

Four-Tunnel Double-Bundle Anatomical Posterior Cruciate Ligament Reconstruction Without Remnant Preservation



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Abstract: Double-bundle posterior cruciate ligament (PCL) reconstruction has long been attempted to obtain better clinical results than single-bundle PCL reconstruction. In most previous reports regarding double-bundle PCL reconstruction, one tibial tunnel and various kinds of grafts were used. We introduce a two-tibial tunnel, double-bundle PCL reconstruction technique with ultra-strong grafts. The critical points of this technique are proper creation of the tibial tunnels and the protection of the posterior neurovascular structures. Our clinical experience indicates this technique can lead to satisfactory stable outcomes. We believe that this technique will provide a reasonable choice for PCL reconstruction without remnant preservation.

The theoretical advantages of double-bundle posterior cruciate ligament (PCL) reconstruction are that better footprint coverage and tendon-bone connection can be realized, and the original two-bundle configuration can be reproduced.¹ Biomechanical studies have shown that double-bundle PCL reconstruction can better restore the stability of the knee than single-bundle PCL reconstruction.² Thus, various methods of double-bundle PCL reconstruction have been reported to improve the clinical results, with one-tibial-tunnel technique as the most common,³⁻⁸ and various grafts.⁹ Here, we introduce a four-tunnel double-bundle PCL reconstruction technique with ultra-strong

grafts, suitable for PCL ruptures whose residual fibers are not available or are of no practical use. In addition, if the surgeon does not master the technique of PCL reconstruction with remnant preservation, it is recommended to remove the residual fibers for double-bundle PCL reconstruction first.

Level of Evidence: Level I: knee; Level II: PCL

Surgical Technique

Preparation of the Grafts

The semitendinosus tendon (ST), the gracilis tendon (GT), and the anterior half of the peroneus longus tendon (AHPLT)¹⁰ are harvested. The GT and the AHPLT are used to make a 6-stranded graft to reconstruct the anterolateral (AL) bundle, and the ST is used to make a 4-stranded graft to reconstruct the posteromedial (PM) bundle (Fig 1). The grafts are measured and pretensioned with 60 N-80 N force (Table 1).

Debriding the Femoral Attachment

The arthroscope is inserted through the AL portal, and the shaver is inserted through the anteromedial (AM) portal to remove residual fibers from the femoral attachment of the PCL. The Humphrey or Wrisberg ligaments are kept intact.

Debriding the Tibial Attachment of the PCL

The arthroscope is inserted through the AL portal to the PM compartment (Video 1). The PM portal is created, and a cannula is inserted. The arthroscope is inserted into the PM compartment through the PM

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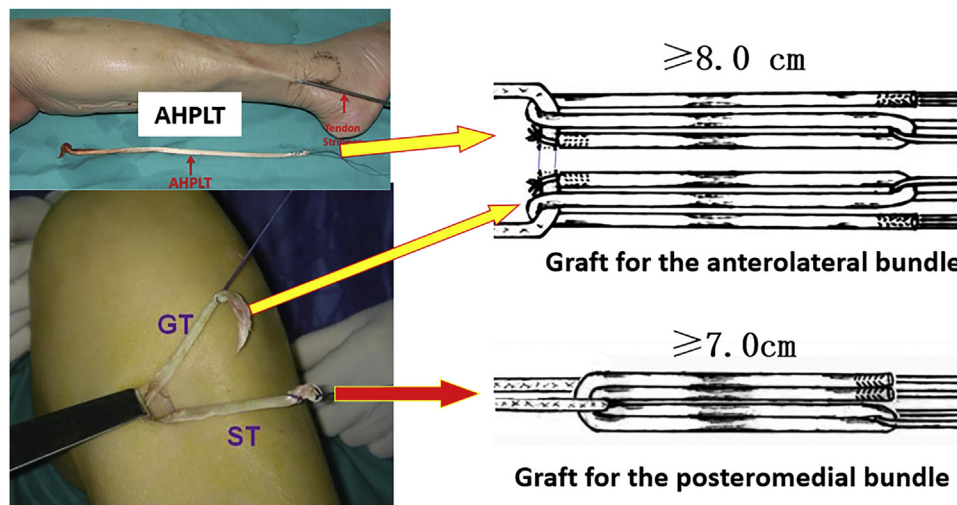


Fig 1. Illustration of the preparation of the grafts. The gracilis tendon and the anterior half of the peroneus longus tendon are used to make a six-stranded graft to reconstruct the anterolateral bundle of the posterior cruciate ligament. The semitendinosus tendon is used to make a four-stranded graft to reconstruct the posteromedial bundle of the posterior cruciate ligament. AHPLT, the anterior half of the peroneus longus tendon; GT, the gracilis tendon; ST, the semitendinosus tendon.

portal and then passed through the posterior septum to the posterolateral (PL) compartment. The PL portal is created, and a cannula is inserted (Fig 2).

A shaver is inserted into the PL compartment. The arthroscope is retrieved and inserted into the PM compartment, and the shaver is inserted into the posterior septum. Part of the posterior septum is removed to connect the posterior compartments. The PCL remnant at the tibial insertion is removed to leave a 2-3-mm stump (Fig 3).

Placing the Guide Wires to Create the Tibial Tunnels

The arthroscope is inserted through the AL portal, and a PCL tibial tunnel locator is inserted through the AM portal, across the femoral notch, to the posterior compartments.

The arthroscope is inserted into the PM compartment through the PM portal. The PCL tibial tunnel locator is set at the AL part of the PCL tibial attachment site. The tibial tunnel aiming pin is mounted and positioned at an angle of approximately 45° to the tibial axis. A K wire is drilled in from the medial edge of the tibial tubercle for later creation of the AL-bundle tibial tunnel (Fig 4A).

The tibial tunnel locator is set at the PM part of the PCL tibial insertion site (Fig 4B), 7 mm anterior to the posterior capsule attachment on the tibia. The tunnel aiming pin is mounted and adjusted to parallel to the K wire for the AL-bundle tibial tunnel. A K wire is drilled in for later creation of the PM-bundle tibial tunnel (Fig 4C).

