Technical Note

Concomitant Opening-Wedge Distal Femoral Osteotomy and Anterior Closing-Wedge Proximal Tibial Osteotomy With Tunnel Bone Grafting for the First Stage of a Revision Anterior Cruciate Ligament Reconstruction

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Abstract: Multiple risk factors for anterior cruciate ligament (ACL) reconstruction graft failure have been reported, including improper tunnel placement, unrepaired meniscus or ligamentous injuries, and coronal/sagittal malalignment. Various biomechanical studies have reported on the increased forces experienced by the ACL graft when there is valgus malalignment or increased posterior tibial slope. This technique describes an opening-wedge distal femoral osteotomy to correct valgus alignment and a closing-wedge proximal tibial osteotomy to correct increased posterior tibial slope in the setting of an ACL reconstruction graft failure. This technique is the first stage of a 2-stage surgery in which the second stage is the revision ACL reconstruction. By performing both osteotomies first, the patient can begin weight bearing earlier after the revision ACL reconstruction.

Anterior cruciate ligament (ACL) graft failure after ACL reconstruction can occur as the result of various reasons, including new traumatic injury, improper graft placement, unrepaired/reconstructed meniscal or ligamentous tears, and coronal/sagittal plane malalignment.[1,2] Valgus alignment and increased posterior tibial slope (PTS) $\geq 12^{\circ}$ are critical risk factors that can potentially play a role in ACL graft failure.[1,3] Before performing a revision ACL reconstruction surgery, careful preoperative planning must be performed, and possible causes of failure should be analyzed. To improve patient-reported outcomes and reduce failure, any risk factors that are present should be corrected, including tunnel osteolysis, coronal malalignment, increased PTS, and any concomitant meniscal or ligamentous pathology.

Previously published biomechanical studies have reported that both increased PTS and valgus alignment result in increased forces on ACL grafts and are associated with ACL graft failure.[4,5] To correct for these malalignments, valgus alignment can be corrected with an opening-wedge distal femoral osteotomy (OW-DFO), and increased PTS can be corrected with an anterior closing-wedge proximal tibial osteotomy (ACW-PTO).[6-9] We describe a concomitant outpatient OW-DFO and ACW-PTO to correct valgus alignment and increased PTS in the setting of a planned 2-stage revision ACL reconstruction.

Surgical Technique

A detailed video of the OW-DFO and ACW-PTO technique is shown in Video 1. The step-by-step guide and surgical pearls are detailed in Table 1.

Determination of Correction

Before surgery, radiographic assessment using the lateral and anteroposterior long-leg images should be used to determine the correction size recommended to correct sagittal (Fig 1) and coronal (Figs 2 and 3) malalignment, respectively.

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Table 1. Step-by-Step Guide and Surgical Pearls for Concomitant Opening-Wedge Distal Femoral Osteotomy and Anterior Closing-Wedge Proximal Tibial Osteotomy

