Technical Note

Slope-Reducing Anterior Closing Wedge Proximal Tibial Osteotomy, Anterior Cruciate Ligament Tunnel Bone Grafting, and Unstable Medial Meniscus Ramp Repair as a First-Stage Procedure

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Abstract: Revision anterior cruciate ligament reconstruction (ACLR) requires heightened levels of preoperative patient planning to evaluate for known risk factors of a primary ACLR graft failure. Risk factors include ≥12° of posterior tibial slope, coronal malalignment, nonanatomic femoral or tibial ACLR tunnel placement, and unaddressed ligament/meniscal injury. This technique describes an anterior closing wedge proximal tibial osteotomy, medial meniscus ramp repair, and bone grafting of the failed ACLR femoral and tibial tunnels. This is the first stage of a 2-stage revision ACLR aimed to address an increased posterior tibial slope that contributes to ACLR graft failure while concurrently bone grafting malpositioned failed ACLR tunnels and repairing an unstable medial meniscal tear to prevent further injury or exacerbation before the second-stage procedure.

Known risk factors for anterior cruciate ligament (ACL) reconstruction (ACLR) graft failure include nonanatomic tunnel placement, residual instability from unrepaired ligament or meniscal injury, tunnel osteolysis/widening, increased posterior tibial slope (PTS) ≥12°, and coronal malalignment.[1-3] Heightened level of complexity are presented to physicians when patients have ACLR failure with increased PTS in combination with unstable meniscal injuries.[4]

Medial meniscus ramp tears have been reported in 9.0% to 40.8% of ACL tears.[5,6] It is well defined that unaddressed meniscal tears can lead to accelerated progression of osteoarthritis, increased translational/rotatory instability, and elevated compartment contact pressures.[7] Whether a single- or multistage procedure, meniscus repair to salvage meniscal anatomy to prevent tear progression should be performed. A multistage procedure provides the opportunity to address sagittal malalignment with an anterior closing wedge proximal tibial osteotomy (ACW-PTO) and bone graft failed ACLR tunnels while repairing any unstable meniscus tears before revision ACLR to prevent irreparable progression.[8] We describe an ACW-PTO, medial meniscus (MM) ramp repair, and ACL tunnel bone grafting in the setting of a planned 2-stage revision ACLR.

Surgical Technique

A detailed video of the assessment, ACW-PTO, MM ramp repair, and tunnel preparation with bone grafting is shown in Video 1. The step-by-step guide and surgical pearls are included in Table 1.

Patient Evaluation

In the setting of recurrent ACL injuries, a holistic approach to patient evaluation should combine the findings from the clinical examination, radiographic assessment (Fig 1), magnetic resonance imaging (Fig 2), and computed tomography. Patients with an increased PTS (Fig 3) and nonanatomic tunnel position or tunnel diameter >12 mm should undergo a concurrent slope-reducing osteotomy and bone grafting of ACLR tunnels. If a multistage procedure is necessary, unstable meniscus

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Table 1. Step-by-Step Guide and Surgical Pearls for Slope-Reducing Anterior Closing Wedge Proximal Tibial Osteotomy, Anterior Cruciate Ligament Tunnel Bone Grafting, and Unstable Medial Meniscus Ramp Repair as a First-Stage Procedure

Step-by-Step Guide	Pearls
A midline incision is made from the mid-patella to the distal aspect of the tibial tubercle.	Incision should be extended to properly expose previously implanted deep hardware if present.
Dissect down under the patellar tendon and place a Z retractor inferiorly.	Properly releasing adhesions beneath the patellar tendon and bone decreases the risk of iatrogenic damage during osteotomy cuts.
Periosteal flaps are made medially and laterally to expose previously implanted deep hardware and prepare the osteotomy approach.	A 1-cm periosteal flap should extend just anterior to the MCL and proximal and then laterally starting at the anterior compartment step-off to the anterior margin or the proximal tibiofibular joint and then continuing 1 cm proximally.
Remove deep hardware as needed.	Ensure proper hardware removal instruments are present.
Create parapatellar arthroscopic portals and insert a shaver and arthroscope to insufflate the joint.	During intra-articular assessment of cruciate ligaments and meniscal anatomy, chondroplasty can be completed if loose bodies or chondromalacia are present.
Release the MCL to gain proper visualization of the medial meniscus.	Release the MCL off the tibial distally with an elevator as part of the surgical approach for the ACW-PTO.
Assess for a medial meniscus ramp tear.	A probe is used to palpate above and below the medial meniscus to assess and approximate the extent of meniscocapsular separation. The transnotch view can provide improved posterior visualization for a potential ramp tear.
Debride the previous failed ACLR graft, ACL femoral tunnel, and intercondylar notch.	Significant scarring presents challenges when delineating intraarticular anatomy. Take caution identifying the underlying posterior root of the lateral meniscus when resecting the failed ACLR reconstruction graft.
Dissect and place a spoon retractor posteriorly.	Place a probe along the medial joint line and dissect down to split the sartorius fascia. Place the spoon between the interval anterior to the medial head of the gastrocnemius and above the semimembranosus tendon.
Repair the medial meniscus ramp tear.	Use a rasp to abrade the edges of the meniscocapsular separation. Then, meticulously place vertical mattress sutures above and below the tear to repair the tear.
Identify and debride the previous tibial ACLR tunnel.	Place a pin and drive it superolaterally through the previous ACLR tunnel and ream over with a 10-mm acorn reamer.
Place the first pair of distal osteotomy guide pins.	The placement of the first 2 pins should be just proximal to the tibial tubercle and oriented perpendicularly to the tibial shaft.
Confirm initial placement with fluoroscopy.	Pins should align parallel with the tibial shaft and just engage the posterior tibial cortex without posterior blowout.
Place the second pair of proximal guide pins.	Measure correction superior to the distal pin placement on the anterior cortex. A 1-mm correction equates to a 1-mm degree correction.
Confirm final placement of guide pins with fluoroscopy.	Angle of proximal pins should meet the distal pins at the posterior tibial cortex, creating a desired bone wedge and the mark the cutting plane with electrocautery.
Cut and remove the bone wedge from osteotomy site.	Use an ACL saw blade to cut the cortex along the demarcated edge. Use a series of curettes to remove excess cancellous bone posteriorly.
Reduce the osteotomy site.	Hyperextend the knee by applying pressure on the distal femur and elevating the heel until closure is complete.
Fixate reduction with large Richard staples.	Place the lateral staple adjacent to the patellar tendon and Gerdy's tubercle and then 2 more medially to complete closure.
Bone graft tibial and femoral ACLR tunnels.	Use the bone wedge removed from the osteotomy site to fill tunnels. A curette can be used to pack and level the intra-articular aperture.
Conduct final fluoroscopic imaging, and then close deep and superficial tissues.	Obtain sufficient anteroposterior and lateral radiographs to confirm reduction. A multilayered closure prevents hematoma buildup once the tourniquet is let down.

ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; ACW-PTO, anterior closing wedge proximal tibial osteotomy; MCL, medial collateral ligament.

Fig 1. Lateral views of bilateral standing anterior cruciate ligament (ACL) stress radiographs show 6.4 mm of increased anterior tibial translation of the left knee compared to the right uninjured knee. Upon physical examination, the patient had evidence of increased anterior tibial translation (ATT) of his left knee with a grade 2+ Lachman's and pivot-shift exams. ACL stress radiographs showing increased ATT of 3 to 4 mm on the injured knee compared to the contralateral side raise concern for an ACL reconstruction graft failure or a primary ACL tear. To measure ATT radiographically, parallel lines are drawn along the posterior tibial cortex and the posterior margin of the lateral femoral condyle. A perpendicular line is then made from the posterior lateral femoral condyle line to the posterior cortex of the lateral tibial plateau, and this distance indicates the ATT.

tears should be repaired to prevent tear exacerbation or complete failure before the second-stage reconstruction.

Anesthesia and Positioning

The patient is placed supine on the operating table and induced under general anesthesia. An examination under anesthesia is performed to confirm the clinical findings. A high-thigh tourniquet is placed on the surgical leg. The surgical leg is placed in an extremity holder (Mizho OSI), and the contralateral leg is placed into an abduction stirrup (Birkova Product LLC). The patient is administered perioperative cefazolin for prophylaxis against infection.

ACW-PTO Preparation and Hardware Removal

An anterior approach is performed through an incision from the mid-patella to 3 to 4 cm distal to the tibial tubercle, completely exposing the patellar tendon (Fig 4). Dissection is continued under the patellar tendon, placing Z retractors inferiorly (Fig 5). Subperiosteal flaps on the tibia are elevated on both sides of the patellar tendon. The medial flap extends from the medial collateral ligament to the patellar tendon and extends 1 cm proximally. The lateral flap mirrors the medial flap but extends from the anterior compartment step-off and just anterior to the proximal tibiofibular joint. The incision may be extended to remove prominent hardware from the previous ACLR(s).

Arthroscopy

Medial and lateral arthroscopic parapatellar portals are made. The camera is inserted into the joint, and the joint is insufflated with normal saline. Assessment of the suprapatellar pouch, medial and lateral gutters, and intra-articular compartment follows. Attention is then brought to the meniscus, where a probe is used to palpate the medial and lateral menisci (Fig 6). If an MM ramp tear is discovered/validated on arthroscopy, the stability of the tear should be assessed. The distal aspect of the medial collateral ligament is released during the ACW-PTO approach, allowing for improved visualization of the MM ramp tear.

Intra-articular Debridement and Tunnel Preparation

Intercondylar notch debridement and notchplasty follow to remove scarring from the failed ACLR surgery and osteophytes. The previously failed ACLR graft is identified and removed with a shaver (Fig 7). The femoral tunnel is exposed and debrided for bone grafting with a series of shavers, curettes, and rasps. The tibial tunnel should be addressed following any

Fig 2. Preoperative magnetic resonance imaging (MRI) of a sagittal view of the left knee. An MRI should be performed to assess the size and tunnel placement from the primary anterior cruciate ligament (ACL) reconstruction while also assessing for a meniscus injury or additional concomitant ligament injury. In this patient, increased signal intensity posteriorly (I) is indicative of posteromedial tibial plateau bone bruising commonly observed with concomitant ACL and medial meniscus ramp tears. Clear posterior meniscocapsular separation (II) provides additional support for a concomitant medial meniscal ramp tear and, if not addressed, heightens the concern for further injury if not repaired in the first stage of a 2-stage procedure. (A, anterior; P, posterior.)

meniscal repair to optimize intra-articular visualization and fluid insufflation.

