here, we describe a bone-plug technique for medial MAT that ensures proper anterior horn placement.

MM Anatomy

The MM covers 51% to 74% of the medial tibial plateau, with its broader posterior horn anchored in front of the posterior cruciate ligament attachment. The anterior horn of the medial meniscus (AHMM) has 4 attachment types; the most common locates 7 mm anterior to the anterior cruciate ligament at the transition of the intercondylar eminence to the descending anterior tibial surface[9] (Fig 1).

Evaluation

Symptoms after meniscal loss differ from meniscal tears. Meniscal tears usually cause pain, joint-line tenderness, and mechanical symptoms, with positive findings found on the McMurray, Apley, and Thessaly

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tests.[10] Conversely, postmeniscectomy syndrome features a dull, nagging pain after a pain-free period after surgery, with knee effusion varying with activity level, and the results of specialized tests usually negative.[11] Injections may offer temporary relief and insight into surgery response. Non–weight-bearing with crutches or unloader brace can sometimes aid in diagnosis.

Lower-extremity alignment and ligament stability evaluation are crucial. MAT is contraindicated for unstable or malaligned knees. Therefore, ligament reconstructions, osteochondral repairs, and realignment osteotomies should precede or be done concurrently with MAT.[12,13] Magnetic resonance imaging is the gold standard for diagnosing, confirming tear patterns, and identifying associated injuries.[14]

Surgical Technique

Graft Selection

Meniscus allografts are sized using preoperative magnetic resonance imaging or radiographs on the basis of the Pollard technique, which involves measuring the width and the length of the MM in anteroposterior and lateral images, respectively.[15] Fresh-frozen, nonirradiated allografts are preferred.

Patient Position

The patient is placed in the supine position with a leg-holder and a tourniquet applied to the affected limb. The contralateral limb rests on a well-padded leg-holder (Fig 2).

Arthroscopy and Medial Compartment Preparation

Via use of the standard anterolateral and anteromedial portals, an arthroscopic examination is performed to carefully evaluate the entire joint. A valgus force is applied to assess the medial compartment. Pie crusting of the MCL may enhance visualization and workplace for MAT (8-10 mm joint space is ideal to allow bone plug flipping during graft insertion). This procedure is performed by identifying the MCL through palpation and repeatedly puncturing it using an 18-gauge spinal needle. Palpate the medial epicondyle and insert a spinal needle approximately 1 cm distal to it. The needle is inserted once through the skin, and multiple puncture holes are made near the joint line in an anterior to posterior direction while simultaneous valgus stress is applied to the knee. During the percutaneous release, the arthroscope is placed through the anterolateral portal and the medial compartment is visualized. Typically, an audible pop is heard and/or felt and a clear increase in the medial compartment is confirmed.[16] The remnant MM is debrided using a biter and a 5.0-mm shaver to prepare a vascularized area for the transplant (Fig 3). Video 1 demonstrates the surgical technique.

MM Transplantation

The posterior horn of the medial meniscus (PHMM) attachment is identified through direct visualization with the arthroscope by locating the residual meniscal tissue. A cautery device is then used to mark the meniscus attachment. A guide (Meniscal Root Repair