Creating the Femoral Tunnels

The arthroscope is inserted through the AL portal, the locations of the femoral tunnels are marked with a radiofrequency probe (Fig 5). The AL bundle is located

12 mm from the most anterior edge of the femoral footprint of the PCL and 7-8 mm from the distal cartilage margin. The PM bundle is located in the most posterior part of the footprint.

The arthroscope is inserted through the AM portal, the AL-bundle femoral tunnel is created sequentially with a K wire, a cannulated drill with a size equal to the size of the proximal end of the graft, and a 4.5-mm cannulated drill (Fig 6). The PM-bundle femoral tunnel is created in the same manner (Figs 7 and 8).

Each femoral tunnel is divided into inner and outer parts. The inner tunnel parts are 25 mm in length, with a size equal to the corresponding grafts, and the outer tunnel parts are 4.5 mm in width.

Creating the Tibial Tunnels

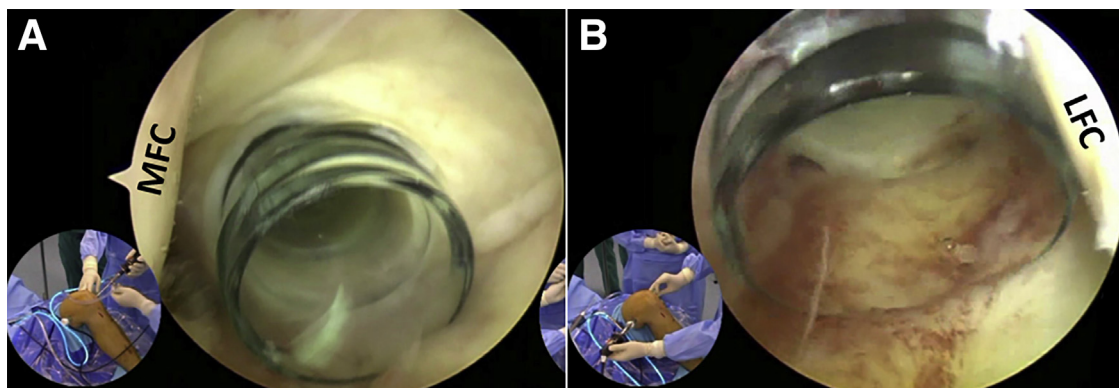
The arthroscope is inserted into the PM compartment through the PM portal. A switching stick is inserted through the PL portal to push the posterior capsule from the PCL tibial insertion to increase the buffer space for drilling. The tibial tunnels are created with corresponding cannulated drills over the K wires (Fig 9).

Placing Guide Suture Loop for Graft Implantation

With the arthroscope in the PM portal, one guide suture loop is passed through each tibial tunnel into the posterior compartments and pulled to the anterior compartment (Fig 10). An incision is made over the medial femoral epicondyle. The arthroscope is inserted through the AM portal, and one guide pin with a tailing suture loop is passed inside-out through the femoral tunnels. The proximal ends of the guide suture loops are passed through the corresponding femoral tunnels out of the medial incision with the suture loop tailing the guide pin (Figs 11 and 12).

Table 1. Step-by-step procedure of four-tunnel double-bundle anatomical posterior cruciate ligament reconstruction without remnant preservation

1. The semitendinosus tendon (ST), the gracilis tendon (GT) and the anterior half of the peroneus longus tendon (AHPLT) are harvested. The GT and the AHPLT are used to make a 6-stranded graft to reconstruct the anterolateral (AL) bundle, and the ST is used to make a 4-stranded graft to reconstruct the posteromedial (PM) bundle.
2. The residual fibers are removed from the femoral attachment of the posterior cruciate ligament (PCL).
3. The arthroscope is inserted through the AL portal to the PM compartment, and the PM portal is created.
4. The arthroscope is inserted into the PM compartment through the PM portal and then passed through the posterior septum to the posterolateral (PL) compartment. The PL portal is created.
5. A shaver is inserted into the posterior septum through the PL portal. Part of the posterior septum is removed to connect the posterior compartments. The PCL remnant at the tibial insertion is removed to leave a 2-3-mm stump.
6. The arthroscope is inserted through the AL portal, and a PCL tibial tunnel locator is inserted through the anteromedial (AM) portal, across the femoral notch, to the posterior compartments.
7. The arthroscope is inserted into the PM compartment through the PM portal. The PCL tibial tunnel locator is set at the AL part of the PCL tibial attachment site. A K wire is drilled in from the medial edge of the tibial tubercle to reconstruct the AL bundle.
8. The tibial tunnel locator is set at the PM part of the PCL tibial insertion site. A K wire is drilled in to reconstruct the PM bundle.
9. The arthroscope is inserted through the AL portal, and the locations of the femoral tunnels are marked with a radio frequency probe.
10. The arthroscope is inserted through the AM portal, and the femoral tunnels are created with an inside-out method through the AL portal.
11. The arthroscope is inserted into the PM compartment through the PM portal. A switching stick is inserted through the PL portal to elevate the posterior capsule from the PCL tibial insertion to increase the buffer space for the drilling. The tibial tunnels are created with corresponding cannulated drills over the K wires.
12. With the arthroscope inserted in through the PM portal, one guide suture loop is passed through each tibial tunnel into the posterior compartments and pulled into the anterior compartment.
13. An incision is made over the medial femoral epicondyle.
14. The arthroscope is inserted through the AM portal, and the proximal ends of the guide suture loops are passed through the corresponding femoral tunnels with the suture loop tailing a guide pin, out of the medial incision.
15. With the guide suture loop, the fixing sutures on the proximal end of the PM-bundle graft are pulled through the tibial tunnel into the joint and through the femoral tunnel out.
16. A switching stick is inserted through the PM portal to the anterior inferior side of the fixing suture at the inner orifice of the tibial tunnel. With constant pulling of the fixing sutures, the graft is moved into the posterior compartment and pulled to the femoral tunnel with repeated maneuvers.
17. The arthroscope is inserted through the AL portal. A switching stick is placed at the inferior posterior side of the fixing sutures at the inner orifice of the femoral tunnel. The graft is pulled into the femoral tunnel.
18. The proximal fixing sutures are fixed to a mini-plate that lies over the outer orifice of the femoral tunnel for the PM bundle.
19. With the arthroscope in the PM portal, a switching stick is inserted through the PL portal to the anterior inferior side of the guide suture loop for the AL bundle graft at the inner orifice of the tibial tunnel. With the guide suture loop, the fixing sutures on the proximal end of the AL bundle graft are pulled through the tibial tunnel into the joint and exit the femoral tunnel.
20. The graft is pulled through the tibial tunnel into the femoral tunnel and fixed onto a mini-plate.
21. The tibial ends of the two grafts are tensioned separately, and the knee joint is repeatedly extended and flexed so that the graft is pulled back into the tibial tunnel until compliance is achieved.
22. Interference screws are inserted into the tibial tunnels to the inner orifices for primary fixation.
23. A 4.0-mm trans-tibial ridge tunnel is created at a transverse plane distal to the orifices of the tibial tunnels.
24. A set of cortical suspensory fixation device with an adjustable loop (Mitek, Raynham, MA) is pulled through this tunnel from the medial to the lateral side. Half of the fixing sutures from the distal end of the graft are passed through the adjustable loop.
25. The cortical button is pulled through the trans tibial ridge tunnel and flipped over the lateral orifice. The sutures passing through the adjustable loop are tied to their counterparts to connect the fixing sutures to the adjustable loop.
26. Finally, the adjustable loop is reduced to apply tension the graft.

