Anatomic Reconstruction of the Anteromedial and Posterolateral Bundles of the Anterior Cruciate Ligament Using Hamstring Tendon Grafts

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Purpose: To develop and evaluate an anatomic reconstruction procedure of the posterolateral and anteromedial bundles of the anterior cruciate ligament (ACL). **Type of Study:** Anatomic study and case series. **Methods:** The femoral attachment of the anteromedial and posterolateral bundles of the ACL was anatomically analyzed with 5 cadaveric knees. Using another 3 cadaveric knees, anatomic reconstruction of the posterolateral and anteromedial bundles was performed with the transtibial technique, and tunnel positioning and graft function in a range of knee motion was observed. Based on this anatomic study, an anatomic reconstruction procedure of the anteromedial and posterolateral bundles was developed using hamstring tendon autografts. This procedure was carried out in 57 consecutive patients with an ACL-deficient knee. The patients were followed-up for a minimum of 24 months. **Results:** We developed the arthroscopically assisted anatomic reconstruction procedure of the posterolateral and anteromedial bundles, involving a new method of creating the tibial and femoral tunnels for the posterolateral bundle. To visualize the femoral attachment of the posterolateral bundle, the medial infrapatellar portal was more useful than the lateral portal. In clinical results, the side-to-side difference of anterior laxity averaged 1.0 mm with a standard deviation of 0.9. **Conclusions:** The anatomic reconstruction of the anteromedial and posterolateral bundles using hamstring tendon autografts is clinically practical in the treatment for the ACL-deficient knee. **Level of Evidence:** Level IV. **Key Words:** Anterior cruciate ligament reconstruction—Two-bundle procedure—Anatomic study—Hamstring tendon autograft—Posterolateral bundle.

Currently, the hamstring tendon graft is used as an alternative to the bone–patellar tendon–bone graft for anterior cruciate ligament (ACL) reconstruction.[1-6] However, some reports comparing the outcome of ACL reconstruction between the 2 grafts have indicated preferable results from bone–patellar tendon–bone with regard to knee stability.[7,8] Conventional ACL reconstruction procedures have grafted only a single bundle that mimics the anteromedial bundle. The reason may be that normal ACL function cannot be restored by 1-bundle ACL reconstruction, because the normal ACL consists of the anteromedial and posterolateral bundles. To improve the results of 1-bundle ACL reconstruction using the hamstring tendon graft, 2-bundle reconstruction procedures have been developed. The idea of such procedures was described by Mott[9] and Zaricznyj[10] in the 1980s. Recently, Rosenberg and Graf[11] introduced an arthroscopically assisted 2-bundle procedure using 2 femo-

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ral tunnels. However, they drilled only 1 tunnel in the tibia. Muneta et al.[12] described an arthroscopically assisted 2-bundle procedure with 2 tunnels in the femur and the tibia, respectively. In their articles, however, the 1:30-o'clock orientation for the left knee (at the 10:30-o'clock orientation for the right knee) was recommended as the location of the femoral tunnel for the posterolateral bundle. This positioning appeared to be similar to that in the Rosenberg and Graf study.[11] No studies have clearly shown a method to identify the location of the femoral attachment of the posterolateral bundle in the arthroscopic visual field. Therefore, there is a high possibility that their tunnel position for the posterolateral bundle is not located on the anatomic attachment. In addition, Hamada et al.[13] reported that there were no significant differences in clinical results of ACL reconstruction with the hamstring graft between the conventional 1-bundle procedure and the Rosenberg and Graf 2-bundle procedure. Thus, we have found that an anatomic ACL reconstruction procedure has not yet been established, specifically concerning posterolateral bundle reconstruction.

The purpose of this multidisciplinary study was to develop an arthroscopically assisted anatomic reconstruction procedure of the posterolateral and anteromedial bundle of the ACL using hamstring tendon autografts. The first specific aim of the study with cadaveric knees was to clarify where and how the anatomic attachment of the posterolateral bundle can be identified on the lateral condyle of the femur under arthroscopic observations, and whether the femoral tunnel for the posterolateral bundle can be created without injuring normal structures of the knee using the transtibial tunnel technique. The second specific aim of the clinical study was to report the 2-year follow-up results of this ACL reconstruction procedure.

METHODS

Study Design

Anatomic Study: An anatomic study was performed with a total of 8 cadaveric knees. In 5 of the 8 knees, the muscles and the tendons around the joint as well as the capsular ligaments were removed. In the primary observation, the shape and function of the ACL were noted in the various positions of the knee. Then the femur was split in the sagittal plane with an oscillating saw, and the posterior cruciate ligament with the medial half of the femur was resected from the tibial insertion. This exposure allowed us to observe the ACL from the medial side of the knee. After the anteromedial and posterolateral bundles of the ACL were identified, the midsubstance of the ACL was sharply resected with a knife, leaving 1-mm long ligament tissues at the femoral and tibial insertions. The femur was fixed to a stainless steel stand with a specially designed clamp so that the longitudinal axis of the femur was set at the horizontal plane. A digital camera (Sony, Tokyo, Japan) was secured to another stand so that a picture of the lateral condyle could be taken with a precise medial view (90° to the axis of the femoral shaft) and anteromedial views (60° and 30° to the axis of the femoral shaft). Proximal, distal, anterior, and posterior direction on the picture were defined as shown in Fig 1, and the attachment of the ACL was 2-dimensionally measured on the picture.

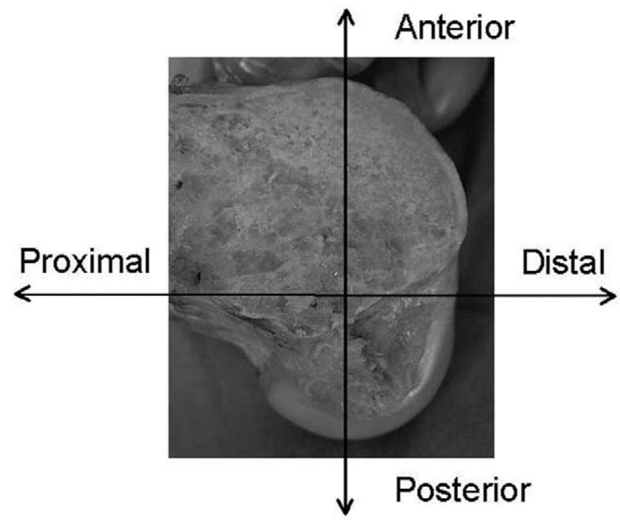

FIGURE 1. Definition of direction on the femur.

