Anatomic Double-Bundle Anterior Cruciate Ligament Reconstruction Using In Situ Hamstring Graft With 4 Tunnels

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Abstract: A careful review of the literature suggests that a significant number of patients undergoing anterior cruciate ligament (ACL) reconstruction have less-than-optimal results. Although overall outcomes of ACL reconstruction are favorable, there remains considerable room for improvement. Anatomically, the ACL consists of 2 major functional bundles, the anteromedial bundle and the posterolateral bundle. Biomechanically, both bundles contribute significantly to the anterior and rotational stability of the knee. Therefore anatomic double-bundle ACL reconstruction techniques may further improve the outcomes in ACL surgery. This article presents a technique for arthroscopic double-bundle ACL reconstruction that includes the use of 2 femoral and 2 tibial tunnels to restore both the anteromedial and posterolateral bundles of the ACL with minimal hardware for fixation.

Anterior cruciate ligament (ACL) reconstruction techniques have improved over the past 20 years, and satisfactory outcomes can be achieved in most patients. However, a careful review of the literature suggests that approximately 15% to 25% of patients undergoing ACL reconstruction have less-than-optimal results. These data suggest that there remains considerable room for improvement in ACL reconstruction. One possible explanation for unsatisfactory outcomes in some patients may be that most ACL replacement techniques focus on the reconstruction of one ACL bundle and do not consider the reconstruction of both major functional ACL bundles.

The ACL can be divided into 2 major functional bundles, namely the anteromedial bundle (AMB) and posterolateral bundle (PLB). The terminology of these 2 bundles is based on their tibial insertion. The AMB originates more proximally on the femoral side and inserts anteromedially on the tibial side, whereas the PLB originates more distally on the femoral side and inserts posterolaterally on the tibial side. Yagi et al. compared the kinematics of ACL-intact knees, ACL-deficient knees, knees with single-bundle ACL reconstruction, and knees with double-bundle ACL reconstruction. They showed that double-bundle ACL reconstruction restores knee kinematics more closely to normal than single-bundle reconstruction, especially during a combined rotatory load of internal tibial torque and valgus torque.

These anatomic and biomechanical considerations suggest that surgical reconstruction of both the AMB and the PLB may result in improved outcomes compared with single-bundle reconstruction of the AMB. Recently, various authors have proposed double-bundle ACL reconstruction as a potential procedure to improve the outcomes of ACL reconstruction. This article presents a 4-tunnel technique for anatomic double-bundle ACL reconstruction with minimal hardware fixation.

Operative Technique

After application of the tourniquet to the proximal thigh, the patient is positioned supine with the knee flexed on the side of the table and the foot resting on the surgeon’s thigh. Routine diagnostic arthroscopy is performed initially to diagnose the injury and evaluate other knee pathologic conditions (Video 1). A standard anterolateral (AL) portal and then a high AM portal are used for the arthroscope and an accessory AM portal for the instrumentation. Any additional operative procedure, such as meniscectomy or chondral lesion debridement, is performed before the ACL reconstruction. The ACL stump is debrided as required for adequate visualization of the lateral intercondylar (resident’s) and bifurcate

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ridges (Fig 1). Fibers that are not obstructive are left intact for possible vascular and cellular ingrowth. No notchplasty is needed except in chronic cases. The diameter of the footprint should be measured with an arthroscopic ruler and should not be less than 16 mm to allow drilling of 2 femoral tunnels measuring 5 mm each with a posterior cortex and a bone bridge measuring at least 2 mm each.

The semitendinosus and gracilis tendons are harvested through the standard 2-cm oblique incision with an open stripper (Arthrex, Naples, FL). The 2 tendons are then dissected free from each other at the insertion site but maintaining their periosteal attachment. This step adds about 2 to 3 cm to their length and facilitates their redirection to the tibial tunnel. Only 20 to 22 cm of the whole length is required for the procedure, and any more than that is excised. Then, both are sutured to each other with No. 2 or 5 Ethibond suture (Ethicon, Somerville, NJ) under tension after adjustment of their lengths in the presumed direction of passage from inferomedial to superolateral while being held with a clamp. This prevents any kinks in the tendons. The tendons are sewn twice beginning at the proximal end, extending distally for 3 to 4 cm with 1 stitch and for another 3 to 4 cm afterward with the other stitch. Each throw should encircle three-quarters to four-fifths of the tendon and be 5 mm apart. This creates a Chinese finger trap–like configuration, which constricts the tendon end and tapers it when tension is imparted on the sutures, facilitating passage of the tendon through the drill holes (Fig 2). The tendons are then kept inside the wound until the tunnels are made.

