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Intraoperative evaluation of anteroposterior and rotational stabilities in anterior cruciate ligament reconstruction: lower femoral tunnel placed single-bundle versus double-bundle reconstruction

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Abstract Twenty-six patients with anteroposterior (AP) laxity of the knee, associated with torn anterior cruciate ligament (ACL), were prospectively randomized for arthroscopic lower femoral tunnel placed single- or double-bundle reconstruction using hamstring tendons. We evaluated AP and rotational stabilities under regular loads (a 100-N anterior load and a 1.5-N m external–internal load) before and after ACL reconstruction, comparing single- and double-bundle reconstruction with our original device for applying quantitative tibial rotation and the navigation system intraoperatively. No significant differences were found between the two groups in AP displacement and total range of tibial rotation at 30° and 60° of knee flexion. We found that a lower femoral tunnel placed single-bundle reconstruction reproduced AP and rotational stability as well as double-bundle reconstruction after reconstruction intraoperatively.

Keywords ACL reconstruction ·
Anteroposterior stability · Rotational stability ·
Navigation system · Intraoperative evaluation

Introduction

The anterior cruciate ligament (ACL) is one of the most frequently injured ligaments of the knee joint and is generally treated with surgical reconstruction [15]. The goal of ACL reconstruction is to restore the normal function of the native ACL. Conventional single-bundle ACL reconstructive procedures have concentrated mainly to restore the function of the anteromedial (AM) bundle. However, the normal ACL can be divided into two bundles, AM and posterolateral (PL). To mimic more closely the normal structure of the ACL, double-bundle reconstruction has been performed [1, 2, 5–7, 11, 21, 24]. Some previous basic and clinical reports have demonstrated the advantage of the double-bundle reconstruction over the conventional single-bundle reconstruction in terms of AP and rotational stability [10, 17, 18, 22, 23]. On the other hand, in recent single-bundle reconstructions, in order to have better tibial rotational stability and AP stability at a nearly extension position of the knee, the femoral tunnel has been placed in a lower position [14]. However, only a few studies have compared the double-bundle reconstruction with the lower femoral tunnel placed single-bundle reconstruction in terms of AP and rotational stability [10, 14, 18, 22]. Therefore, the purpose of this study was to evaluate AP and rotational stabilities using our original device and the navigation system for applying quantitative loads before and after ACL reconstruction, comparing the lower femoral tunnel placed single-bundle ACL reconstruction with double-bundle ACL reconstruction intraoperatively.

Patients and methods

From July 2006 to July 2007, we carried out a randomized, prospective study to compare AP displacement and rotation of tibia in lower femoral tunnel placed single-bundle ACL reconstruction, with those in anatomical double-bundle reconstruction before and after ACL reconstruction in Hiroshima University Hospital; 18 patients underwent

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lower femoral tunnel placed single-bundle ACL reconstruction (SB group) and 15 underwent anatomical double-bundle reconstruction (DB group), using multistranded autologous hamstring tendons under general anesthesia with muscle relaxant. We did not use a tourniquet throughout the surgery and included the measurements. They were randomized according to the identification number in their medical record, even number as single-bundle ACL reconstruction group and odd number as double-bundle reconstruction group. These patients had a side-to-side difference of more than 3 mm with an anterior force of 30 lb or symptomatic rotational instability showing positive pivot-shift phenomenon. We excluded patients with prior intraarticular or extraarticular ligament reconstructed knees, or those with presence of the posterior drawer sign, varus/valgus instability of the knee, or those with severe osteoarthritic changes (joint space narrowing of more than 50% in any compartment). After these exclusions, 13 were in the SB group (9 men and 4 women) with a median age of 21 years (15–31) at the time of surgery. The DB group comprised 13 patients (8 men and 5 women) with a median age of 21 years (13–49) at the time of surgery. There were no significant differences in background factors regarding gender, age, the tendons used for the reconstruction, meniscal injuries treated by partial meniscectomy or meniscal repair. This study was reviewed and approved by the ethics committee of our university, and an informed consent was obtained from all patients.

Operative technique

One of the senior authors (M.O.) performed all reconstructions arthroscopically with a few assistant surgeons. A skin incision of 4 cm was made on the medial side of the proximal tibia, over the insertion of the pes anserinus. After incising the expansion of the sartorius, only the semitendinosus tendon was harvested using a tendon stripper.

