Technical Note

Posterior Opening-Wedge Osteotomy for Posterior Tibial Slope Correction of Failed Anterior Cruciate Ligament Reconstruction

Keiji Tensho, M.D., Ph.D., Daiki Kumaki, M.D., Kazushige Yoshida, M.D., Ph.D., Hiroki Shimodaira, M.D., Ph.D., Hiroshi Horiuchi, M.D., Ph.D., and Jun Takahashi, M.D., Ph.D.

Abstract: A large posterior tibial slope (PTS) has been widely recognized as a potential risk factor in loosening and retear after anterior cruciate ligament reconstruction. Anterior closed-wedge osteotomy is an effective surgical approach to mitigate this risk factor but presents several disadvantages. We describe in this Technical Note an original PTS correction technique called the posterior open-wedge osteotomy. The posterior surface of the proximal tibia is exposed, and 2 K-wires are inserted anteroposteriorly as osteotomy guides, and one wire is inserted mediolaterally as a hinge blocker. The osteotomy is performed from the posterior side and advanced to the anterior side using a single-bladed reciprocating saw. The slope is corrected by opening the osteotomy plane posteriorly with a spreader. The correction is maintained by inserting the harvested fibula fragments into the open space, and the fixation is completed with a locking plate to ensure firm fixation and allow early rehabilitation. This procedure can be an effective solution for patients with various risk factors for retear of the anterior cruciate ligament graft, including abnormal PTS.

Although good results have been reported for anterior cruciate ligament (ACL) reconstruction, loosening of the reconstructed graft and reinjury after surgery have been noted in the literature. An abnormal tibial morphology known as posterior tibial slope (PTS) has been noted as a major risk factor for these poor results.[1-5] To address this problem, anterior closed-wedge osteotomy has been reported in recent years[6-8]; however, this surgical procedure is complicated and invasive, and the intraoperative control of correction angle is difficult. Therefore, we describe a tibial osteotomy technique—posterior open-wedge tibial osteotomy (POWO)—that is less invasive and easy to intraoperatively control the correction. If this technique is successfully implemented, we expect to reduce the number of poor results in ACL reconstruction due to high PTS.

From the Department of Orthopedic Surgery, Shinshu University School of Medicine, Matsumoto Japan.

The authors report no conflicts of interest in the authorship and publication of this article. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Investigation performed at Department of Orthopedic Surgery, Shinshu University School of Medicine, Matsumoto, Japan.

Received June 12, 2023; accepted July 31, 2023.

Address correspondence to Keiji Tensho, M.D., Ph.D., Department of Orthopedic Surgery, Shinshu University School of Medicine, Asahi 3-1-1, Matsumoto, 390-8621, Japan. E-mail: kten@shinshu-u.ac.jp

2212-6287/23849

https://doi.org/10.1016/j.eats.2023.07.059

Surgical Technique (With Video Illustration)

A detailed account of the surgical technique is summarized in Figure 1 and Video 1. The surgical jig for POWO is shown in Figure 2. Surgical tips and pearls are listed in Table 1, and advantages, disadvantages, and limitations are summarized in Table 2.

Indications and Contraindications

This procedure is indicated for patients with recurrent instability after ACL reconstruction and a PTS of 12° or greater. Patients with a PTS of 15° or more with other risk factors (adolescent, female, pivoting sports) also may be indicated, even for primary surgery. Contraindications to this surgery include hyperextension of the knee (>10°), cases of osteoarthritis and high body mass index (>30), and heavy smokers (>20 cigarettes per day).