**Femoral Tunnels**

The knee is hyperflexed to 120°. First, the site for the tunnel of the PLB is marked with a straight microfracture awl (Conmed Linvatec, Largo, FL) from the accessory AM portal. It lies anterior to the bifurcate ridge and below the lateral intercondylar ridge while being viewed from the high AM portal in this hyperflexed knee position. The guide pin is inserted from the AM portal to the mark and is advanced until it passes the femoral cortex (Fig 3). A cannulated drill, 4.5 to 5.5 mm in diameter, is inserted along the guide pin under arthroscopic visualization to create the femoral tunnel. The reaming debris of the tunnels is removed, and the sharp edges of the osseous tunnel are smoothed with a shaver. Next, the same steps are performed for the AMB, but the mark will be posterior to the bifurcate ridge. After drilling, there will be a bone bridge of at least 2 mm between the 2 tunnels (Fig 4).

**Tibial Tunnels**

While one is viewing the tibial attachment of the ACL from the anterolateral portal, first, the tip of the ACL C-guide system (Arthrex) is positioned in the footprint of the PLB, just anterior and lateral to the PCL and posterior to the level of the posterior aspect of the anterior horn of the lateral meniscus. The guide pin is inserted from the medial aspect of the proximal tibia just above the sartorius tendon through the graft harvest incision. The angle of the C-guide is 45° to the horizontal plane and 30° to the sagittal plane. With the position of the tip of the guidewire confirmed, it is overdrilled with a cannulated reamer measuring 4.5 to
5.5 mm in diameter. Next, the same steps are performed for the tunnel of the AMB. The footprint is 7 mm anterior to the PCL and anterior to the level of the posterior aspect of the anterior horn of the lateral meniscus behind the transverse meniscal ligament (Fig 5).

**Passage of AMB**

A 2-cm longitudinal incision is made immediately proximal to the lateral femoral epicondyle, distal to the exit of the guide pin, and through the iliotibial band. The vastus lateralis muscle is bluntly elevated off the intermuscular septum. When it has been clearly identified, it is possible to reach the posterior aspect of the joint capsule passing over this structure. Then, the gastrocnemius muscle is subperiosteally elevated off the posterior notch of the lateral femoral condyle. The exits of both the AMB and PLB femoral tunnels with the guidewire first in the PLB and then in the AMB can be palpated with a finger and debrided of soft tissue with a curette. The PLB tunnel is retro-drilled from the lateral incision to remove any soft-tissue obstacles on the mouth of the tunnel and facilitate graft passage (Fig 6).

The ends of a monofilament No. 2 suture or a thin metal cerclage wire are passed through the eyelet of the guidewire, which is pulled out, passing the suture from the AM portal to the lateral incision through the femoral AMB tunnel (Fig 7). A grasper is inserted from the tibial AMB tunnel intra-articularly to pull the loop
end of the monofilament suture out from the graft incision. The stitches of the graft are then passed through the monofilament suture loop end, which is driven out with the stitches from the lateral incision, followed by the graft (Fig 8).

Passage of PLB

Again, the guidewire is passed from the lateral incision through the PLB femoral tunnel and out from the AM portal. The ends of a monofilament No. 2 suture are passed through the eyelet of the guidewire, which is pulled out, passing the suture from the lateral incision to the AM portal through the femoral PLB tunnel. A grasper is inserted from the tibial PLB tunnel intra-articularly to pull the ends of the monofilament suture out from the graft incision. The stitches of the graft are then passed through the monofilament suture loop end, which is driven out with the stitches from the graft incision, followed by the graft (Fig 9).

Fixation of Reconstruction Graft

The graft is tensioned after the knee is cycled through a full range of motion approximately 20 times and secured with a 6-mm bio-interference screw (ConMed Linvatec) in the tibial PLB tunnel or with 2 staples on the proximal tibia 2 cm distal to the tunnels while the knee is in 20° of flexion (Fig 10). Tips for this technique are summarized in Table 1.

An intra-articular drain is inserted through the anterolateral portal. The iliotibial tract defect is then closed. The medial fascia over the pes anserinus is closed. The skin is closed with No. 3-0 monofilament suture (Fig 11). The drain is removed after 48 hours with a new light wound dressing if soaked. Patients are kept in a knee immobilizer while ambulating from the first day for 2 to 3 weeks.

