Technical Note

Combined Medial Meniscus Allograft Transplantation and Open-Wedge High Tibial Osteotomy Using a Patient-Specific Instrumentation Guide

Sylvain Aubret, M.D., Cédric Ngbilo, M.D., Michaela Winkler, M.D., Brigitte Neyret, O.R.N., and Eric Choudja Ouabo, M.D.

Abstract: Despite technical advances in meniscus allograft transplantation, there remains a need to improve postoperative outcomes.[1,2] The bone plugs technique using osseous fixation of the anterior and posterior roots has demonstrated increased stability and long-term survival. Recently, the importance of limb alignment has been demonstrated for this procedure. In case of malalignment, osteotomy is essential to improve the long-term viability of both meniscus allograft and cartilage. The recent introduction of patient-specific instrumentation has raised the possibility of making instrumentation specific to each patient achieving an optimal correction in a safe and reliable manner. This Technical Note describes the use of a combined medial meniscus allograft transplantation and open wedge high tibial osteotomy using a patient-specific instrumentation guide.

The meniscus is important for load distribution, shock absorption, and stability of the knee joint.[1-3] Meniscus injury should be treated to preserve as much meniscus function as possible, and "saving the meniscus" is a recent slogan of meniscal surgery.[4,5] Despite this, meniscectomy is occasionally required to treat irreparable tears. Meniscus injury or meniscectomy results in increased tibiofemoral contact pressures and ultimately early osteoarthritic changes in the knee.[6] Meniscal transplant has become a widely accepted procedure in the attempt to restore normal joint biomechanics and to preserve the cartilage in the involved compartment. In this procedure, the importance of limb alignment has been demonstrated. Correct alignment reduces the overload and protects both the articular cartilage and any graft implanted from further damages. A coronal malalignment tends to exert abnormal pressure on the allograft leading to graft failure. In case of malalignment, osteotomy is essential to improve the long-term viability of both graft and cartilage.[7,8] Several studies report that medial meniscal allograft transplant (MMAT) with open-wedge high tibial osteotomy (OW-HTO) showed a greater survival rate than the isolated MMAT.[9-11] Although several techniques for MMAT have been proposed, osseous fixation has demonstrated increased stability, improved outcomes, and improved long-term survival.[12] The recent introduction of patient-specific instrumentation (PSI) has raised the possibility of making instrumentation specific to each patient achieving an optimal correction in a safe and reliable manner.[13] This Technical Note describes the technique for combined MMAT and OW-HTO using PSI guide (Video 1).

Patient Selection: Indications and Contraindications

This procedure is recommended for young patient (<45 years old) and compliant with minimal cartilage degeneration, joint line pain localized to the involved compartment, and varus deformity. A correct physical

From the Orthopaedics Department, Hôpital Privé la Châtaigneraie (S.A.), Clermont-Ferrand, France; and Clinique Bois-Cerf, Hirslanden (C.N., M.W., B.N., E.C.O.), Lausanne, Switzerland.

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Address correspondence to Sylvain Aubret, M.D., Hôpital Privé la Châtaigneraie, Clermont-Ferrand, France; Eric Choudja Ouabo, M.D., Clinique Bois-Cerf, Hirslanden, Avenue d'Ouchy 31, 1006 Lausanne, Suisse. E-mail: sylvain.aubret@gmail.com or e_choudja@hotmail.com

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Table 1. Indications and Contraindications to Combined Medial MAT With HTO Using PSI

Absolute Indications	Indications	Contraindications	Absolute Contraindications
Complete meniscal deficiency in a young, healthy patient with good articular cartilage status (grade II or better)	Complete meniscal deficiency in a young, healthy patient with grade III or better articular cartilage	Age >50 y	Severe arthritic degeneration (grade III or IV)
With varus deformity	With varus deformity	Skeletal immaturity	Unaddressed cruciate insufficiency
		Synovial disease or inflammatory arthritis	Lack of knowledge about MAT and HTO surgery
		Obesity (body mass index >35)	

HTO, high tibial osteotomy; MAT, meniscus allograft transplantation; PSI, patient-specific instrumentation.

therapy program should be performed before considering surgery. The main contraindication to MMAT is severe articular cartilage damage in the meniscal-deficient compartment, although prophylactic transplantation for asymptomatic patients should not be considered. The procedure is contraindicated in older patients, unstable knees, and in severe arthritic degeneration (grade 3 or 4) of the meniscal-deficient compartment. Advantages, indications, contraindications, tips and pearls, and pitfalls and risks are summarized in Table 1.

Surgical Technique (With Video Illustration)

Surgical Planification

A thorough workup is imperative and must include standing anteroposterior, lateral, and Schuss views of the knee; bilateral weight-bearing long-leg radiographs; bilateral knee magnetic resonance imaging (MRI); and computed tomography scan respecting ACTIVMOTION protocol (Newclip Technics, Haute-Goulaine, France). MRI helps surgeon to plan surgery. It is also sent to the tissue bank to ensure accuracy in the sizing of the meniscal