Specifically, in order to determine the center of the attachment of the anteromedial bundle, an offset guide system (Transtibial Femoral ACL Drill Guide; Arthrex, Naples, FL) was used, because there were no obvious landmarks on the most posterior aspect of the notch at the junction of the intercondylar roof and the medial wall of the lateral femoral condyle. This guide system, which consists of 5 guide sizes (4-, 5-, 6-, 7-, and 8-mm offsets), provided placement of Kirshner wire by referencing the over-the-top position. Each guide was used in the standard manner and a Kirshner wire was inserted through the guide. Then, when the tip of the wire pointed out of the center of the attachment of the anteromedial bundle, the offset size and the so-called clock orientation of the wire were recorded.

In the remaining 3 knees, after the muscles and the tendons around the joint were removed, the patella and the patellar tendon were resected so that we could directly observe the ACL. The midsubstance of the ACL was sharply resected with a knife, leaving 1-mm long ligament tissues at the femoral and tibial attachments. Then, anatomic reconstruction of the posterolateral and anteromedial bundles was performed in the same manner as that described later. The movement of the 2 bundles was observed in the various positions of the knee.

Clinical Study: Based on the previously described anatomic study, a clinical study was carried out with 57 consecutive patients (33 men, 24 women; average age, 23 years) with isolated ACL unilateral deficiency. Fifteen patients were classified as acute cases and they underwent reconstruction surgery between 4 and 6 weeks after injury. The remaining 42 patients were classified as chronic cases. Each patient underwent the anatomic anteromedial and posterolateral bundle reconstruction using hamstring tendon autografts, which was newly developed in this study. Surgery was performed by one of the authors (K.Y.) using an arthroscopically assisted technique. The medial meniscus was injured in 5 knees, the lateral meniscus in 7 knees, and the bilateral menisci in 2 knees. Seven menisci were sutured, and the remaining 9 menisci were resected. The patients were prospectively followed-up for a minimum of 24 months (range, 24 to 36 months). Subjective evaluation was performed using the modified Noyes scoring system (maximum score, 50 points) preoperatively and postoperatively.[14] Objective evaluations involved a range of knee motion, the side-to-side anterior laxity measured with a KT-2000 arthrometer (MEDmetric, San Diego, CA), and quadriceps and hamstring strength. The side-to-side anterior laxity was measured at 30° and 90° of knee flexion. Peak isokinetic torque of the quadriceps and the hamstrings was measured at 60°/second of angular velocity using Cybex II (Lumex, Ronkonkoma, NY) in both knees before and after surgery. Muscle torque measured in the uninvolved knee at each period was represented as a ratio (%) to the uninvolved value. In addition, the patellofemoral grinding test and manual knee laxity tests were clinically investigated.

Operative Procedure and Postoperative Management

After the knee was examined under spinal or general anesthesia, a routine diagnostic arthroscopy was carried out with the tourniquet inflated. According to the arthroscopic diagnosis, meniscus tears were repaired with an inside-out technique, although sutures were not tied until completion of the ligament reconstruction. In cases where a torn meniscus could not be repaired because of degeneration or avascularity, it was partially resected. No treatments were administered for softening or fissuring of the articular cartilage. At this point, arthroscopy was temporarily stopped. An approximately 4-cm long longitudinal incision was made in the anteromedial portion of the proximal tibia. The semitendinosus and gracilis tendons were harvested using a tendon stripper.

Arthroscopy was resumed through the lateral infrapatellar portal. The ACL remnant was resected, leaving a 1-mm long ligament tissue at the femoral and tibial attachments to obtain landmarks for inserting guidewires. Notchplasty was not performed. First, we created a tibial tunnel for the posterolateral bundle. To insert a Kirschner wire as a guidewire, we used a Wire-navigator (Meira, Nagoya, Japan) that had been reported in our previous study.[3,6] This device was composed of a Navi-tip portion and a Wire-sleeve portion (Fig 2A). The Navi-tip portion consisted of sharp tibial and femoral indicators. The axis of the Wire-sleeve passed through the tip of the tibial indicator. The Navi-tip portion was introduced into the joint cavity through the medial infrapatellar portal. The surgeon held the tibia at 90° of knee flexion, keeping the femur horizontal. We placed the tibial indicator of the Navi-tip portion at the center of the posterolateral bundle attachment on the tibia, which was located at the most posterior aspect of the area between the tibial eminences, and 5 mm anterior to the posterior cruciate ligament (Fig 2B). Then, keeping the tibial indicator at this point, we aimed the femoral indicator at the center of the posterolateral bundle attachment on the femur (defined as the PL point) (Fig 2B). Commonly, the ACL attachment on the femur could be identified arthroscopically. In such cases, we determined the PL point using method I that is reported later in Results. However, in some cases, the attachment of the PL point could not be identified. In such cases, we determined the PL point using method II that is also described later. When we determined the 2 intra-articular points for the posterolateral bundle, the direction of the extra-articularly located Wire-sleeve was automatically decided (Fig 2A). The proximal end of the sleeve was fixed on the anteromedial aspect of the tibia through the skin incision made for the graft harvest. A Kirschner wire 2 mm in diameter was drilled through the sleeve in the tibia. Careful observation was made to confirm that the wire did not penetrate the medial collateral ligament.