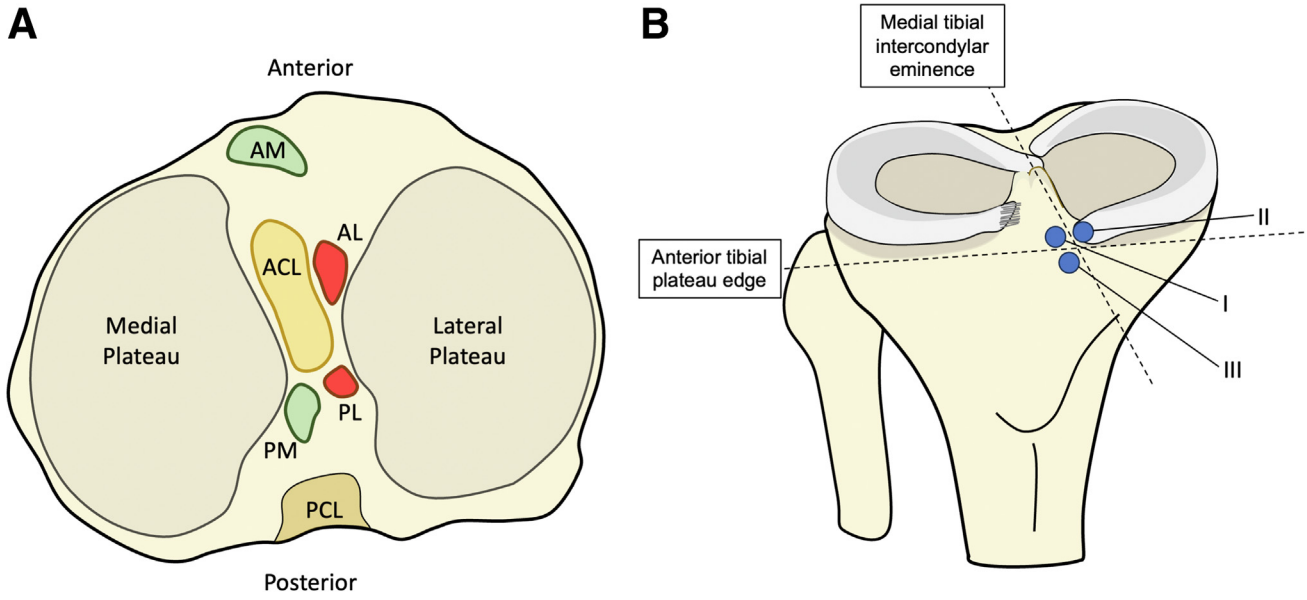

Fig 1. (A) Illustration of the axial cut of the tibia plateau showing the anatomy of the menisci medial (green) and lateral (red) and ligaments. (B) Berlet and Fowler classification of medial meniscus anterior horn attachment site: on the flat intercondylar area lateral to the medial tibial intercondylar eminence (most common) (I); on the downward slope from the medial articular plateau, medial to medial tibial intercondylar eminence (II); very anterior, on the downslope of the medial tibial plateau, anterior to the anterior tibial plateau edge (III); and no bony attachment of the meniscus to the tibia (IV).

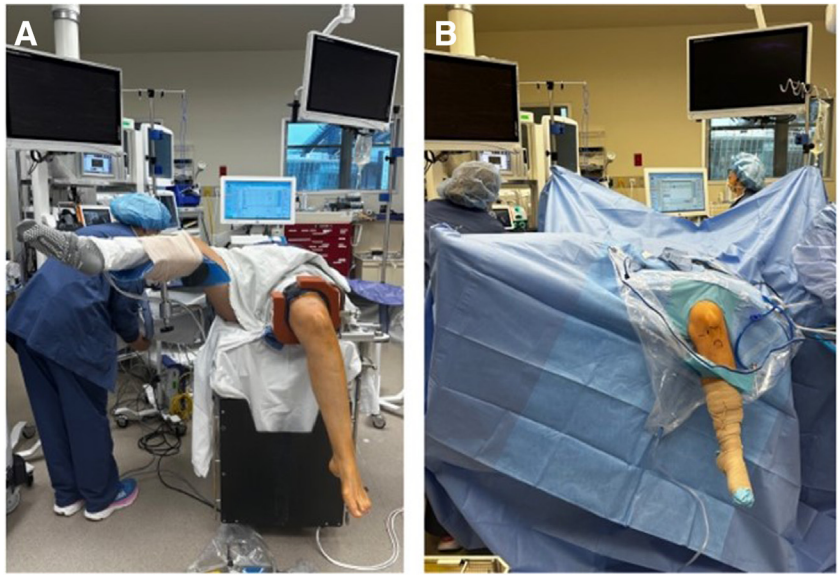

Fig 2. Patient setup for medial meniscus allograft transplantation. (A) The patient is placed in the supine position using a leg holder on the left (affected) limb. The right (contralateral) limb rests on a well-padded leg-holder. (B) Sterile drapes are placed to isolate the affected limb.

system; Arthrex, Naples, FL), inserted through the anterolateral portal, is positioned at the center of the PHMM attachment according to anatomic studies.[17] The guide is angled and positioned on the anterolateral aspect of the proximal tibia. A 2-cm incision is made over the anterolateral aspect of the proximal tibia, approximately one finger breadth lateral to the tibial tubercle, and the soft tissues are carefully dissected to allow the tibial guide sleeve to be firmly pushed against the bone. A 7-mm FlipCutter (Arthrex) is inserted through the guide (Fig 4). Retrograde reaming creates a 10-mm depth socket. The FlipCutter is then unflipped and removed. A Smith & Nephew looped suture retriever is inserted through the tibial tunnel and the loop is retrieved through the anterolateral portal. Then, a No. 2 FiberWire (Arthrex) suture is shuttled through the suture loop. The No. 2 FiberWire loop will be exiting the anterolateral portal, and its tails will be exiting the tibia tunnel (Fig 5). This FiberWire suture will serve as a shuttle suture for the PHMM bone plug.