Discussion

Using the semitendinosus and gracilis tendons for double-bundle reconstruction of the ACL is becoming more popular with time. Harvesting these tendons will result in minimal subtraction from the knee joint’s supporting structures. Measurement of hamstring power with the Cybex machine (Lumex, Ronkonkoma, NY) showed an average hamstring strength of 97% of the normal side in a period of 6 to 12 months after harvesting both tendons. This negligible loss of power could be explained partly by vigorous postoperative rehabilitation and partly by the possibility of regrowth of the semitendinosus and gracilis tendons.

The technique of using the semitendinosus and gracilis tendons as a distally based graft described by Cho appears attractive because the retained tibial attachment of the tendons would probably maintain a source of blood supply through the medial inferior genicular artery as it pierces the pes anserinus tendons and through the osseous attachment, which could improve the neoligamentization process. They allow different architectural reconstructions because of their length and versatility. Moreover, the literature confirms the structural and mechanical validity of this choice with biomechanical properties similar to those of the ACL, especially when used in a double-bundle method.

Other element that favors the use of hamstring tendons graft in a double-bundle technique is the requirement of relatively small femoral drill holes with a consequently larger surface contact area for rapid healing and graft incorporation. In addition, pulling the free femoral end of the graft against the physiologically fixed tibial attachment and then over the femoral bone bridge allowed easier setting of the desired tension of the PLB and then the AMB compared with all other methods that use free grafts.

The current clinical assessments of ACL reconstructions have been largely based on the ability of surgical intervention to reduce the positive finding of anterior...
drawer test in response to anterior tibial loads. Daniel et al.\textsuperscript{14} showed that restoration of certain laxity parameters alone, such as KT-1000 measurements (MEDmetric, San Diego, CA) and the Lachman test, after ACL reconstruction does not prove restoration of normal function. A meta-analysis performed by Yunes et al.\textsuperscript{15} estimated that only 60% to 64% of patients undergoing single-bundle hamstring tendon ACL reconstruction returned to their preinjury levels of activity.

Woo et al.,\textsuperscript{16} in a laboratory study, showed that the single-bundle reconstruction is certainly effective in restoring anterior knee stability in response to an anterior tibial load but it is not so effective in reducing the coupled anterior tibial translation resulting from combined valgus and internal tibial torque. They questioned the real effectiveness of the single-bundle ACL reconstruction, which has been developed to reproduce the AMB, and suggested a more anatomic reconstruction that restores the 2 major bundles of the ACL.

The double-bundle anatomy of the ACL was first described in 1938\textsuperscript{17} and was confirmed by Girgis et al.\textsuperscript{18} in 1975. The bundles are believed to act in concert to provide anterior translational and rotational stability to the tibia on the femur. Although some clinical studies have shown improved results for double-bundle versus single-bundle reconstructions in terms of anterior laxity and pivot-shift examination findings,\textsuperscript{6,19,20} several have shown equivalent results\textsuperscript{21,22} and none has shown improved patient outcomes. Analysis of these studies is difficult because of widely variable surgical and experimental methods.

A limitation of single-bundle reconstruction that predominantly replicates only the AMB is that such a construct cannot withstand the load distributed in the normal ACL, where the 2 bundles have different behavior according to the amount of stress and direction in which they are loaded.\textsuperscript{23} Gabriel et al.\textsuperscript{24} have shown that the AMB and PLB have different distributions of in situ forces when the knee is subjected to anterior tibial and rotatory loads. In cadaveric knees they have quantitatively described that the 3-dimensional orientations during passive motion of the AMB and PLB are significantly different. In fact, the PLB has an almost constant orientation in the 3 planes during passive range of motion, whereas the AMB has 20° of variation.

Using the same investigation method, Loh et al.\textsuperscript{25}—in a laboratory study using a robotic device—evaluated the anterior tibial translation and the ACL’s in situ forces in the native ACL, in the deficient ACL, and in the reconstructed ACL under a 114-N anterior tibial load and 5-Nm internal rotation torque. The ACL was reconstructed with a single-bundle technique, and the

Table 1. Tips

| Tips                                                                 |
|---------------------------------------------------------------------|
| Releasing the 2 tendons from each other near their tibial attachment allows more length of the graft and easier redirection into the tunnels. |
| Good preparation of the graft to be tapered at its proximal end makes its passage through the tunnels easier.                   |
| The AM portal for femoral tunnel drilling should be tangential to the medial femoral condyle with the knee hyperflexed to allow short tunnel drilling without articular cartilage injury. |
| The lateral thigh incision should be midway between the lateral femoral condyle and the exit of the guidewire.                |
| Retro-drilling of the PL tunnel through the lateral thigh incision makes passage of the graft easier.                        |
femoral tunnels were drilled at the 10- and 11-o’clock positions for the right knee. Loh et al. found that the 10-o’clock femoral position restored anterior tibial translation and in situ forces toward knee extension significantly better than the 11-o’clock femoral position. However, the 10-o’clock femoral position was also not effective in restoring intact knee kinematics.