Next, we inserted a Kirschner wire for the antero-

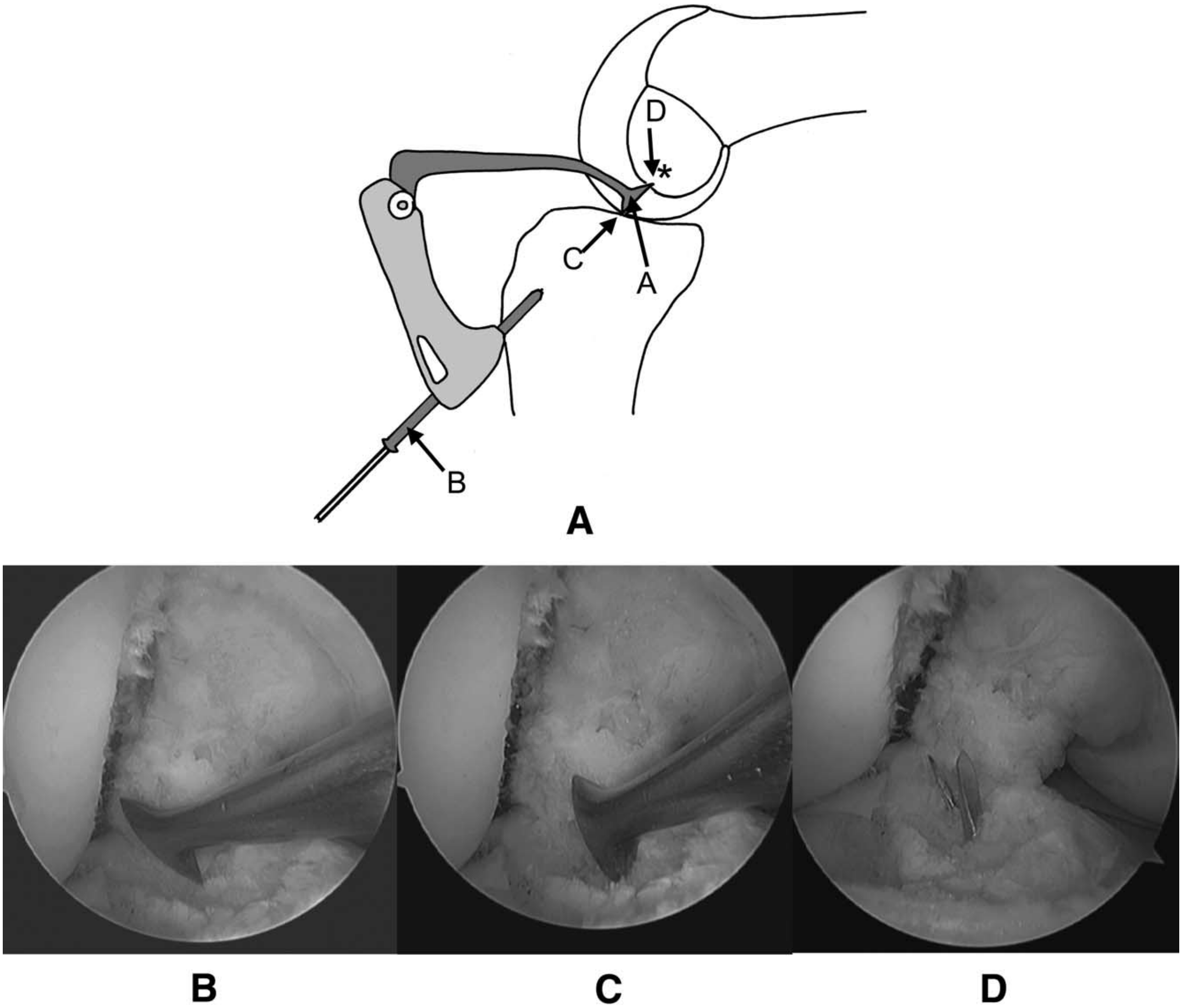

FIGURE 2. Navigation for the tibial tunnels in arthroscopic surgery. (A) A guidewire navigation device (Wire-navigator) composed of a Navi-tip (*A*) and a Wire-sleeve (*B*). The Navi-tip consists of a tibial indicator (*C*) and femoral indicator (*D*). The axis of the Wire-sleeve passed through the tip of the tibial indicator. The direction and position of the Wire-sleeve was automatically decided, independent of those of the Navi-tip. (B) Placement of the Navi-tip of the Wire-navigator to create the posterolateral bundle. (C) Placement of the Navi-tip to create the anteromedial bundle. (D) Two Kirschner wires were drilled through the sleeve in the tibia. Note the difference in the direction between the 2 wires.

medial bundle with the same Wire-navigator. We placed the tibial indicator of the Navi-tip at the center of the tibial attachment of the anteromedial bundle, when the remnant of the normal attachment was identified (Fig 2C). When the attachment of the anteromedial bundle could not be identified, we placed the tibial indicator at the point approximately 7 mm anterior to the Kirschner wire inserted for the posterolateral bundle. Keeping the tibial indicator at this point, we then aimed the femoral indicator at the center of the femoral attachment of the anteromedial bundle (defined as the AM point), which was positioned at the 1:30-o'clock orientation for the left knee or at 10:30 o'clock for the right knee (Fig 2C). The Wire-sleeve was fixed on the anteromedial cortex. This point was located more anterior and distal to the first wire. The knee was extended to ensure that the tip of the second wire was located at the point 5 mm posterior to the anterior edge of the roof in the intercondylar notch. A Kirschner wire 2 mm in diameter was drilled through the sleeve in the tibia (Fig 2D). The 2 tibial tunnels were made with a cannulated drill corresponding to the measured diameter of the prepared substitute.

