Technical Note

Anatomic Double-Bundle Anterior Cruciate Ligament Reconstruction with Hamstring Tendon Autograft through Single Femoral Tunnel and Single Branched Tibial Tunnel

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Abstract: Conventional single-bundle anterior cruciate ligament (ACL) reconstruction cannot improve the rotational stability of the knee. Traditional double-bundle ACL reconstruction requires is demanding, complex, time- and implant consuming, and associated with a high incidence of complications. Double-bundle ACL reconstruction using a free quadriceps tendon autograft through 3 independent tunnels provides some advantage, but the antegrade graft passage, tibial tunnel confluence, and graft site morbidity represent disadvantages. This Technical Note describes a modification of double-bundle ACL reconstruction using the hamstring tendon autograft through a single branched tibial tunnel and a single femoral tunnel using 2 interference screws (Arthrex, Naples, FL). The gracilis tendon autograft is passed through tibial tunnel stem to the posterolateral tibial tunnel branch to the posterolateral position in the femoral tunnel. The semitendinosus tendon autograft is passed through the tibial tunnel stem to the anteromedial tibial tunnel branch to the anteromedial position in the femoral tunnel. Both grafts are fixed by 2 interference screws: 1 at the femoral tunnel and 1 at the tibial tunnel stem with the knee at 20° flexion.

Because of technical, economic, biomechanical, and sometimes clinical causes, many surgeons prefer anatomic single-bundle than double-bundle anterior cruciate ligament (ACL) reconstruction.[1-5] Double-bundle reconstruction needs 4 independent tunnels and 4 methods of fixation, which increases surgical time, cost, and possible complications.[1,2]

Sergiu et al.[6] describe a technique that has some advantages over traditional double-bundle ACL reconstruction. They performed anatomic double-bundle ACL reconstruction through 3 independent tunnels and passed the free quadriceps tendon autograft through 1 femoral tunnel and then through 2 separate tibial tunnels, creating 3 points of fixation. The antegrade passage of the graft to tibial tunnels is difficult and demanding.

This article describes a tunnel branching method for double-bundle ACL reconstruction. The femoral tunnel

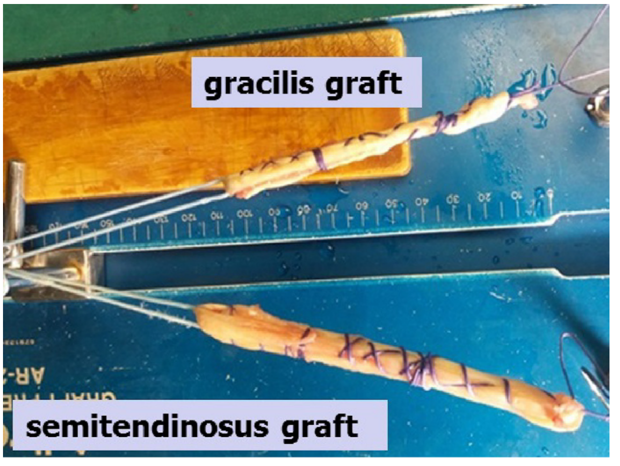

Fig 1. Graft preparation. The gracilis tendon is tripled to represent the posterolateral bundle. The semitendinosus tendon is doubled to represent the anteromedial bundle.

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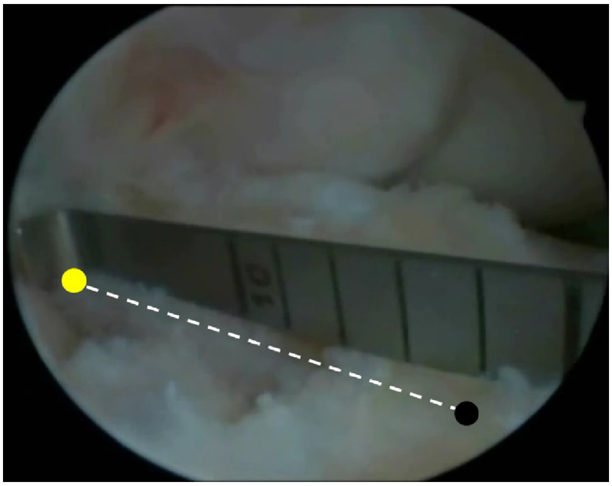

Fig 2. Arthroscopic view of right knee at 90° flexion showing measurement of ACL tibial footprint (white dotted line). Black and yellow circles roughly represent the anterior and posterior ends of the anterior cruciate ligament tibial footprint, respectively. The footprint should be > 16 mm.

has a socket and 2 holes; the tibial tunnel has a stem and 2 branches. The hamstring tendon autograft is passed through 2 tunnels and fixed by 2 interference screws (Arthrex).

The posterolateral (PL) bundle is passed through tibial tunnel stem to the PL tibial tunnel branch to the PL position in the femoral tunnel. The anteromedial (AM) bundle is passed through the tibial tunnel stem to the AM tibial tunnel branch to the AM position in the femoral tunnel. Both bundles are fixed by interference screws: 1 at the femoral tunnel and 1 at the tibial tunnel stem with the knee at 20° flexion.[7]

Through this procedure, the reconstruction restores 2 separate bundles at the anatomic position and with the correct bundle position and orientation. The fixation by 2 interference screws only decreases the cost of surgery and the possible biologic reactions and complications.