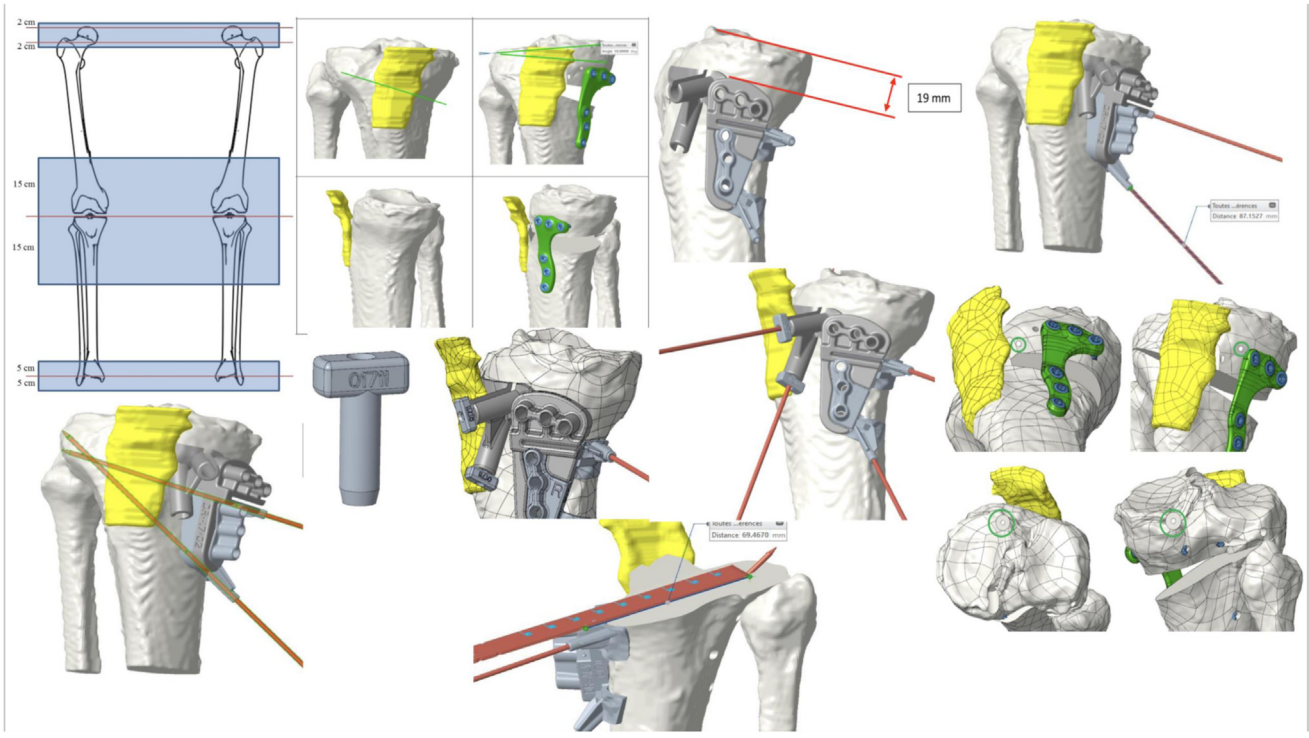

Fig 1. Right knee view. Surgery planification with Acquisition zones for computed tomography scan analysis of both full legs respecting Activmotion PSI protocol (Newclip). A virtual OW-HTO is performed. The 3-dimensional planning determines the planes of the osteotomy as well as the dimensions of the wedge to be opened in the proximal tibia for the determined correction and positioning of the plate (ACTIVMOTION HTO, Newclip Technics) and tunnels for anterior and posterior roots for MAT. It is important to note that a 3° valgus correction of a neutrally aligned knee with concurrent MMAT can decrease the peak and total medial compartment contact pressures significantly. (MAT, meniscal allograft transplant; MMAT, medial meniscal allograft transplant; OW-HTO, open-wedge high tibial osteotomy; PSI, patient-specific instrumentation.)

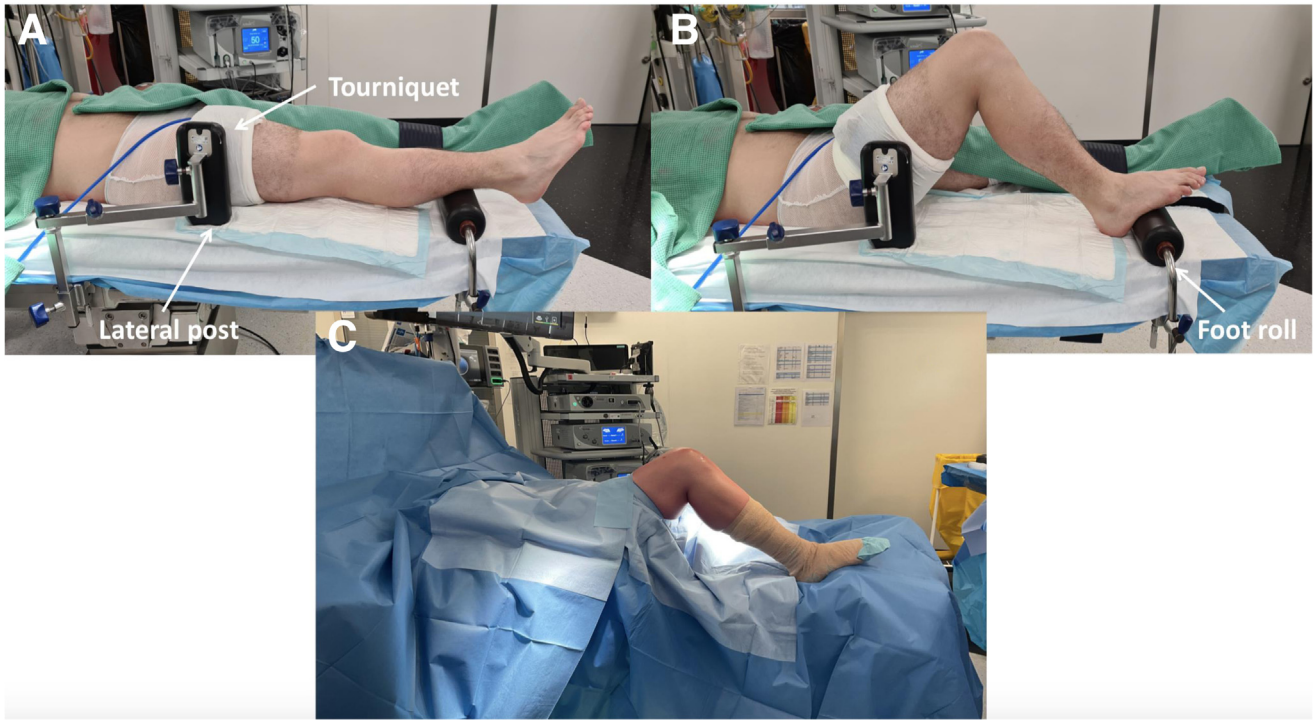

Fig 2. Right knee view. The patient is positioned supine as usual for knee arthroscopic surgery with a lateral post proximal to the knee, at the level of the padded tourniquet (A). A foot roll is placed to prevent the hip from externally rotating and to maintain knee flexion at 90° when required but also permit unrestricted range of motion (B, C).

graft (Unité de Thérapie Tissulaire et Cellulaire de l'Appareil Locomoteur, Cliniques Universitaires Saint-Luc, Bruxelles, Belgium). Authors believe in MRI in determining the required size, and it is a reproducible and accurate method of measuring both the width and length of both menisci.[14] Preoperative allograft sizing is essential to ensure that the graft can be anatomically reduced within the medial compartment.