**Fig 2.** Creation of the posteromedial portals. (A) Arthroscopic view of the posteromedial compartment of the left knee through the anterolateral portal. (B) Posterolateral arthroscopic view of the posterolateral compartment of the left knee through the posteromedial portal and the posterior septum. LFC, lateral femoral condyle; MFC, medial femoral condyle.

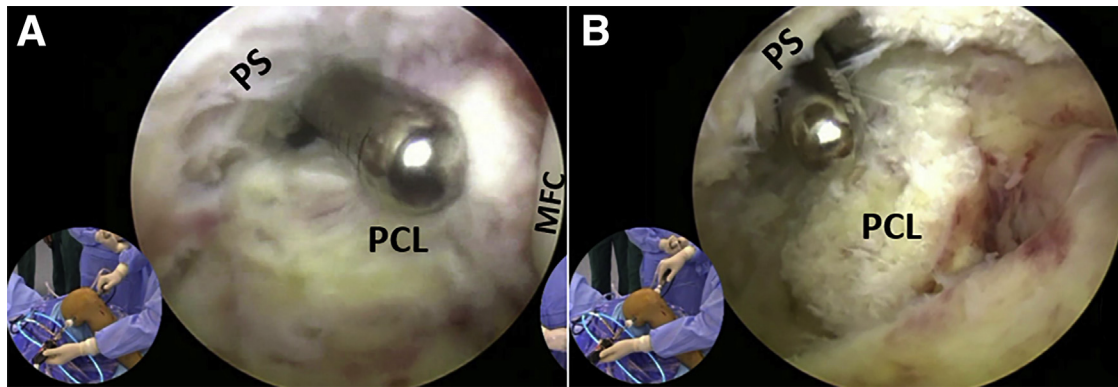


Fig 3. (A) The remnant of the posterior cruciate ligament is removed through the posterolateral portal to leave a 5 mm-long stump at the tibial insertion. (B) Arthroscopic view of the posterior compartments of the left knee through the posteromedial portal. PCL, posterior cruciate ligament; PS, posterior septum.

Implantation and Proximal Fixation of the Grafts

Along with pulling the guide suture loop, the fixing sutures on the proximal end of the PM-bundle graft are pulled through the tibial end of the tunnel into the joint and exit through the femoral tunnel. A switching stick is inserted through the PM portal to the anterior inferior side of the fixing suture at the inner orifice of the tibial tunnel. With constant pulling of the fixing sutures, the graft is moved to the posterior compartments and

pulled through the femoral tunnel with repeated maneuvers (Fig 13).

The arthroscope is inserted through the AL portal. A switching stick is placed at the inferior posterior side of the fixing sutures at the inner orifice of the femoral tunnel. The graft is then pulled into the femoral tunnel (Fig 14). The proximal fixing sutures are attached to a cortical fixation button that lies over the outer orifice of the femoral tunnel for the PM bundle.

