ORIGINAL ARTICLE

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Arthroscopic single-bundle versus triple-bundle anterior cruciate ligament reconstruction

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Objective: The aim of this prospective, randomized study was to compare the clinical results of arthroscopic single-bundle (SB) and triple-bundle (TB) anterior cruciate ligament (ACL) reconstruction.

Methods: The study included 105 patients who underwent arthroscopic SB ACL and TB ACL reconstruction. Anterior stress radiographs and the maximal manual muscle test using a KT-2000 arthrometer were used to assess anteroposterior stability and rotational stability was investigated using the lateral pivot shift test at the 24th month follow-up. Clinical results were assessed using the International Knee Documentation Committee (IKDC) and Orthopädische Arbeitsgruppe Knie (OAK) scores preoperatively and at the 24th month follow-up. Postoperative thigh circumference, strength and range of motion (ROM) were compared between groups.

Results: Rotational stability was significantly superior in the TB group than in the SB group. There were no statistically significant differences with regard to residual anteroposterior laxity determined at the 24th month follow-up. No significant difference in terms of IKDC score, OAK score, thigh circumference, strength and ROM was detected between the two groups.

Conclusion: Both arthroscopic SB and TB ACL reconstruction resulted in satisfactory subjective outcome and objective stability. Rotational stability was significantly superior in the TB group.

Key words: Anterior cruciate ligament; arthroscopy; single-bundle; triple-bundle.

Traditional arthroscopic single-bundle (SB) anterior cruciate ligament (ACL) reconstruction has previously been considered the gold standard for the treatment of symptomatic ACL rupture.[1,2] Many patients who undergo SB ACL reconstruction are able to return to sports.[1,3] However, several *in vitro* kinematic studies have described the ACL as consisting of two major functional bundles: the anteromedial and posterolateral bundle.[4,5] Single-bundle reconstruction alone was found to be insufficient in controlling the combined valgus torque and rotatory load that simulated the pivot shift test.[6,7] Therefore, greater focus has recently been directed at double-bundle (DB) ACL reconstruction.[6,8,9] Even though such anatomic studies and biomechanical studies support the basis of DB ACL reconstruction, debate continues regarding the comparison of SB and DB results.[10,11] Moreover, a variety of meta-analysis studies have indicated that DB ACL reconstruction failed to result in significant differences as compared to SB reconstruction.[12,13]

Recently, progress in anatomic studies has suggested that the ACL is composed of three functional bundles;

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the anteromedial, the intermediate, and the posterolateral bundle.[14] Biomechanical studies have shown that triple bundle (TB) ACL reconstruction significantly reduced internal rotation.[15] Clinical researches have also demonstrated that TB ACL reconstruction possesses satisfactory clinical and radiological results.[16-19] Furthermore, a recent clinical study has also reported that TB ACL reconstruction resulted in better immediate postoperative anterior knee stability than DB ACL reconstruction.[20]

However, the clinical and functional benefits of arthroscopic TB ACL reconstruction remain unclear and undefined on a larger scale. Moreover, no prospective, randomized comparison between SB and TB ACL reconstruction has been documented.

The purpose of the current study was to compare the 24-month results of arthroscopic SB and TB ACL reconstruction for the treatment of symptomatic ACL rupture.

Materials and methods

This prospective randomized study included 105 patients who underwent arthroscopic SB or TB ACL reconstruction between January 2006 and December 2008. Of the 105 total patients, 79 were available at the 24-month follow-up. The SB group included 38 patients (mean age: 38.5 years) and the TB group 41 patients (mean age: 36.7 years). Inclusion criteria were primary ACL reconstruction with no combined posterior cruciate ligament injury, lateral collateral ligament injury, posterolateral rotatory instability, or fracture around knee; no previous knee ligament surgery; no arthritic changes; no subtotal or total meniscectomy; no malalignment; and a normal contralateral knee. Patients were excluded from the study when the examination under anesthesia or intraoperative findings did not meet the previously mentioned inclusion criteria. Patients were divided into two groups by rolling a die; patients with odd digits were assigned to the SB group and those with even digits to the TB group.