When selecting the meniscal allograft, we accept a 7% margin on the requested measurements. The graft is prepared by hemi tibial plateau with at least 3 cm of bone on the tibial plateau. The graft is stored in the tissue bank

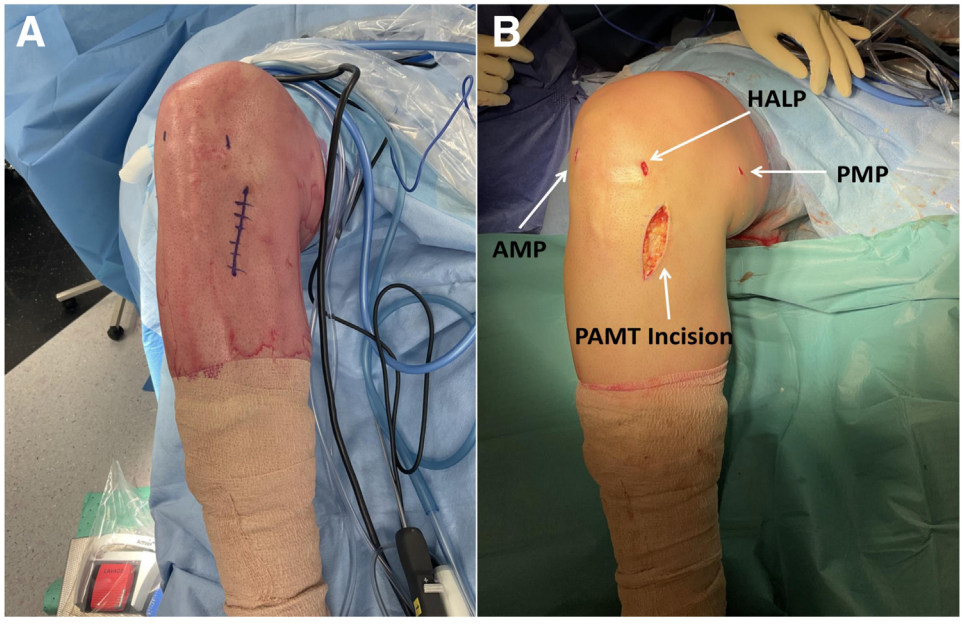

Fig 3. Right knee view. Landmarks for proximal anteromedial tibia (PAMT) incision (A), high anterolateral portal (HALP) to avoid Hoffa tissue, anteromedial portal (AMP), and posteromedial portal (PMP) are drawn (B).

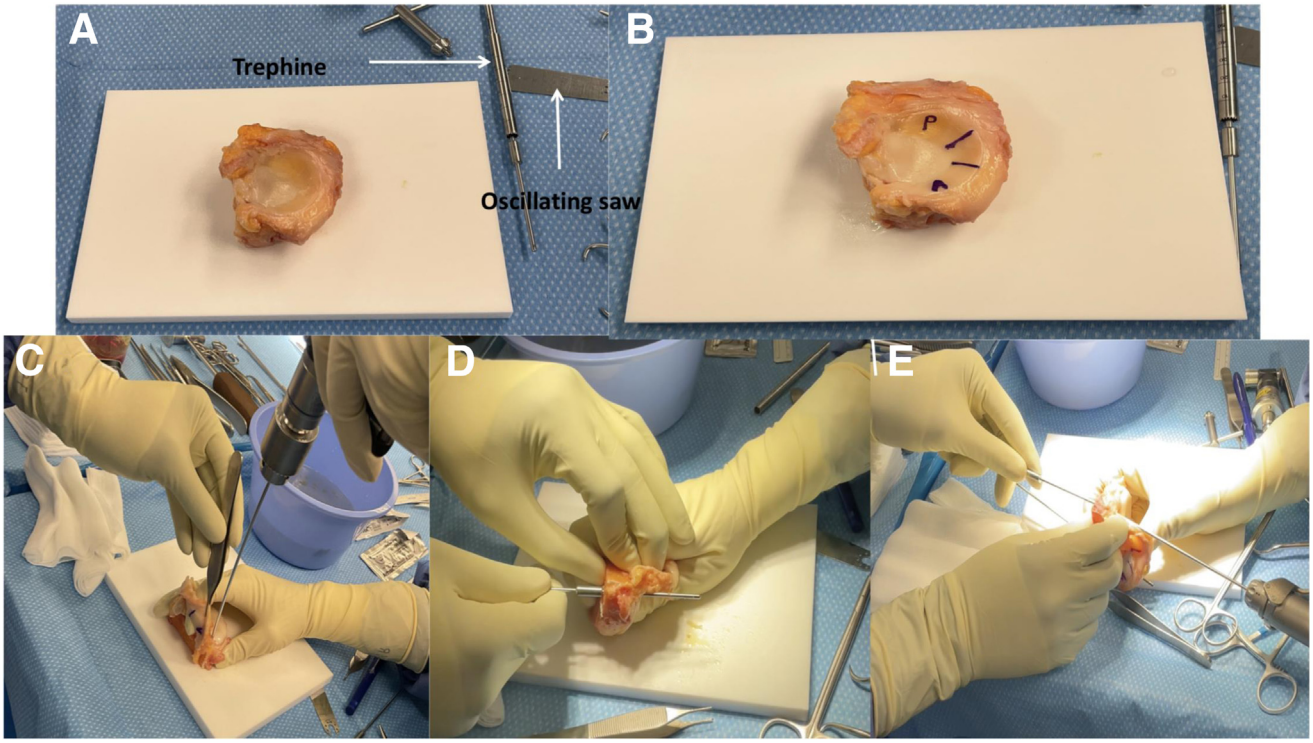

Fig 4. Right knee medial tibia plateau with meniscus allograft and capsule (A, B). Marking of the anterior, middle, and posterior horn of the meniscus (B); K-wire positioning for root bone plug preparation (C); and trephine guide positioning for bone plug preparation (D, E).

at −80°C, transport to the reimplantation center takes place at −30°C, and then it's stored in the operating room ideally at −20°C before reimplantation. A virtual OW-HTO is performed helping to preoperative computed tomography scan. The 3-dimensional planning determines the planes of the osteotomy as well as the dimensions of the wedge to be opened in the proximal tibia for the determined correction and positioning of the plate (ACTIVMOTION HTO, Newclip Technics) and tunnels for anterior and posterior roots for MAT (Fig 1). It is important to note that a 3° valgus correction of a neutrally aligned knee with concurrent MMAT can decrease the peak and total medial compartment contact pressures significantly.[15] Therefore, authors recommend correction lens between neutral and 3° of valgus.