Surgical Technique

Tunnel Branching Method

Creation of the tibial tunnel makes 1 extra-articular entry point and 2 apertures; therefore, the tibial tunnel has a distal stem and 2 proximal branches: the AM branch at the AM corner of the tunnel and the PL branch at the PL corner of the tunnel. Creation of the femoral tunnel makes 1 aperture and 2 extra-articular exit points; therefore, the femoral tunnel has a socket and 2 holes: the AM hole at the AM corner of the tunnel and the PL hole at the PL corner of the tunnel. These holes are used for the suture passage and then the graft passage to be oriented and settled in the correct position in the tunnel.

Graft Preparation

The gracilis tendon autograft is used to represent the PL bundle. It is tripled to make a graft 8 cm in length and at least 4 to 5 mm in diameter. The semitendinosus tendon autograft is used to represent the AM bundle. It is doubled or tripled to make a graft 9 cm in length and at least 5 to 6 mm in diameter (Fig 1).

Tibial Tunnel Creation

After debridement, the ACL tibial footprint is measured; to accommodate double bundle reconstruction, it should be > 16 mm (Fig 2). The centers of native bundle tibial attachment sites are determined.

The tunnel branches are created first, followed by the tunnel stem. The ACL tibial drill guide is fitted between an extra-articular point just anterior to the distal attachment of the superficial medial collateral ligament[8] 4 to 5 cm distal to the joint line and an intra-articular point just medial to the posterior margin of anterior horn of the lateral meniscus[9] at the center of the native AM bundle. A guide pin of 2.7 mm is drilled making a 20° angle to the sagittal plane (Fig 3).

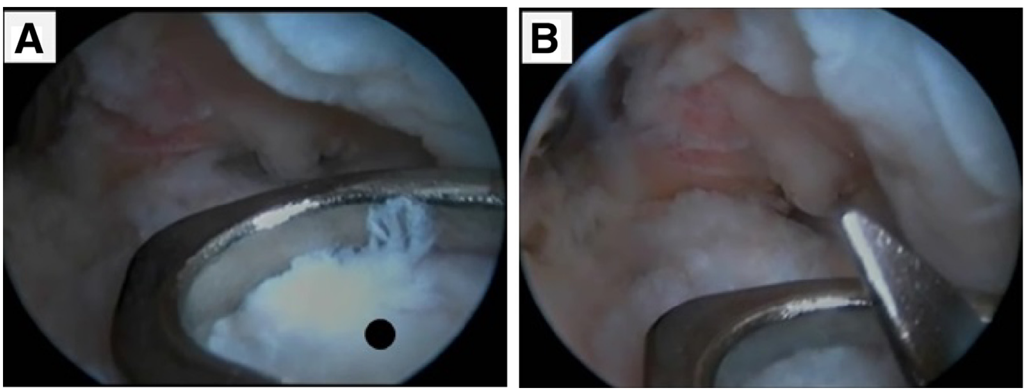

Fig 3. Arthroscopic view of the right knee showing anteromedial (AM) tibial tunnel drilling. (A) Anterior cruciate ligament tibial drill guide fitted on the center of the native AM bundle just medial to the posterior margin of the anterior horn of the lateral meniscus (black circle). (B) A 2.7-mm guide pin drilled at the center of the native AM bundle.

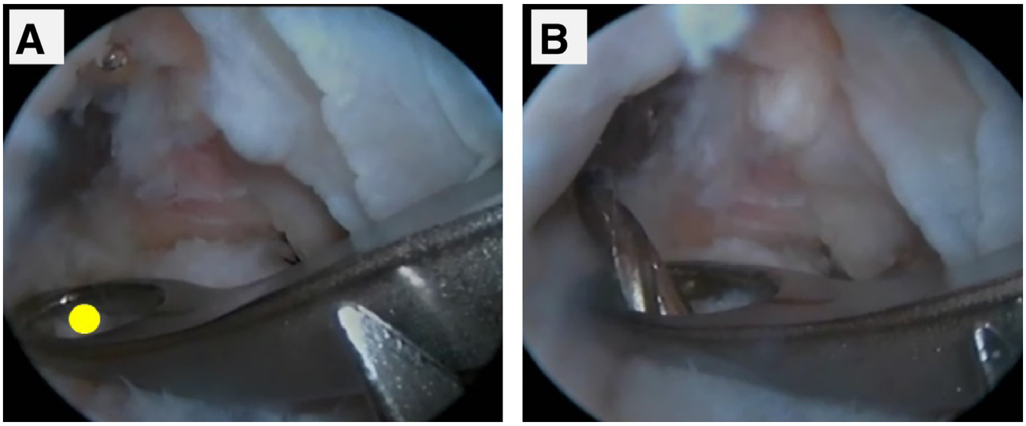

Fig 4. Arthroscopic view of the right knee showing posterolateral (PL) tibial tunnel drilling. (A) Anterior cruciate ligament tibial drill guide fitted on the center of the native PL bundle just medial to the lateral tibial spine (yellow circle) and the tip of the guide pin drilled at the center of the native anteromedial bundle. (B) A 2.7-mm drill guide pin drilled at the center of the native PL bundle.