Step-by-Step Guide	Surgical Pearls
The distal femoral opening-wedge osteotomy exposure should be performed first; this begins with a lateral incision starting just proximal to the Gerdy tubercle and extending 10 cm proximal.	This incision should be centered over the inferior third of the iliotibial band to allow for the best approach for the osteotomy.
Dissection is carried down to the iliotibial band when the iliotibial band is split at the site for the osteotomy.	The iliotibial band should be split at the inferior third to allow for subperiosteal dissection and elevation of the vastus lateralis at the osteotomy site.
The vastus lateralis musculature is elevated up and subperiosteal dissection is carried down on the femur.	A Z retractor can be used to hold the tissues back; the femur should be cleared off enough to allow for placement of the osteotomy plate.
The anterior approach is performed for the anterior closing-wedge proximal tibial osteotomy with an incision from the midpatella to 4-5 cm distal to the joint line.	This incision should be large enough to remove the previous tibial tunnel ACLR hardware.
The medial and lateral periosteum is elevated up first at the desired position of the tibial osteotomy with a 1-cm tissue flap from distal to proximal. The patellar tendon is elevated up to visualize the proximal tibial cortex underneath	The periosteum should be elevated up carefully so the tissue can be closed with suture at the end of the procedure.
Arthroscopy is performed at this step to evaluate intra-articular structures.	At this point, any indicated meniscal tears can be repaired and the femoral tunnel can be cleaned out.
The distal femoral osteotomy is outlined by placing 2 pins at a 45° toward the adductor tubercle. An osteotomy guide is used to delineate the cutting plane.	The guide pin placement should be verified with fluoroscopy to ensure proper orientation.
A saw blade is used to cut to a depth of 5 mm and an assortment of osteotomes are used to complete the osteotomy. A 1-cm medial cortical hinge should remain.	Palpation with a finger of the osteotome should be used to ensure the cortex is fully cut.
The osteotomy site is opened with an opening tine device and an osteotomy plate is placed within the gap.	The medial hinge osteotomy should be allowed to relax for 5 minutes before placing the plate to avoid a hinge fracture.
Four 4.5-mm cortical screws should be placed proximally, and two to three 6.5-mm cancellous screws should be placed distally.	Fluoroscopy should be used to validate the proper placement of the screws.
Four pins are placed around the patella tendon to mark the location for the closing wedge proximal tibial osteotomy. The portions medial and lateral to the patellar tendon are marked with a bovie.	The pins should meet at the posterior aspect of the tibia to ensure a wedge is cut out of the bone.
A small saw blade is used to cut out the osteotomy wedge. A rongeur and curette are used to remove any remaining bone.	The osteotomy site should be carefully cleaned out to ensure a flush closure.
The osteotomy site is closed by lifting the ankle while maintaining pressure on the femur above the patella.	This should be done slowly to avoid fracturing any bone left at the posterior cortex of the tibia.
The bone from the closing wedge osteotomy resection is used to fill in the tibial and femoral ACL tunnels and the opening wedge osteotomy.	If the distal femoral osteotomy opening wedge is greater than 7.5 mm, it should be bone grafted. Allograft can be used if there is not enough autograft.
The deep and superficial tissues are closed with sutures.	Deep closure is important to reduce the risk of hematoma.

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

Anesthesia and Positioning

The patient is positioned in the supine position on the operating table and induced under general anesthesia. A bilateral knee examination is performed to validate clinical examination findings. A well-padded high left thigh tourniquet is placed. The surgical leg is placed in a leg holder (Mizho OSI, Union City, CA) and the nonsurgical leg into an abduction stirrup (Birkova Product LLC, Gothenburg, NE). For infection prophylaxis, 2 g of perioperative cefazolin is administered.

Distal Femoral Osteotomy Site Preparation

The site for the OW-DFO is approached with a lateral incision over the iliotibial band starting just proximal to the Gerdy tubercle and extending 10 cm proximally (Fig 4). Dissection is carried down to expose the superficial layer of the iliotibial band. The inferior third of the iliotibial band is split. The vastus lateralis musculature is elevated and an anterior subperiosteal dissection is performed. The entire area where the osteotomy will be performed should be properly cleared off (Fig 5).

Proximal Tibial Osteotomy Site Preparation

The exposure for the ACW-PTO begins with an anterior incision from the midpatella, extending 4 to 5 cm distally below the joint line (Fig 6). The medial periosteum is elevated up first at the desired position of the tibial osteotomy with a 1-cm tissue flap from distal to proximal. Next, a similar 1-cm flap is elevated up laterally above the anterior compartment musculature and posteriorly to the fibular head. Then, dissection is performed deep to the patellar tendon to visualize the proximal tibial cortex underneath (Fig 7).