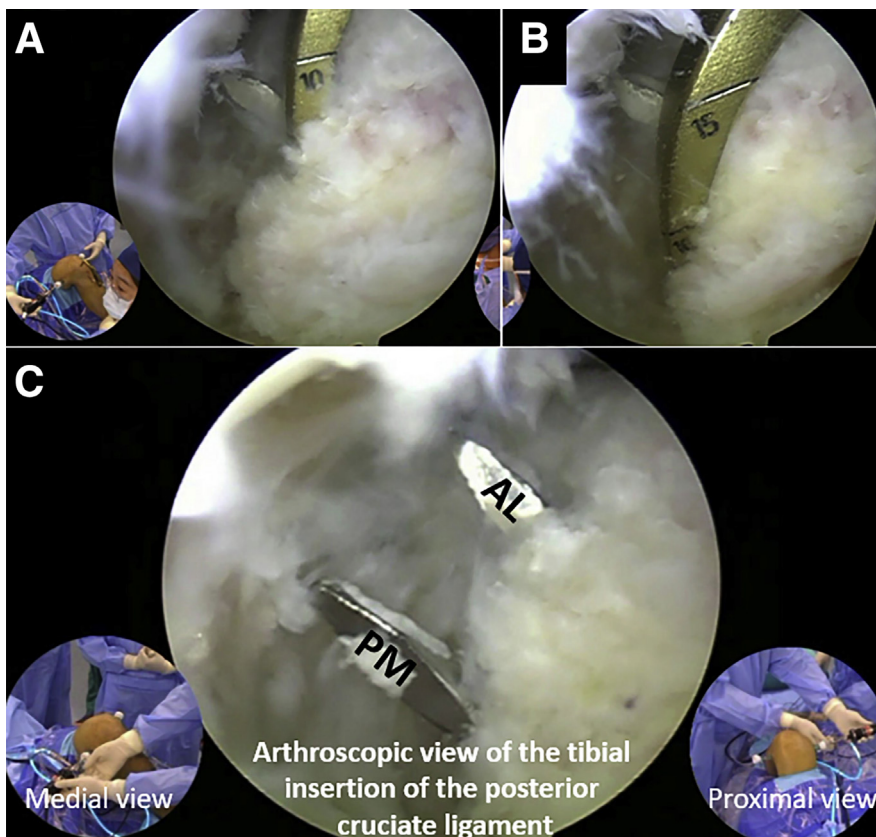


Fig 4. Placement of the K wires to create the tibial tunnels (arthroscopic view of the posterior compartments of the left knee through the posteromedial portal). (A) K wire for the anterolateral tibial tunnel is drilled. (B) Tibial tunnel locator is set at the posteromedial part of the tibial footprint of the posterior cruciate ligament to drill in the K wire. (C) Spatial locations of the K wires are set in an anteromedial to posterolateral arrangement. AL, anterolateral bundle. PM, posteromedial bundle.

Fig 5. The locations of the femoral tunnels are marked (arthroscopic view of the medial wall of the femoral notch of the left knee through the anterolateral portal). AL, anterolateral bundle; PM, posteromedial bundle.

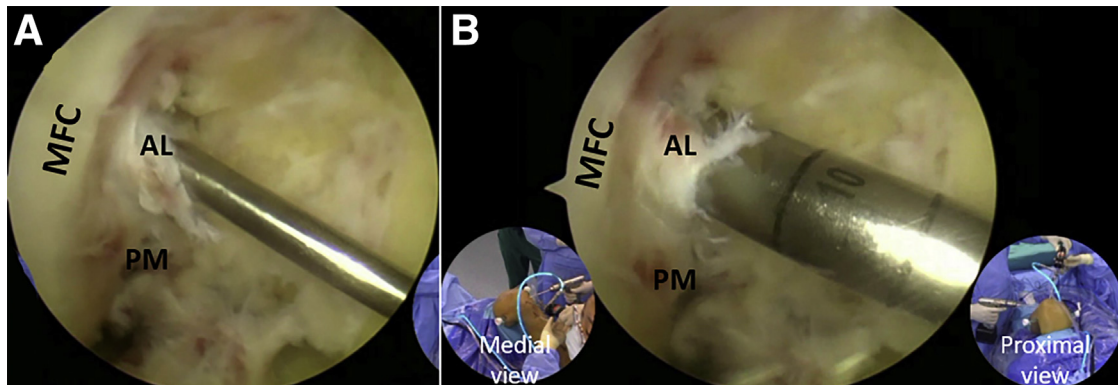
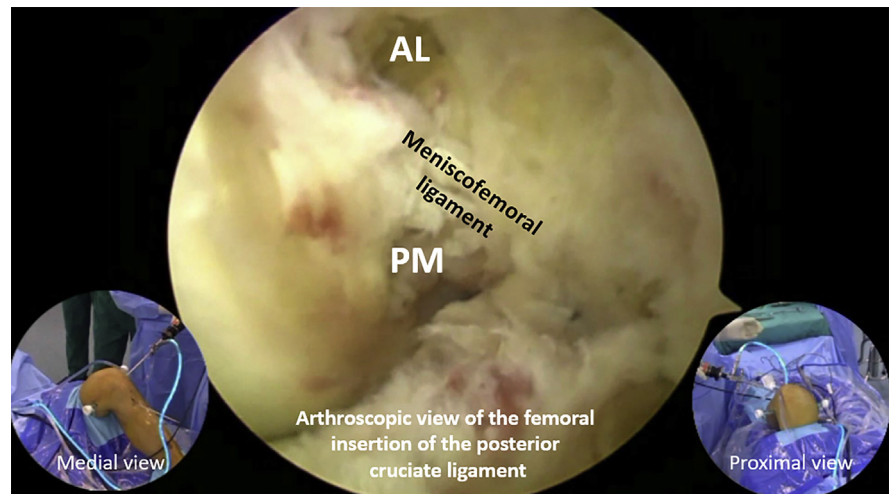


Fig 6. Creation of the femoral tunnel for the anterolateral bundle of the posterior cruciate ligament sequentially with a K wire and a cannulated drill (arthroscopic view of the medial wall of the femoral notch of the left knee through the anterolateral portal). AL, anterolateral bundle; MFC, medial femoral condyle; PM, posteromedial bundle.

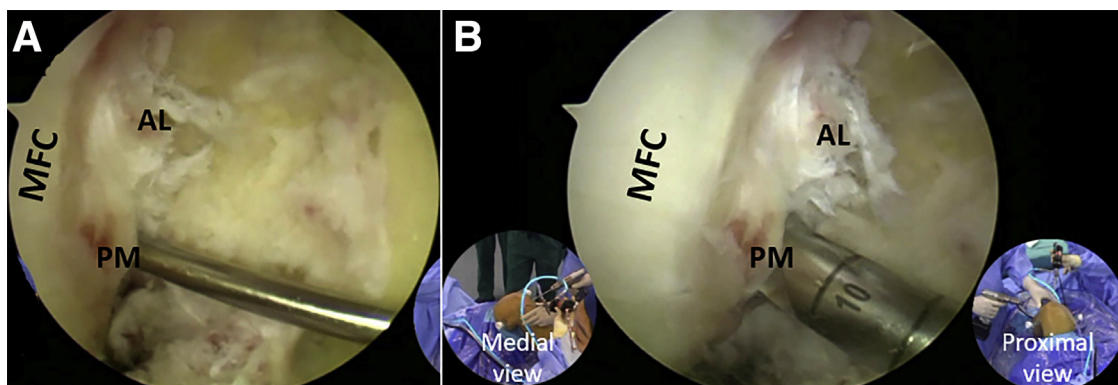


Fig 7. Creation of the femoral tunnel for the posteromedial bundle of the posterior cruciate ligament sequentially with a K wire and a cannulated drill (arthroscopic view of the medial wall of the femoral notch of the left knee through the anterolateral portal). AL, anterolateral bundle; MFC, medial femoral condyle; PM, posteromedial bundle.