By using the Zone-Specific Meniscal Repair System (CONMED, Largo, FL) cannulas, a medial inside-out traction suture is placed at the junction of the posterior horn and the body sites at the capsule (Fig 6). This suture will assist with pulling the graft during meniscal allograft insertion.

Allograft Preparation

The allograft is thawed in saline at room temperature and marked at its posterior and anterior aspect for plug removal. A sagittal saw releases bone plugs from the donor block, leaving 2 small plugs at the meniscus root attachment sites (Fig 7).

Each of the bone plugs is trimmed and countered to result in a 10 × 10-mm cube for the anterior root bone plug and 10 mm in length and 7 mm in diameter for the posterior root bone plug. A 1.5-mm drill is used to

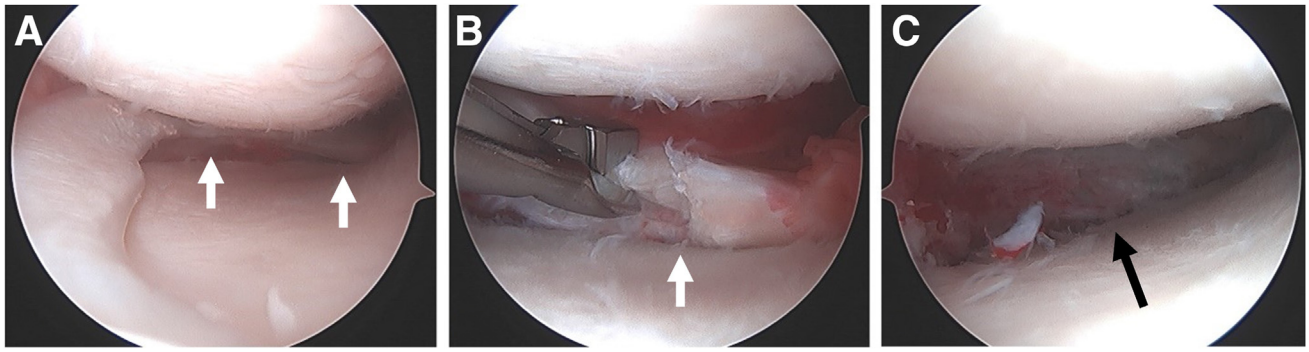

Fig 3. Left knee from the anterolateral viewing portal. medial compartment inspection showing a missing mid- to posterior horn of the meniscus (white arrows) (A); remnant of MM is debrided (white arrow) (B); and view of the medial compartment after debridement (black arrow) (C).

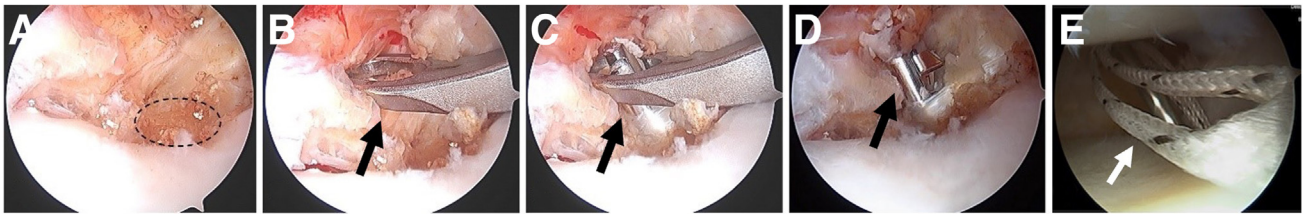

Fig 4. Left knee from the anteromedial viewing portal. Posterior horn of the medial meniscus attachment site demarcated by the dashed oval (A); The meniscal Root Repair system guide placed in the center of the PHMM attachment (black arrow) (B); FlipCutter is inserted (C); guide is removed and FlipCutter is flipped to 90° for retrodrilling (black arrows) (D); and a No. 2 FiberWire suture is shuttled through the tibial tunnel and retrieved through the anteromedial portal (white arrow) (E).

create a hole in the center of the posterior root bone plug in its longer axis. A No. 2 FiberWire suture is passed through this bone plug hole, and then it is passed on the meniscal root. It is important to pass the suture through the soft tissue of the PHMM as to avoid cutting the bone plug with the high-strength suture during passage and suture handling. These sutures will be used to assist the graft passage and insertion of the posterior bone plug onto the socket. In addition, a No. 0 polydioxanone (PDS) suture is placed at the junction of the posterior horn and body of the meniscus (Fig 8).