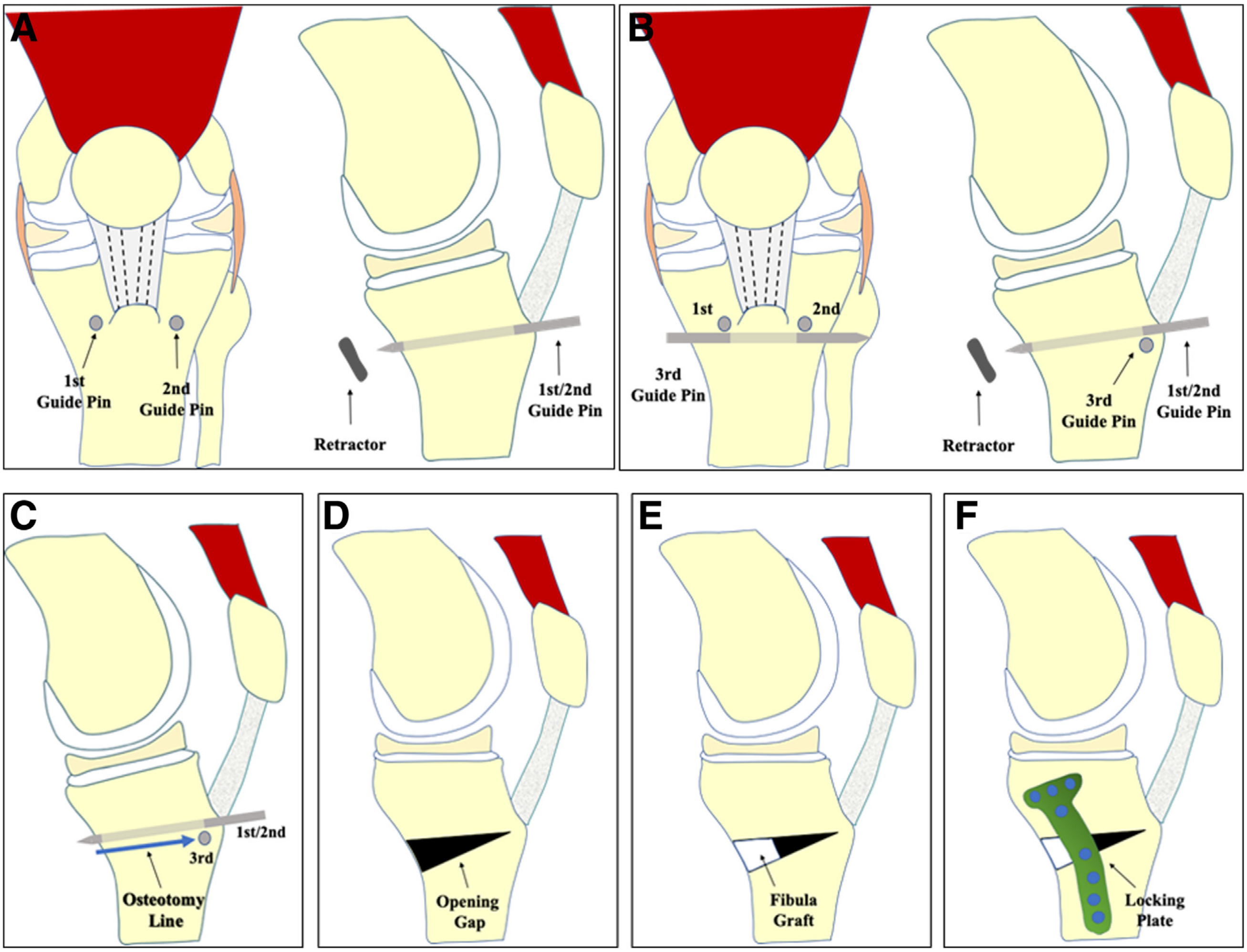

Fig 1. Illustration of a series of posterior opening-wedge osteotomy for left knee. (A) Guide pins for osteotomy are inserted anteriorly to posteriorly from both sides of the tibial tubercle, with the 2 pins placed parallel and overlapping in the sagittal plane. The tips of the 2 pins are adjusted while in contact with the retractor placed posteriorly. (B) A third pin is inserted from the medial margin of the tibial tubercle toward the lateral margin. The third pin contacts the underside of the 2 pins already inserted and is used as protection for the hinge during osteotomy. (C) Osteotomy advances to the underside of the first/second guide pins from the posterior to anterior direction. (D) Open the osteotomy plane posteriorly using a gap spacer or a spreader. (E) Graft the harvested fibular fragments into the opening gap. (F) The osteotomy is secured with a locking plate.

Preoperative Planning

The hinge point of the opening osteotomy should be 7 to 8 mm posterior to the tip of the tibial tubercle, and the osteotomy plane should be set perpendicular to the functional axis. The target PTS is 6 to 8°, the average PTS of a normal subject. The height, direction, and length of the osteotomy line should be established on the lateral radiographic view of the knee joint, and the required opening gap should be estimated from the length and corrective angle of the osteotomy.

Patient Setup

The nonaffected leg is placed in a drooping position, and a leg positioner (AssistArm; CONMED, Largo, FL) is attached to the affected side to allow for free positioning during the operation (Fig 3). During osteotomy, the hip is positioned in flexion, abduction, and external rotation. A fluoroscopic C-arm is placed from the affected side so that a true lateral view of the knee joint can be viewed.

Fibular Osteotomy and Preparation

A 4-cm longitudinal incision is made in the skin just above the fibula on the mid-lateral side of the lower leg. The fascia is incised, and the fibular diaphysis is exposed from the posterior border of the peroneus longus muscle. A retractor is applied anteriorly and posteriorly to expose the diaphysis. A 20- to 25-mm long fibular osteotomy is performed using a bone saw. The extracted fibula is used for the grafting of the opening gap.

Fig 2. Surgical equipment used for posterior opening-wedge osteotomy. (A) The equipment includes a lamina spreader (1), posterior retractor (2), gap spacer (3), and chisels (4). (B) The gap spacer is available in 3-, 4-, 5-, 6-, and 7-mm sizes and is used to widen the posterior gap and to make measurements. The handle is detachable and designed for smooth insertion into the osteotomy plane.

Three slightly tapered grafts are prepared with the planned opening width, and these are grafted to the lateral, central, and medial part of the opening gap.