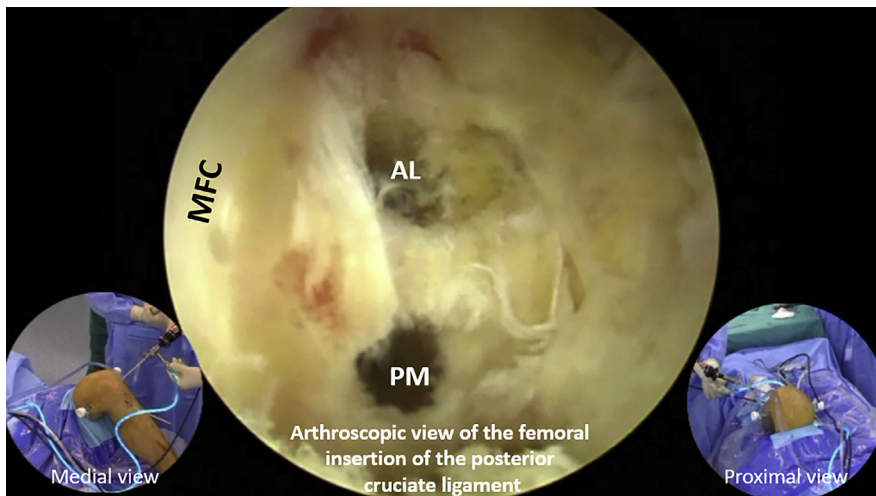


Fig 8. The location of the created femoral tunnels (arthroscopic view of the medial wall of the femoral notch of the left knee through the anterolateral portal). AL, anterolateral bundle; MFC, medial femoral condyle; PM, posteromedial bundle.

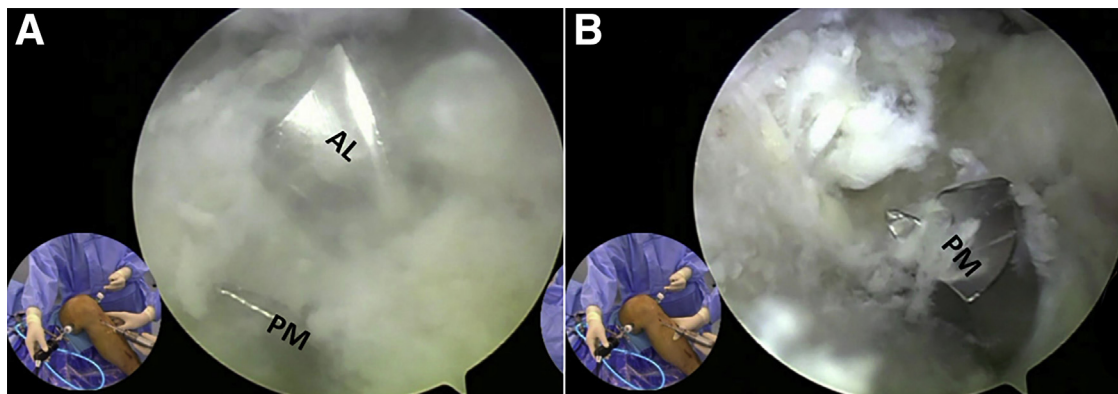


Fig 9. (A) Creation of the tibial tunnels for the anterolateral bundle. (B) Posteromedial bundle: arthroscopic view of the posterior compartments of the left knee through the posteromedial portal. AL, anterolateral bundle; PM, posteromedial bundle.

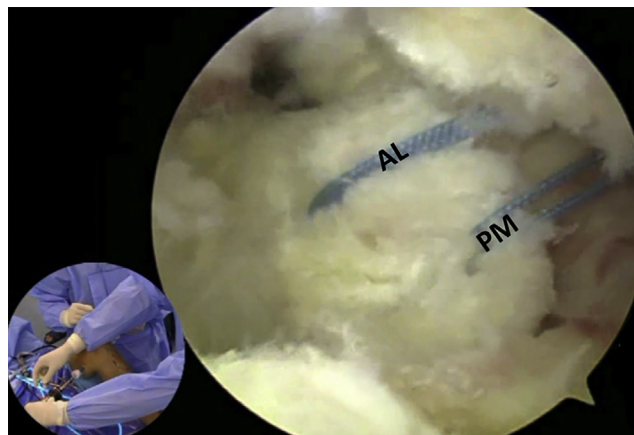


Fig 10. Placement of the guide suture loops through the tibial tunnels into the joint and pulled to the anterior compartment. Arthroscopic view of the posterior compartments of the left knee through the posteromedial portal. AL, anterolateral bundle; PM, posteromedial bundle.