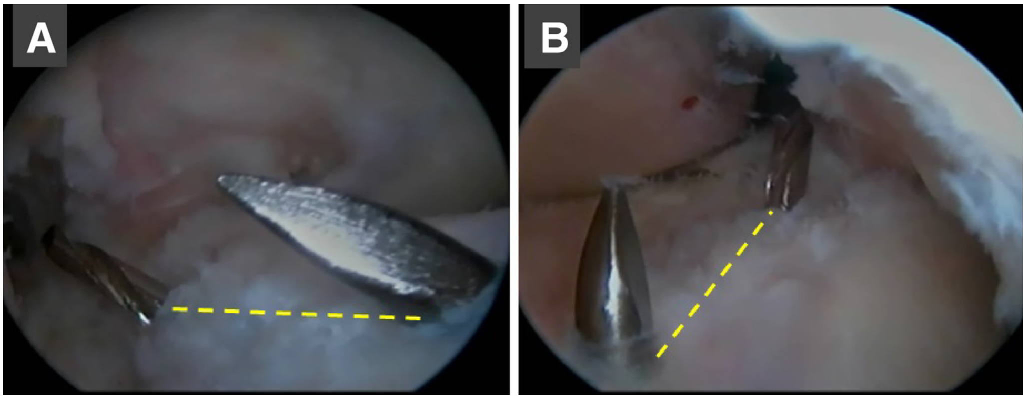

Fig 5. Arthroscopic view of the right knee showing the intra-articular position of the guide pins. The guide pins should be separated by a distance not <10 mm (yellow dotted line) to avoid tunnel merging after tunnel drilling. (A) Arthroscopic view through the anterolateral portal. (B) Arthroscopic view through the slandered anteromedial portal.

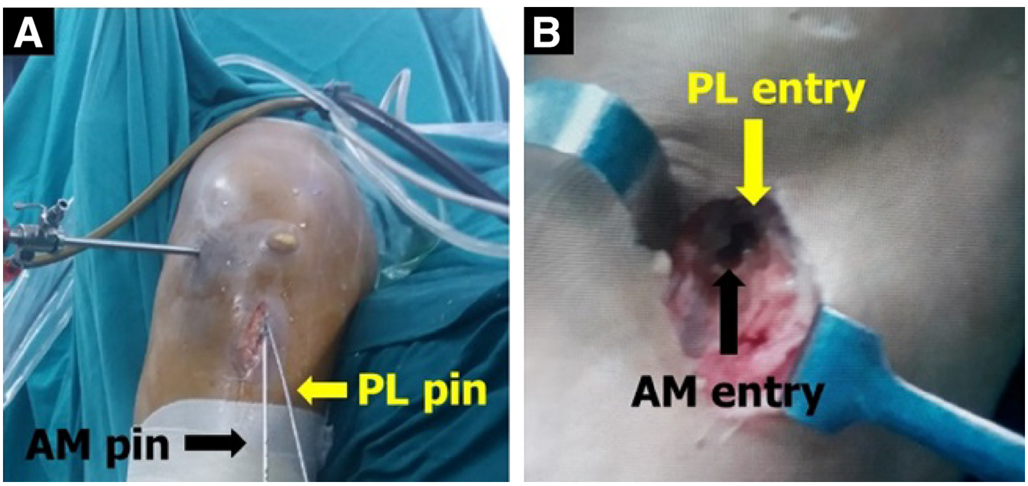

Fig 6. An intraoperative view of a flexed right knee showing tibial tunnel drilling and reaming. (A) After drilling, the anteromedial (AM) guide pin (black arrow) is inclined 20° to the sagittal plane; the posterolateral (PL) guide pin (yellow arrow) is inclined 40° to the sagittal plane. (B) After reaming and before creation of the tunnel stem, the PL entry on the tibial cortex (yellow arrow) medial, posterior, and superior to the AM entry (black arrow) is shown.

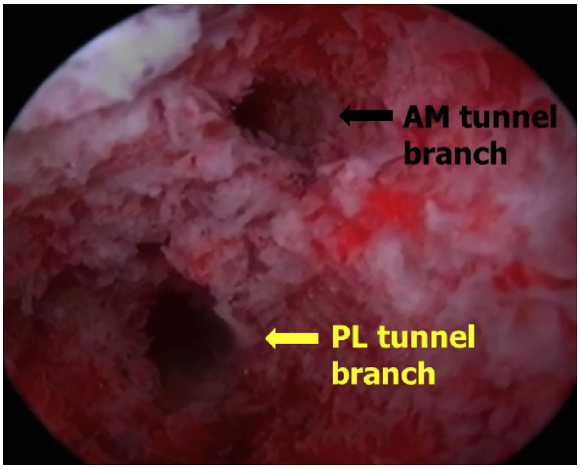

Fig 7. An intratunnel view of the right knee through the stem of the tibial tunnel showing the anteromedial (AM) tibial tunnel branch (black arrow) and the posterolateral (PL) tibial tunnel branch (yellow arrow).

