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ORIGINAL PAPER

Stability comparison of anterior cruciate ligament between double- and single-bundle reconstructions

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Abstract The purpose of this study was to evaluate the intra-operative stability during double-bundle anterior cruciate ligament (ACL) reconstructions (20 knees) using a navigation system and compare the results with those obtained from single-bundle reconstructions (20 knees). After registering the reference points during ACL reconstruction, antero-posterior and rotational stability tests with 30° knee flexion using a navigation system were measured before and after reconstructions on both groups. The change of antero-posterior translation after and before reconstruction was 12.5 mm in the double-bundle group and 10.5 mm in the single-bundle group, showing significant inter-group difference (p=0.014, from 17.5 mm to 5.1 mm in the double-bundle and from 16.6 mm to 6.1 mm in the single-bundle group). The mean rotational stability of the double-bundle group also showed more significant improvement after reconstruction compared to that of the single-bundle group (9.8° in the double- and 5.6° in the single-bundle groups, p<0.001). These findings suggest that a double-bundle ACL reconstruction restores greater knee stability with respect to the antero-posterior and rotational stability than a single-bundle reconstruction.

Résumé Le propos de cette étude est d’évaluer la stabilité per opératoire de la reconstruction du ligament croisé antérieur par deux faisceaux à propos de 20 genoux avec utilisation d’un système de navigation. Ces résultats ont été comparés à ceux obtenus par une reconstruction par un seul faisceau (20 genoux). Après enregistrement des différents points de références, la stabilité des genoux est testée à 30° de flexion en utilisant le système de navigation avant et après la reconstruction dans les deux groupes. La modification de la translation antéro postérieure après et avant la reconstruction était de 12,5 mm dans le groupe à deux faisceaux et de 10,5 mm dans le groupe à un seul faisceau, montrant une différence significative (p=0,014, 17,5 mm à 5,1 mm dans les réfections avec deux faisceaux et de 16,6 mm à 6,1 mm dans les réfections à un seul faisceau). La stabilité en rotation a également été améliorée dans le groupe de reconstruction à deux faisceaux (9,8° contre 5,6° dans le groupe à un seul faisceau, p<0,001). Ces données confirment que la reconstruction des ligaments croisés antérieurs par la technique à deux faisceaux permet d’avoir un genou beaucoup plus stable tant sur le plan antéro postérieur que sur le plan rotatoire si l’on compare cette technique à celle de la reconstruction avec un seul faisceau.

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Introduction

Anterior cruciate ligament (ACL) reconstruction techniques have improved over the last several decades. However, the improvements in function have been achieved with a single-bundle ACL reconstruction, which does not completely reproduce the anatomy and function of the ACL and even patients with apparently stable reconstructed knees occasionally report a feeling of instability or giving way, and/or develop a degenerative joint [11, 12, 20, 21].

Several in vitro kinematic investigations demonstrated that single-bundle reconstructions alone were insufficient in controlling the combined rotatory load and valgus torque that simulates the pivot shift test [9, 22, 27]. Subsequently, they suggested that anatomical double-bundle reconstruction may produce a better biomechanical outcome, especially in controlling rotatory torque, compared to the conventional single-bundle reconstruction.

In a recent biomechanical study, Zantop et al. [27] showed that anteromedial (AM) and posterolateral (PL) bundles stabilise the knee joint in response to anterior tibial loads and combined rotational loads in a synergistic fashion. Therefore, from a biomechanical point of view, double-bundle ACL reconstructions may be more appropriate to restore normal anterior translation and combined rotation than the conventional single-bundle reconstructions.

As a result, double-bundle ACL reconstruction has been advocated to more closely replicate the anatomy [22] and function of the native ligament and to improve the rotational control. Several authors have reported good clinical results [1, 2, 6, 7, 13, 14, 17, 18, 23–25] but few have provided a quantitative evaluation of the rotational stability compared with those of a single-bundle technique.