To create a femoral tunnel for the anteromedial bundle in the lateral condyle, we used the previously described 5- or 6-mm offset guide, with which the distance from the most posterior aspect of the notch to a point of the guidewire could be measured. A Kirschner wire was drilled at the 1:30-o'clock orientation for the left knee or at 10:30 o'clock for the right knee. As described later in Results, the wire was inserted at the AM point with this technique. Then, a tunnel was made with a 4.5-mm cannulated drill using this wire as a guide. The length of the tunnel was measured with a scaled probe. Then, the surgeon again held the tibia at 90° of knee flexion, keeping the femur horizontal. The portal for an arthroscope was changed to the medial infrapatellar portal because it was difficult to precisely identify the attachment of the ACL through the lateral infrapatellar portal. Through the tibial tunnel created toward the PL point, a Kirschner wire was inserted, precisely aimed at the PL point, which is described in Results, and then drilled into the lateral condyle. A 4.5-mm diameter tunnel was created there (Fig 3A), and its length was measured in the same manner as that used for the AM point. Finally, 2 sockets were created for the anteromedial and posterolateral bundles, respectively (Fig 3B), with cannulated drills for the EndoButton fixation system (Acufex Microsurgical, Mansfield, MA),[11] the diameter of which was matched to the 2 grafts prepared with the technique described later. To avoid drilling the socket eccentrically, we increased the drill diameter step by step by approximately 2 mm, and repeated the drilling once or twice. This technique, similar to drilling for an intra-medullar nail, allowed us to create the concentric socket.

The harvested semitendinosus tendon was cut in half. Regarding the gracilis tendon, both ends were resected so that the thickest portion was used for the graft and the length was matched to the length of half of the semitendinosus tendon. One half of the semitendinosus tendon and the resected gracilis tendon were doubled and used for anteromedial bundle reconstruction. The remaining half of the semitendinosus tendon was also doubled and used for the posterolateral bundle reconstruction. Before grafting, a commercially available polyester tape (Neoligament; Leeds-Keio Artificial Ligament, Leeds, UK) was mechanically connected in series with each end of the doubled tendons, using the following original technique.[3] Briefly, 1 or 2 tendons were doubled, both the ends were firmly sutured side-by-side (approximately 1 cm in length) using No. 2-0 polyester threads so that a tennis racket–shaped loop was made. The sutures were made with the circumferential ligation technique around the tendons.[3,8] Then we passed the polyester tape through the tendon loop and wrapped the side-by-side sutured end of the tendon loop with the tape. This tape is flexible, meshed, 10-mm wide, 15-cm long, and strong.[3] Then, this chain-like junction was firmly sutured using the previously described ligation technique. An EndoButton was attached at the looped end with another polyester tape and the previously described circumferential ligation technique. The length of the tape was matched to the femoral tunnel measured during surgery. The diameter of this tendon portion measured with a sizing system (Acufex) showed 7 to 9 mm for the anteromedial bundle graft and 6 to 7 mm for the posterolateral bundle graft. The autogenous tendon portion was fashioned so that the 20-mm long autogenous tendon portion would be placed within each bone tunnel.

This substitute used in the present study was named the hybrid substitute.[3] This substitute involved the following advantages[3,8]: First, short autogenous material can be easily processed by surgeons to be sufficiently thickened and lengthened for grafting, keeping acceptable structural properties. Second, only the doubled tendon autograft portion was placed across the joint with appropriate tendon insertions of approximately 20 mm. Third, fixation of the whole graft to the bone can be easily achieved with an EndoButton and staples. The biomechanical properties of the femur-hybrid substitute-tibia complex were evaluated in previous studies with tensile tests and cyclic loading tests.[15,16] These tests showed that the maximum failure load of the complex fixed with the turn-buckle technique, which is approximately 900 N, is superior to the femur–bone-patella-bone–tibia complex fixed with interference screws, although the stiffness of the former complex is inferior to the latter.[15,16]

The graft for the posterolateral bundle was introduced through the tibial tunnel to the femoral tunnel using a passing pin. The EndoButton was flipped on the femoral cortical surface. Then the graft for the anteromedial bundle was placed in the same manner. Thus, the 2 bundles were intra-articularly placed with different directions (Fig 3C). Postoperative 3-dimensional computed tomograms showed that the 2 tunnels were created at the expected positions, respectively (Figs 3D and E). We confirmed that the 2 grafts did not impinge on the lateral condyle of the femur. For graft fixation, the