## Lower femoral tunnel placed single-bundle ACL reconstruction

Routine arthroscopic inspection was performed through lateral and medial infrapatellar portals with a 30-oblique arthroscope. The tibial and femoral stumps of the torn ACL were excised using a motorized shaver system. While viewing the tibial attachment of the ACL, a 2.0 mm Kirschner wire was inserted into the point which is 2 mm anterior and 2 mm medial to the center of its attachment from the medial aspect of the proximal tibia, using the Protrac ACL guide system (Acufex; Smith and Nephew) with 40° of tibial drill angles. With the position of the tip of the

Kirschner wire confirmed, we overdrilled the wire with a cannulated reamer of the same diameter as that of the largest diameter of the graft. The position of the femoral tunnel was between the target point of the AM bundle and PL bundle in the double-bundle ACL reconstruction (10 o'clock position) (Fig. 1a). When a 2.4 mm guide-wire could not be inserted into the selected position for the femoral attachment through the tibial tunnel, it was inserted through the medial infrapatellar portal. The guide-wire was drilled through the femur to emerge on the lateral aspect of the thigh. After overdrilling using the Endobutton drill, the diameter of which was 4.5 mm, the femoral tunnel was created using an endoscopic cannulated drill. The length of the femoral tunnel should be at least 21 mm (15 mm for the graft and 6 mm for the Endobutton flipping). The proximal ends were fixed using an Endobutton CL (Acufex; Smith and Nephew, Mansfield, Massachusetts), and the distal ends were sutured with Endobutton tape (Acufex; Smith and Nephew). In all cases, tension was applied to the graft with the knee approaching full extension. The median total amount of the excursion of the graft was 3 mm (1–4). We used a quadrupled semitendinosus tendon to make a graft of at least 7 mm in diameter and more than 60 mm in length. The median diameter of the proximal end of the graft as measured by the sizing tubes was 7 mm (7–8). Only the autologous multistranded tendon spanned the joint space. Notchplasty was not performed in any of the cases. We applied a tension force of 50 N to the distal Endobutton tape of the graft and secured it with two staples with the knee at 30 of flexion.

Double-bundle ACL reconstruction

For the double-bundle reconstruction, a 2.0 mm Kirschner wire was inserted into the posterior half of the tibial attachment of the ACL and it was overdrilled with a cannulated reamer of the same diameter for the PL bundle. We inserted the second K-wire into the anterior half of the tibial attachment of the ACL, and overdrilled it to the same diameter for the AM bundle. A femoral targeted point for AM bundle reconstruction is determined at the point 5–6 mm distal from the back of the femur, which is oriented at the 10:30 orientation for right knee. Concerning the PL bundle reconstruction, with the femur being kept horizontal with the knee flexed at 90° of flexion, the targeted point was determined as the insertion site of the PL bundle 6–7 mm arthroscopically posterior to the anterior cartilage of the lateral femoral condyle (9:30 orientation for the right knee) (Fig. 1b). When the bone tunnel of the femur could not be created through the tibial tunnel, the diameter of each graft was created through the medial infrapatellar portal. Care was taken to leave a distance of at least 1 mm

Fig. 1 a Right knee: view from AM portal at 90° of flexion. The position of the femoral tunnel was between the anatomical footprint of the AM bundle and PL bundle (10 o'clock position), distal to the resident's ridge (*dotted line*) in lower femoral tunnel placed single-bundle ACL reconstruction. **b** Right knee: view from AM portal at 90° of flexion. The positions of the two femoral tunnels were at each anatomical attachment of the AM bundle (10:30 clock position) and PL bundle (9:30 clock position), distal to the resident's ridge (*dotted line*) in double-bundle ACL reconstruction
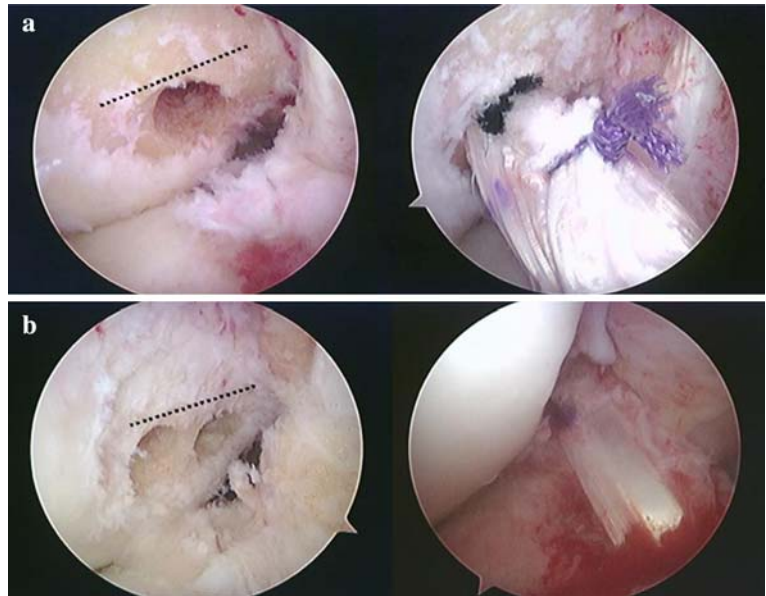