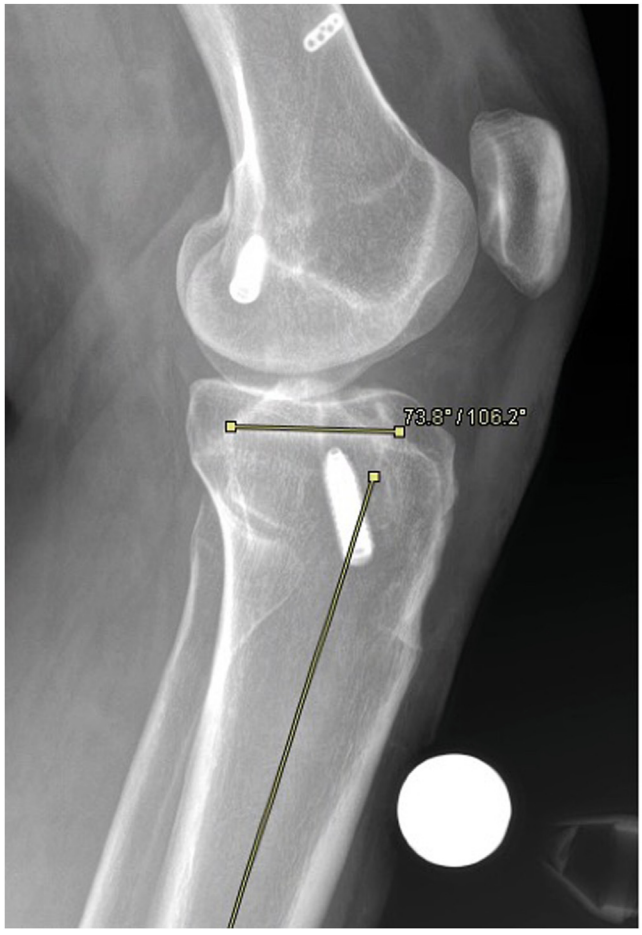

Fig 1. Left knee assessment for posterior tibial slope on lateral standing radiographs. Posterior tibial slope (PTS) (yellow lines) is measured using the anatomic axis of the tibia and the lateral tibial plateau. The anatomic axis of the tibia is determined by drawing a line though the center of the tibia at 5 cm distal to the joint line and 5 cm proximal to the ankle joint (not visualized). The measurement (73.8°) should be subtracted from 90° to obtain the measurement for PTS, 16.2° in this case. The size of the correction should aim to restore the patient to about 5-7° of PTS and is calculated by about 1 cm per 1° for the anterior closing wedge proximal tibial osteotomy.

Arthroscopy

Meniscus repair can be performed if indicated during this first stage or it may wait until the second stage if the meniscus tear is stable. Scar tissue, remnant of the ACL graft, and the ACL femoral tunnel should be debrided.

Opening-Wedge Distal Femoral Osteotomy

Imaging is now brought in to begin the OW-PTO. Two guide pins are placed at a 45° angle entering the lateral cortex of the femur, aiming toward the adductor tubercle (Fig 8). An osteotomy guide (Arthrex, Naples, FL) is placed on the pins and is used to guide the oscillating saw to cut to a depth of about 5 mm along the lateral cortex.