Meniscal Repair

For the inside-out MM ramp repair, a vertical incision along the posteromedial joint line is performed, and an interval is created anterior to the medial head of the gastrocnemius and above the semimembranosus tendon in preparation for the repair (Fig 8). A Sharp-Shooter (Stryker) is used to place inside-out vertical mattress sutures above and below the length of the meniscocapsular separation (Fig 9). A transnotch view of the meniscocapsular junction determines if additional sutures are required. A probe is used to assess the tear's stability and to confirm adequate fixation.

ACW-PTO and Bone Grafting

The tibial tunnel of the previous reconstruction is now identified, a tibial guide (Arthrex) is used, and a guide pin is drilled through the midportion of the failed tibial tunnel. A Kocher is used to hold the guide pin while over-reaming, removing significant intra-tunnel scarring.

The extremity holder is now removed, and the foot of the bed is brought up sterilely and redraped. Two guide pins are drilled perpendicular to the tibial shaft and parallel to the tibial plateau on each side of the patellar tendon and should engage the posterior cortex (Fig 10). For slope-reducing osteotomies, the general rule of thumb is 1 mm equates to 1° of correction for the correction distance between the guide pins.[9] The proximal pins are placed at an angle to engage the other guide pins at the posterior cortex. Fluoroscopy is used to confirm the desired trajectory (Fig 11).

A small ACL saw blade (Stryker) is used to cut along the cortex, removing the desired bone wedge beginning laterally and moving medially, navigating under the patellar tendon insertion. A curette is then used to curette posteriorly, ensuring adequate bone removal to facilitate a flush osteotomy closure. The removed tibial bone wedge is now used to bone graft the over-reamed ACLR tunnels through a cannula (Fig 12).

Osteotomy Reduction and Closure

The knee is carefully hyperextended to reduce the osteotomy, ensuring the posterior cortex remains intact. A large Richards staple (Smith & Nephew) is placed between the patellar tendon and Gerdy's tubercle, with 2 more placed medially, completing the closure (Fig 13). Fluoroscopic anteroposterior and lateral images are obtained to verify final ACW-PTO fixation.

Deep and superficial tissues are closed in layered fashion with 0 and 2-0 Vicryl (Ethicon), and a Monocryl stitch is used for the skin. A knee immobilizer is applied in full extension.

Postoperative Protocol

Following the procedure, the patient is non-weightbearing on the lower extremity for 8 weeks, avoiding hyperextension for 3 months postoperatively. Physical therapy starts on postoperative day 1, focusing on quadriceps activation, edema control, and knee motion.

Baseline anteroposterior and lateral knee radiographs are obtained on postoperative day 1 following physical therapy. This will be repeated at the 8-week time point. If there is evidence of sufficient healing, the weightbearing progression can begin, advancing at one-quarter body weight per week until the patient is fully weightbearing at 3 months. At this point, radiographs are repeated, and if sufficient healing progression has occurred, they may wean off crutches. Radiographs are obtained at 6 months postoperatively to document sufficient healing to proceed with the second-stage surgery.