Recently, computer navigation systems have been developed to improve ACL reconstruction results [4, 8, 10, 16, 19]. In several pilot studies [3, 8, 15, 26], a computer navigation system also provides an accurate evaluation of knee kinematics, including antero-posterior translation and internal–external rotation of the tibia in different knee conditions. To our knowledge, there are few reports concerning the comparison of in vivo stability between single- and double-bundle reconstructions in different groups.

Our hypothesis was that a double-bundle reconstruction would provide better antero-posterior and rotational stability than a single-bundle reconstruction. Therefore, we performed this prospective comparative study to evaluate the antero-posterior and rotational stability between double-bundle and single-bundle reconstruction.

Materials and methods

Patients

Forty consecutive patients awaiting ACL reconstruction using an allograft tibialis anterior tendon were enrolled into this prospective comparative study. Written informed consent was obtained from all patients and they were alternately allocated to a single-bundle (20 patients) or a double-bundle group (20 patients). The patients were excluded if they had an associated collateral ligament injury and grade III or IV radiological degenerative changes. This study was approved by our institutional review board.

Patient demographic data, such as age, gender distribution, time from injury to surgery and the rate of meniscectomy, were comparable in both groups (Table 1). During the reconstruction, a navigation system (OrthoPilot® ACL Version 2.0, B. Braun-Aesculap, Tuttlingen, Germany) was used to evaluate the stability before and after the reconstruction.

Surgical techniques

A single surgeon performed both single-bundle and double-bundle arthroscopic ACL reconstruction techniques using tibialis anterior allografts. Femoral-side fixation was performed with an EndoButton CL® (Smith & Nephew®; Andover, MA) and tibial-side fixation was performed with a bioabsorbable interference screw (Linvatec®; Largo, FL), together with stapling in all patients. Routine diagnostic arthroscopy was performed before ACL reconstruction using the standard anterolateral and anteromedial arthroscopic portals. When concomitant meniscal injuries were present, we performed additional procedures, such as inside-out meniscal repair and partial meniscectomy.

For the double-bundle reconstruction, the allograft was prepared as two double-looped grafts of more than 12 cm in length and 5–6 mm in diameter for posterolateral bundles (PLBs) or 7 mm in diameter for anteromedial bundles (AMBs). The graft loop ends were connected to the EndoButton CL® with 15-mm (PLB) and 20-mm (AMB) loops, and the free ends were prepared with whip stitches. The PL tibial tunnel was located at the centre of the PLB footprint on the tibia (5 mm anterior to the PCL) using a tibial drill guide set at an inclination angle of between 55° and 45° from the sagittal plane (the starting point is just anterior to the superficial medial collateral ligament fibres). The AM tunnel was positioned in a more anteromedial position on the tibial footprint (7 mm anterior and 5 mm medial to the PL tunnel) using a tibial drill guide set at an inclination angle of between 45° and 20° from the sagittal plane. The AM femoral tunnel through the AM portal was prepared at the 1 o'clock position on the left or at the

Table 1 Comparison of the preoperative demographic data of the double- and single-bundle groups

	Double-bundle	Single-bundle	*p*-value
Mean age (years, range)	35.5 (19–50)	30.3 (17–50)	0.308
Gender (male/female)	16/4	15/5	0.705
Time from injury to surgery (months, range)	8.3 (1–26)	7.6 (2–20)	0.352
Number of meniscectomy	6/20	5/20	0.723

11 o'clock position on the right. The PL femoral tunnel was determined as follows: at 5 to 8 mm from the anterior lateral femoral condyle cartilage and 3 to 5 mm from the inferior lateral femoral condyle cartilage with 90° knee flexion and prepared through the accessory AM portal. In order to establish a femoral fixation, the grafts for the PLBs and AMBs were then passed through each bony tunnel and the EndoButton loop was flipped over the anterolateral femoral cortical surface. The knee was then cycled approximately ten times through a full range of motion. The PL graft was fixed with the knee in 10–20° of flexion and manual maximal tension. The AM graft was then fixed at 60–70° of flexion with bio-absorbable interference screws and manual tension. One ligament staple was used for direct additional fixation of protruded AM and PL grafts on the tibial side.