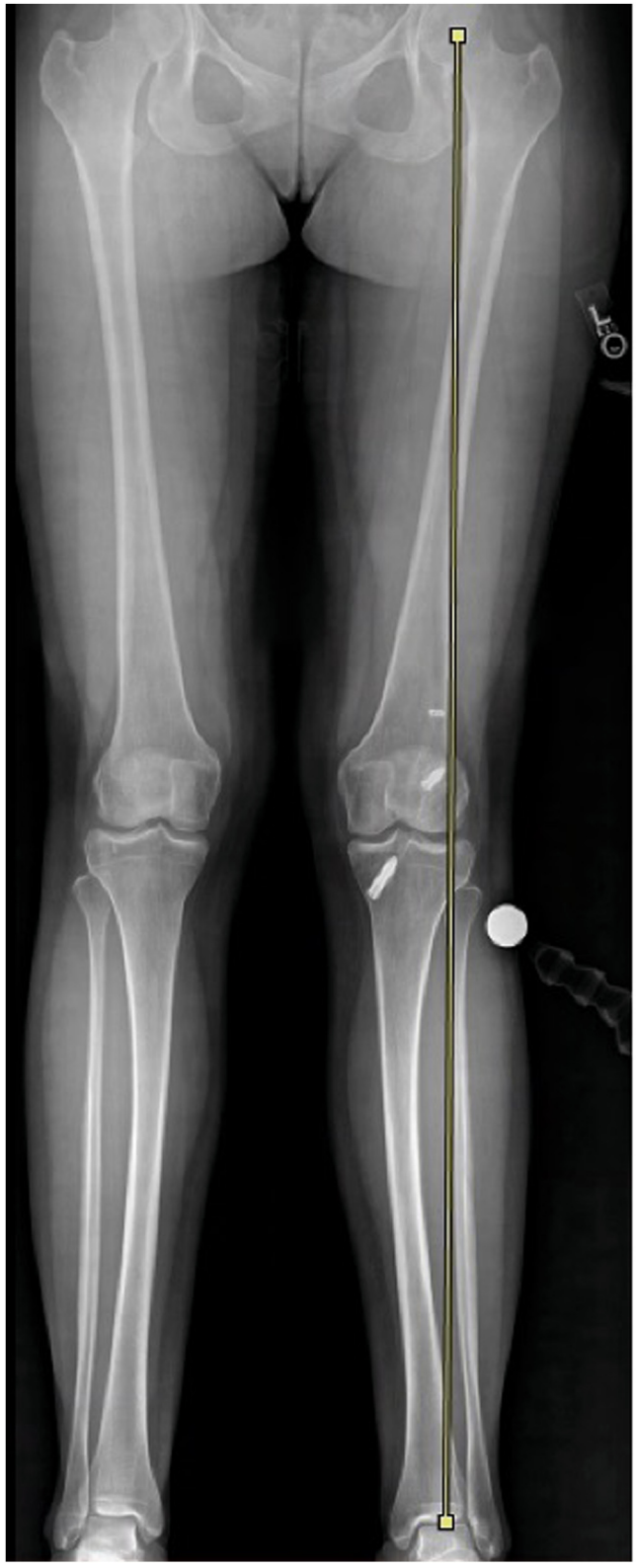

Fig 2. Left knee assessment for coronal malalignment on long leg standing radiographs. A line is draft from the center of the femoral head to the center of the talus (yellow line). A patient is valgus if the line crosses lateral to the lateral tibial eminence and is varus if the line passes medial to the medial tibial eminence. This patient is exhibiting valgus coronal plane deformity.