Patient Setup

After anesthesia, bilateral examination of the knee is performed. The patient is positioned supine as usual for knee arthroscopic surgery with a lateral post proximal to the knee, at the level of the padded tourniquet (Fig 2A). A foot roll is placed to prevent the hip from externally rotating and to maintain knee flexion at 90° when required but also permit unrestricted range of motion (Fig 2 B and C).

Surgical Landmarks

After preparation of the skin and draping, surgical landmarks for arthroscopic portals (anteromedial and high anterolateral portals for avoid Hoffa tissue are used with a posteromedial portal. An anteromedial incision of the proximal tibia over 5 to 6 cm is necessary for OW-HTO procedure. These are shown in Fig 3 A and B.

Meniscus AlloGraft Preparation

Fresh-frozen and nonirradiated grafts have our preference for MAT. Thawing is done in the operating room

Table 2. Equipment Required to Perform a MMAT Using the Bone Plug Technique

Graft preparation
Oscillating saw
No. 15 blade knife
Rongeur
No. 2 FiberWire (Arthrex) with Straight Needle (×3)
Transtibial meniscal root fixation
No. 2-0 FiberStick (Arthrex) Suture (×2)
KingFisher (Arthrex) Retriever/Grasper
3.5-mm × 19.5-mm BioComposite PushLock (Arthrex) Anchor (×2)
Special drill for 3.5-mm PushLock anchor (Arthrex)
Fishmouth spear for 3.5-mm PushLock anchor (Arthrex)
Meniscal suturing
No. 2-0 FiberWire Meniscal Repair Needles
Suture Lasso 25° (Arthrex)
FastFix 360 (multiple) (Smith & Nephew)
PDS 2-0 suture (multiple) (Ethicon)
Percutaneous needles for outside-in suture Perican Tuohy G18, 80 mm (B. Braun)

MMAT, medial meniscus allograft transplantation.

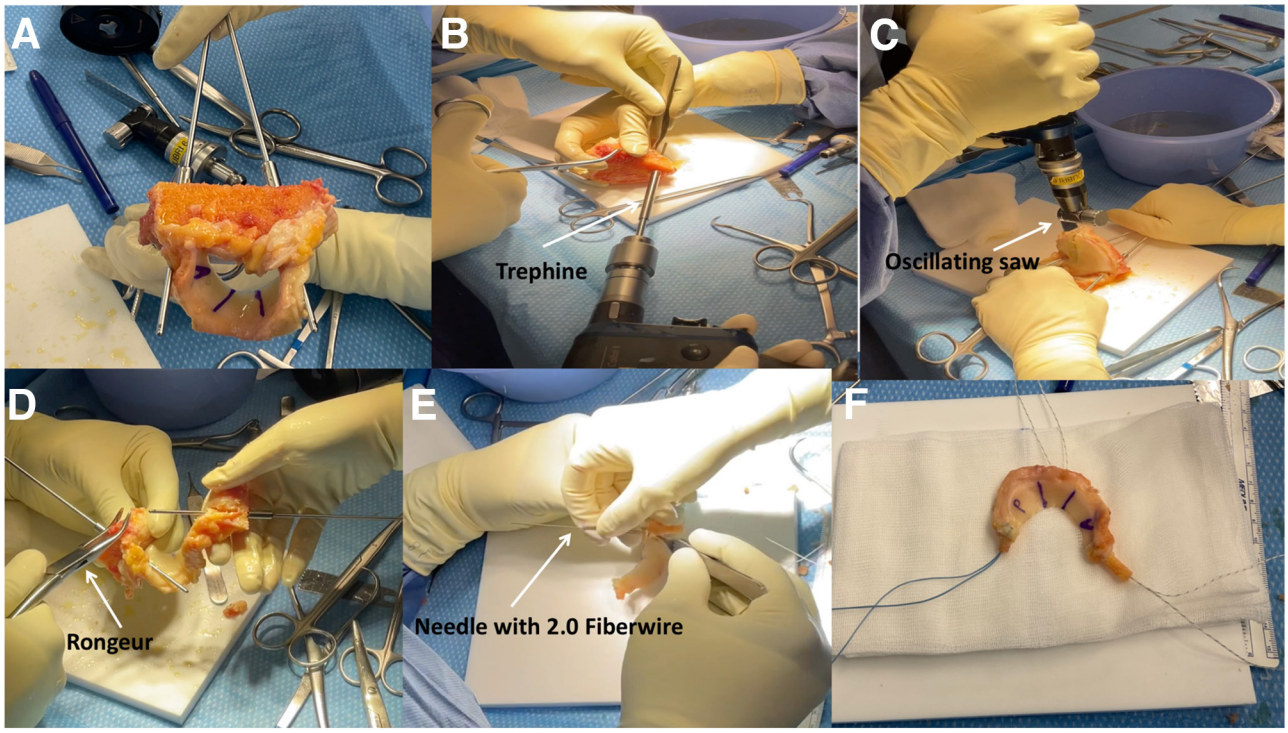

Fig 5. Right knee medial tibia plateau with meniscus allograft and capsule (A), 7-mm root bone plug creation with trephine (B), anterior and posterior roots bone plug preparation with oscillating saw and rongeur (C, D). Both plugs are armed with 2−0 FiberWire sutures (E). Final allograft presentation with 2 bone plugs at anterior and posterior roots, traction sutures used for transtibial pull-trough fixation, and one traction suture on the middle horn (F).

in saline solution combined with an ampoule of rifampicin for 30 minutes (Fig 4 B and C). Special equipment is required for this procedure; it's resumed in Table 2. An oscillating saw, a rongeur, and a rasp are used to create two 2-cm height and 7-mm cylindrical bone plugs at the anterior and posterior meniscal roots (Fig 4 D-E). Sizing is confirmed using the sizing block to ensure easy reduction into the 8-mm tibial tunnels (Fig 5 A-D). Both plugs are armed with 2-0 FiberWire sutures (Arthrex, Naples, FL) going through the bony plug and the root tissue of the meniscus (Fig 5E). These traction sutures are used for transtibial pull-trough fixation. One other traction suture with 2-0 FiberWire (Arthrex) is advanced through the midpoint of meniscus to guide the allograft (Fig 5F).