Exposure of Osteotomy Site

Residual tibial implants are removed from the incision of initial surgery. A 6- to 7-cm longitudinal incision is placed 2 cm anterior to the posterior border of the tibia. Dissect the subcutaneous tissue to identify the boundary between the posterior border of the tibia and the gastrocnemius muscle. Care should be taken not to injure the saphenous nerve during the exposure. The gastrocnemius muscle is dissected from the posterior surface of the proximal tibia, and a retractor is inserted posteriorly. Carefully ensure that no soft tissues such as

Table 1. Surgical Tips and Pearls

Preoperative assessment for presence of hyperextension is important.
Estimate the amount of opening gap from the length of the osteotomy and the corrective angle on the preoperative radiograph.
Set up an intraoperative fluoroscopic view of the true lateral aspect of the proximal tibia.
The hinge point is set 7 to 8 mm posterior to the patellar tendon attachment on the tibial tubercle.
After fully retracting the neurovascular bundle, proceed with the osteotomy using a single-bladed reciprocating saw from the posterior to anterior side under direct vision.
The osteotomy on the medial side is likely to remain, so retract the MCL and then osteotomize from underneath it.
For initial stability, 3 fibular fragments should be implanted firmly on the posterior tibia cortex.
The locking plate should be placed as posteriorly as possible to avoid interference with the tibial tunnel during ACL reconstruction.

ACL, anterior cruciate ligament; MCL, medial collateral ligament.

Table 2. Advantages, Disadvantage, and Limitations of Posterior Opening-Wedge Osteotomy

Advantages	
	Simple and familiar technique to surgeons who perform medial open-wedge osteotomy (MOWO).
	The plate used for MOWO can be used for fixation without the need for a specialized plate.
	Easy to approach the osteotomy site.
	Retracting neurovascular bundles during osteotomies with a single-blade reciprocating saw with direct visualization allows a more reliable prevention of intraoperative injuries.
	Easy to adjust the corrective angle.
	Rehabilitation, including early weight-bearing, is possible.
Risks and limitations	
	Fibula must be harvested for correction and bone grafting.
	Possibility of hinge fracture for a large correction case.
	Possibility of knee hyperextension is similar to that of an anterior osteotomy.
	Patellar tendons cannot be used for graft sources.

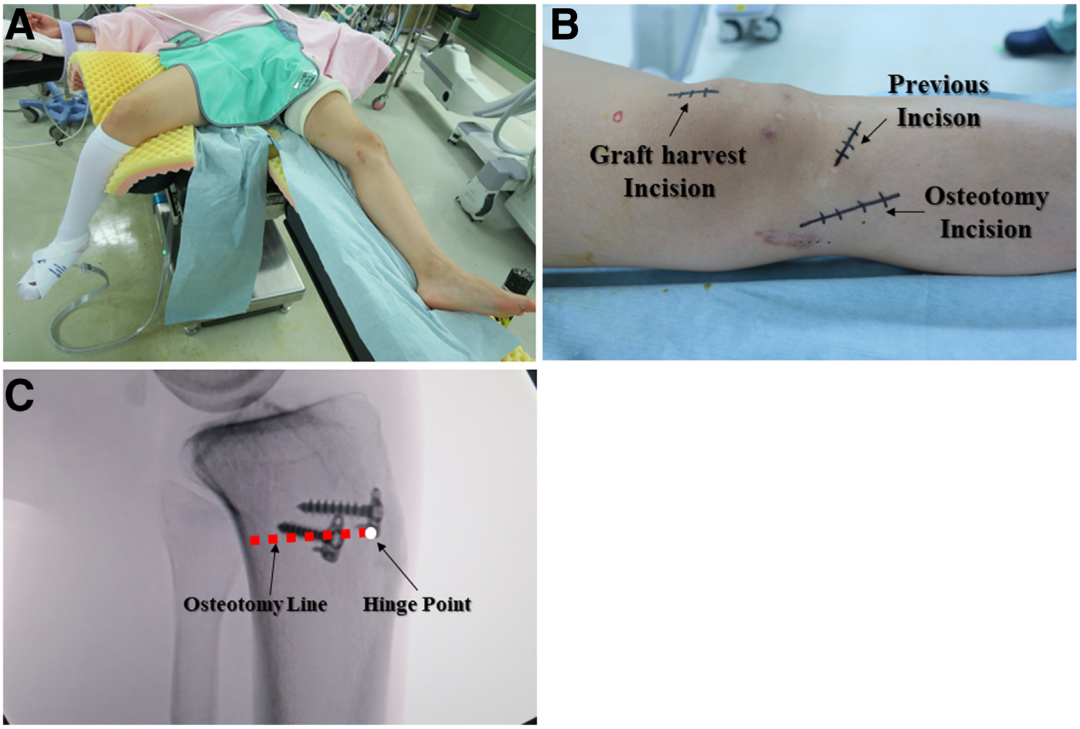

Fig 3. Surgical position. (A) The nonaffected leg (right) is drooped, and a working space is secured on the medial side of the knee on the affected side (left). (B) Location of skin incision on the medial side of the left knee. In addition to the skin incision for QT tendon harvest and for initial surgery, a skin incision for osteotomy is placed on the posteromedial side of the proximal tibia. (C) Fluoroscopic true lateral image of the proximal tibia. The hinge point is set 7 to 8 mm posteriorly from the apex of the tibial tubercle and the osteotomy line running posteriorly from the hinge point.

major blood vessels or nerves are present anterior to the retractor (Fig 4A). The posterior margin of the superficial layer of the medial collateral ligament (MCL) is identified, and an elevator is inserted at the level of the osteotomy for partial dissection.