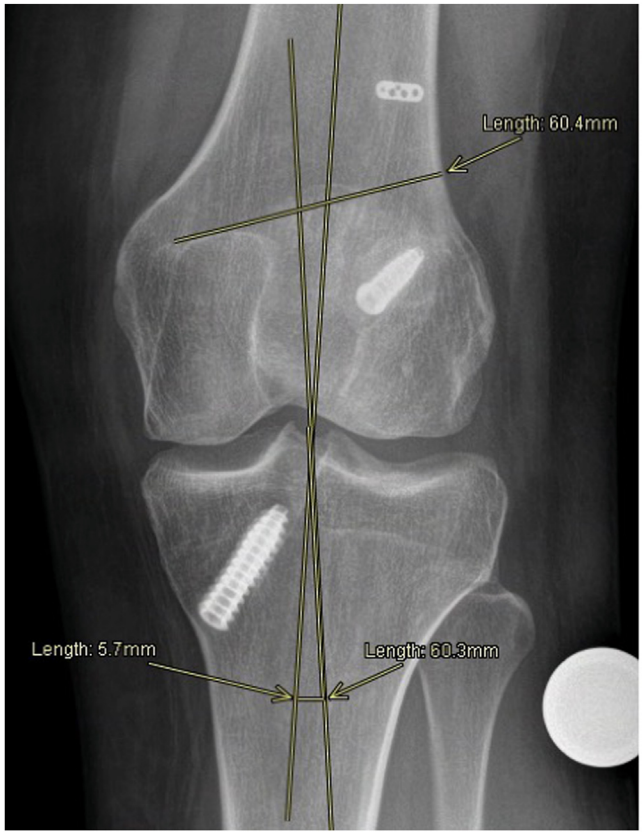

Fig 3. Radiographic determination for the degree of correction for an opening-wedge distal femoral osteotomy on the left knee to correct for valgus alignment. Long-leg standing radiographs are used for the assessment. To determine the size of correction for valgus alignment, 2 lines should be drawn, one from the center of the femoral head through the center of the knee, and another from the center of the talus to the center of the knee. Next, a line is measured where the osteotomy correction will occur in the femur, ensuring to maintain a 1-cm cortical hinge medially. That same distance should be measured distally from where the 2 vertical lines intersect in the center of the knee, at which point the distance between the 2 verticals is the size of the correction to obtain neutral alignment. For this patient, the plate was determined to require a 5-mm osteotomy plate.

The osteotomy is completed using a small osteotome anteriorly, a medium osteotome in the midportion, and a small osteotomy posteriorly using a finger to palpate posteriorly as the osteotome is advanced slowly. All osteotomes are used under direct visualization from fluoroscopic imaging with a one cm medial cortical hinge left intact. The opening spreader device (Arthrex) is placed inside the osteotomy and slowly opened to the desired correction size. The opening spreader device is left in place for 5 minutes to allow for stress relaxation of the 1-cm medial cortical hinge. The opening spreader device is then replaced by the opening tine device (Arthrex).

A prebent distal femoral opening wedge osteotomy plate (Arthrex) is inserted into the osteotomy site. Four

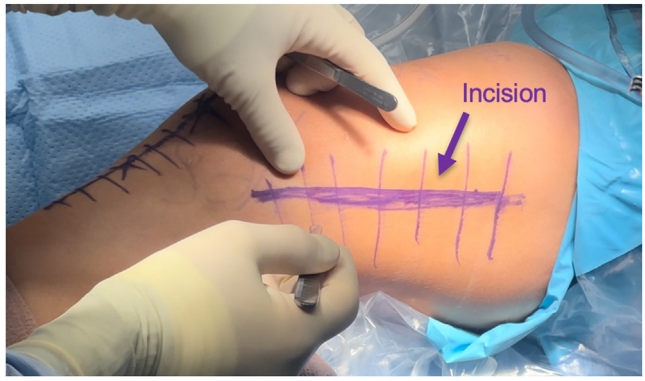

Fig 4. Left knee lateral incision for lateral opening-wedge distal femoral osteotomy with the patient in the supine position. The incision extends proximally for 10 cm originating at the Gerdy tubercle and is centered over the inferior third of the iliotibial band (purple arrow). This incision will allow for the dissection down to the femur for the opening-wedge fixation plate for the distal femoral osteotomy.

4.5-mm cortical screws (Synthes, West Chester, PA) are used proximally, and two 6.5-mm cancellous screws (Synthes) are used distally to secure the plate (Fig 9). All screws are predrilled and measured to determine the proper screw length. Fluoroscopic imaging is performed in the anteroposterior and lateral views to confirm the osteotomy, plate, and screws are in the correct position.