Meniscus AlloGraft Transplantation

Diagnostic knee arthroscopy is performed (Fig 6 D-F). A high anterolateral portal is preferred in order to avoid Hoffa's fat pad (Fig 3), and a posteromedial portal is used for meniscal preparation and fixation on ramp aspect. The remaining meniscus is debrided using a 4.0-mm shaver (Arthrex) to stimulate bleeding and graft healing (Fig 6 D and E). Then, the meniscal roots footprints are identified. The PSI guide must be placed under fluoroscopic control (Fig 6 A and B). Then, we individualized the internal collateral ligament, which is reclined posteriorly. The Newclip made-to-measure cutting guide is applied. Two 2.2-mm guidewires are drilled through canula guide across the proximal tibia from medial to lateral following Newclip (Newclip Technics) operative technique (Fig 1) to fix the PSI guide in the right position (Fig 6A). Then, we drill the pre-holes for screws with 4.0 mm drill bit through the guide. Hinge pins (ANC774 rods; Newclip Technics) should be positioned and left on until final fixation of the plate to preserve the integrity of the lateral hinge during opening (Fig 6 B and C). Under arthroscopic view, two 2.4-mm wire are advanced through the cannula of the PSI guide and we control that their extremities are positioned at the posterior and anterior roots footprints of the medial meniscus (Fig 7 A, B, and F). The outer cannula is impacted into the anterior cortex of the tibia through the wires which are then removed (Fig 7C). A FlipCutter (Arthrex) is drilled through the cannula in the same trajectory as the 2.4-mm wire (Fig 7D). The FlipCutter (Arthrex) is converted to a 8.0-mm reamer under direct arthroscopic visualization and 8-mm-diameter sockets are drilled 2-cm height for the anterior and posterior bone blocks at the anterior and posterior roots footprints (Fig 7E). A No. 2-0 FiberStick suture (Arthrex) is advanced

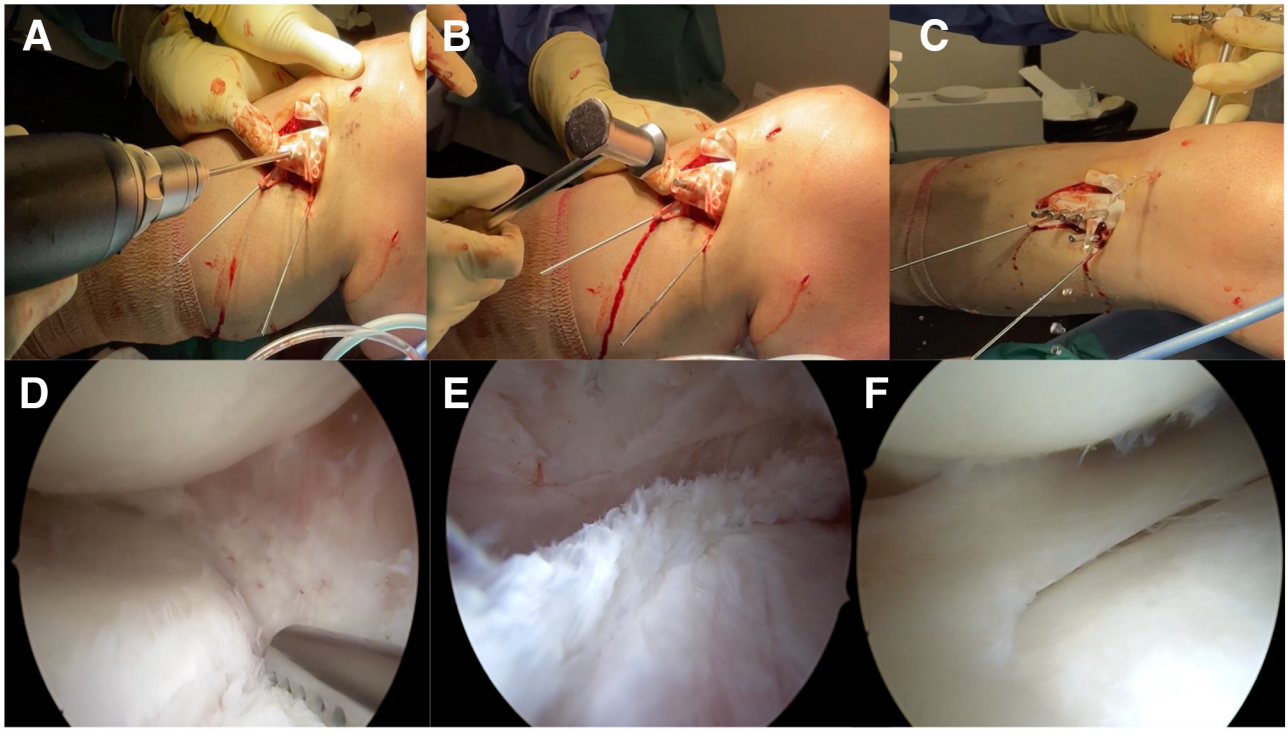

Fig 6. Right knee view. The Newclip made-to-measure cutting guide is applied. Two 2.2-mm guidewires are drilled through canula guide across the proximal tibia from medial to lateral following Newclip operative technique to fix the PSI guide in the right position (A). Then, we drill the pre-holes for screws with a 4.0-mm drill bit through the guide (A). Hinge pins (ANC774 rods) should be positioned and left on until final fixation of the plate to preserve the integrity of the lateral hinge during opening (B, C). Diagnostic knee arthroscopy is performed and the remaining meniscus is debrided using a 4.0-mm shaver (D, E). Lateral compartment and status of cartilage and meniscus are verified (F). (PSI, patient-specific instrumentation.)

through the tibial tunnel and the FiberWire passing suture is retrieved through the lateral portal. The PSI guide is then removed.

Graft Passage

In preparation for graft passage, the anterior and posterior shuttling sutures are retrieved through the anteromedial portal together to prevent soft-tissue bridge formation (Fig 8A). Alternatively, a small cannula (Fig 8A) can be used to pass the sutures avoiding a soft-tissue bridge and then removed. The anteromedial portal is expanded to 2 to 3 cm in size to allow easy passage of the graft and instrumentation during implantation (Table 5). The posterior root sutures are then shuttled through the tibial tunnel, leaving the graft extra-articular. These sutures are then used to apply mild traction while the posterior root bone block and graft are advanced intra-articular using a KingFisher grasper (Arthrex). While viewing from the anterolateral portal, the bone block is reduced into the posterior socket. This is then repeated anteriorly. The anterior root sutures are shuttled through the tibia. The midpoint traction suture (Fig 8B) helps to orient and avoid twisting of the meniscus (Table 5). Tension is applied, and the anterior bone block is advanced into the joint using a KingFisher grasper (Video 1). The free suture ends are fixed with two 3.5-mm PushLock anchors (Arthrex) to the anterior tibial cortex under arthroscopic control of right positioning, firstly for posterior root and then for anterior root.