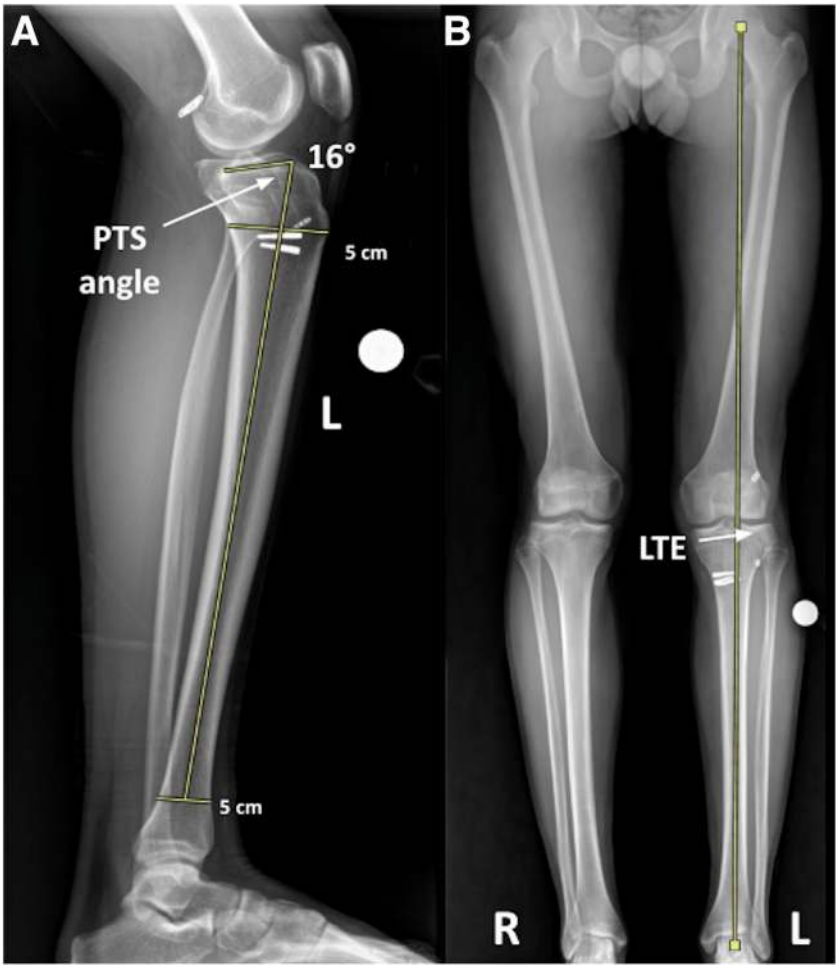

Fig 3. Lateral standing radiograph of the left knee (A) measuring posterior tibial slope (PTS), assessed through the anatomic axis technique. A line is drawn both 5 cm distal to the knee joint line and 5 cm proximal to the tibiotalar joint, in between the anterior and posterior tibial cortices. A line is then drawn vertically from their midpoints on the sagittal axis. A horizontal line is then made parallel to the lateral tibial plateau, and the corresponding angle is representative of the tibial slope. The left knee PTS measures 16°. Excessive loading on anterior cruciate ligament (ACL) grafts occurs when a slope of ≥12° is present and predisposes individuals to recurrent ACL graft failure following revision reconstruction. Furthermore, anteroposterior long-leg standing radiographs assess the coronal malalignment of the left knee, showing slight valgus alignment. (L, left; R, right.)

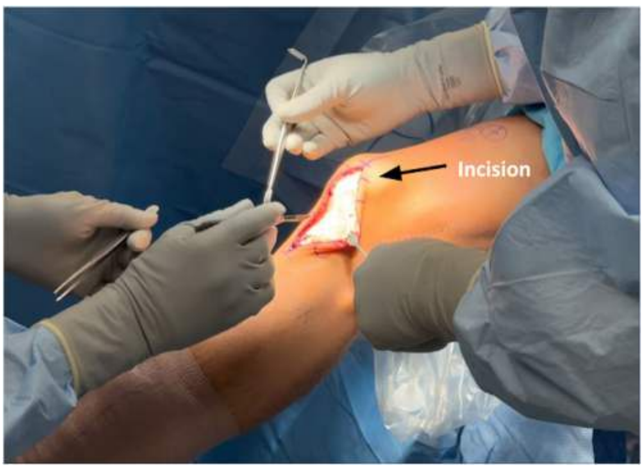

Fig 4. Left knee anterior midline approach for the anterior closing wedge proximal tibial osteotomy with the patient in a supine position. The incision begins from the mid-patella and extends distal to the tibial tubercle. Adequate exposure is ensured to remove external hardware from the previous anterior cruciate ligament reconstruction and can be extended medial or lateral if necessary.

Fig 5. Left knee anterior midline approach with the patient in a supine position. Subperiosteal flaps are created medial and lateral to the patellar tendon (PT), and a Z retractor is placed inferiorly to expose the tibial tubercle. Isolation of the patellar tendon is performed to protect the extensor mechanism during the closing wedge proximal tibial osteotomy.

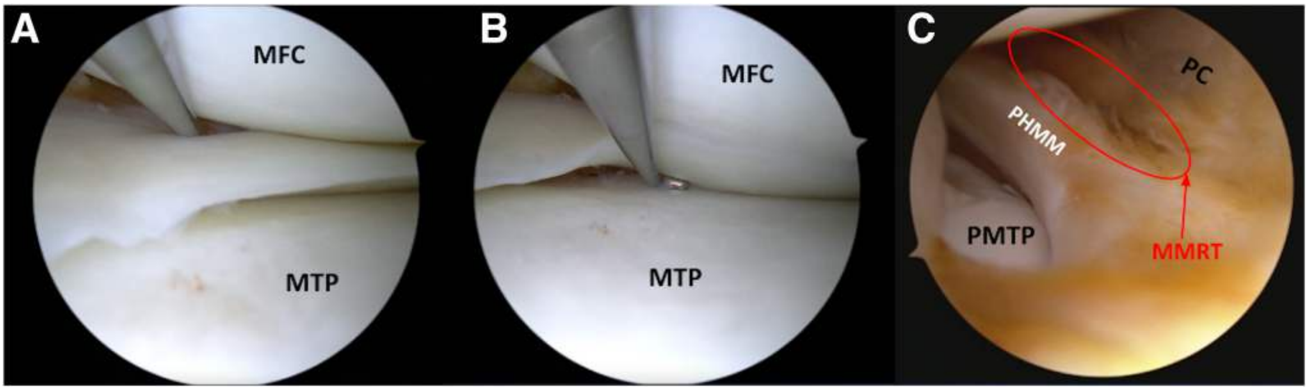

Fig 6. Left knee arthroscopic view from the anterolateral portal of the medial meniscus ramp tear (MMRT) and unstable posterior horn tear of the medial meniscus (PHMM). The medial collateral ligament has been released off the proximal tibia as part of the osteotomy approach, which allows for increased visualization of the ramp tear and improved access for repair. A probe is inserted into the medial compartment, and the medial meniscus is palpated both superiorly (A) and inferiorly (B) until the margins of the tear are identified. The arthroscope is then inserted through the intercondylar notch from the anterolateral portal (C) to confirm the meniscocapsular separation of the ramp tear. (MFC, medial femoral condyle; MTP, medial tibial plateau; PC, posterior capsule; PMTP, posteromedial tibial plateau.)