between the two tunnels to avoid overlapping. Both grafts had been passed through the tibial tunnel towards the femoral tunnels. The excursion of each graft was checked. In all cases, both grafts were pulled tight with the knee approaching full extension. The median total amount of the AM bundle excursion was 2 mm (0–4), and that of the PL bundle was 3 mm (1–5). The length of the semitendinosus tendon was greater than 24 cm in all cases, so the tendon was cut at the midpoint. Each tendon was doubled and secured by an Endobutton and Endobutton tape. Thicker grafts were used for the AM bundle and more slender ones for the PL bundle. The proximal diameter was more than 5 mm in all cases. The median diameter of the proximal end of the PL and AM bundles was 5 mm (5–6) and 6 mm (5–7), respectively. Femoral notchplasty was not performed in any of the cases. Tension of 30 N was applied equally to the distal Endobutton tape of each graft. Using double staples, first the PL bundle was fixed with the knee at 15° of flexion, and then the AM bundle was fixed with the knee at 30° of flexion.

Intraoperative measurements and statistics

We evaluated the AP displacement of the tibia in neutral rotation, and the total range of tibial rotation with the knee at 30° and 60° of flexion before and after reconstruction intraoperatively, using our original device and navigation system (Orthopilot ACL reconstruction V 2.0, B. Braun Aesculap, Tuttlingen, Germany). This original device has three components which include the boot, the rotational torque wrench and the stock (Fig. 2a–c). Fixing the patient's ankle in this boot prevents rotation of the ankle

when a rotational load is applied using the torque wrench. In addition, to keep the femur neutral position we fixed the femur on the operated side to the leg holder and the assistant surgeon held the femur tight. This device enables us to apply a quantitative tibial rotational torque equally. We used the navigation system only for the measurement of AP displacement of the tibia and total range of tibial rotation, but not for the placement of femoral and tibial bone tunnels.