Meniscal Suturing

First, the midpoint suture is tied to stabilized the meniscus. A posteromedial approach is necessary for the suture of the meniscal ramp (Fig 8C). While viewing from the anteromedial portal, the meniscus is reduced. Then, using Suture Lasso 25° (Arthrex), multiple 2-0 PDS (Ethicon, Somerville, NJ) vertical out-in suture are proceed in the posterior horn. Using FAST-FIX 360° (Smith & Nephew, Watford, UK) multiple all inside vertical mattress sutures are then placed in the mid-portion of the meniscal graft. Finally, using percutaneous needles, multiple out-in 2-0 PDS (Ethicon) vertical sutures are finally placed in the anterior horn. Using hook, we check the stability of the meniscus throughout its circumference (Fig 8 D-F).

Open-Wedge High Tibial Osteotomy

Special equipment is required for this procedure (Table 3). The PSI guide (Newclip) is applied again in

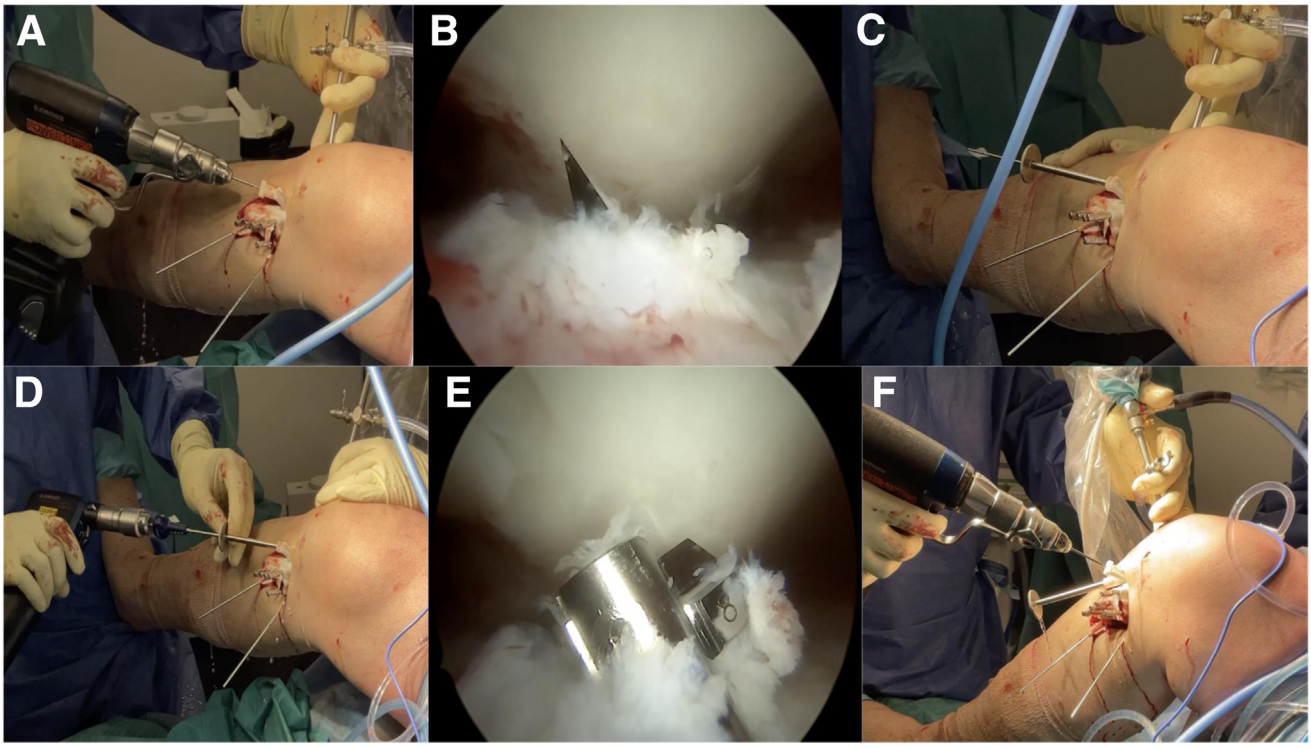

Fig 7. Right knee view. Under arthroscopic view, a 2.4-mm wire is advanced through the cannula of the PSI guide (A), and we control that the extremity is positioned to the anterior roots footprints of the medial meniscus (B). The outer cannula is impacted into the anterior cortex of the tibia through the wires which are then removed (C). A FlipCutter (Arthrex) is drilled through the cannula in the same trajectory as the 2.4-mm wire (D). The FlipCutter (Arthrex) is converted to a 8.0-mm reamer under direct arthroscopic visualization and 8-mm-diameter sockets are drilled 2-cm height for the anterior bone blocks at the anterior roots footprints (E) the same procedure is realized for the posterior root of medial meniscus (F). (PSI, patient-specific instrumentation.)

the same position using the 2 guide pins left in place (Fig 9A).

Then, we perform the osteotomy under radiologic control in the frontal and sagittal planes behind the anterior tibial tuberosity with an oscillating saw for the remnant cortex to the predetermined depth (Fig 9 B and C). Once the osteotomy has been nearly completed, the medial opening is created to the predetermined high for right correction using flexible and rigid chisels or Meary pliers or metallic wedge. The PSI guide makes it possible to obtain the predetermined correction. Intraoperative tibiofemoral alignment and posterior slope are verified under fluoroscopic control. The PSI guide prevents from damaging the tunnel and the leading suture during plate fixation and proximal screws holes drilling. The predefined ACTIVMOTION medial plate with polyaxial locking system (Newclip) is positioned in such a way that the holes in the plate are corresponding to the holes already drilled in the bone helping PSI guide. The plate is fixed proximally with 4.5-mm locking screws and distally with 4.5-mm cortical and locking screws (Fig 9 D-F). A suggested length and a maximum length for screws are proposed by the surgical technique. Radiologic control is recommended. Allograft bone TBF (TBF Tissue Engineering, Mions, France) is used to bone graft the osteotomy site. The PSI guide is useful to prevent tunnel coalition.