Osteotomy and Plate Fixation

The affected leg is positioned with hip flexion, abduction, external rotation, and 90° knee flexion to achieve a true lateral view of the proximal tibia that is visible under fluoroscopy. The first 2.0 Kirchner wire is inserted from an anterior to posterior direction at the medial border of the tibial tubercle during the initial incision. The tip of wire should be adjusted so that it contacts a retractor placed on the posterior surface of the proximal tibia. A second Kirchner wire is inserted percutaneously parallel to the first wire in the fluoroscopic lateral view from the lateral margin of the tibial tuberosity. The third pin is inserted from the medial to lateral direction at the hinge point, passing through the lower side of the previously inserted 2 Kirchner wires. The first and second wires are used as guides, and the third wire is used as a hinge blocker during osteotomy (Fig 4 B-D). A single-bladed reciprocating saw is used for osteotomy. The reciprocating saw is advanced from the posterior to anterior side along the underside of the 2 protruding wires (Fig 5A). After a sufficient amount of bone is osteotomized with a reciprocating saw, the remaining parts are cut with a chisel. The osteotomy of the medial aspect of the tibia is likely to remain; therefore, the MCL is retracted, and the inferior aspect of the retractor is osteotomized from the anterior or posterior side of the MCL so as not to damage the ligament. Finally, 4 chisels are inserted into the osteotomy plane to check for adequate opening (Fig 5 B and C). After ensuring that these osteotomies are completed with the hinge area intact, a gap spacer is inserted posteriorly to open the osteotomy site (Fig 6A). A spreader is inserted into the posterior medial region of osteotomy site, and the opening is adjusted to the target PTS on the lateral fluoroscopic view (Fig 6B). After confirming that the target PTS has been obtained, the gap spacer is removed, and the opening gap is retained only by the spreader (Fig 6 C and D). After creating fibular fragments equal to the width of the opening, a fibular fragment is inserted between the lateral side of the opening gap, and the spreader is removed (Fig 7 A and B). The remaining 2 fibular fragments are implanted at the middle and medial side of opening gap. Care should be taken to ensure that the fibular

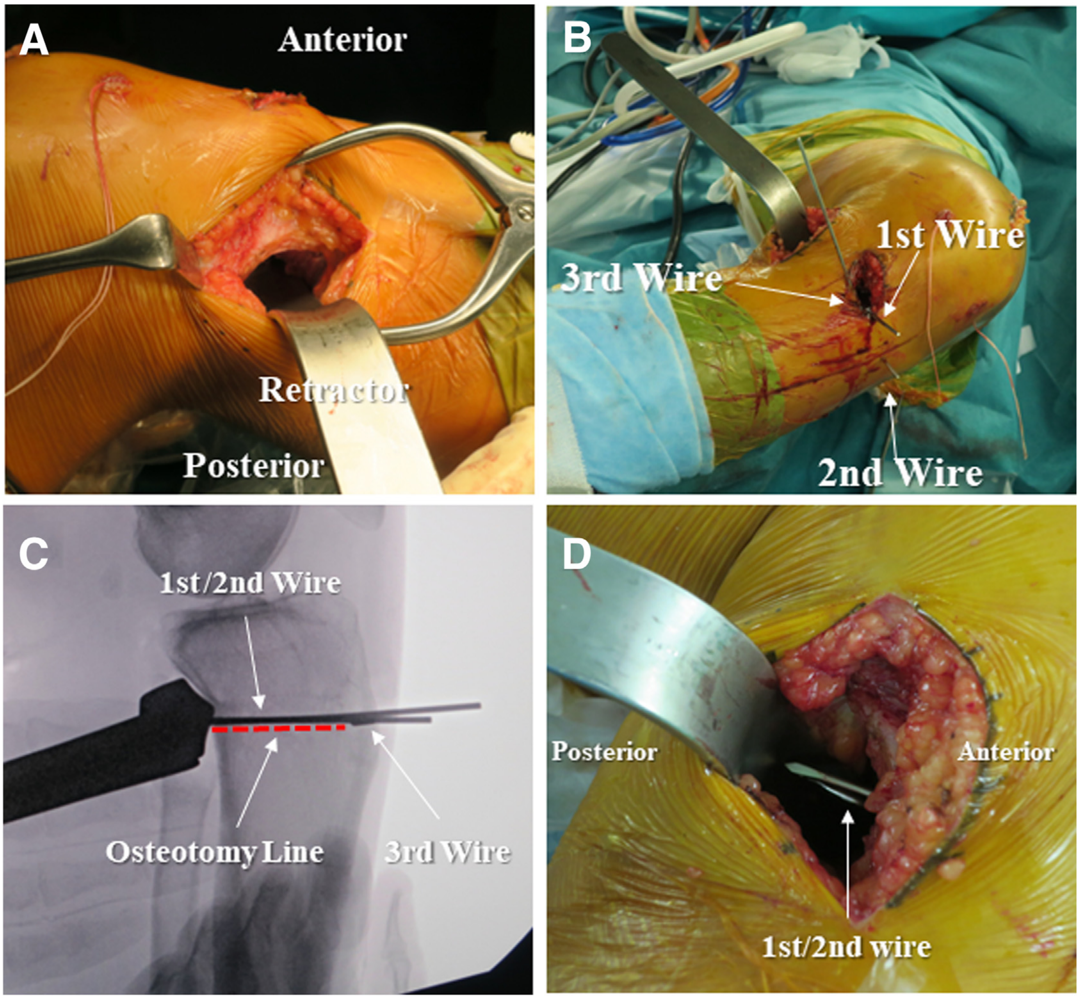

Fig 4. Medial side of the left knee. (A) Expose the posterior surface of the proximal tibia and insert a retractor to protect the neurovascular structures. (B) Anterior side of the left knee. Affected leg, hip abduction external rotation, knee flexion 90°. First/second wires are placed in the anteroposterior direction from the medial and lateral sides of the tibial tubercle. A third wire is placed from the medial to lateral direction at the hinge point. (C) Intraoperative fluoroscopic lateral view of the left knee joint. Three guide pins are inserted; osteotomy lines are set on the underside of the first and second pins. (D) The tips of the first and second guide pins, inserted from the anterior to posterior side, are protected by a retractor placed in the posterior side.