Allograft Insertion and Fixation

The medial portal is enlarged. The fat pad is divided, and the native AHMM is resected using a No. 11 blade or a shaver. The No. 0 PDS suture is shuttled through the medial capsule, and the posterior bone-plug suture is passed through the posterior suture placed in the socket tunnel. Applying valgus stress, the allograft is introduced into the joint through the anteromedial incision. Care is taken to position the posterior bone plug so that it can be pushed into the posterior notch next to the posterior cruciate ligament. This will allow the suture to pull the bone plug anteriorly into the created socket rather than at an angle. By pulling the posterior suture down through the tibial tunnel, the posterior bone plug is then carefully docked into the socket (Fig 9). After allograft insertion, the knee is moved through full range of motion multiples times and the medial compartment is inspected to evaluate graft positioning. Next, the posterior suture through the posterior bone plug is secured with a button over the anterolateral tibial cortex or with a suture anchor placed at least 1 cm distal to the tibial tunnel exit. We found that anchor fixation (we use the Smith & Nephew 4.5-mm footprint anchor) is easier to accommodate than attempting to tie a suture over a larger button. Inspection is done to assess graft positioning and address any extrusion.

Meniscus repair sutures are placed in the body of the meniscus using zone-specific cannulas and double-armed needles to attach the MM to the deep MCL and capsule. These outside-in sutures are passed but not tightened. Typically, 2 or 3 sutures stabilizes the meniscus. The anterior root is positioned over the centerline of the joint until the medial rim of the

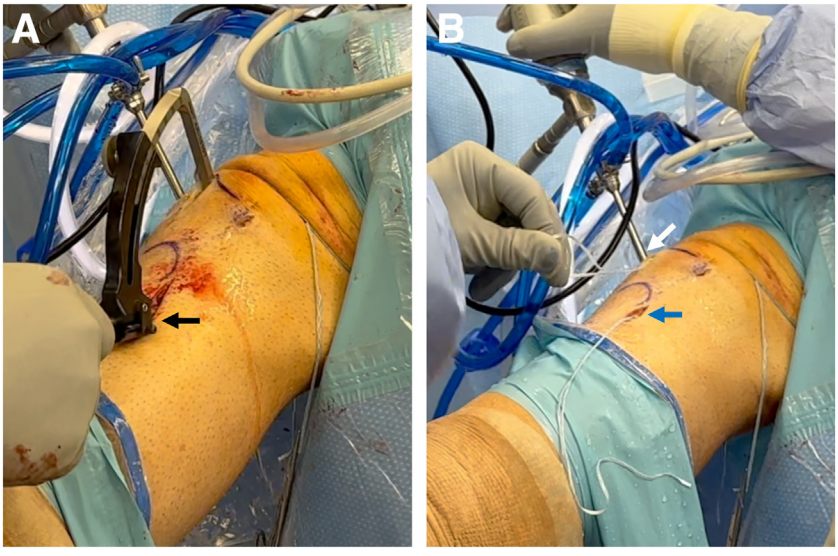

Fig 5. (A) The Meniscal Root Repair system guide positioned on the anterolateral aspect of the proximal tibia (black arrow). (B) The No. 2 FiberWire loop exits through the anteromedial portal (white arrow), with its tails exiting from the tibial tunnel (blue arrow).

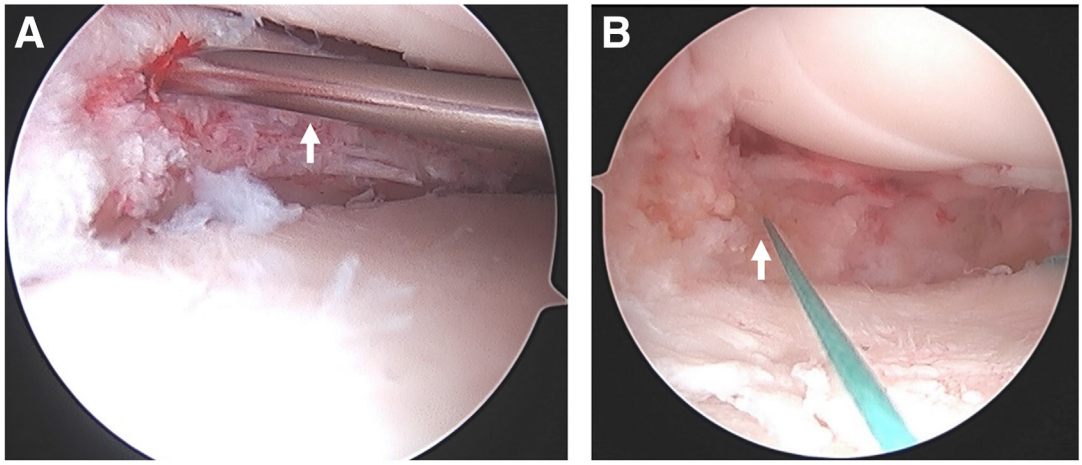

Fig 6. Left knee from the anteromedial viewing portal. Using the zone-specific meniscal repair system (ConMed) cannulas (white arrow) (A), a medial inside-out traction suture is placed at the junction of the posterior horn and the body sites at the capsule (white arrow) (B). This suture will assist pulling the allograft into the joint.