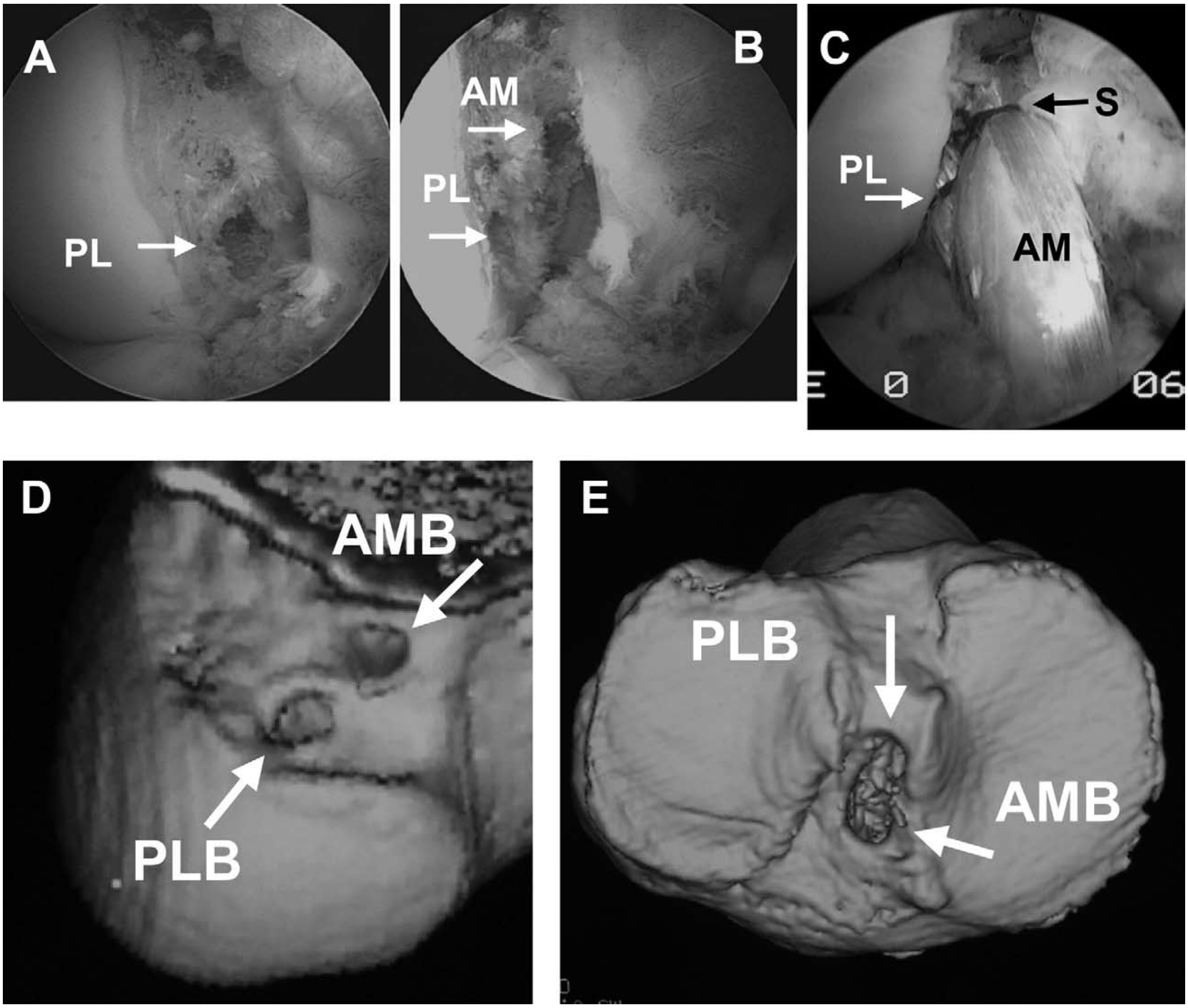

FIGURE 3. Arthroscopic observation of the femoral tunnels and grafted tendons. (A) A tunnel for the posterolateral bundle (PL) observed from the medial infrapatellar portal. Note the position in the femoral condyle. (B) Two tunnels for posterolateral bundle and anteromedial bundle (AM) were observed from the lateral infrapatellar portal. (C) The graft for the anteromedial bundle (AM) is seen anteriorly. The posterolateral bundle was observed behind the anteromedial bundle. Note the difference in the direction between the 2 grafts. An absorbable suture marker (S) is attached to each graft to show the point of flip of the EndoButton. (D and E) Postoperative 3-dimensional computed tomograms show that the 2 tunnels were created at the expected positions.

thigh was manually fixed on a sterilized hard pillow placed on an operating table. This allowed the knee to be flexed to 20° with the unsecured leg, although only the heel was in contact with the operating table. A spring-type tensiometer (Meira) was attached at each end of the polyester tape portion of the graft. An assistant surgeon simultaneously applied a tension of 40 N to the anteromedial graft and a tension of 20 N to the posterolateral graft for 2 minutes using the tensiometer. A surgeon simultaneously secured the 2 tape portions onto the anteromedial aspect of the tibia using a spiked staple (Richards, Smith & Nephew Endoscopy, Memphis, TN). Then, the assistant surgeon pulled the distal end of the tape toward the proximal direction, and the surgeon inserted the second spiked staple onto the tibia to simultaneously fix all the tapes (the turn-buckle stapling technique[3,8]) (Fig 4). After the Lachman test was performed, the incisions were sutured in layers over closed suction drains. Identical postoperative management was followed according to our original rehabilitation protocol based