Anterior Closing-Wedge Proximal Tibial Osteotomy

To begin the ACW-PTO, 2 guide pins are placed on both sides of the patella tendon just proximal to the tibial tubercle and parallel to the tibial plateau. The guide pins are drilled to engage the posterior cortex. Two more guide pins are placed proximally and are drilled at an angle to meet the other guide pins at the posterior cortex (Fig 10). The distance between the top and bottom guide pins should be the calculated size of

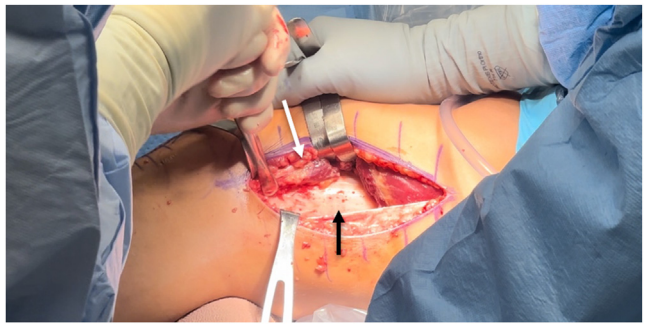

Fig 5. Left knee lateral approach for lateral opening-wedge distal femoral osteotomy with patient in supine position. The vastus lateralis musculature has been elevated anteriorly (white arrow). This location should be cleared of soft tissues to allow for flush placement of the opening wedge distal femoral osteotomy plate on the femur (black arrow).

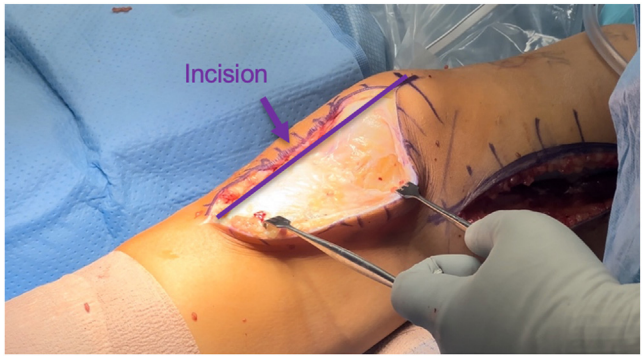

Fig 6. Left knee anterior incision for anterior closing-wedge proximal tibial osteotomy with patient in supine position. An anterior incision is made from the center of the patella distally to 4-5 cm below the joint line (purple line). This incision allows for the proper approach for the anterior closing-wedge proximal tibial osteotomy to correct for increased posterior tibial slope.

correction to obtain the desired PTS angle. Fluoroscopic imaging is used to confirm the desired wedge is created.

A small ACL saw blade is used to cut out the wedge of the bone starting laterally, then under the patellar tendon, and finally medially. A small curette and rongeur is used to facilitate closing the osteotomy. The osteotomy site is slowly closed, and 3 large Richard staples (Smith & Nephew, London, United Kingdom) are used to hold the osteotomy in position (Fig 11).

The bone taken from the wedge is used to bone graft the femoral and tibial ACL tunnels. The

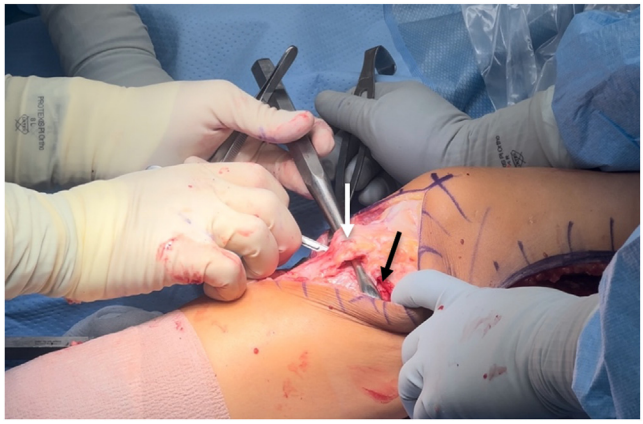

Fig 7. Left knee anterior approach for anterior closing-wedge proximal tibial osteotomy with the patient in the supine position. The medial periosteum is elevated up first (black arrow) at the desired position of the tibial osteotomy with a 1-cm tissue flap from distal to proximal. For this patient, the tibial screw was in this area and was removed. Next, a similar 1-cm flap is elevated up laterally above the anterior compartment musculature and back to the fibular head. Then, the patellar tendon (white arrow) is elevated up to visualize the proximal tibial cortex underneath.