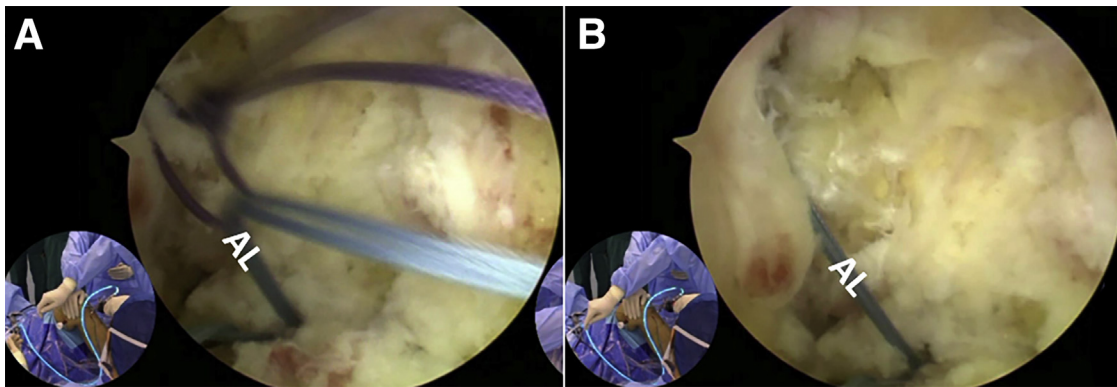


Fig 11. (A) With a suture loop tailing a guide pin, passing the guide suture loop for the anterolateral bundle through the corresponding femoral tunnel. (B) Arthroscopic view of the medial wall of the femoral notch of the left knee through the anteromedial portal. AL, anterolateral bundle.

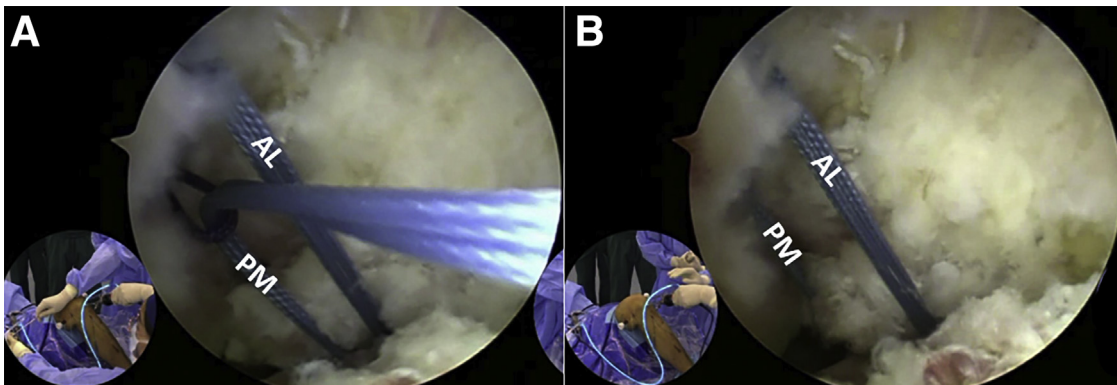


Fig 12. (A) With a suture loop tailing a guide pin, passing the guide suture loop for the posteromedial bundle through the corresponding femoral tunnel. (B) Arthroscopic view of the medial wall of the femoral notch of the left knee through the anteromedial portal. AL, anterolateral bundle; PM, posteromedial bundle.

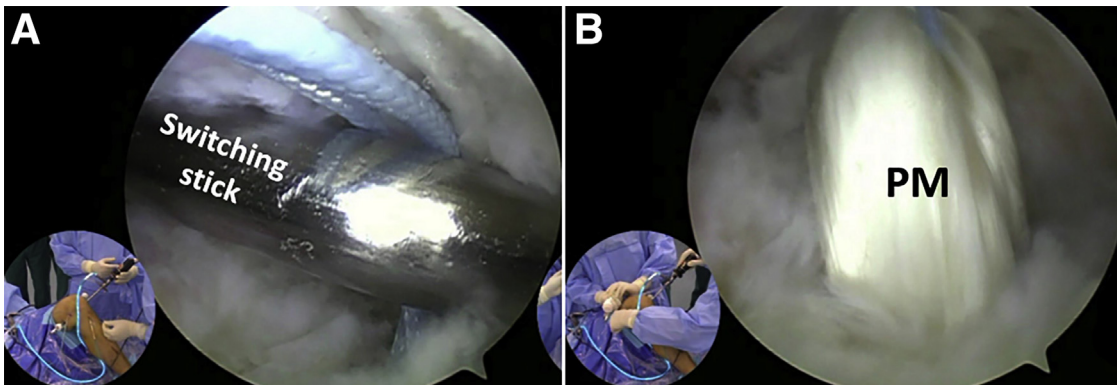


Fig. 13. Placement of the graft for the posteromedial bundle into the joint (arthroscopic view of the posterior compartments of the right knee through the anterolateral portal). (A) Switching stick is placed through the posteromedial portal to the anterior inferior side of the fixing sutures. (B) Graft of the posteromedial bundle is moved into the joint. PM, posteromedial bundle.

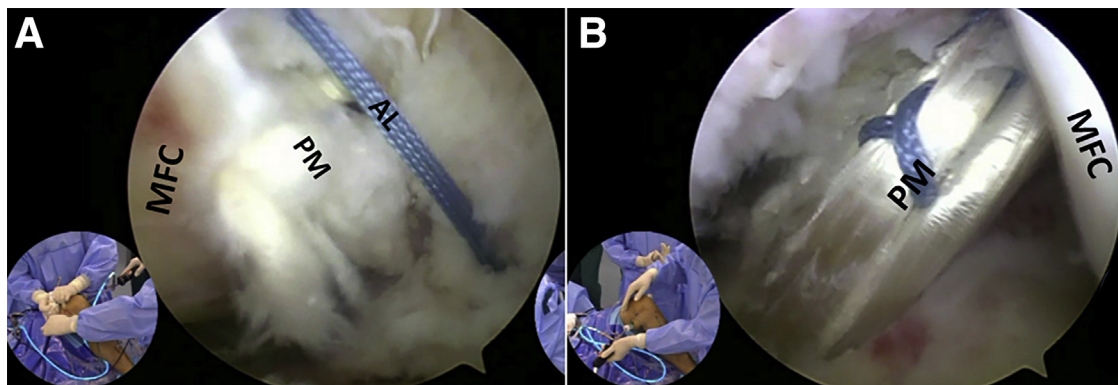


Fig. 14. Placement of the graft of the posteromedial bundle into the femoral tunnel. (A) Arthroscopic view of the medial wall of the femoral notch of the left knee through the anterolateral portal. (B) Arthroscopic view of the posteromedial compartment of the left knee through the posteromedial portal. AL, anterolateral bundle; MFC, medial femoral condyle; PM, posteromedial bundle.