Then the ACL tibial drill guide angle is changed to be fitted to a point on the tibial cortex just posterior and superior to the first entry point and an intra-articular point at the center of the native PL bundle just medial to the lateral tibial spine.[9] A second guide pin of 2.7 mm making a 40° angle to the sagittal plane is drilled (Fig 4). The distance between the entry point on the tibial cortex and the aperture is measured. It should not be < 35 mm to allow tunnel branching.

At this point, the ACL tibial drill guide is removed and the intra-articular position of the pins is assessed through both the anterolateral (AL) and AM portals (Fig 5). Then the knee is extended to show if the pins (proposed graft sites) impinge on the intercondylar notch or the posterior cruciate ligament (PCL).

According to the graft diameter, the AM guide pin is reamed by a 5- to 6-mm reamer, forming the AM tibial tunnel, and the PL guide pin is reamed by a 4- to 5-mm reamer, forming the PL tibial tunnel. The inclination angles of the AM and PL guide pins to the sagittal plane are different. This makes the PL aperture lateral and posterior to the AM aperture, and the entry of the PL tunnel on the tibial cortex is medial, posterior, and superior to the entry AM tunnel (Fig 6).

At the tibial cortex, a 9- to 11-mm reamer is used to merge the distal 25 mm of the 2 tunnels forming the tunnel stem. The tunnel stem angle of inclination is midway between that of the branch inclination both in the sagittal and coronal planes. This makes the entry point of tunnel branches eccentric in the end of the stem. Intratunnel arthroscopy is done to evaluate tunnel branching. The distance between entry points of tunnel branches should not be < 3 mm (Fig 7).

Femoral Tunnel Creation

The medial portal technique[10] is used to create the femoral tunnel. The freehand technique achieves better flexibility. The femoral tunnel stem is created first, then the AM hole, and then the PL hole.

The entry point of the femoral tunnel is determined on the lateral intercondylar and bifurcate osseous landmarks on the posterior aspect of the medial wall of the lateral femoral condyle.[11] Through the AM portal, a 2.7-mm guide pin is drilled through this entry point. A tunnel 25 mm in length and 9 to 11 mm in diameter is reamed over the guide pin. This is the femoral tunnel.

Through an accessory AM portal, the PL corner of the femoral tunnel is drilled by a 2.7-mm guide pin directed posteriorly and laterally, with the knee flexed 120°,[9] forming the PL hole. Then, through the AM portal, the AM corner of the femoral tunnel is drilled by a 2.7-mm guide pin directed anteriorly and medially, with the knee flexed 90°,[9] forming the AM hole. The AM hole is medial, anterior, and superior to the PL

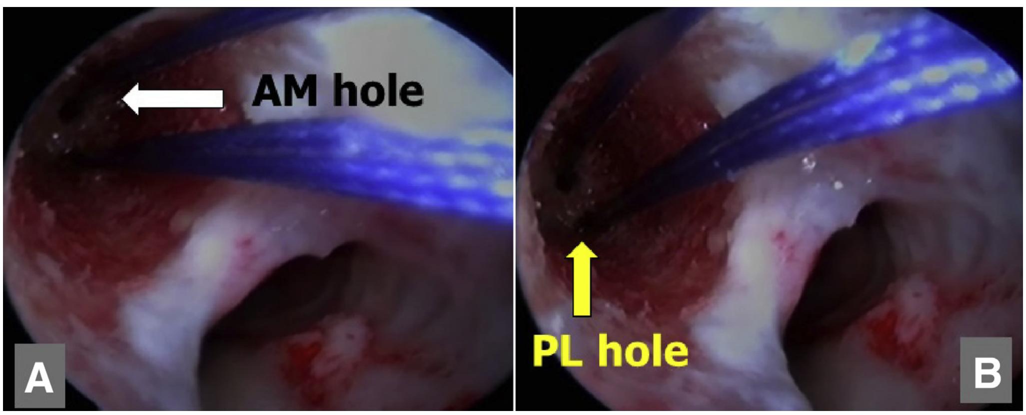

Fig 8. En face arthroscopic view of the right knee through the anteromedial (AM) portal shows the femoral tunnel after drilling, tunnel holes, and passing sutures. (A) AM tunnel hole (white arrow) in anterior, medial, and superior positions in the femoral tunnel. (B) Posterolateral (PL) tunnel hole (yellow arrow) in the posterior, lateral, and inferior position in the femoral tunnel.