For the single-bundle reconstructions, the allograft was also prepared as two double-looped grafts of more than 12 cm in length and of 8–9 mm in diameter. After tibial tunnel preparation using a drill guide within the posterior aspect of the ACL insertion, a femoral tunnel was then created through the tibial tunnel, which was located at an orientation of 1 o'clock (or 11 o'clock) for the left (or right) knee. Graft passage and fixation material were the same as those of the double-bundle reconstructions done. The knee was then cycled approximately ten times through a full range of motion and a manual tension was applied at 10–20° of knee flexion during the tibial fixation.

Stability study

A computer navigation system was used for the stability test. After confirming the rupture of the ACL by routine diagnostic arthroscopy, the femoral and tibial transmitters were firmly secured to the femur or tibia using a fixation instrument with two K-wires (Fig. 1).

Fig. 1 Navigation setup showing the secured fixation of the femoral and tibial transmitters with two K-wires

Extra-articular anatomical landmarks such as the tip of the tibial tuberosity and the anterior tibial crest of the lower third of the tibia, medial and lateral points of the tibia plateau were registered. After registering the knee kinematics between 0° to 90° flexion, the knee stability test was carried out with 30° knee flexion with maximal manual force using a computer navigation system to determine the antero-posterior translation and the total rotation (internal plus external rotation) of the tibia by a single surgeon (Fig. 2). After complete fixation of the graft in both groups, the anterior translation of the tibia and the total tibial rotation were again measured at the same position with manual maximal force by the same surgeon.

Statistical analyses were performed using SPSS for Windows Release 11.0 (SPSS Inc., Chicago, IL), and tests for normality and distribution were carried out using the Kolmogorov-Smirnov test. The preoperative and postoperative stability for each group were compared using a paired *t*-test. The changes of stability achieved by the operation between the two groups were compared using Student's *t*-test. Significance was determined at $p<0.05$.

Results

The mean antero-posterior translations before the reconstruction in the double-bundle and single-bundle groups were 17.5±2.5 mm and 16.6±2.4 mm, respectively, which were not significantly different ($p=0.219$). The corresponding antero-posterior translation in the double-bundle and single-bundle groups after the reconstruction were improved to 5.1±1.5 mm and 6.1±1.2 mm, showing a significant difference between the two groups ($p=0.020$). The change

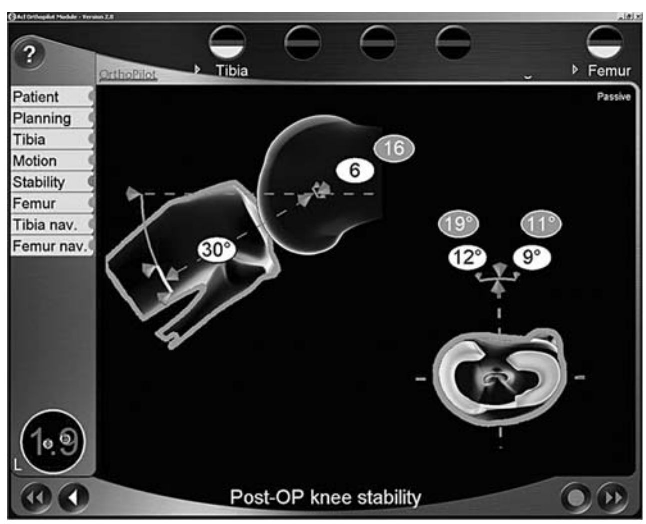

Fig. 2 Measurement of the knee stability after a single-bundle anterior cruciate ligament (ACL) reconstruction. The preoperative antero-posterior tibial translation (16 mm) and total rotation of the tibia (30°) improved to 6 mm and 21° after the graft fixation, respectively

of antero-posterior translation after and before reconstruction also showed a significant inter-group difference (10.5 mm in the single and 12.5 mm in the double-bundle groups, p=0.014, Table 2).

The mean tibial total rotations also improved significantly after the reconstructions in both groups (from 33.2° to 23.3° in the double- and from 35.1° to 29.5° in the single-bundle groups, p<0.001). However, with regard to the change of the total tibial rotation after the reconstruction, the double-bundle group showed a more significant improvement than the single-bundle group (9.8° in the double and 5.6° in the single-bundle groups, p<0.001, Table 2).