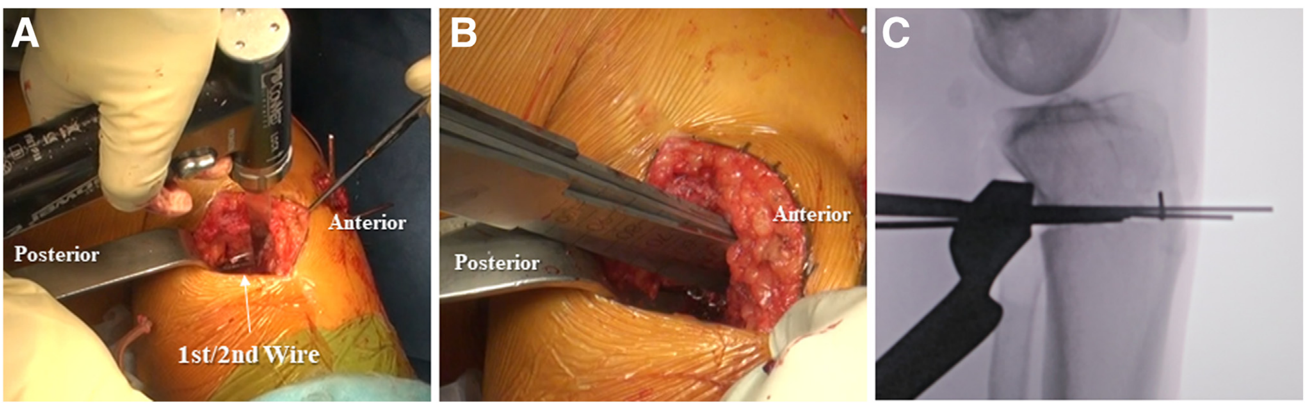

Fig 5. Medial posterior view of the left knee joint. (A) The osteotomy is advanced from the posterior to anterior side using a single-bladed reciprocating saw along the first/second wires. (B) Four chisels are inserted to check if the osteotomy is sufficient. (C) Fluoroscopic lateral view of the left knee joint. Insert four chisels to check for adequate openings.