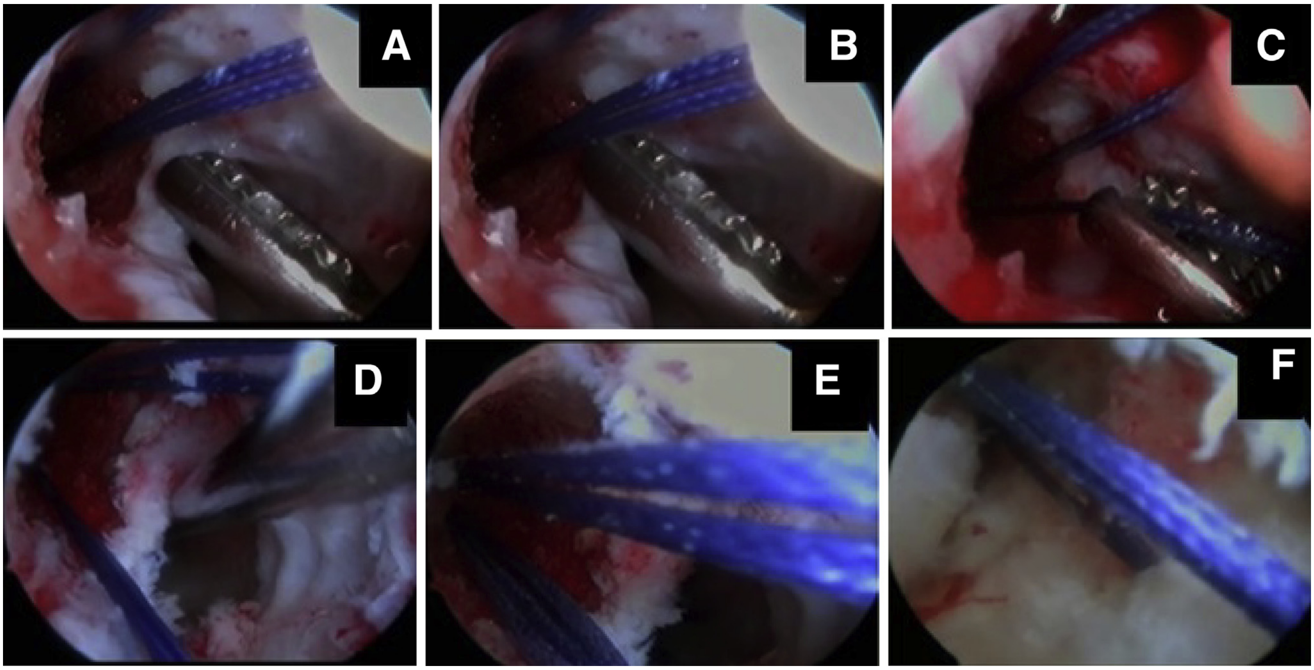

Fig 9. Arthroscopic views of the right knee through the anterolateral portal (A-D, F) and anteromedial (AM) portal (E) showing steps of passing suture management. The suture loop passed through posterolateral hole in the femoral tunnel is retrieved through the PL tibial tunnel branch (A-D), and the suture loop passed through the AM hole in the femoral tunnel is retrieved through the AM tibial tunnel branch (D-F); then the 2 loops are passed to the tibial tunnel stem to the exterior and used for graft passage.

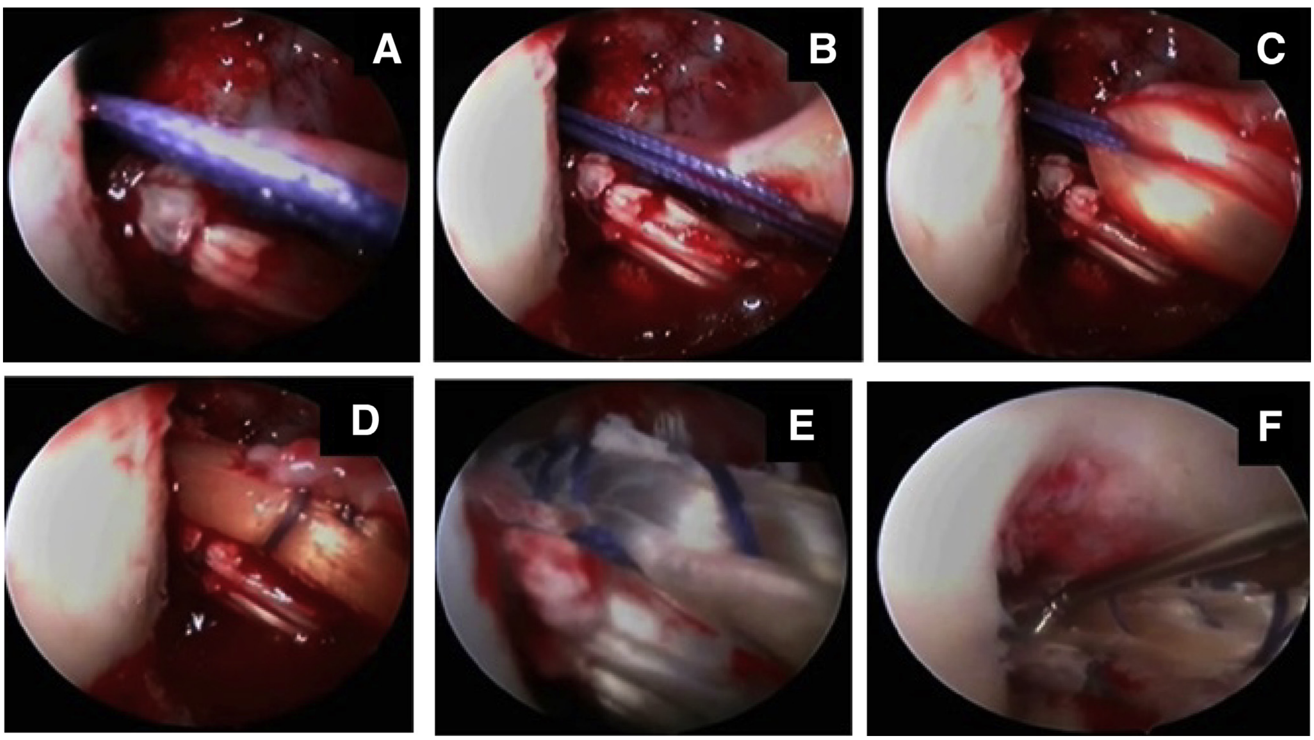

Fig 10. Arthroscopic views of the right knee through the anterolateral portal showing steps of graft passage. (A-B) The gracilis tendon graft (posterolateral bundle) is passed first; (C-D) second is the semitendinosus tendon graft (anteromedial bundle). (E) Graft after fixation with the knee is flexed. (F) Graft after fixation with the knee extended.