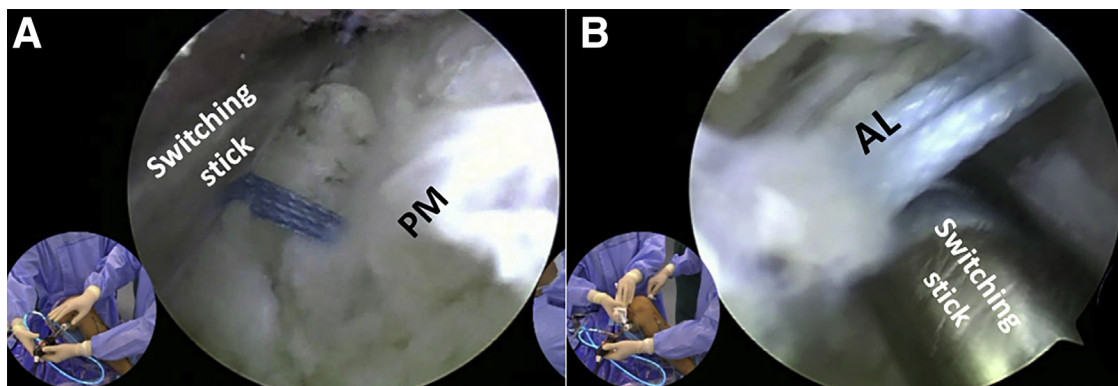


Fig 15. (A) With a switching stick placed at the anterior inferior side of the guide suture loop for the anterolateral bundle, the fixing sutures from the proximal end of the graft of the anterolateral bundle are inserted. (B) Arthroscopic view of the posterior compartments of the left knee through the posteromedial portal. AL, anterolateral bundle; PM, posteromedial bundle.

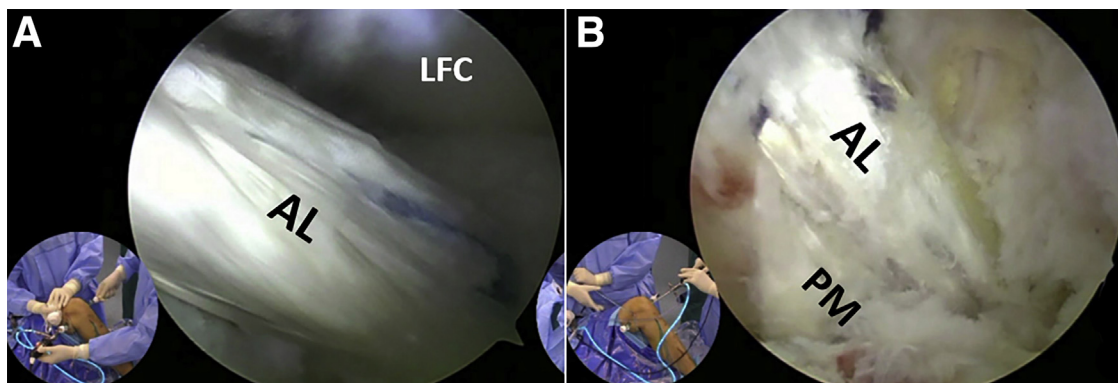


Fig 16. (A) The graft of the anterolateral bundle is moved into the joint. Arthroscopic view of the posterior compartments of the left knee through the posteromedial portal. (B) The graft of the anterolateral bundle is pulled into the femoral tunnel (arthroscopic view of the medial wall of the femoral notch of the left knee through the anterolateral portal). AL, anterolateral bundle; LFC, lateral femoral condyle; PM, posteromedial bundle.

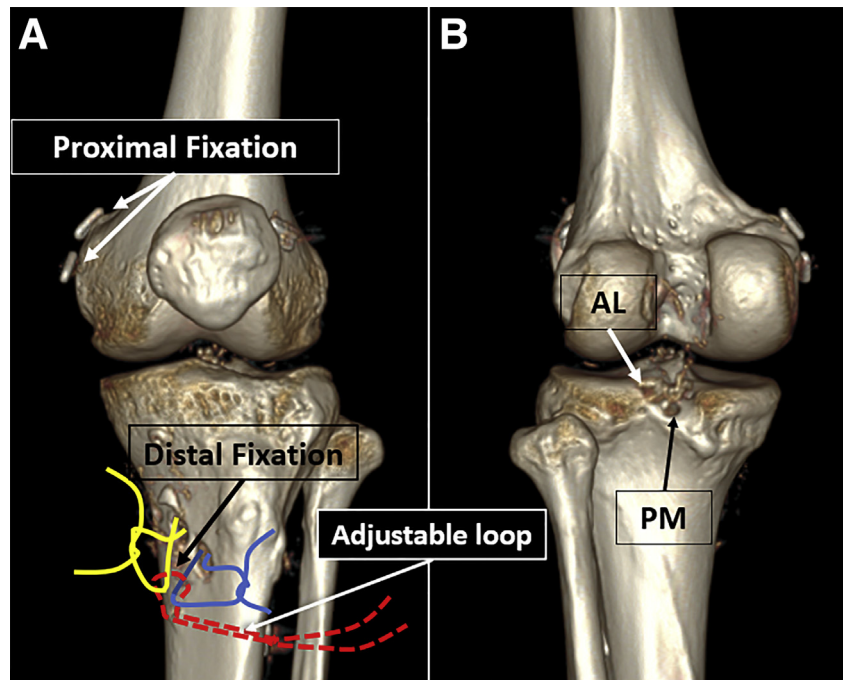


Fig 17. Postoperative computerized tomographic images indicating the proximal and distal fixation of the grafts (A) and the inner orifices of the tibial tunnels (B). AL, anterolateral bundle; PM, posteromedial bundle.