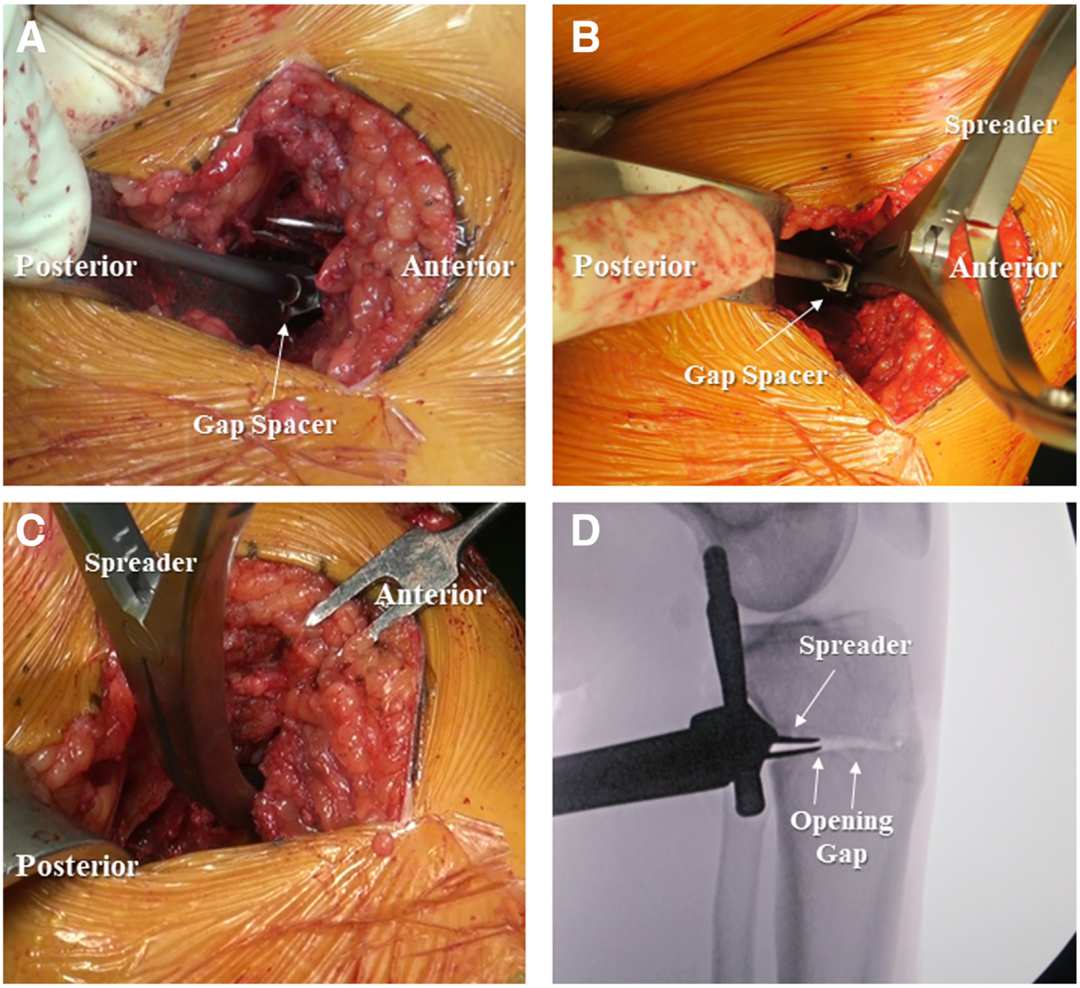

Fig 6. Medial posterior view of the left knee joint. (A) The gap spacer is inserted lateral to the osteotomy surface in order to open the osteotomy. (B) Spread the osteotomy site with the Gap Spacer and reapply the spreader medially. (C) The spreader only retains the opening gap after removal of the gap spacer. (D) Fluoroscopic lateral view of the left knee joint, with posterior tilt corrected by spreader opening.

fragments are grafted firmly on the posterior tibial cortex (Fig 7 C and D). Fixation is accomplished with a locking plate system (TRIS plate, Olympus, Tokyo, Japan). The locking plate should be placed as posteriorly as possible so as not to interfere with the tibial tunnel creation during ACL reconstruction (Fig 8).

Rehabilitation

Partial weight-bearing is started the day after surgery, and flexion is limited to 90° until 3 weeks postoperatively. After 3 weeks, weight-bearing and range of motion restrictions are lifted, and the patient is allowed to walk without crutches. Jogging and running are allowed at 3 to 6 months, pivoting and noncontact sports at 9 months, and pivoting and contact sports at 1-year postoperatively.

Discussion

PTS recently has become the focus of increasing attention in ACL reconstruction surgery. High PTS increases tension on the ACL[9] and causes anterior displacement of the tibia, which can lead to ligamentous injuries and retears of the reconstructed graft. In recent years, biomechanical and clinical studies have shown that an increased tibial slope also affects the control of rotation.[10] Therefore, surgical intervention of PTS may provide a useful supplementary procedure for clinical improvement of ACL reconstruction.

Anterior closed-wedge osteotomy for PTS correction was developed to correct the slope via anterior closed osteotomies, and good mid-term results have been reported in the literature.[7,8,11] However, this method requires an additional osteotomy of the tibial tubercle.