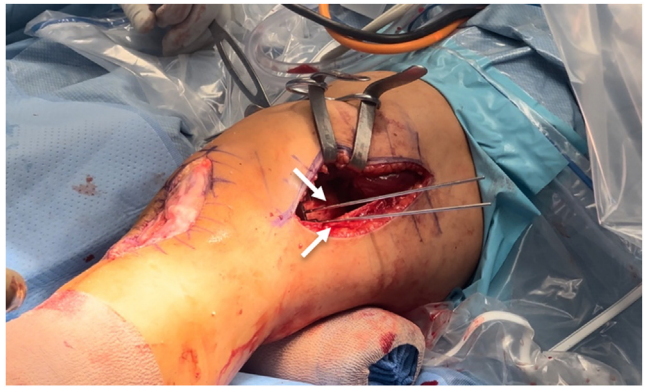

Fig 8. Left knee pin placement for opening-wedge distal femoral osteotomy with patient in supine position. Two pins (white arrows) are placed in the desired location for the opening-wedge distal femoral osteotomy. An osteotomy guide is placed between the pins to delineate the cutting plane for the osteotomy. The osteotomy is completed using a saw cutting to a depth of 5 mm, followed by a variety of osteotomes to cut through the bone. A 1-cm medial cortical hinge should be maintained and verified by fluoroscopy.

remaining bone graft is used to fill in the distal femoral osteotomy. A final fluoroscopic image is obtained, and the deep and superficial tissues are closed with suture (Fig 12).

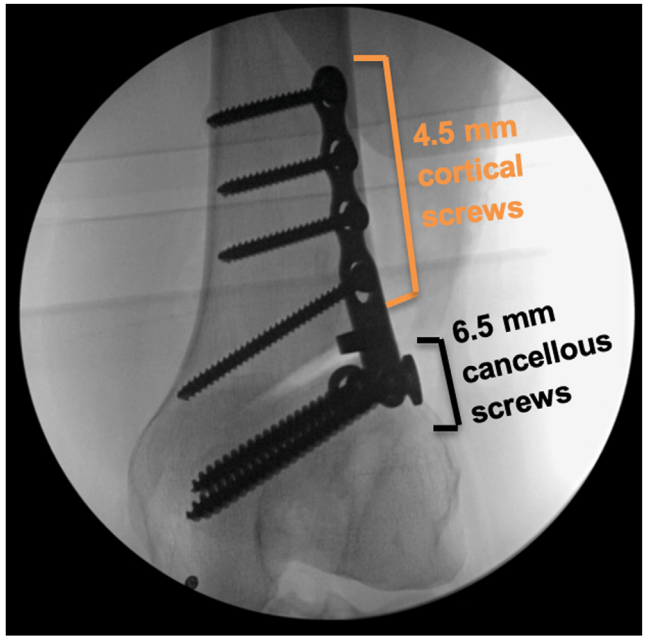

Fig 9. Left knee fluoroscopic image of the osteotomy plate placement for opening wedge distal femoral osteotomy with patient in supine position. Four 4.5-mm cortical screws (orange bracket) are used to secure the plate proximally and two 6.5-mm cancellous screws (black bracket) are used to secure the plate distally. The plate placement should be verified with fluoroscopy to ensure the opening wedge is fully inserted into the osteotomy site.