meniscus traces the tibial border. This may require repositioning of the arthroscope in the medial gutter in order to judge the position of the MM transplant edge over the tibia. The AHMM position on the anteromedial edge of the tibia is marked with a Bovie cautery, then medial and lateral periosteal flaps (5 mm) are raised. A quarter-inch (8-10 mm in width) osteotome is used to remove a square cortical window from the anterior aspect of the medial tibia. The AHMM bone plug is then inserted onto this socket and tamped down using a bone tamp. The periosteal flaps can then be sutured back over the bone plug which renders an appropriate fixation of the bone plug. Alternate ways to additionally secure the bone plug are by using a 4.5-mm footprint anchor, a small fragment partially threaded 3.5-mm cancellous screw (DePuy Synthes, Warsaw, IN), or a suture passed through the bone block and recovered anteriorly through the cortical bone below the bone plug. Then, the soft tissues are secured to the menisco-tibial ligaments (Fig 10). A 4.5-mm footprint anchor is occasionally used to centralize the MM. This anchor is positioned through a small accessory portal and will capture a No. 2 FiberWire suture that is inserted from outside in using a PDS shuttle. This should be the last suture positioned.

The sutures passed along the meniscus body are tied down. A 3-cm longitudinal incision is made between the exit points of the sutures, followed by joint capsule dissection with a Metzenbaum scissors. Care is taken to preserve the inferior branch of the saphenous nerve, which should be palpated usually well proximal to all sutures. The scope is reintroduced to confirm graft placement (Fig 11), then sutures are tied underneath the skin and over the capsule, avoiding the nerve. Knee flexion at 90° is maintained during tying. Range of motion is checked to ensure suture stability and full knee extension.

Postoperative Rehabilitation

After surgery, patients are non–weight-bearing for 6 weeks then transition to weight-bearing as tolerated. Crutches are discontinued at week 6. A locked full-

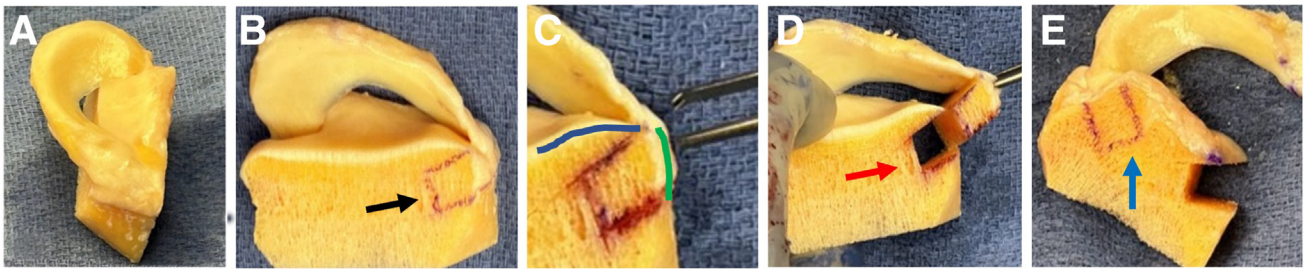

Fig 7. The medial meniscal allograft. (A) Graft block. (B) Nark the cuts for the anterior horn (black arrow). (C) The green line indicates the anterior descending surface of the proximal tibia and the blue line shows the tibial plateau, indicating the far anterior edge position of the medial meniscus anterior horn attachment. (D) The anterior horn is cut out from the anterior surface of the tibia as a single plug (red arrow). (E) The posterior meniscus horn attachment is outlined (blue arrow).