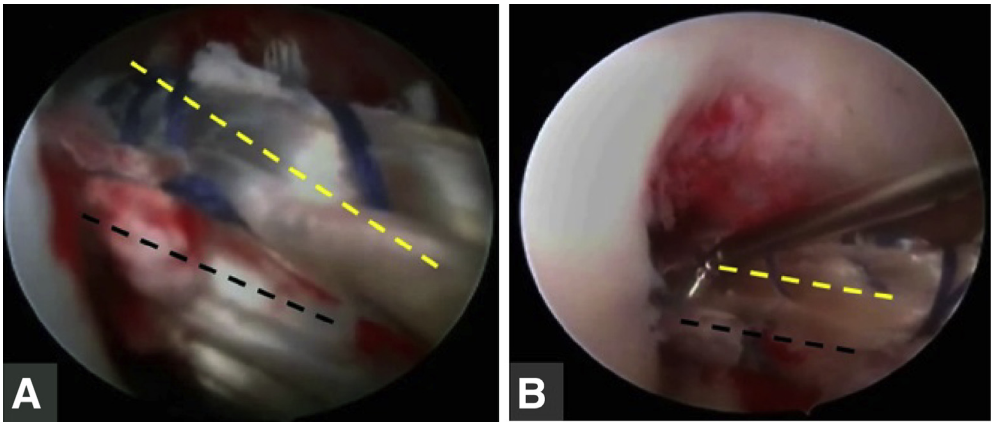

Fig 11. Arthroscopic views of the right knee through the anterolateral portal showing graft direction and orientation. The yellow dotted line represents the direction and orientation of anteromedial bundle graft in flexion (A) and extension (B). The black dotted line represents the direction and orientation of posterolateral bundle graft in flexion (A) and extension (B). The bundle grafts are crossed in flexion and parallel in extension.

hole. The holes are used for passage of 2 suture loops. En face arthroscopic viewing through the AM portal helps evaluate the tunnel, tunnel holes, and passing sutures (Fig 8). The suture loop passed through PL hole is retrieved through the PL tibial tunnel branch; the loop passed through the AM hole is retrieved through the AM tibial tunnel branch, both to the tibial tunnel stem to the exterior and used for graft passage (Fig 9).

Graft Passage and Fixation

The interference screw wire is passed in the AL corner of the femoral tunnel before graft passage. Using the passing sutures, the PL bundle graft (gracilis tendon) is passed first and then the AM bundle graft (semitendinosus tendon).[8] Fixation is done at the femoral tunnel and then at the tibial tunnel stem with the knee at 20° flexion using 2 interference screws (Fig 10).

Arthroscopic Evaluation

At the end of the procedure, arthroscopic evaluation is performed. The bundles should be crossed in flexion and parallel in extension (Fig 11) and occupy most of the native ACL tibial footprint, with no notch or PCL impingement (Fig 12). The AM bundle should be tight in flexion, and the PL bundle should be tight in extension.[7] Tables 1, 2, and 3 review the advantages, pearls and pitfalls, and risks and limitations of the technique, respectively.

Discussion

Single-bundle ACL reconstruction can restore anteroposterior stability but is not able to improve rotational stability.[12] Single-bundle reconstruction represents 66% of the native ACL in response to valgus and internal rotation force.[13] Although double-bundle reconstruction can restore both anteroposterior and rotational stability,[13-18] it is similar to a native ACL in response to anterior translation force and represents a 91% response to valgus and internal rotation forces.[13]

With double-bundle reconstruction, there is improved anterior laxity and pivot-shift testing,[19,20] and decreased failure rates as low as 4%.[21] Anatomic double-bundle reconstruction is better than anatomic single-bundle reconstruction; however, the differences are small and may not be clinically relevant.[5]

Double-bundle ACL reconstruction needs 2 independent tibial tunnels, 2 independent femoral tunnels,