It is worth noting that the coupled anterior tibial translation after anatomic double-bundle ACL reconstruction was 24% less than that after traditional single-bundle ACL reconstruction. In addition, the in situ force in the ACL graft was 93% of the intact ACL as compared with only 68% for single-bundle ACL reconstruction. Of course, anatomic double-bundle ACL reconstruction involves more surgical variables, which could affect the final outcome. One of the major concerns is the force distribution between the anteromedial (AM) and posterolateral (PL) grafts and the potential of overloading either 1 of the 2 grafts. Shorter in length and smaller in diameter, the PL graft would have a higher risk of graft failure.

The tensioning protocols described are highly variable, with tensioning of the grafts at a wide range of knee flexion angles, using different amounts of initial tension, which is not uniformly measured. Yet, the tensioning protocol used has been shown to affect initial loading of ACL grafts.

To find a range of knee flexion angles for graft fixation that would be safe for both of the grafts, Gabriel et al. discovered that when both the AM and PL grafts were fixed at 30°, the in situ force in the PL graft was 34% and 67% higher than that in the intact PLB in response to an anterior tibial load and combined rotatory load, respectively. Meanwhile, when the AM graft was fixed at 60° and the PL graft was fixed at full extension, the force in the AM graft was 46% higher than that in the intact AMB under an anterior tibial load. A follow-up study found that when the PL graft was fixed at 15° and the AM graft was fixed at either 45° or 15° of knee flexion, the in situ forces in the AM and PL grafts were below those of the AMB and PLB (i.e., neither graft was overloaded). Thus these flexion angles are safe for graft fixation.

In a cadaveric model, Cuomo et al. investigated the effects of different tensioning protocols on anterior and rotational laxity. They used 3 tensioning protocols: sequential tensioning of the AMB at 90° and PLB at 20°, sequential tensioning of the PLB at 20° and AMB at 90°, and tensioning of both bundles at 20°. The amount of tension was determined by the amount required to match the intact knee’s anteroposterior (AP) laxity. They found that tensioning the PLB first required the most tension to restore AP laxity (48 N). The tension in each bundle required to restore normal laxity in the other tensioning protocols was 17 to 19 N. Tensioning both bundles at 20° best restored normal AP and rotational laxity. Tensioning the PLB first at 20° led to too

### Table 2. Advantages

| Advantage | Description |
|-----------|-------------|
| Double-bundle orientation of natural ACL | |
| Easier setting of desired tension against physiologically fixed tibial attachment and then over femoral bone bridge | |
| Minimal hardware for fixation with lowest possible cost | |

### Table 3. Limitations

| Limitation | Description |
|------------|-------------|
| The graft length should be ≥22 cm. | |
| The femoral footprint diameter should be ≥16 mm. | |
much tension on it; tensioning the AMB first at 90° led to unpredictable laxity restoration.

Similarly, Mae et al.\textsuperscript{33} investigated the effect of flexion angle on relative motion of the tibia on the femur in single-bundle ACL reconstructions in cadaveric knees. They tensioned the grafts to 44 N at 0°, 20°, and 90° of knee flexion. They found that the relative motion of the tibia on the femur as the knee was brought through passive ROM was closest to the intact knee when the grafts were tensioned with the knee at 20°. In addition, they measured the load between the femur and tibia and found that this was also closest to the values in the intact knee when the grafts were tensioned with the knee at 20°.

A critical point in drilling the femoral tunnels is the position of the AM portal. It should be approximately at the level of the ACL footprint, not too medially; otherwise, the drill bit will injure the articular surface of the medial femoral condyle and the exit of the tunnel will be too lateral on the posterior femoral notch, which increases the used length of the graft. If it is too lateral, the femoral tunnels will be oblique with oblong orifices and the posterior cortex will be thin and weak, with the risk of blowout.

In this 4-tunnel double-bundle ACL reconstruction technique, the 2 bundles in the joint are positioned in a more anatomic fashion, which should improve the kinematic performance of the grafts with promising better results, especially in rotation control. It has the advantages of double-bundle orientation of the natural ACL, easier setting of the desired tension against the physiologically fixed tibial attachment and then over the femoral bone bridge, and minimal hardware for fixation with the lowest possible cost (Table 2). Limitations of this technique include that the footprint diameter should be more than 16 mm to avoid posterior cortex blowout or opening of the femoral tunnels on each other and the graft length should be more than 22 cm (Table 3).

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