First, the femoral and tibial transmitters were fastened to the femur and tibia using special fixation elements with two K-wires (2.4 mm each), respectively. Then we registered extra-articular anatomic landmarks which included tibial tuberosity, the anterior edge of the tibia, and medial and lateral points of the tibial plateau with the pointer. We registered the knee kinematics between 0° and 90° of knee flexion. After these registrations, we fixed the ankle on the operated side to the original device. Then we measured the AP displacement of the tibia in neutral position under the anterior tibial load of 100 N and the total range of tibial rotation under the rotational torque of 1.5 Nm with the knee at 30° and 60° of flexion before and after reconstruction intraoperatively (Fig. 2b, c). These measurements before reconstruction were performed after removal of the ACL remnant. The observers were the same individuals who performed the surgery. To examine the intra- and interobserver measurement reliability, repeated measurements of six patients were performed. Three observers measured the AP displacement of tibia and the total range of tibial rotation with the knee at 30° and 60° of flexion before and after reconstruction three times each. The differences in the parameters between the two groups were analyzed using the Mann–Whitney U and χ^2 tests. All data are shown as
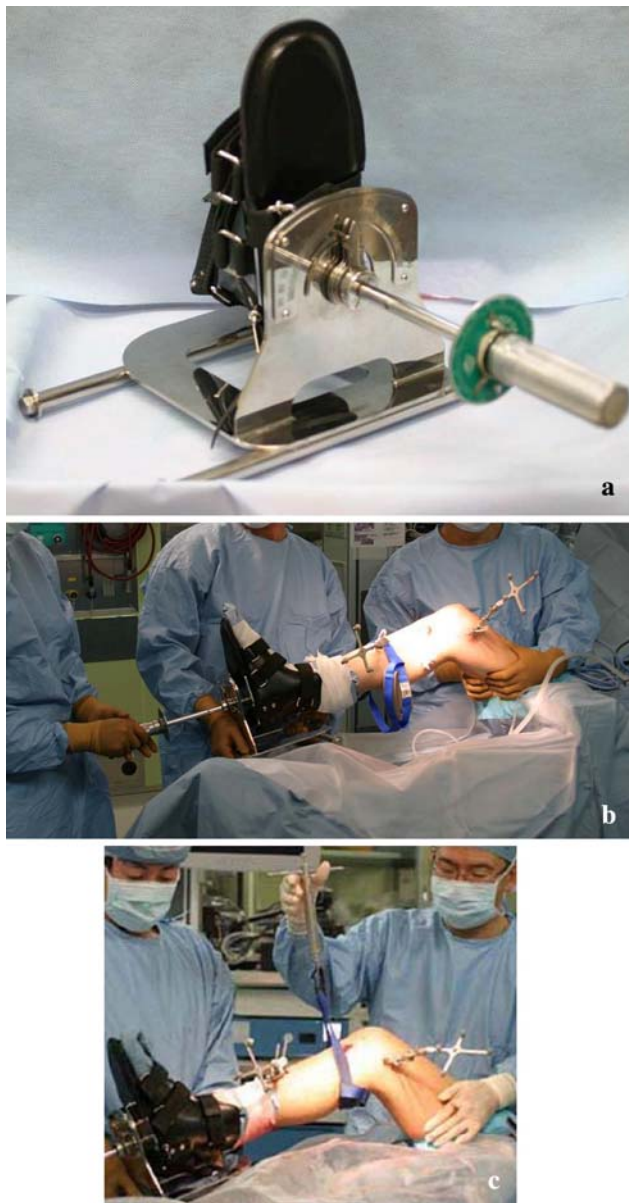
Fig. 2 **a** Our original device for applying quantitative tibial rotational torque has three components, which include the boot, the rotational torque wrench and the stock. **b** Fixing the patient's ankle in this boot can prevent rotation of the ankle when we apply a rotational load by the torque wrench. Using this device, we can apply the quantitative tibial rotational torque evenly. **c** We measured the AP displacement of the tibia in neutral position under the anterior tibial load of 100 N and the total range of tibial rotation under the rotational torque of 1.5 Nm with the knee at 30° and 60° of flexion before and after reconstruction intraoperatively

median (range). The AP displacement of tibia and the total range of tibial rotation were compared by using the Wilcoxon signed-rank test before and after ACL reconstruction and the Mann–Whitney U test between the groups. The threshold for statistical significance was set at $P < 0.05$. To quantify the reliability of the measurement using our

original device and navigation system, intraclass correlation coefficients (ICCs) were calculated for the intra- and interobserver analyses. The ICC values above 0.75 represent good reliability/accuracy. All statistical analyses were carried out on Statview-J5.0 (SAS Institute Inc.).

Results

The ICCs values for both intraobserver and interobserver reliability in the AP displacement of tibia and the total range of tibial rotation with the knee at 30° and 60° of flexion before and after reconstruction were all more than 0.75. These results indicate good intra- and interobserver reliability in the measurements using our original device and navigation system. The AP displacement of the tibia at 30° knee flexion in the SB and DB groups was 11 mm (8– 24) and 9 mm (4–16), respectively, before the operation, and 3 mm (2–9) and 2 mm (1–3) after reconstruction (Fig. 3). At 60° knee flexion in the SB and DB groups, displacement was 7 mm (5–13) and 9 mm (4–13), respectively, before reconstruction, and 3 mm (1–6) and 2 mm (0–5) after reconstruction (Fig. 4). The AP displacement of the tibia after reconstruction significantly decreased compared to displacement before reconstruction in both groups at each flexion angle ($P < 0.05$). There was no significant difference between the two groups with regard to AP displacement of the tibia before and after reconstruction (Figs. 3, 4).