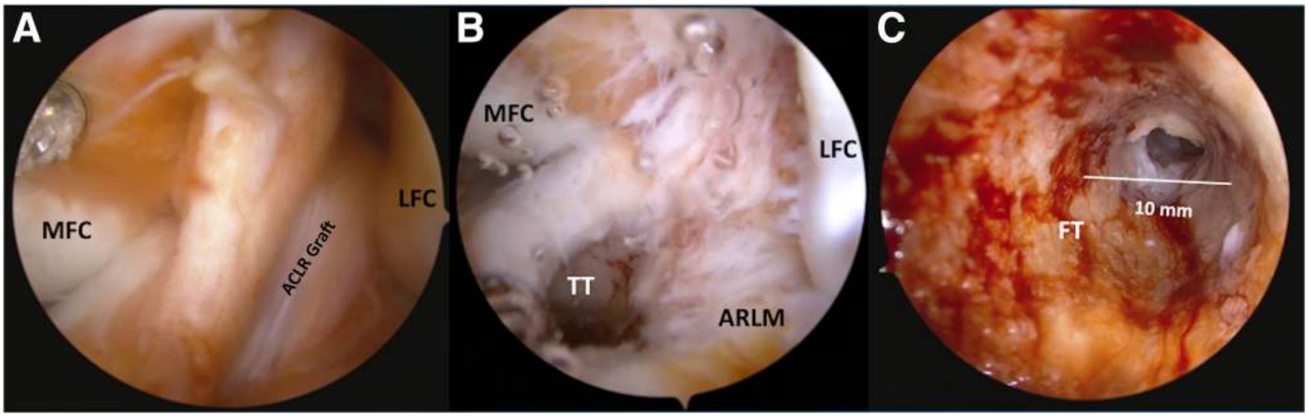

Fig 7. Left knee arthroscopic view from the anterolateral portal of the failed anterior cruciate ligament reconstruction (ACLR) graft is confirmed. Moderate scarring and adhesions encompass the ACLR graft (A), tibial (B), and femoral (C) tunnel margins. Tunnels are reamed to 10 mm in diameter, and bleeding bony margins are created. Caution should be taken when resecting the posterior femoral attachment of the ACLR graft due to the proximity of the lateral meniscus root attachment. (ARLM, anterior root of the lateral meniscus; FT, femoral tunnel; LFC, lateral femoral condyle; MFC, medial femoral condyle; TT, tibial tunnel.)

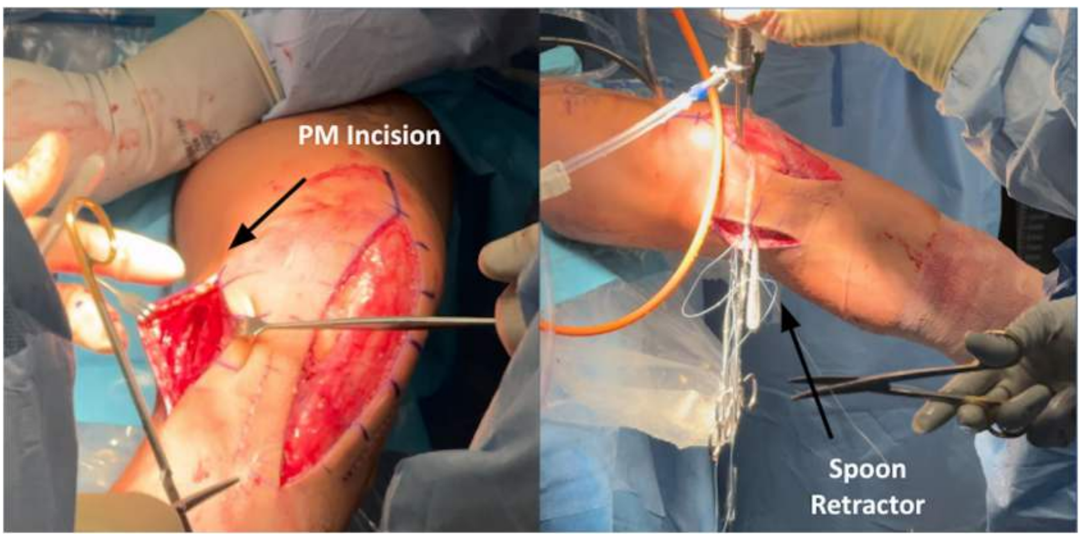

Fig 8. Left knee posteromedial (PM) incision and approach for inside-out repair. A PM incision allows for visualization of suture placement to ensure position and secure fixation, especially in the setting of complex tear patterns involving the posterior horn of the meniscus. A spoon retractor is placed posteriorly to protect the posterior neurovascular structures.