Discussion

Anatomically, the ACL can be divided into two functional bundles: the AMB and the PLB [5]. The AMB appears to be an important stabiliser against an antero-posterior load, particularly when the knee is flexed by more than 15°. On the other hand, the PLB provides additional antero-posterior knee stability when the knee is in the near-extended position [21]. Woo et al. [22] reported that single-bundle ACL reconstruction techniques were mainly designed to resist anterior tibial loading, but were insufficient for controlling a combined rotatory load. The complex role of an intact ACL cannot be restored by a conventional single-bundle ACL reconstruction using either hamstring tendons or bone–patellar tendon–bone (BPTB). Hence, unfavourable results may be encountered.

Therefore, several authors have suggested that an anatomical double-bundle ACL reconstruction has some biomechanical advantages over a single-bundle ACL reconstruction [1, 2, 6, 7, 13, 14, 17, 18, 23–25]. Although they reported the superior results of a double-bundle reconstruction with respect to Lachman's test and the pivot shift phenomenon compared with a single-bundle reconstruction after a mid-term follow-up, they did not provide objective quantitative data about the rotational stability [18, 25].

Table 2 Comparisons of the mean antero-posterior translation and total rotation of the tibia before and after the reconstructions between the two groups

	Double-bundle	Single-bundle	p-value
Antero-posterior translation (mm)			
Before reconstruction	17.5±2.5	16.6±2.4	0.219
After reconstruction	5.1±1.5	6.1±1.2	0.020
Change amount	12.5±2.6	10.5±2.3	0.014
Total rotation (°)			
Before reconstruction	33.2±3.6	35.1±3.1	0.077
After reconstruction	23.3±4.0	29.5±3.8	0.000
Change amount	9.8±3.8	5.6±2.1	0.000

The data are presented as mean±SD

Recently, a navigation system has been introduced in ACL reconstruction for the improvement of tunnel placement [4, 8, 10, 16, 19]. Moreover, in cadaveric pilot studies, Colombet et al. [3] showed that a computer-assisted navigation system could be used to evaluate the kinematics and precise quantitative stability of the knee in different knee conditions. Concerning the clinical stability test using the OrthoPilot® navigation system, Ishibashi et al. [8] reported that double-bundle reconstruction was more effective for the reduction of antero-posterior translation and tibial rotation than AMB or PLB reconstruction. However, this study was performed to compare the stability of AM fixation with AMB and PMB fixations in the same patients during double-bundle ACL reconstruction, but they could not carry out an objective comparison because of the different thicknesses of graft (AM: 7 mm; PL: 6 mm; double: both groups). To our knowledge, there have been no reports concerning the stability comparison between single-bundle and double-bundle reconstructions. In this comparative study, we found that a double-bundle ACL reconstruction tended to be more stable than a single-bundle reconstruction in both total antero-posterior translation and tibial rotation. Our study also provided objective data for antero-posterior and rotational stability using a navigation system to support the superior result of a double-bundle reconstruction compared to a single-bundle ACL reconstruction noted in the clinical studies reported by Muneta et al. [17] and Yasuda et al. [25].

However, there were some limitations in this stability study using navigation data. One was that the load was applied manually and not by a testing machine. Other limitations were that all stability tests were done just once by one surgeon and these stabilities were measured during the intra-operative procedure rather than after some follow-up period. However, several validation studies for the stability measured by navigation systems have shown an overall accuracy of less than 1 mm or 1°. Therefore, the data was deemed to be reliable and suitable for this comparative study. However, a further objective study evaluating stability in the clinical setting after a significant follow-up will be needed in order to achieve general acceptance of the observation that double-bundle ACL reconstruction is more effective than single-bundle reconstruction with regard to both antero-posterior and rotational stability.

In conclusion, our results may indicate that double-bundle ACL reconstruction, which attempts to reproduce anteromedial and posterolateral bundles, can provide better antero-posterior and rotational stability than single-bundle reconstruction.

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