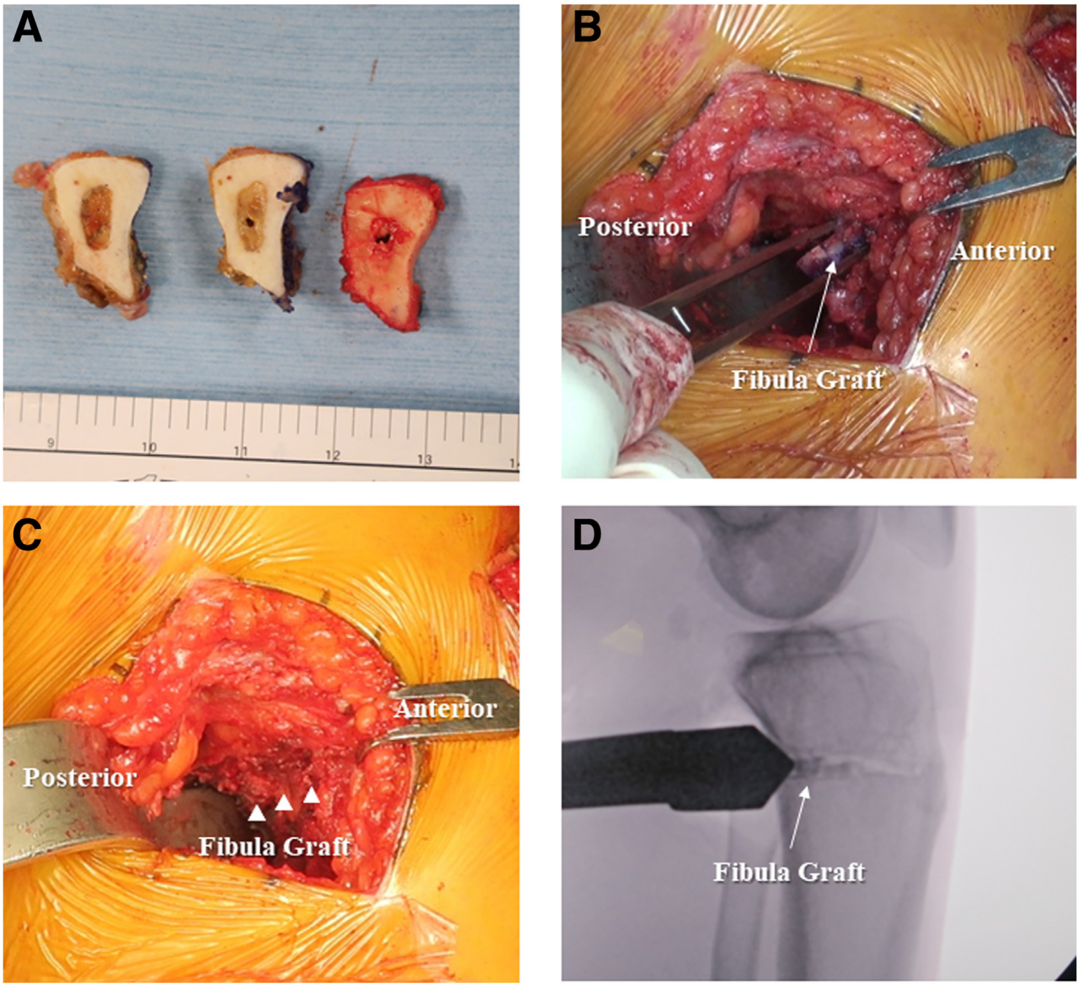

Fig 7. (A) The harvested fibula is sliced into 3 fragments and used for grafting. (B) Medial posterior view of the left knee joint. Grafting a fibular fragment to the opening gap. (C) After grafting the fibular fragments, the posterior gap is filled with fibular bone. (D) Fluoroscopic lateral view. The fibula is grafted to the posterior gap, and the corrective position is maintained even after the spreader is removed.

Recently, various methods have been proposed to improve this method by performing an osteotomy distal to the tibial tubercle[6,12]; however, leg shortening due to the lengthening of the osteotomy surface remains a problem. Moreover, a major problem is the difficulty in fine-tuning the intraoperative correction angle, which is unique to closed osteotomies. Recent cases series has shown that postoperative varus collapse may occur due to poor fixation.[13]

The POWO technique we have described in this article is a simple technique that corrects the slope by opening the osteotomy from the posterior side. Neurovascular injuries, which are a potential risk during osteotomy, can be almost completely prevented by (1) retracting the neurovascular bundles backward under direct vision with a retractor and (2) advancing the osteotomy forward with a single-blade reciprocating saw. The correction angle can be predicted preoperatively according to the width of the opening, and the angle can be easily adjusted intraoperatively while viewing the fluoroscopic images. The osteotomy part is then stabilized by inserting multiple fibular grafts into the opening gap and securing them with locking plates from the medial side, allowing weight-bearing gait at a relatively early phase. We strongly believe that POWO is a superior technique that overcomes the disadvantages of conventional techniques and is more appropriate for complex revision cases.

This procedure has several disadvantages. One is the need to dissect and harvest the fibula for correction and bone graft. Although the donor-site morbidity of fibular harvesting on young athletes are not known, there are no reports to our knowledge that describe problems with the harvesting. Also, unlike medial opening-wedge osteotomy, buttress plating to the open space is not possible, which raises some concerns about initial stability. However, the opening gap can be stabilized and retained with just a few pieces of harvested fibular