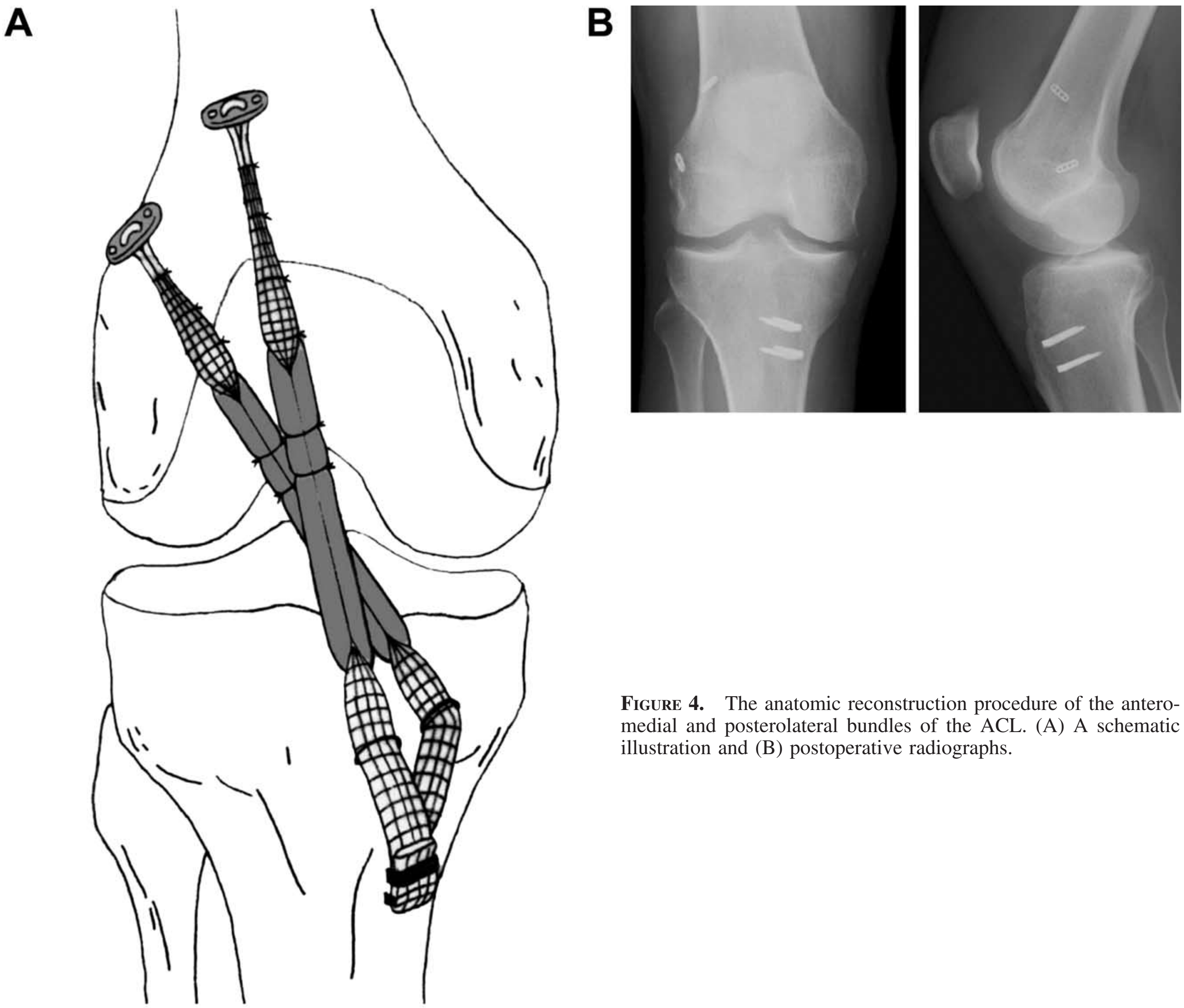

FIGURE 4. The anatomic reconstruction procedure of the anteromedial and posterolateral bundles of the ACL. (A) A schematic illustration and (B) postoperative radiographs.

on the results of our previous biomechanical studies.[16-18]

RESULTS

Anatomic Observations

On the medial surface of the lateral femoral condyle, a footprint of the ACL attachment was in the form of an egg with its long axis inclined toward the posterior direction by 30° to the long axis of the femur (Fig 5A). When we drew a vertical line (defined as V-line) through the contact point between the femoral condyle and the tibial plateau on a digital image taken at 90° of flexion, the V-line and the long axis of the ACL attachment were crossed at the point on the vertical line 5 to 8 mm anterior to the edge of the joint cartilage (Fig 5B). The center of the attachment of the posterolateral bundle (the PL point) was located approximately at this crossing point. Based on these observations, the authors developed 2 methods to determine the PL point intraoperatively. Method I was that the PL point could be determined as the crossing point between the V-line and the long axis of the ACL attachment at 90° of flexion (Fig 5B). Method II, which was proposed for the cases in which the ACL attachment on the femur could not be identified, was that the PL point could be determined as the point 5 to 8 mm anterior to the edge of the joint cartilage on the V-line at 90° of flexion (Fig 5B). Additionally, the PL point could be identified in the 60° anteromedial view.

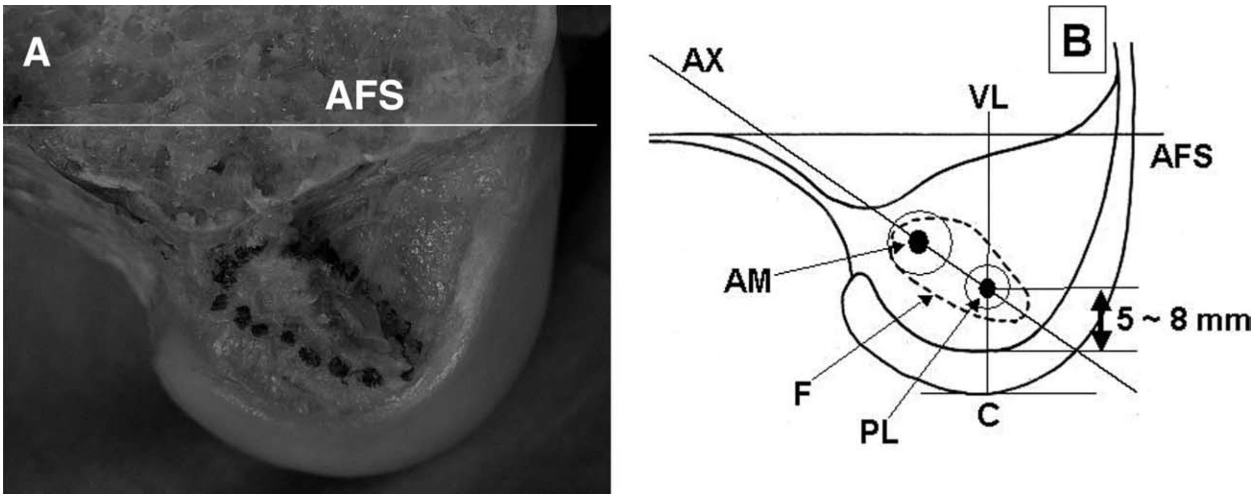

Figure 5. Attachment of the ACL on the femur. (A) A picture of the lateral condyle taken with a precise medial view (AFS, a parallel line of the axis of the femoral shaft). The attachment of the main fibers of the ACL (dotted line) was in the form of an egg. (B) When we drew a vertical line (VL) through the contact point (C) between the femoral condyle and the tibial plateau on a picture taken at 90° of flexion, this line and the long axis of the ACL attachment (AX) crossed at the point (PL) on the vertical line 5 to 8 mm anterior to the edge of the joint cartilage. The center of the attachment of the posterolateral bundle was located approximately at this crossing point. The center of the attachment of the anteromedial bundle (the AM point) was located at the point 5 to 6 mm distal from the back of the femur in measurement using the offset guide.

However, in the 30° anteromedial view, the PL point could not be identified.

The center of the attachment of the anteromedial bundle (the AM point) was located at the point 5 to 6 mm distal from the back of the femur in measurement using the offset guide. This point was oriented at the 1:30-o'clock orientation for the left knee or at the 10:30-o'clock orientation for the right knee.