Fig 10. Left knee pin placement for the anterior closing wedge proximal tibial osteotomy with the patient in the supine position. Four pins (white arrows) are placed around the patellar tendon (black arrow) to delineate the cutting plane for the closing-wedge osteotomy. The superior and inferior pins should meet at the posterior aspect of the tibia to achieve a proper wedge. The cuts medially and laterally should be measured out and marked with a bovie. An anterior cruciate ligament saw blade is used to cut the cortical portion of the wedge and a combination of a rongeur, and curette are used to remove the deeper cancellous bone.

Postoperative Protocol

After the procedure, the patient is to remain non−weight bearing for 8 weeks. There is no limit on motion; however, hyperextension should be avoided for the first 8 weeks to avoid developing increased heel height. Plain radiographs are obtained at 8 weeks postoperatively to ensure adequate bone healing to begin weight-bearing protocol. Weight-bearing progression increases weight bearing by 25% each week until full weight bearing at 12 weeks.

Fig 11. Left knee osteotomy site closure for the anterior closing-wedge proximal tibial osteotomy with the patient in the supine position. After the bone from the wedge is removed, the osteotomy site (white arrow) should be slowly closed. Pressure should be maintained with a hand above the patella and the knee is hyperextended to close the osteotomy site. Visualization and palpation with a finger should be performed to ensure proper closure of the wedge. Once the site is closed, 3 Richard staples will be used to hold the osteotomy site closed.

Fig 12. Left knee osteotomy site closure staples for the anterior closing-wedge proximal tibial osteotomy with the patient in the supine position, lateral view. After the 3 Richard staples are placed to hold down the closing-wedge osteotomy, their location should be visualized with fluoroscopy. If the staples are not in the correct position, they should be repositioned.

Discussion

When performing the workup for a failed ACL reconstruction, the reason for failure must be evaluated. Increased PTS (slope $\geq 12^{\circ}$) and valgus coronal alignment are both known risk factors for ACL graft failure. A study by Mehl et al.[4] reported that an OW-DFO significantly decreased the forces experienced by an ACL graft in the setting of valgus malalignment. Another study by Bernhardson et al.[10] reported that the forces experienced by the ACL graft increase linearly as the PTS increases. Concomitantly performing an ACW-PTO and an OW-DFO attempts to correct increased PTS and valgus alignment in one surgery. By eliminating both these osseous risk factors simultaneously for ACL reconstruction failure, the revision ACL reconstruction will be more likely to be successful.

The advantages of performing the ACW-PTO and OW-DFO in a single stage before revision ACLR include the patient not being restricted by the osteotomy weight-bearing status for the second-stage revision ACL reconstruction. In addition, bone graft from the bone wedge can be used for both filling in the

Table 2. Advantages and Disadvantages of a Concomitant Opening-Wedge Distal Femoral Osteotomy and Anterior Closing-Wedge Proximal Tibial Osteotomy

Advantages	Disadvantages
Allows for correction of increased posterior slope and valgus coronal malalignment simultaneously	Potential increase in hyperextension
Anterior approach allows optimal access to ACL tibial tunnel for bone grafting in staging process	Requires extended 8-week period of non−weight bearing after the procedure
Not limited by bone healing in second stage of surgery for revision ACLR.	Potential for damage to popliteal and other posterior neurovascular structures with anteroposterior drilling
Bone from closing wedge can be used for ACL tunnel and distal femoral osteotomy bone grafting	More difficult to properly correct valgus angle when performing concomitant closing-wedge proximal tibial osteotomy.
Weight-bearing and extension work during postoperative rehabilitation for the revision ACLR can begin sooner.	

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

previous ACL reconstruction tunnels and the OW-DFO. Some limitations of this technique are that careful calculations are required to account for both osteotomies and care must be taken to avoid intra-operative fractures and the posterior neurovascular bundle. Furthermore, there is a risk of increased recurvatum for ACW-PTO; however, this can be managed during the early rehabilitation stage by avoiding knee hyperextension. A full list of advantages and disadvantages is available in Table 2.

Disclosures

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