The total range of tibial rotation at 30° knee flexion in the SB and DB groups was 14° (7–24) and 17° (9–29), respectively, before the operation, and 8° (5–16) and 12° (3–24) after reconstruction (Fig. 5). At 60° knee flexion in the SB and DB groups, the rotation was 16° (12–30) and 18° (8–31), respectively, before reconstruction, and 11° (5–18) and 14° (6–23) after reconstruction (Fig. 6). The total range of tibial rotation before reconstruction significantly decreased compared to the range after reconstruction in both groups at each flexion angle ($P < 0.05$). There was no
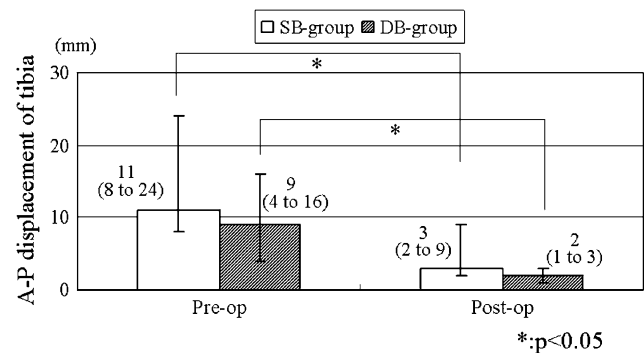
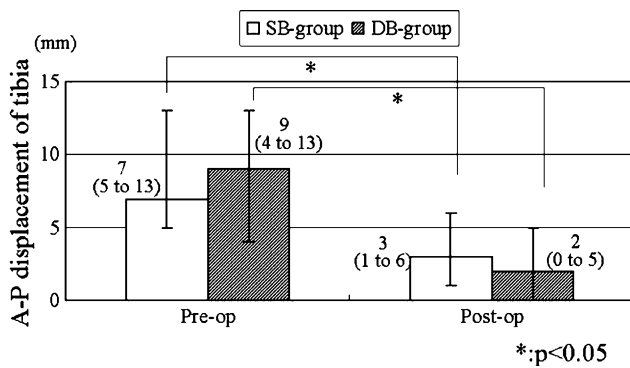**Fig. 3** A–P displacement of the tibia with the knee at 30° flexion

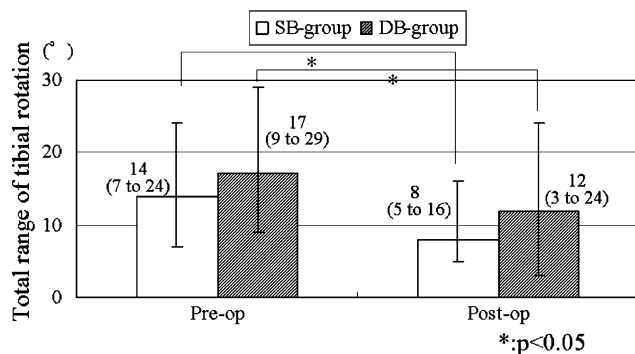**Fig. 4** A–P displacement of the tibia with the knee at 60° flexion

Fig. 5 Total range of tibial rotation with the knee at 30° flexion
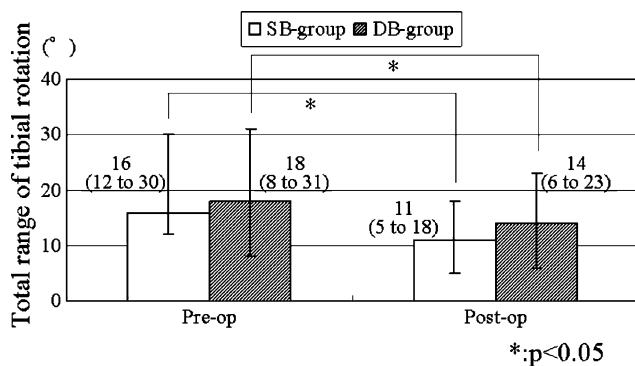

Fig. 6 Total range of tibial rotation with the knee at 60° flexion

significant difference between the two groups with regard to tibial rotation before and after reconstruction (Figs. 5, 6).

Discussion

The normal ACL can be divided into two bundles, the AM and the PL. Amis and Dawkins identified a separate intermediate bundle in the cadaver ACL [3]. The AM bundle of the ACL is normally tighter in flexion and the PL bundle is tighter in extension [3, 8, 13]. The goal of ACL

reconstruction is to restore the normal function of the native ACL. The intact ACL provides both AP stability and tibial rotational stability [4, 9, 12, 20]. To reproduce the anatomical structure and function of the ACL through ligament reconstruction, procedure modifications such as the use of a double-bundle technique or a lower femoral tunnel placement have been proposed, and initial favorable results have been reported [1, 14, 21, 24].

Biomechanical studies using cadaveric knee specimens have reported that a more horizontally oriented graft using single-bundle ACL reconstruction techniques increases transverse plane rotational knee stability and anterior tibial translational stability [16, 19, 23]. Scopp et al. [19] reported that in ex vivo biomechanical studies with a quantitative rotational load, single-bundle ACL reconstructed knees with the oblique (more horizontal) femoral tunnel position at the lateral wall of intercondylar notch in the coronal plane showed less internal tibial rotation than those with the standard femoral tunnel, and no significant difference was found in internal tibial rotation between the oblique tunnel reconstruction and the intact knee.