In ACL reconstruction with the cadaveric knees, the Kirschner wire that was inserted through both the center of the posterolateral bundle attachment on the tibia and the PL point on the femur did not penetrate the medial collateral ligament. The insertion point of the wire on the anteromedial aspect of the tibia was located several millimeters anterior to the medial collateral ligament (Fig 6A and B). This point was also closer to the joint surface than the insertion point for the wire for the anteromedial bundle reconstruction (Fig 6C).

In gross observations on functions of the 2 bundles reconstructed with this procedure during knee motion, the reconstructed anteromedial bundle appeared taut throughout a range of knee motion, but tautness was relatively greater in flexion position greater than 60°. On the other hand, the reconstructed posterolateral bundle appeared to be taut in the nearly extension position of 0° to 45° of knee flexion.

Clinical Results

No complications were experienced either intraoperatively or postoperatively. The whole operation time from the initial incision for arthroscopy to the final skin closure was 55 ± 6 minutes in the cases with only ACL reconstruction.

The average subjective score was 47.5 points. Concerning the postoperative range of knee motion, 2 of the 57 patients had an extension deficit of approximately 5°. Five patients had a flexion deficit of approximately 5°. Regarding the postoperative manual knee laxity tests, positive Lachman test results were detected in 4 patients. Of the 4 patients, all were evaluated as + and none was evaluated as ++. Positive pivot-shift test results were detected in only 1 patient. This patient was evaluated as +, and no patients were evaluated as ++. On the patellofemoral grinding test, there were no complaints of patellofemoral pain nor was any crepitation detected.

The side-to-side differences of anterior laxity measured with the KT-2000 at 20 lb averaged 1.0 ± 0.9 mm; the differences at manual-maximum pull averaged 1.5 ± 1.1 mm. In KT-2000 measurements at manual-maximum pull, 49 patients showed 0- to 2-mm differences, and 8 patients showed 3- to 5-mm differences. There were no patients with more than 5-mm differences in the measurements.

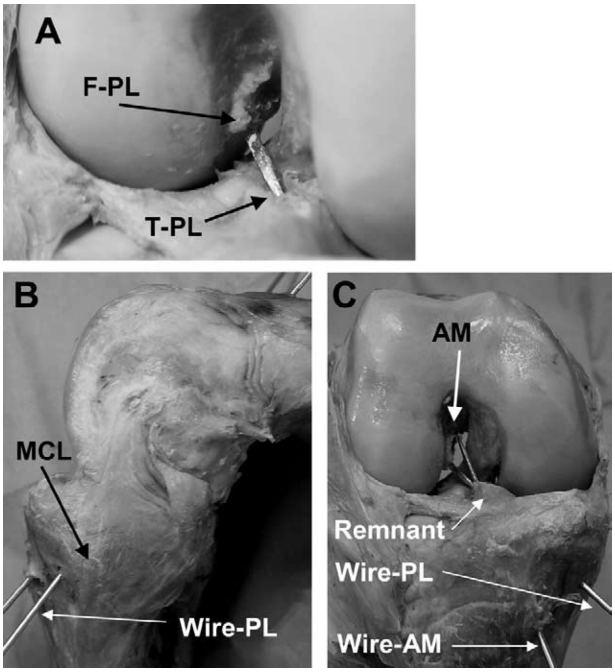

FIGURE 6. The key principle of the transtibial tunnel technique for posterolateral bundle reconstruction. (A) A guidewire could be inserted through the center of the tibial attachment and the center of the femoral attachment of the posterolateral bundle. (B) The insertion point of the wire on the anteromedial aspect of the tibia was located several millimeters anterior to the medial collateral ligament (MCL). (C) This point was also closer to the joint surface than the insertion point for the wire for the anteromedial bundle reconstruction.

Knee extension strength measured with the Cybex averaged 96.7% ± 20.5% at 60° per second, compared with each of the uninjured knees. Knee flexion strength measured with the Cybex averaged 95.0% ± 14.5% at 60° per second, compared with each of the uninjured knee.

DISCUSSION

This study demonstrated a new procedure to anatomically reconstruct the anteromedial and posterolateral bundles of the ACL. Concerning tunnel positioning on the femur, the first important point was that we found the following anatomic facts: The footprint on the femur is egg-like in shape, and its long axis inclines toward the posterior direction by 30° to the long axis of the femur. Specifically, the center of the attachment (the PL point) of the posterolateral bundle is located approximately at the crossing point between the 2 lines, the long axis line of the ACL attachment and the vertical line (V-line) drawn through the contact point between the femoral condyle and the tibial plateau at 90° of flexion. These observations are supported by the previous study reported by Harner et al.[20] This knowledge obtained from the anatomic study conducted for arthroscopic surgery is considered to be practically useful for knee surgeons.

The second important point was that, based on the anatomic facts, we showed how to arthroscopically determine the center (PL point) of the femoral tunnel for posterolateral bundle reconstruction. Namely, when the ACL attachment on the femur can be identified, the PL point can be determined as a crossing point between the V-line and the long axis of the ACL attachment at 90° of flexion (Fig 6B). If the attachment cannot be identified in chronic or avulsion cases, the PL point can be determined as a point on the V-line and 5 to 8 mm anterior to the edge of the joint cartilage at 90° of flexion (Fig 6B). It is noted that the PL point cannot be represented with the traditional clock method (for example, 3 o'clock), because this point is located more distal to each point on the clock, which is vertically located at the posterior outlet of the intercondylar notch. To arthroscopically determine the PL point, we recommend the use of the medial portal. Regarding tunnel positioning for the anteromedial bundle, a Kirshner wire was inserted at the point 5 to 6 mm distal from the back of the femur in measurement using the offset guide. This point was oriented at the 1:30-o'clock orientation for the left knee or at the 10:30-o'clock orientation for the right knee. These guidelines are useful for arthroscopic surgeons who want to anatomically reconstruct the 2 bundles of the ACL.