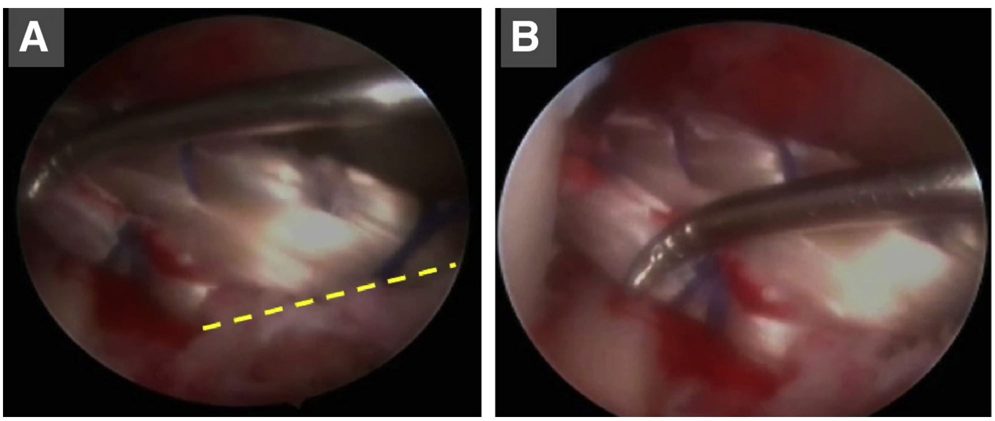

Fig 12. Arthroscopic views of the right knee through the anterolateral portal showing that the 2 grafts occupy most of the footprint of the native anterior cruciate ligament at its tibial attachment (yellow dotted line; A) with no posterior cruciate ligament or notch impingement (B).

Table 1. Advantages of the Technique

Anatomic ACL reconstruction
1. 2 separate bundles
2. At anatomic position
3. With correct orientation
4. Bundles reciprocally act
Hamstring tendon autograft
1. Preserves quadriceps tendon
2. Retrograde passage easier than antegrade passage of graft through tibial tunnels
Branched tibial tunnel
1. Less injury to intra-articular structures (small tibial apertures)
2. Less synovial fluid passage to upper tibia (the tibial branch axis is not in line with tibial stem axis)
3. Less biologic reactions and little cost (only 1 interference screw at tibial stem)
4. Tunnel branching restores tibial footprint of ACL, allows more contact area between proximal part of graft and tunnel in tibial tunnel branch
Single femoral tunnel
1. One tunnel reduces risk of tunnel blowout/confluence
2. Correct graft position and orientation (2 eccentric femoral holes)
3. Reduces surgical time, cost, and biologic reactions (1 interference screw)

ACL, anterior cruciate ligament.

and 4 points of fixation. This is demanding and increases surgical time and requires many implants, increasing both costs and possible complications.[1,2]

Other complications reported with double-bundle reconstruction are overconstrained knee and tension imbalance within AM and PL bundle grafts.[7,22] Tunnel confluence,[9] fractures between tunnels, osteonecrosis of the lateral femoral condyle, and difficult revision surgery were also reported.[23]

Because of anatomic considerations, tunnel malposition, or a large-diameter reamer, meniscal injury is 1 of the risks of ACL reconstruction. It was recently shown that the AM meniscal root can suffer iatrogenic injury during tibial tunnel creation for ACL reconstruction.[24] In addition, anatomic single-bundle ACL reconstruction can significantly decrease AL meniscal root attachment area and strength[25,26] because the mean percentage of ACL fibers overlapping the AL meniscal root insertion was 41.0%, 68.9%, 53.9%, and 64.3% in the coronal and sagittal planes, respectively.[27]

A posterolateral location of the tibial tunnel aperture within the footprint of the native ACL increases extrusion of the lateral meniscus postreconstruction, in which extrusion provides a measure of injury to the anterior root,[28] whereas using an average tibial tunnel diameter of 9.32 mm in the center of the tibial footprint is associated with no magnetic resonance imaging evidence of AL meniscal root injury even >1 year postoperation.[29] A case report on the occurrence of iatrogenic injury to the PL meniscal root from a posteriorly malpositioned double-bundle ACL tibial tunnel has been described.[30]

Using a greater size reamer causes a relatively higher risk of lateral meniscal anterior root injury in single-bundle reconstruction than in double-bundle ACL. Lateral meniscus and stability should be examined arthroscopically after reaming with large reamers.[31]

Aiming at decreasing these complications, Sergiu et al.[6] performed an anatomic double-bundle ACL reconstruction with a free quadriceps tendon autograft through a single femoral tunnel and 2 independent tibial tunnels. They created 3 independent tunnels and 3 points of fixation. In this technique, the quadriceps tendon is harvested, and antegrade graft passage to the tibial tunnels is difficult and complex.

Other modified techniques were limited by difficulty, graft/suture entanglement,[32] graft length <22 cm, femoral footprint diameter <16 mm,[33] and difficulty in passing the graft through the anteromedial portal except after its widening and removal of the ACL remnant.[34]

Sometimes when using a modified technique with 2 femoral sockets and 1 tibial tunnel,[35] it is nearly impossible to pass the graft through the tibial tunnel without consideration of each bundle length and using a specially designed dilator for tibial tunnel preparation. In addition, the fixation of the AM bundle at a lower angle is not easy to obtain.[35]

In this article, ACL reconstruction is performed with a hamstring tendon autograft passed through a single branched tibial tunnel and a single femoral tunnel. The graft fixation is done by 2 interference screws: 1 screw at the femoral tunnel and the second at the stem of the tibial tunnel.

Both the AM and PL bundles are tensioned and fixed at 20° of knee flexion, as recommended by Patrick et al.[7] The 20/20 tensioning protocol restores relatively normal tension curves in each bundle and allows reciprocal action between bundles, as well as avoiding excessive stress on the AM bundle in full flexion.