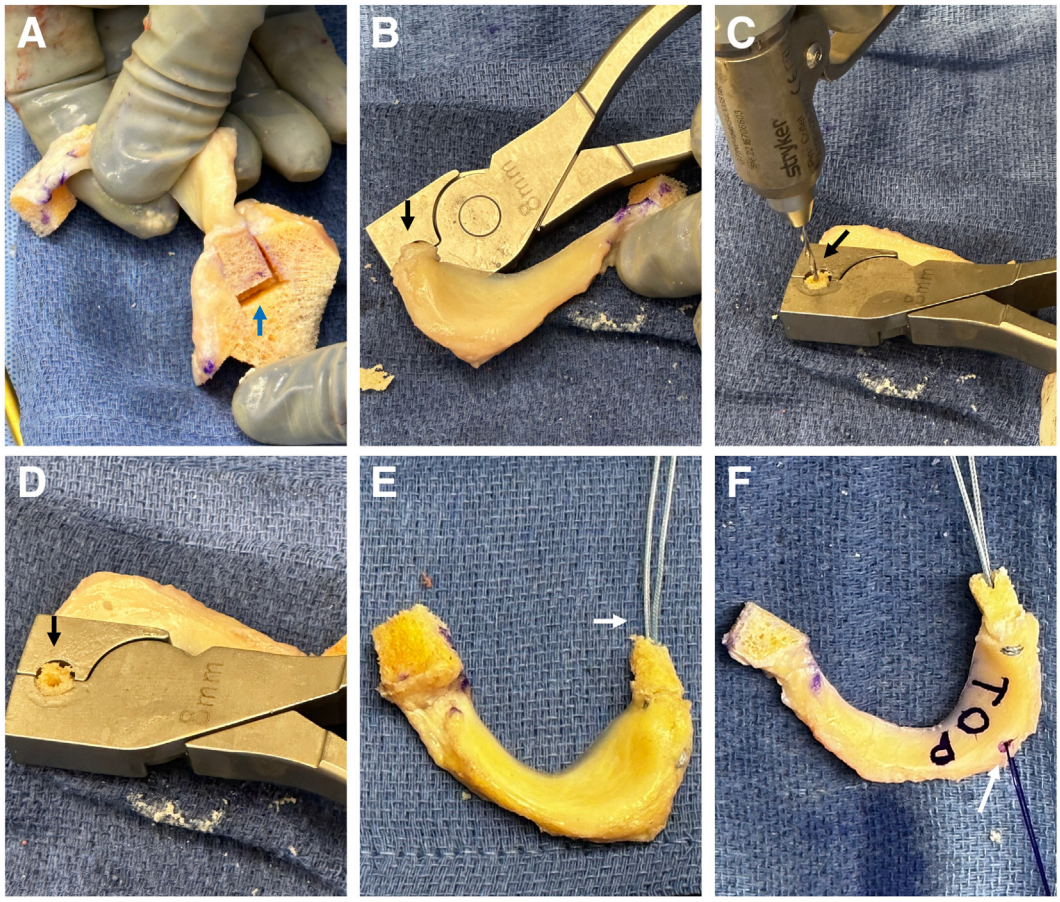

Fig 8. The medial meniscal allograft. (A) Posterior bone plug is detached (blue arrow). (B) Contouring the posterior bone plug to an 8-mm fit using the compression pliers (black arrow). (C-D) A 1.5-mm drill is used through the long axis of the bone plug (black arrows). (E) A No. 2 FiberWire suture is passed through the drill hole and through the posterior horn of the medial meniscus (white arrow). (F) A No. 0 polydioxanone suture is placed at the junction of the posterior horn and the body of the meniscus (white arrow).

extension knee brace is worn for 2 weeks, then unlocked for weight-bearing up to 90° until week 6. Flexion exercises are limited to 90° for 8 weeks, then advanced as tolerated. Twisting, rotational movements, and weight-bearing beyond 90° flexion are avoided. The non–weight-bearing period may extend on the basis of associated procedures. Stationary bikes, closed-chain, and proprioception exercises are recommended

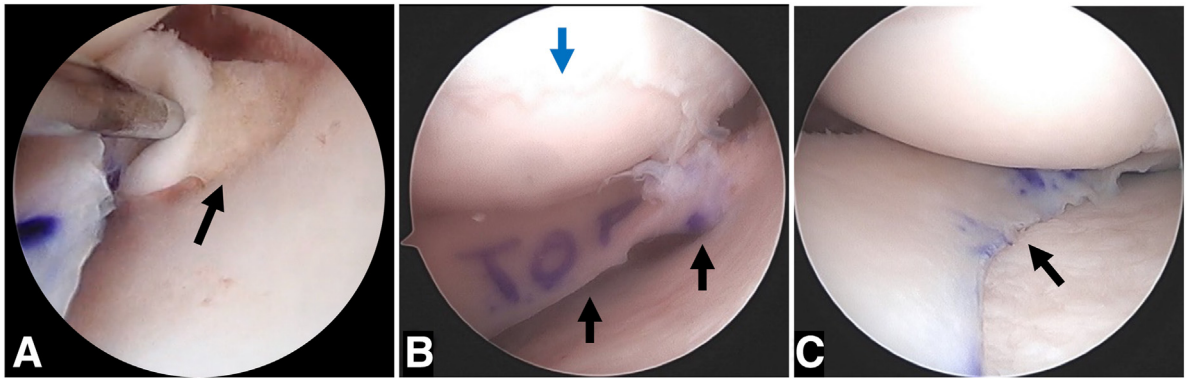

Fig 9. Left knee from the anterolateral viewing portal. (A) The posterior horn of the medial meniscus (PHMM) is pulled into the bone socket (black arrow). (B) View of the posterior horn and body of the medial meniscus allograft (black arrows) (this patient also received an osteochondral allograft to the medial femoral condyle; blue arrow). (C) View of the medial meniscus allograft after its insertion into the medial compartment (black arrow).