Postoperative Re-education

Compressive cryotherapy (Game Ready program 2; CoolSystems, Inc., Concord, CA) is commenced immediately in the recovery room for 4 hours continuously and then 30 minutes every 3 hours for 15 days.

Weight-bearing is limited to 10 to 15 kg bearing for 6 weeks and then a gradual increase in weight bearing by 10 kg every week, until full charge at 3 months. Knee flexion is limited to 30° for 15 days, then 60° up to 4 postoperative weeks and 90° up to 6 postoperative weeks. We do not recommend to use a brace. A gradual return to sports activities is allowed starting at 6 months for nonpivoting sports, at 9 months for pivoting noncontact sports, and at 12 months for pivoting contact sports.

Discussion

MMAT combined with HTO has been shown to be a safe and effective procedure.[16,17] OW-HTO using plates with polyaxial locking system and PSI technique has

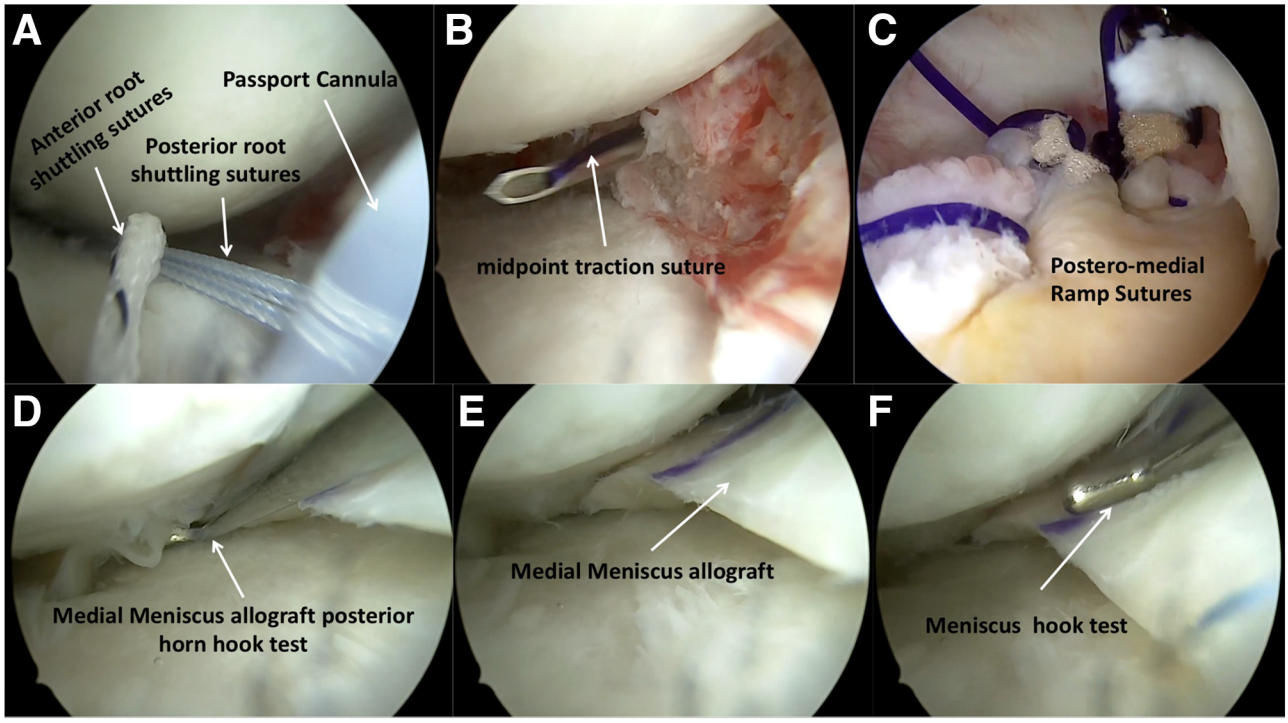

Fig 8. Right knee arthroscopic view. In preparation for graft passage, the anterior and posterior shuttling sutures are retrieved through the anteromedial portal together to prevent soft-tissue bridge formation (A). Alternatively, a passport cannula can be used to pass the sutures avoiding a soft tissue bridge (A). A midpoint traction suture helps to orient and avoid twisting of the meniscus (B). The posterior root sutures are then shuttled through the tibial tunnel leaving the graft extra-articular (A). These sutures are then used to apply mild traction while the posterior root bone block and graft are advanced intra-articular using a KingFisher grasper (Arthrex). While viewing from the anterolateral portal, the bone block is reduced into the posterior socket. This is then repeated anteriorly. A posteromedial approach is necessary for the suture of the meniscal ramp (C) using Suture Lasso 25° (Arthrex), multiple sutures are proceeded in the posterior horn and mid-portion of meniscal graft Using Fast-Fix® 360° (Smith &Nephew, Watford, UK). Finally, using percutaneous needles, multiple out-in 2-0 PDS (Ethicon, Somerville, NJ) vertical sutures are finally placed in the anterior horn. Using hook, we check the stability of the meniscus throughout its circumference (D-F).

shown good results with a low rate of complications.[18,19] The present technique combines the 2 procedures. To our knowledge, no Technical Notes are reported in the literature that combine these 2 procedures: MMAT using bone plugs with tibial tunnels combined to OW-HTO using PSI guide for both. The most important advantage of the present technique is to control tunnel position and to avoid damaging of the tunnel while osteotomy is done. The bone plug technique described in this article provides several advantages (Table 4). First, it allows osseous integration and graft stability. In addition, it can be performed arthroscopically through small incisions. Finally, cortical fixation is obtained and prevents graft displacement.

It's recommended to perform the MMAT first and the OW-HTO second (Table 5). It is also mandatory to complete the osteotomy once the meniscal graft is sutured in the joint. This allows the surgeon to stress the knee in valgus while seating medial meniscus graft into the joint, without the risk of any fracture starting from the osteotomy line. The HTO and tunnels using PSI also provides several advantages. First, we control the anatomic roots position. Second, we control the HTO degree of correction. Third, we avoid collision of tunnels and HTO. In conclusion, MMAT using bone-plug technique combined with tunnels and OW-HTO using

Table 3. Equipment Required to Perform HTO and Tunnels Using PSI Technique

Special Equipment
Newclip made-to-measure cutting guide (Newclip)
Two 2.2 mm wire to fix the PSI guide
wo 2.4 mm wire for the tunnels
3.5-mm-diameter FlipCutter guide (Arthrex)
8-mm FlipCutter Retrograde Reamer (Arthrex)
4.0 mm drill bit for screws
Oscillating saw blade
Activemotion medial plate with polyaxial locking system
ANC774 rods
4.5-mm cancellous screws (Newclip)
4.5-mm cortical screws (Newclip)

HTO, high tibial osteotomy; PSI, patient-specific instrumentation.