The procedure restores nearly native ACL anatomy with regard to size, location, and orientation. The grafts occupy most of the native ACL tibial footprint. The PL graft passes from the tibia to the femur in a posterolateral direction, whereas the AM graft passes from the tibia to the femur in an anteromedial direction.

The use of only 2 interference screws is advantageous from an economic and biologic point of view. It decreases cost and reduces the amount of hardware capable of promoting foreign body reactions.[36,37]

Tibial tunnel branching increases the contact area between the graft and the tunnel in the tunnel branch; this might be beneficial in graft incorporation and remodeling. Tibial tunnel branching also makes small tibial apertures in which their axes are not in line with the stem axis. This, with graft fitting in the tibial tunnel, partially seals the tunnel and decreases synovial fluid passage to the upper tibia, which might cause tunnel widening (Video 1).

Table 2. Surgical Steps, Pearls, and Pitfalls

Surgical Steps	Pearls	Pitfalls
Graft harvest	Closed tendon stripper is used to free the graft	Use of an open tendon stripper may be associated with premature graft cutting
	Tendon graft of adequate length and thickness should be used	Short or thin graft may lead to reconstruction failure later on
Tibial tunnel creation	Tibial anterior cruciate ligament footprint should be at least 16 mm	Size <16 mm is a contraindication to double-bundle reconstruction
	Tibial tunnel is created before femoral tunnel	Femoral tunnel creation first increases joint debris accumulation
	Tibial tunnel branches are created before the stem	Stem creation first may lead to difficult tunnel branching and central entry of the tunnel branch at the end of the stem
	Anteromedial (AM) tibial tunnel length should be $\geq$ 35 mm	Size <35 mm may lead to difficult tunnel branching—tunnel confluence
	Correct entry point positions lead to easy, correct, and accurate apertures	Incorrect entry point positions lead to difficult, incorrect, or inaccurate apertures
	Entry point of the AM tunnel branch on the tibial cortex is anterior, lateral, and inferior to the entry point of the posterolateral (PL) tunnel branch	
	Aperture of the AM tunnel branch is anterior and medial to the aperture of the PL tunnel branch	The same angle of inclination leads to incorrect apertures
	Angle of inclination of the PL tibial tunnel to the sagittal plane (40°) is more than that of the AM tibial tunnel (20°)	
	Extend the knee after pin insertion and before tunnel reaming to evaluate notch impingement	
	Clean the tunnel branches from any debris or soft tissues, especially at apertures	Bone and/or soft-tissue debris at the tunnel branches may prevent graft passage
	Intratunnel arthroscopy helps in washing out the tunnel and evaluating tunnel branching	
	Plastic tube is used at the tibial tunnel stem after completion of the tibial tunnel creation	If not used, loss of joint distension and bad visualization may occur
Femoral tunnel creation	Femoral tunnel stem is drilled first, then the PL hole, and then the AM hole	Stem creation first leads to correct hole drilling
	Freehand technique is used	Femoral guide use is associated with less flexibility
	PL hole is made using the accessory AM portal	PL hole drilling through the AM portal is difficult and inaccurate
	AM hole is made using the AM portal at the AM corner of the tunnel	AM hole drilling through the AM portal is correct and easy
	Entry (the portal) to the AM hole is anterior and lateral to the entry to the PL hole	Use of 1 portal gives an inaccurate hole site only
	AM hole is anterior, superior, and medial to the PL hole	
	Passage sutures in the PL hole in the femoral tunnel are passed, then those in the AM hole	
	Sutures loops are retrieved through the PL tunnel tibial branch, then those in the AM tibial tunnel branch	If the reverse is done, this leads to false passage of the graft
	Passage sutures for the gracilis tendon graft should appear under/posterior to the passage sutures for the semitendinosus tendon graft	
	Use of suture loops allows correct position of grafts in the femoral tunnel	
	En face arthroscopy viewing helps in evaluation of the tunnel, tunnel holes, and tunnel sutures	
Graft passage and fixation	Interference screw wire is passed in the anterolateral (AL) corner of the femoral tunnel before graft passage	This allows easy fixation after graft passage
	Gracilis tendon graft (PL bundle) is passed first	The reverse is difficult
	Graft tensioning is done at 20° knee flexion for both bundles	Different angles cannot be accommodated; a 45/15 tensioning protocol is not applied here
	Interference screw fixation is used in the AL corner at the femoral tunnel	It is difficult to apply the interference screw at the posteromedial corner; if applied, the graft may impinge on it
	Interference screw fixation is better used in the posteromedial corner at the tibial tunnel stem below the graft	If screwed at the AL corner above the graft, the interference screw will be prominent anteriorly, elevating the anterior tibial cortex

Table 3. Risks and Limitations

Risks and Pitfalls	Limitations
Confluence of tibial tunnel branches, incorrect or inaccurate tibial apertures, difficult graft passage at tibial tunnel, inaccurate femoral hole site, false passage of the graft bundles	Tibial footprint <16 mm Tibial tunnel length <35 mm (the short tunnel is associated with difficult tunnel branching and may cause merging of the branches)

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