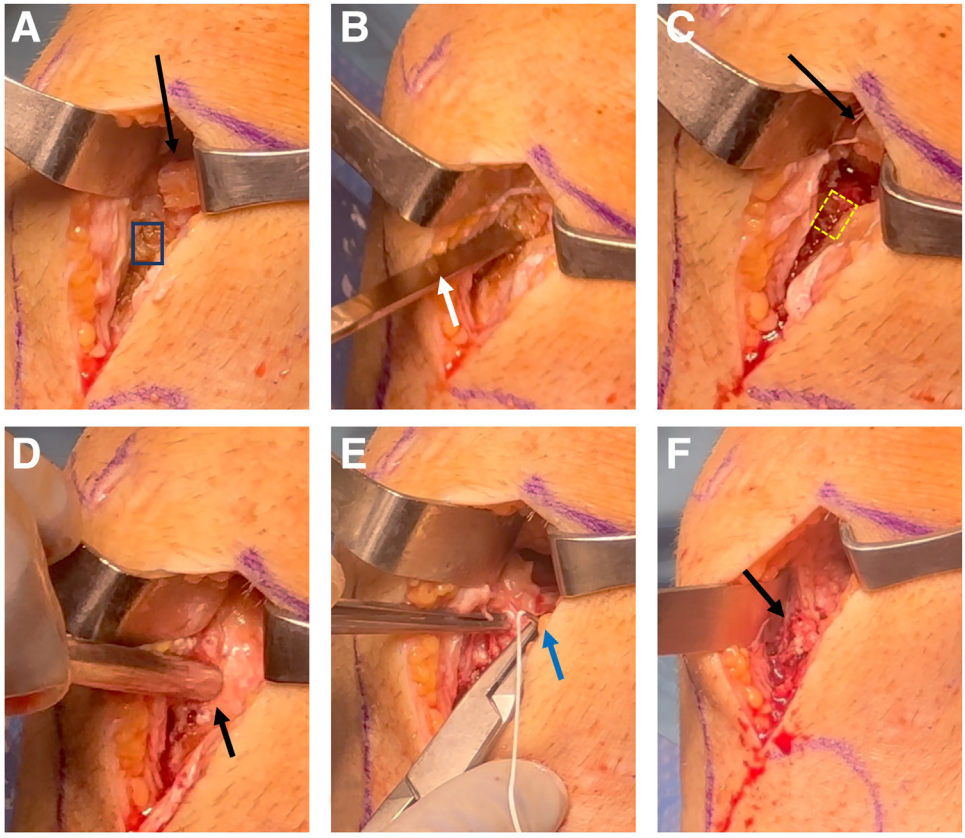

Fig 10. Left knee. (A) The bone plug is pulled anteriorly (black arrow), and the position of the bone plug is marked on the anterior tibia (blue square). (B) The quarter-inch osteotome (white arrow) is used to create a socket on the anterior aspect of the medial tibial plateau. The AHMM bone plug (black arrow) is inserted into the socket (yellow dashed line) (C) and tapped down for a press fit (black arrow) (D). (E) Periosteal flaps are sutured back over the bone plug (blue arrow). (F) The anterior horn of the graft is attached to the anterior edge of the tibia (black arrow).

after 8 weeks. Return to daily activities is allowed after 3 months, nonimpact activities between 4 and 6 months, and jogging after 1 year. Full activity is permitted after 18 months. Patients are cautioned against knee-abusing activities because of the risk of reinjury.