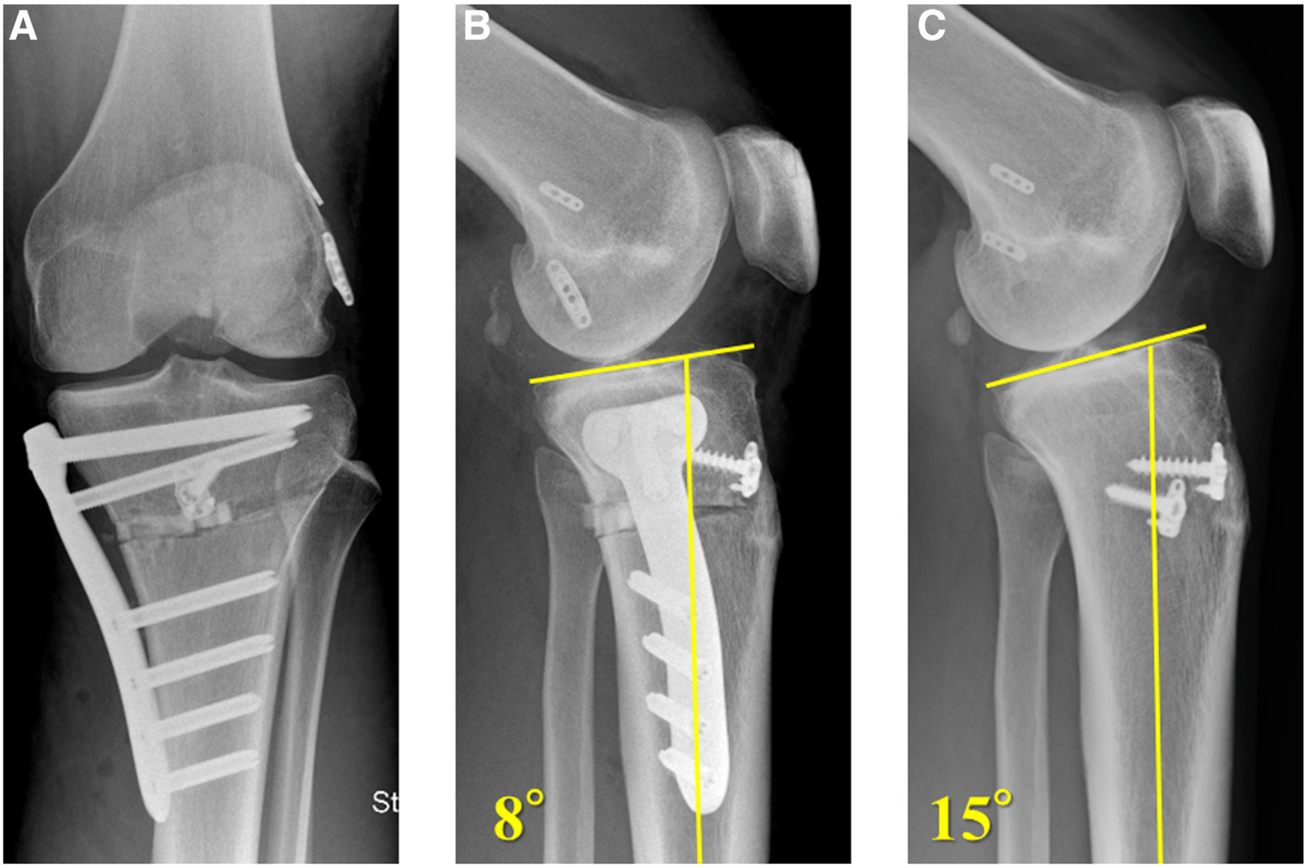

Fig 8. Radiographs of the left knee. (A) Postoperative anteroposterior, (B) lateral, and (C) preoperative lateral radiographs demonstrating adequate correction to the desired alignment of the PTS was achieved.

fragments, and the addition of medial locking plating provides sufficient stability to allow early weight-bearing. In our experience, we have yet to experience a case of postoperative correction loss. In addition, the tibial tuberosity is a hinge point during osteotomy, making it difficult to use the bone—patellar tendon—bone as a graft source.

In conclusion, large PTS increases the load on the reconstructive grafts and is now widely recognized as a factor in poor postoperative outcomes in ACL reconstruction. The POWO presented in this paper has many advantages and should be considered as a new option for large slope correction procedures.

References

1. Kiapour AM, Yang DS, Badger GJ, et al. Anatomic features of the tibial plateau predict outcomes of ACL reconstruction within 7 years after surgery. *Am J Sports Med* 2019;47:303-311.
2. Bongbong DN, Oeding JF, Ma CB, Pedoia V, Lansdown DA. Posterior tibial slope, notch width, condylar morphology, trochlear inclination, and tibiofemoral mismatch predict outcomes following anterior cruciate ligament reconstruction. *Arthroscopy* 2022;38:1689-1704.e1681.
3. Beel W, Schuster P, Michalski S, et al. High prevalence of increased posterior tibial slope in ACL revision surgery demands a patient-specific approach. *Knee Surg Sports Traumatol Arthrosc* 2023;31:2974-2982.
4. Yoon KH, Park SY, Park JY, et al. Influence of posterior tibial slope on clinical outcomes and survivorship after anterior cruciate ligament reconstruction using hamstring autografts: A minimum of 10-year follow-up. *Arthroscopy* 2020;36:2718-2727.
5. Ganokroj P, Peebles AM, Mologne MS, Foster MJ, Provencher MT. Anterior closing-wedge high tibial slope-correcting osteotomy using patient-specific preoperative planning software for failed anterior cruciate ligament reconstruction. *Arthrosc Tech* 2022;11:e1989-e1995.
6. Hees T, Petersen W. Anterior closing-wedge osteotomy for posterior slope correction. *Arthrosc Tech* 2018;7:e1079-e1087.
7. Sonnery-Cottet B, Mogos S, Thaunat M, et al. Proximal tibial anterior closing wedge osteotomy in repeat revision of anterior cruciate ligament reconstruction. *Am J Sports Med* 2014;42:1873-1880.
8. Dejour D, Saffarini M, Demey G, Baverel L. Tibial slope correction combined with second revision ACL produces good knee stability and prevents graft rupture. *Knee Surg Sports Traumatol Arthrosc* 2015;23:2846-2852.
9. Bernhardson AS, Aman ZS, Dornan GJ, et al. Tibial slope and its effect on force in anterior cruciate ligament grafts:

Anterior cruciate ligament force increases linearly as posterior tibial slope increases. *Am J Sports Med* 2019;47: 296-302.

10. Rahnemai-Azar AA, Abebe ES, Johnson P, et al. Increased lateral tibial slope predicts high-grade rotatory knee laxity pre-operatively in ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2017;25:1170-1176.
11. Akoto R, Alm L, Drenck TC, Frings J, Krause M, Frosch KH. Slope-correction osteotomy with lateral extra-articular tenodesis and revision anterior cruciate ligament reconstruction is highly effective in treating high-grade anterior knee laxity. *Am J Sports Med* 2020: 363546520966327.
12. Queiros CM, Abreu FG, Moura JL, et al. Anterior closing-wedge osteotomy for posterior slope correction with tibial tubercle preservation. *Arthrosc Tech* 2019;8:e1105-e1109.
13. MacLean IS, Tyndall WA, Schenck RC, Miller MD. Varus collapse following anterior closing wedge proximal tibial osteotomy for ACL revision reconstruction: A case series. *J Exp Orthop* 2022;9:100.