With the arthroscope in the PM portal, a switching stick is inserted through the PL portal to the anterior inferior side of the guide suture loop for the AL-bundle graft at the inner orifice of the AL-bundle tibial tunnel. With the guide suture loop, the fixing sutures on the proximal end of the AL-bundle graft are pulled through the tibial tunnel into the joint and exit the femoral tunnel (Fig 15). Then the graft is pulled through the tibial tunnel into the femoral tunnel and attached to a cortical fixation button in the same manner as the PM bundle (Fig 16).

Distal Fixation of the Grafts

The tibial ends of the two grafts are tensioned separately, and the knee joint is repeatedly extended and flexed so that the graft is pulled back into the tibial tunnel, and compliance is achieved. Interference screws are inserted into the tibial tunnels to the inner orifices for primary fixation at knee extension.

A 4.0-mm trans-tibial ridge tunnel is created at a transverse plane distal to the orifices of the tibial tunnels. A set of cortical suspensory fixation device with an adjustable loop (Mitek, Raynham, MA) is pulled through this tunnel from the medial to the lateral side. Half of the fixing sutures from the distal ends of the grafts are passed through the adjustable loop. The cortical button is pulled through the transverse tibial tunnel and flipped over the lateral orifice. The sutures passing through the adjustable loop are tied to their counterparts to connect the fixing sutures to the

adjustable loop. Finally, the adjustable loop is reduced to apply tension the graft (Fig 17).

Postoperative Treatment and Rehabilitation

A PCL protecting brace (MEDI, Bayreuth, Germany) is used for the first 6 weeks, which allows immediate range of motion exercises, with support at the posterior side of the proximal leg. Partial to full weight-bearing is allowed, as tolerated. Muscle strengthening exercises begin immediately after the operation. Proprioceptive and agility training begin 6 weeks after the operation.

Discussion

There are many methods of double-bundle PCL reconstruction, but most of them use one tibial tunnel or tibial inlay technique and two femoral tunnels. To increase the tendon-bone contact area, we recommend the use of two tibial tunnels. However, we do not arrange the two tibial tunnels in an anteroposterior manner, which increases the risk of vascular injury during creation of the posterior tibial tunnel.^{11,12} We design the two tibial tunnels in an AL to PM arrangement. The other main feature of this technique is that we use 10 strands of tendons to ensure the strength of the grafts. A previous study indicated that stronger grafts could improve the final stability results of the knee.¹³

The pearls and pitfalls are listed in Table 2. The most critical point in this procedure is how to prevent neurovascular injury during the creation of the tibial tunnels.

Table 2. Pearls and pitfalls of four-tunnel double-bundle anatomical posterior cruciate ligament reconstruction without remnant preservation

1. The length of the anterolateral (AL) bundle graft should be at least 75 mm (i.e., the length of both the gracilis tendon and the AHPLT should be no less than 225 mm), with 35 mm indwelling in the joint and 20 mm indwelling in the tunnel at both sides. If the graft is long enough, an indwelling of 25 mm in the femoral tunnel, 35 mm in the joint, and more than 20 mm in the tibial tunnel is recommended.
2. The length of the posteromedial (PM) bundle graft should be at least 70 mm (i.e., the length of ST should be no less than 280 mm), with 30 mm indwelling in the joint and 20 mm indwelling in both the femur and the tibial tunnels. If the graft is long enough, an indwelling of 25 mm is inserted in the femoral tunnel. If the ST length is less than 280 mm, a 3-strand graft is recommended to ensure enough graft length.
3. At the proximal end of each graft, an absorbable suture is used to suture and ligate the tendons together as a marker. The marking line is 25 mm from the proximal end of the graft, to facilitate the determination of the length of the graft into the femoral tunnel when the graft is pulled in.
4. When fabricating the PM portal, cut only the skin layer, and the subcutaneous tissue is separated by forceps to avoid the injury of the saphenous nerve.
5. The remnant does not need to be completely removed in the debridement. On the one hand, residual fiber at the attachment can be used as a reference for tunnel location. Secondly, the retention of residual fiber at the insertion can reduce the cutting of the graft by the sharp cortical edge at the tunnel orifice.
6. In middle-aged and elderly patients, osteophyte proliferation on the medial wall of the intercondylar notch will cause friction to the PM-bundle graft and should be removed.
7. Do not ever remove the posterior septum, which may provide blood supply to the reconstructed PCL.
8. The inner opening of the tibial tunnel for the PM bundle should not be located too medial, otherwise the graft will be impinged by the medial femoral condyle, which will cause range of motion limitation or graft failure.
9. In the double-bundle PCL reconstruction, the accurate positioning of the femoral tunnels of both bundles is especially important.
10. Because the attachment of the PCL is in the posterior middle of the tibia, the risk of neurovascular injury in the popliteal fossa should be focused on first. Special care should be taken when debriding the area around the attachment and establishing bone tunnels. The popliteal fossa structure is protected by manually drilling and hyper knee flexion when the tunnel reached the posterior cortex. When drilling in guide wires and creating tunnels, risk can be reduced by using rear-protecting locators and special protective devices to pry the posterior soft tissue backward to increase the posterior buffer space.
11. It is recommended to implant the PM bundle first and then the AL bundle. If the AL bundle is implanted first, the monitoring and operation of the PM-bundle grafts will be hindered.
12. Ensure that the cortical fixation buttons for proximal fixations are in close contact with the cortex to prevent the soft tissue beneath it from liquefaction and subsequent loosening of the button.
13. Long surgical time, high perfusion pressure, or postoperative bleeding may cause osteofascial compartment syndrome (OCS) of the leg, especially when the operation is performed in an acute stage of a multiligament injury. If high leg tension is found intraoperatively, suction drainage can be inserted in the joint and the deep compartment of the leg at the end of the operation, which can effectively avoid compartment syndrome. If there are any signs of OCS, take immediate routine measures, including opening the bandage, checking for peripheral circulation, and fascial tension release.
14. PCL is subjected to great stress during normal daily activities and, therefore, requires long periods of protection after repair and reconstruction. The harmful effect of active knee flexion and gravity on PCL should be avoided in rehabilitation training.

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