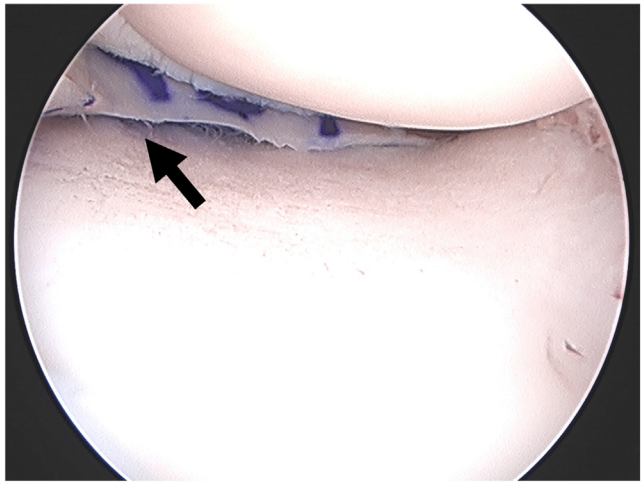

Fig 11. Left knee is viewed from the anterolateral viewing portal. Final position of the medial meniscus allograft is shown (black arrow).

Discussion

Medial MAT has been used to effectively treat patients with persistent symptoms after subtotal or total medial meniscectomy.[7,18] However, graft extrusion remains a concern, with reports ranging from 0% to 78%, potentially jeopardizing success.[7,19] Anatomic positioning of the MM allograft on the basis the tibial plateau outline, as described in our technique, is crucial for proper integration and function. Bone-plug fixation, which relies on bone-to-bone healing, provides better healing potential and results in less meniscal extrusion than soft-tissue fixation, although clinical outcomes are similar.[20,21] Bone fixation also restores native load parameters.[21,22] In addition, anatomic fixation of the meniscus horns appears seems crucial, as nonanatomic PHMM attachment negatively affects joint pressure distribution.[23] Furthermore, medially shifted AHMM fixation increases graft extrusion after 2 years,[24] whereas positioning the graft in the native meniscus footprint reduces extrusion rates postmedial MAT.[19]

Despite efforts to precisely place the meniscal allograft at native footprints, studies show that both AHMM and PHMM tend to shift medially.[19,24,25] Recreating the anatomic position for these horns is technically demanding, particularly during arthroscopy.[25] The PHMM footprint is determined by the use of

Table 1. Advantages and Disadvantages

Advantages	Disadvantages
• The centralization ensures the meniscus body is aligned with the tibial plateau. • The fixation of the anterior bone block onto the anterior aspect of the tibia is anatomic and allows for correction of potential donor-recipient size mismatch. • Bone plug technique has advantage of direct bone-to-bone healing and avoids interference with ACL fibers (as seen in the medial bone bridge techniques).	• Requires greater anterior incision. • May be more challenging to perform the arthroscopic portion after the anterior arthrotomy because of fluid extravasation. • Centralization requires an additional medial portal. • Posterior bone plug may be difficult to flip.

ACL, anterior cruciate ligament.

Table 2. Pearls and Pitfalls

- Pie-crusting is paramount to have access to the posterior medial compartment.
- To perform the pie crusting, insert the spinal needle approximately 1 cm distal to the medial epicondyle at the posterior third of the femoral condyle. The tendency is to err anteriorly.
- Continuous valgus stress when pie-crusting.
- Place the tourniquet and leg holder distal enough to allow maximum valgus stress. If they are too proximal, the leg will rotate when valgus stress is applied, and will not be effective in opening the medial compartment.
- When preparing the bone plug, use of a compression plier will allow the surgeon to perform 3 steps.
- Shape the bone plug to the appropriate size cylinder.
- Cut the plug to its final length size.
- Drill the central hole.
- When drilling the posterior socket, the tibial guide is placed on the anterolateral tibia because this allows creation of a socket in a direction that is in line with the posterior root anatomy, facilitating pulling the bone plug inside the socket.
- When passing the inside-out sutures through the meniscus body, there is small risk of damage to the nerve because it is usually not present at the level of the joint line. However, before tying the sutures, the surgeon should palpate and can usually feel the nerve over the medial joint capsule.

arthroscopy, whereas the AHMM is identified through the use of arthroscopy or direct visualization via the anteromedial portal incision. Determining the PHMM correct position is challenging because of the lack of clear landmarks.[19,25] Conversely, visualizing the AHMM is difficult as the result of obstructing soft tissues.[26] Our technique ensures accurate AHMM fixation by direct visualization and accommodating the graft, which also allows for correction of potential donor-recipient size mismatch. Moreover, performing the centralization of the meniscus allograft ensures that its body is aligned with the tibial plateau. Table 1 describes advantages and disadvantages, and Table 2 describes pearls and pitfalls of this technique.

In conclusion, we describe a modified arthroscopic-MAT technique that ensures safe, anatomic positioning of the anterior and posterior horns, allowing small adjustments for an optimal fit along the tibial plateau. Follow-up studies assessing long-term outcomes of this technique are ongoing.

Disclosures

All authors (G.M., C.B.G.L., G.M., C.L.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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