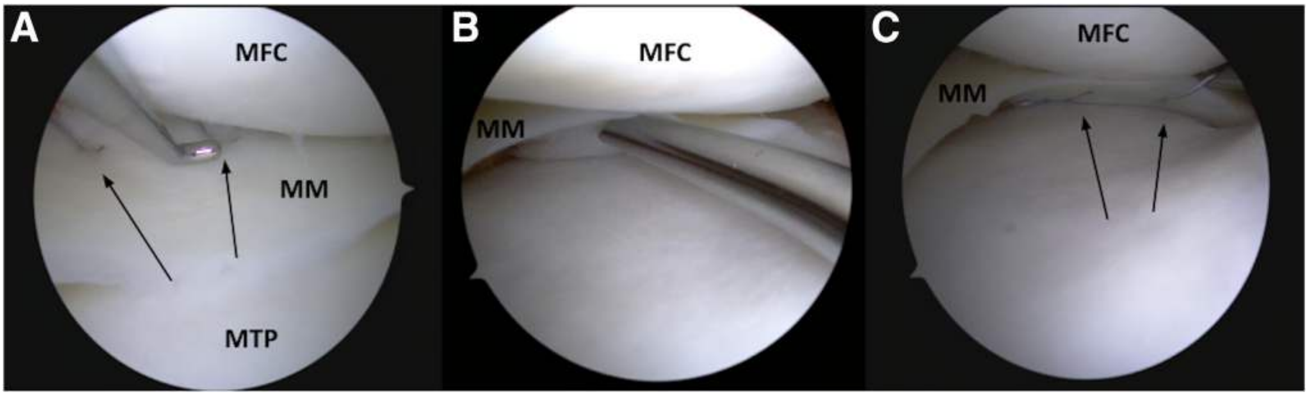

Fig 9. Left knee arthroscopic view from the anteromedial portal of the medial meniscus ramp repair (MMRR) and reduced posterior horn of the medial meniscus (MM). Inside-out vertical mattress sutures are placed both superiorly (A) and inferiorly with a sharpshooter (Stryker) (B) until the margins of the tear are completely reduced (C). A probe is placed into the medial compartment to palpate the repair to ensure adequate fixation and determine if additional sutures are needed. The arthroscope is then inserted through the transnotch view to ensure the reduction of the meniscocapsular separation from the ramp tear. (MFC, medial femoral condyle; MTP, medial tibial plateau.)

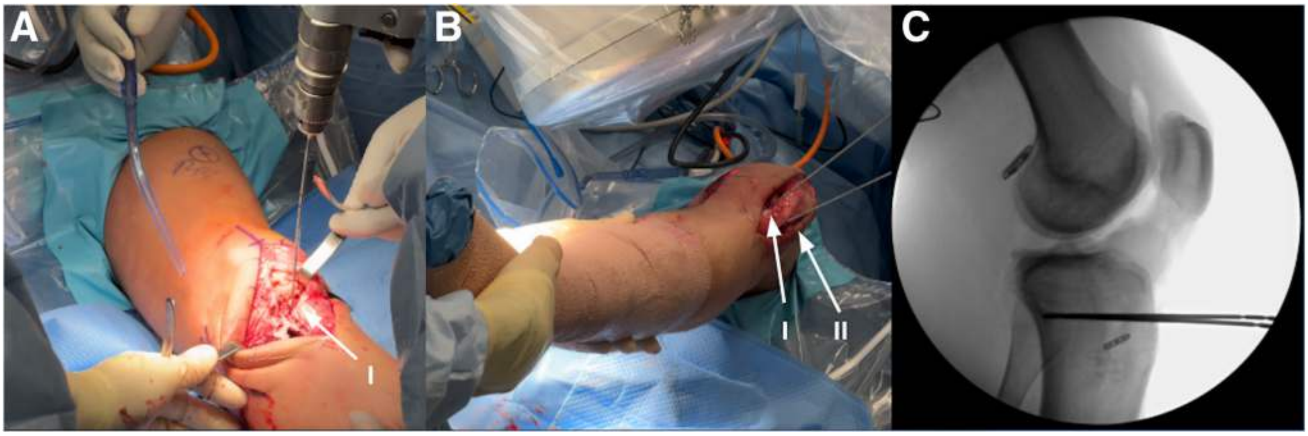

Fig 10. Left knee distal pin placement progression for the slope-reducing anterior closing wedge osteotomy with the patient in a supine position. Two pins (I, II) are placed medial and lateral adjacent to the tibial tubercle and drilled perpendicularly to the tibial shaft and should contact the posterior tibial cortex (A). Intraoperative fluoroscopy (B, C) is used to obtain lateral radiographs to confirm the pin placement without posterior protrusion and the trajectory remains parallel to the tibial shaft.