The semitendinosus tendon was harvested through an oblique approach on the medial side of the proximal tibia. For the SB reconstructions, the graft was prepared as a double-looped graft of more than 12 cm in length and of 7 to 8 mm in diameter. For the TB reconstructions, the tendon was transected into half to make 2 double-looped grafts of 60 to 70 mm in length and 5 to 6 mm in diameter. An ENDOBUTTON CL fixation device (Smith & Nephew plc, London, United Kingdom) was connected to the loop end and thick polyester sutures were placed in each free end of the graft with the baseball glove or whip stitches.

For the SB reconstructions, a tibial tunnel was made by inserting a 2.0-mm Kirschner wire into the center of the ACL insertion to the tibia and then drilled with a cannulated drill and a dilator to create a bone tunnel with the same diameter as the tendon graft. Next, a femoral bone hole with the same diameter as the tendon graft was made by the transtibial method using a dilator and a cannulated drill. The femoral side was fixed with ENDOBUTTON and the tibial side with spike staples by double-stapling method. The graft was fixed with the knee at approximately 30° flexion, with a tension of 50 N applied to the tendon graft.

For the TB reconstruction, two 2.4-mm guide pins were inserted to the points between the resident's ridge and the posterior margin of the notch at 2 or 3 o'clock for the left or at 9 or 10 o'clock for the right knee using the anterolateral entry femoral aimer. For the tibia, three parallel guide pins were inserted using the offset parallel pin guide. Then, each wire was overdrilled with a drill bit of appropriate diameter. For the tibial fixation, two double-spike plates and a tensioning boot were used. The tensioning sutures were connected to the tensioners. After retightening the tensioning suture using repetitive manual pulling to remove stress relaxation, each graft was fixed at 15 to 20 degrees of knee flexion.

Preoperative and 24-month follow-up clinical results were measured using the International Knee Documentation Committee (IKDC) and Orthopädische Arbeitsgruppe Knie (OAK) scores. Additional information associated with subsequent injuries and reoperations of the knee was also investigated. Two independent investigators conducted full clinical knee examinations such as swelling and range of motion (ROM).

Isokinetic testing of muscle strength was performed by experienced physiotherapists using a Biodex 6000 dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA) at the 24th month follow-up. Objective assessment of anteroposterior (AP) stability was performed using of radiographs taken with a Telos stress device (Telos GmbH, Hamburg, Germany) and a KT-2000 arthrometer (MEDmetric Corp., San Diego, CA, USA), and rotational instability was assessed using the lateral pivot shift test.

Roentgenograms taken with the Telos device were evaluated by an observer blind to the study groups at the 24th month follow-up. Measurement of differential laxity, which was based on the anatomical references described by Stäubli and Jakob,[21] was obtained by a trained radiology technician first and then by a radiologist in the study with more than 5 years of experience with the device.

The pivot shift test was conducted at the 24th month follow-up by a single tester and was repeated three times. The navigation system then reported the maximum anterior tibial translation (ATT) and tibial translation during the pivot shift examination. The P-shaped motion path is seen in the sagittal plane and is a result of the anterior subluxation of the tibia relative to the femur during early flexion followed by the reduction in the tibia and resumption of a flexion/extension arc. The presence of this motion path during pivot shift testing appears to be pathognomonic for a positive pivot shift. In addition to the ATT and tibial translation, the presence or absence of a P-shaped motion path was recorded during the pivot shift examinations.

To measure extension, a passive knee extension was assessed: one hand was placed above the knee to stabilize the femur while the forefoot was grasped with the other hand and the knee passively extended by lifting the foot while stabilizing the femur on the table. To assess knee extension with a goniometer, the patient was positioned with both heels propped on a bolster high enough to allow the knees to fall into hyperextension.

A power of $1\text{-}\beta=0.80$ and Type 1 error rate of $\alpha=0.05$ were used. Descriptive statistics were calculated for all variables with SPSS 13.0. The Student's t-test was used for analysis of the continuous variables and dichotomous variables were completed using the likelihood ratio chi-squared test. Statistical significance was set at $p<0.05$.