Table 4. Advantages and Disadvantages of the Bone Plug Technique for Medial Meniscal Allograft Transplant Combined With HTO and Tunnels Using PSI

Advantages	Disadvantages
Osseous integration of meniscal roots.	Requires accurate bone plug preparation.
Minimally invasive avoiding stiffness.	Bone plug reduction is technically challenging.
Cortical fixation giving more stability to meniscal roots.	Increase in operative time.
Anatomic roots position.	Increase in cost.
3-dimensional preplanned correction of deformities are all integrated within the patient-specific cutting guide.	
Avoid the risk of tibia tunnel collision with HTO procedure.	

HTO, high tibial osteotomy; PSI, patient-specific instrumentation.

Table 5. Pearls and Pitfalls

Pearls	Pitfalls
Create a large anteromedial portal to ensure easy passage graft throughout a cannula passport	Failure to adequately expose the posterolateral capsule and protect posterior structures; places neurovascular structures at risk of injury
Leave a 2-mm peripheral rim of normal meniscus to aid in obtaining secure allograft fixation	Transtibial fixation in patients with open physis can lead to growth arrest
Use one midpoint suture through the meniscal body to orient the meniscus	Fixation failure can occur if the patient is not able to comply with the rehabilitation protocol
	Failure to identify/address concomitant pathology (i.e., ligamentous instability; full-thickness cartilage defects) will lead to poor outcome
Marking of the saw blade based on the computed depth minimizes the risk of injury to the lateral structures. and hinge fracture	Risk of neurovascular injury if dissection posterior to the MCL is not performed well
Perform first MAT before HTO avoids lateral tibial stress and risk of tibial fracture	Risk of lateral hinge fracture

HTO, high tibial osteotomy; MAT, meniscus allograft transplantation; MCL, medial collateral ligament.

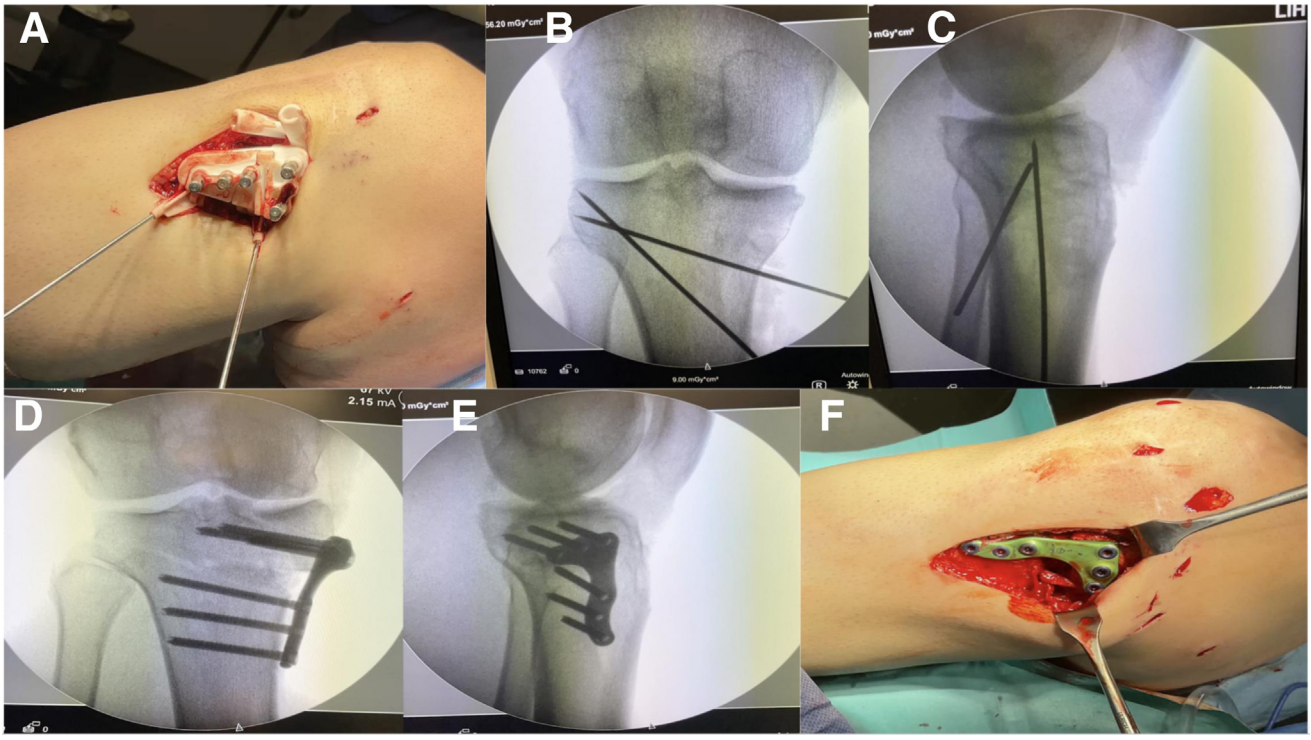

Fig 9. Right knee view. The PSI guide (Newclip) is applied again in the same position using the 2 guide pins left in place (A). We perform the osteotomy under radiologic control in the frontal and sagittal planes (B, C) behind the anterior tibial tuberosity with an oscillating saw for the remnant cortex to the predetermined depth. Intraoperative tibiofemoral alignment and posterior slope are verified under fluoroscopic control (D, E). The PSI guide prevents from damaging the tunnel and the leading suture during plate fixation and proximal screws holes drilling (A). The predefined ACTIVMOTION medial plate with polyaxial locking system (Newclip) is positioned in such a way that the holes in the plate are corresponding to the holes already drilled in the bone helping PSI guide. The plate is fixed proximally with 4.5-mm locking screws and distally with 4.5-mm cortical and locking screws (F). (PSI, patient-specific instrumentation.)

PSI described in this Technical Note provides a safe and easy approach to achieve MMAT in varus knees. With the careful adherence to the recommended surgical technique the risk of complications is extremely low.

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