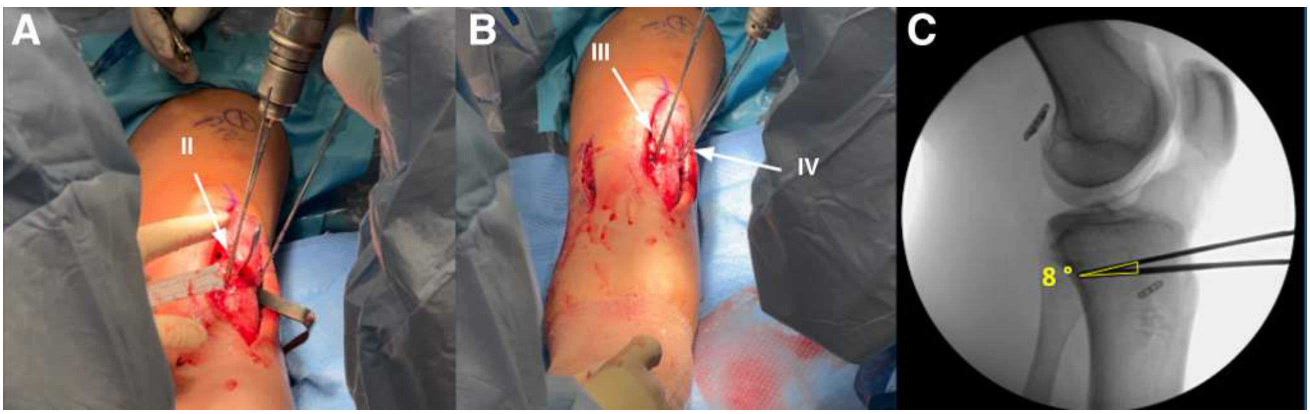

Fig 11. Left knee proximal pin placement progression for the slope-reducing anterior closing wedge osteotomy with the patient in a supine position. The correction is measured on the anterior cortex with 1 mm of correction equated to a 1° reduction. Pin trajectory is approximated, and 2 pins (III, IV) are placed 8 mm superiorly from the distal pins on the anterior cortex, meeting the previous pins at the posterior cortex to achieve a wedge (A and B). Intraoperative fluoroscopy (C) is used to obtain lateral radiographs to confirm the pin placement, and the desired wedge correction angle is established.

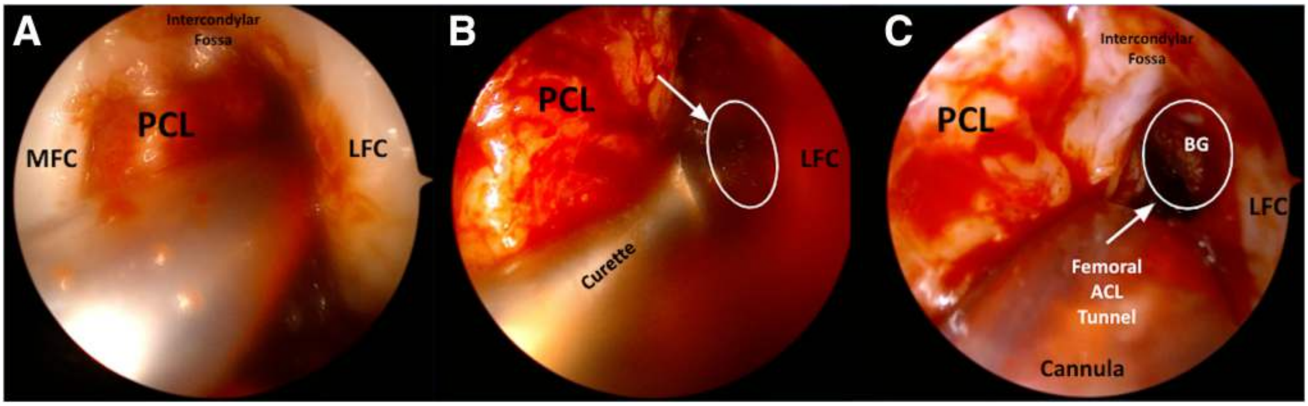

Fig 12. Arthroscopic view from the anterolateral portal of a left knee bone grafting of debrided anterior cruciate ligament (ACL) reconstruction tunnels. Bone graft (BG) from the removed bone wedge was thoroughly packed through a cannula into both the tibial and femoral tunnels. The BG is dispensed through the femoral tunnel posterolaterally (A) and the tibial tunnel superolaterally until it is visualized intra-articularly. Protrusion of bone matrix from tunnels is leveled and excess graft is positioned in the tunnels with a curette to optimize packing density (B). Final confirmation of the leveled femoral tunnel aperture is made prior to final closure (C). (LFC, lateral femoral condyle; MFC, medial femoral condyle; PCL, posterior cruciate ligament.)