Some biomechanical studies have compared single-bundle reconstruction with double-bundle reconstruction using cadaveric knee specimens [17, 21]. Yagi et al. [21] reported that with a combined rotatory load, the normalized in situ force for the single-bundle and anatomical double-bundle reconstruction at 30° flexion was 66 and 91%, respectively. They concluded that the anatomic double-bundle reconstruction produced a better biomechanical outcome, especially during rotatory load. Comparing laterally placed single-bundle ACL reconstruction simulating the PL bundle with double-bundle reconstruction, Yamamoto et al. [23] reported that for the stability test such as tibial rotation and AP displacement, there was no significant difference between the single- and double-bundle technique at 15° or 30° flexion, but at 60° and 90° the single-bundle technique displayed more tibial rotation. They supported the need to reproduce both AM and PL bundle function with ACL reconstruction. However, in the current study, total range of tibial rotation significantly decreased after reconstruction at each flexion angle in both groups, and there were no significant differences between the laterally placed single-bundle and anatomical double-bundle reconstruction. These differences in the results may be due to methodology. His studies used cadaver specimens and a robotic system to apply a combined load, such as valgus and internal tibial torque. In a clinical study comparing and evaluating tibial rotation before ACL reconstruction and after PL bundle fixation, anteromedial bundle fixation, and double-bundle ACL reconstruction using the navigation system, Ishibashi et al. [10] reported that no difference occurred at more than 30° knee flexion, and that no variations between reconstruction phases occurred.

However, in our study there were significant differences between pre- and post-reconstruction in both groups at 30° and 60° knee flexion for anterior and rotational tibial stability. In their study, evaluation of the stabilities of the various reconstruction phases was carried out, and the stability test itself was performed manually unlike our method in the current study. However, in our study, accurate load was applied using our original device, and rather than comparing reconstruction phases, we compared single-bundle reconstruction and double-bundle reconstruction. Therefore, our results may not be in accord with those of Ishibashi et al.

In our current study, we showed that lower femoral tunnel placed single-bundle ACL reconstruction reproduced knee stability such as AP displacement and rotation of the tibia as well as double-bundle ACL reconstruction after reconstruction intraoperatively, and we could not demonstrate the advantage of the double-bundle reconstruction in terms of stability of the knee joint over the lower femoral tunnel placed single-bundle ACL reconstruction. We used hamstring tendons, whereby we fixed the graft with 50 N in the single-bundle reconstruction and each graft with 30 N in the double-bundle reconstruction. These high tensions may induce no significant differences between the two groups regarding AP and rotational stabilities.

There are some limitations to the current study. Firstly, there were intraoperative data but no follow-up data. Therefore, in the future we will have to evaluate these stabilities after reconstruction such as at second-look arthroscopy 2 years after surgery. Secondly, we could not evaluate these stabilities comparing the reconstructed knee with the intact knee, because in the intact knee using K-wires to fasten the transmitters to the femur and tibia seems to be invasive beyond the consensus of patients and doctors for a clinical study. Therefore, it is unclear whether normal knee kinematics was restored after ACL reconstruction. Third, for measurements using this navigation system, there is a need to fasten the transmitters to the femur and tibia using the K-wire, which seems too invasive for only measurements. Therefore our current study contained a limited number of patients within both groups, causing insufficient power for statistical analysis. This may cause type II error with the results. Fourth, we applied 1.5 Nm torque in rotational load, which seemed to be low forces a little bit. In previous biomechanical cadaver studies, many authors chose 5 Nm torque in rotational load. However, in this clinical study, we applied 1.5 Nm in rotational load, because we did not want to apply high stress to the grafts after fixation to prevent the slackness of the graft. Finally, because the observers were the same individuals who performed the surgery, there is the potential danger of biased evaluation, although this is difficult to avoid.

Conclusions

This study showed that a lower femoral tunnel placed single-bundle reconstruction reproduced AP and rotational stability as well as double-bundle reconstruction after reconstruction, intraoperatively. Although the exact clinical importance of these findings is unknown, our current data suggest that we may not need to persist in double-bundle reconstruction as long as the single-bundle reconstruction is performed with lower femoral tunnel placement.

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