Also concerning tunnel positioning on the tibia, we developed a new concept for the creation of a tibial tunnel for ACL reconstruction in this study. Previously, the position and the direction of the tibial tunnel were determined independent of the femoral tunnel. The new concept is that the position and the direction of the tibial tunnel should be determined depending on the intra-articular graft position and direction to be placed later on. Namely, the tibial tunnel is created at 90° of flexion so that the axis of the tunnel is identical to the axis of the intra-articular portion of the graft. This concept is considered to be more useful for posterolateral bundle reconstruction. To achieve this concept with high reproducibility, we developed the guidewire navigator. This tool allowed us to imagine the intra-articular position and the direction of each bundle to be reconstructed, and to determine the extra-articular insertion point on the tibia for a guidewire, which was located directly on the axis of the bundle. The tibial tunnel for the posterolateral bundle did not injure the medial collateral ligament and had an extra-articular outlet at the appropriate portion on the femur. These results provided a key principle of the transtibial tunnel technique for anatomic posterolateral bundle reconstruction. Actually, we did not clinically experience any problems in creating the tunnels. The guidewire navigator is considered to be an essential tool needed for this surgery. The orientation of the 2 intra-articular grafts resembles that of the normal ACL. However, it is unclear at the present time how much of the normal function of the ACL is restored. This should be clarified in the near future.

It is important to compare our procedure with others concerning tunnel positioning. To our knowledge, only 2 reports are available for review at the present time. Concerning the 2 tunnels in the femur, Muneta et al.[12] recommend the 12:30-o'clock orientation for the anteromedial bundle and 1:30-o'clock orientation for the posterolateral bundle. Rosenberg and Graf[11] did not clearly describe the tunnel positions. However, because they used a single tunnel in the tibia with the transtibial technique, the 2 tunnels had to be drilled in the relatively narrow area around the 1:00- or 11:00-o'clock positions. Therefore, it is considered that they created the 2 tunnels at positions similar to those reported by Muneta et al.[12] In our procedure, the tunnel for the anteromedial bundle was created at the point similar to the point for the posterolateral bundle in Muneta et al.'s procedure, and the tunnel for the posterolateral bundle in our procedure was created at the extremely different point that was located more posterior and more distal to Muneta et al.'s point, as described earlier. Regarding the tunnels in the tibia, Rosenberg and Graf[11] used 1 tunnel, as discussed previously. Muneta et al.[12] reported that the tibial guidewire for the anteromedial bundle was positioned in the center of the natural ACL insertion and that for the posterolateral bundle it was aimed about 3 mm posterior of the anteromedial guidewire. We placed the intra-articular outlet of the tibial tunnel for the posterolateral bundle at a position similar to theirs. However, our placement of the extra-articular outlet of this tibial tunnel was different, because this outlet was placed at the point more proximal and more posterior than their point. In addition, concerning the intra-articular outlet of the tibial tunnel for the anteromedial bundle, we did not place it at the center of the whole ACL insertion, but placed it at the center of the attachment of the anteromedial bundle itself, which was located more anterior to the center of the ACL insertion. Thus, tunnel positioning was obviously different between our 2-bundle procedure and the previous 2-bundle procedures.

Now the advantages and disadvantages of the anatomic 2-bundle procedure should be discussed. The normal ACL has a 3-dimensional structure consisting of collagen fibrils that will respond to various shear and rotational stresses to the knee.[21-23] Theoretically, ACL reconstruction with the anatomic 2-bundle procedure has some possible advantages over a 1-bundle reconstruction. First, it can help restore functions that resemble those of the normal ACL. Yagi et al.[24] suggested biomechanical advantages of the 2-bundle procedure to the 1-bundle procedure in their in vitro study. The second possible advantage is concerned with graft healing within the bone tunnel. Because only the margin of the tendon graft anchors with collagen fibers resembling Sharpey's fiber to the tunnel wall in ACL reconstruction,[25,26] there is a high possibility that tendons located at the core portion of the thick multi-strand graft are not directly fixed to the bone tunnel. From this viewpoint, the reconstruction with 2 relatively thin bundles is superior to that of 1 thick bundle when the same tendon materials are used for reconstruction. On the other hand, possible disadvantages of the anatomic 2-bundle procedure involve the difficulty of the technique, the subsequent long operation time, the economically high cost, the dysfunction of the 2 reconstructed bundles, and no significant difference in clinical results compared with the 1-bundle reconstruction.

In our anatomic study, however, the 2 bundles reconstructed with this procedure appeared to be functioning during knee motion. Namely, the anteromedial bundle graft appeared to be taut throughout a range of knee motion, although the tautness was greater in the flexion position over 60° than in the extension position less than 45°. In addition, the posterolateral bundle graft appeared taut in the nearly extension position less than 45°. These functions of the 2 bundles during knee motion appeared similar to those of the normal bundles.[27,28] These observations were encouraging for continuing this clinical study on the long-term follow-up results. However, we did not quantify the observed functions as the tension pattern or the length pattern. Therefore, we could not compare our observations with those reported by quantitative studies,[28,29] although our observations appeared to correspond with the biomechanical results from the cadaveric anatomic reconstruction model reported by Yagi et al.[24] The functions of the 2 bundles should be evaluated by quantitative methods in the near future.

In our clinical study, the incision-to-closure operation time was only 55 ± 6 minutes. We did not experience any intraoperative problems concerning the tunnel positioning, the graft placement, or the graft fixation. There were no postoperative complications, such as infection, neurovascular injury, cartilage injury, injuries in other knee structures, or delayed wound healing. In addition, our preliminary clinical results seem to be encouraging. The 2-bundle procedure showed a better trend with respect to anterior stability in manual knee laxity tests and there were fewer patients with more than 5-mm differences measured with the KT-2000, compared with the results of our experience using a 1-bundle technique under the same aggressive rehabilitation 2 years after surgery.[3,5] We believe that the arthroscopically assisted anatomic reconstruction procedure of the anteromedial and posterolateral bundles using the hamstring tendon autografts is a clinically practical treatment for the ACL-deficient knee. However, for establishing the efficacy of this 2-bundle reconstruction, further prospective comparative study is needed.

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