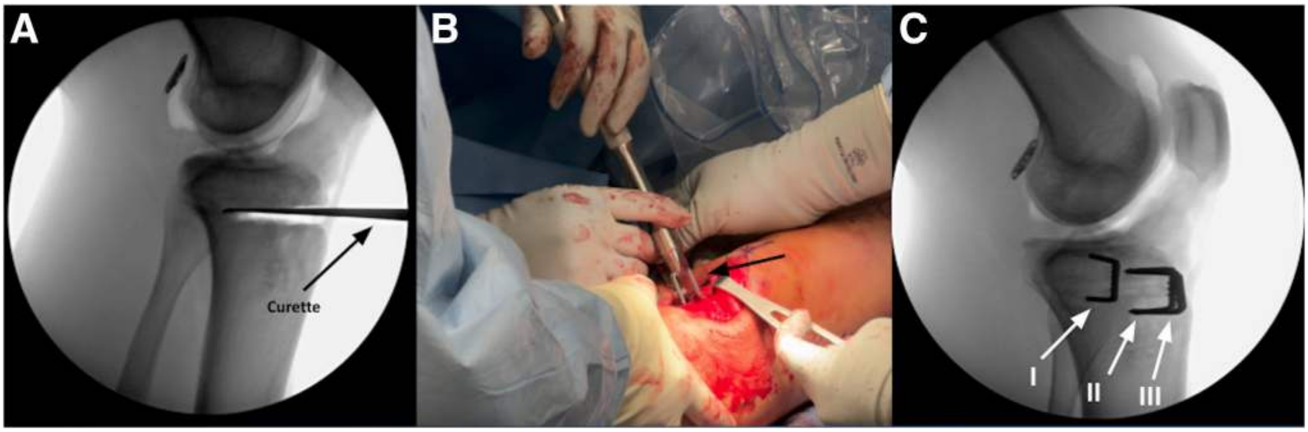

Fig 13. Left knee steps for the slope-reducing anterior closing wedge osteotomy with the patient in a supine position begin with the removal of the delineated tibial wedge. An anterior cruciate ligament saw blade is used to cut along the medial and lateral cortices, and then a curette and rongeur are used to remove excess cancellous bone (A). Once adequate bone is removed, the osteotomy site should be carefully closed by applying pressure on the distal femur and gradual hyperextension. Three bone staples are placed, and the closure and correct staple trajectories are visualized with intraoperative fluoroscopy (B, C).

Table 2. Advantages and Disadvantages of a First-Stage Slope-Reducing Anterior Closing Wedge Proximal Tibial Osteotomy, Anterior Cruciate Ligament Tunnel Bone Grafting, and Unstable Medial Meniscus Ramp Repair

Advantages	Disadvantages
Ramp repair in the first stage helps stabilize the knee and prevent further meniscal tearing.	With an unstable knee still present, the ramp repair is at risk for a retear.
An inside-out suture repair allows for additional sutures compared to all-inside repair when addressing ramp tears of unknown size and mobility.	Require accessory incision, have a heightened technical requirement, and risk damage to posterior neurovascular structures.
Vascularity of the joint capsule and the peripheral meniscus has been reported to have favorable outcomes and healing rates for meniscus repair, especially in the setting of an ACLR.	Unidentified ramp tears in an unstable ACL-deficient knee are at a higher risk for tear progression.
Anterior closing wedge proximal tibial osteotomy allows posterior tibial slope correction before ACLR.	Risk of osteotomy overcorrection that increases hyperextension of the knee.
Decreased weightbearing restrictions in the second-stage ACLR delegated to bone healing from the osteotomy site.	Requires an 8-week nonweightbearing protocol following the first stage of the procedure.
The bone wedge from the osteotomy can be used to bone graft the ACL tibial and femoral tunnels.	Requires 2 stages, both with weightbearing restrictions and at least 5 to 6 months between stages.

ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction.

Discussion

When performing the first stage of a 2-stage revision ACLR surgery, mitigating further injury progression in the time leading to the second stage must be prioritized. A large, unstable ramp tear should be repaired in the first stage. A retrospective clinical analysis from Tuphe et al.[10] reported on the long-term viability of stable ramp lesions associated with ACL tears and whether repairs should be more frequently indicated. They reported that 28.6% of patients experienced further medial meniscus tears with unrepaired stable ramp tears, and of those, 21.4% of patients developed bucket-handle tears. By performing an ACW-PTO and medial meniscus ramp repair in combination, one can utilize the nonweightbearing postoperative ACW-PTO protocol to offload excessive axial forces that jeopardize early-stage ramp repairs and prevent future risk for reinjury or tear exacerbation in the 6 months leading up to the revision ACLR.

With any surgery, risks and limitations exist. Overcorrection of PTS may contribute to an increased risk of PCL tears, genu recurvatum has been reported in several series, the postoperative course with a concomitant meniscus repair becomes more complicated, and it further increases the technical difficulty of the surgery itself. A full list of advantages and disadvantages is included in Table 2. The combination of ACW-PTO and MM ramp repair should be patient-specific and intricately planned to ensure optimal patient outcomes.

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: R.F.L. has received funding grants from Ossur, Smith & Nephew, Arthroscopy Association of North America, and American Orthopaedic Society for Sports Medicine; is a consultant or advisor for Ossur, Smith & Nephew, and Responsive Arthroscopy; has received travel reimbursement from Smith & Nephew; has received speaking and lecture fees from Foundation Medical, LLC; and has a patent with royalties paid to Ossur. All other authors (E.P.S., L.V.T., M.T.R., D.R.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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