Results

No significant difference with regard to patient characteristics was detected between the two groups (Table 1).

Muscle strength was measured at the 24-month follow-up (Table 2). The total flexion values in the injured knee, compared to the uninjured knee, improved by 4.1 N/m in Group SB and 3.9 N/m in Group TB ($p>0.05$). The mean peak flexion torque declined by 5.2 N/m in the SB group and 5.4 N/m in the TB group compared to the uninjured knee ($p>0.05$).

The pivot shift test measured at the 24-month follow-up was negative in 30 and positive in 8 patients in the SB group and negative in 38 and positive in 3 subjects in the TB group. Rotational stability, as evaluated by the pivot shift test, was significantly superior in the TB group than the SB group ($p=0.0078$).

Preoperative IKDC scores in the SB group were B in 3 patients (7.9%), C in 18 (47.4%) and D in 17 (44.7%). At the 24-month follow-up, the scores improved to A in 26 patients (68.4%), B in 9 (23.7%) and C in 3 (7.9%). In the TB group, preoperative scores of B in 4 patients (9.8%), C in 19 (46.3%) and D in 18 (43.9%) improved to A in 27 patients (65.9%), B in 10 (24.4%) and C in 4

Table 1. Comparison of patient characteristics.

	Group SB	Group TB	p
Number of cases	38	41	–
Mean age (range)	38.5 (27-54)	36.7 (26-52)	>0.05
Men/women	20/18	21/20	>0.05
Height (m)	1.68	1.70	>0.05
Weight (kg)	71.2	70.1	>0.05
BMI (kg/m^2)	24.3	24.1	>0.05
Injured leg: left/right	19/19	21/20	>0.05

Table 2. Strength measurements at the 24-month follow-up (N/m).

	Group SB	Group TB	p
Peak torque quadriceps of UK	197.3±10.2	193.7±11.4	>0.05
Peak torque quadriceps of IK	178.5±12.4	173.4±12.4	>0.05
Total work quadriceps of UK	783.2±34.5	779.5±41.7	>0.05
Total work quadriceps of IK	683.1±24.4	691.3±30.1	>0.05
Peak torque hamstrings of UK	167.8±12.7	161.1±10.5	>0.05
Peak torque hamstrings of IK	150.2±11.5	154.9±15.3	>0.05
Total work hamstrings of UK	573.4±10.5	568.1±9.8	>0.05
Total work hamstrings of IK	512.7±12.3	521.1±10.1	>0.05

IK: Uninjured knee; UK: Uninjured knee.

Table 3. Clinical outcomes in two groups preoperatively and at the 24-month follow-up.

	Group SB			Group TB			Post-op		
	Pre-op	Post-op	p	Pre-op	Post-op	p	Group SB	Group TB	p
IKDC score	53.2±1.13	67.3±1.41	<0.05	52.9±1.22	68.3±1.03	<0.05	67.3±1.41	68.3±1.03	>0.05
OAK score	73.2±1.37	90.2±1.44	<0.05	71.9±2.01	91.3±1.08	<0.05	90.2±1.44	91.3±1.08	>0.05
ROM (°)	127.3±2.3	132.6±3.1	>0.05	125.9±4.1	131.3±3.7	>0.05	132.6±3.1	131.3±3.7	>0.05
TC (cm)	1.5±0.02	1.4±0.03	>0.05	1.4±0.07	1.5±0.09	<0.05	1.4±0.03	1.5±0.09	>0.05
KT-2000	5.43±0.42	1.67±0.33	<0.05	5.42±0.55	1.75±0.12	<0.05	1.67±0.33	1.75±0.12	>0.05
Telos (mm)	5.78±1.01	1.81±0.07	<0.05	5.64±0.09	1.79±0.13	<0.05	1.81±0.07	1.79±0.13	>0.05

TC: Thigh circumference.

(9.8%) at the 24-month follow-up. Although the subjective IKDC scores significantly increased in each group, no statistically significant difference was obtained at 24-month follow-up between the two groups (Table 3).

The OAK score increased from 73.2±1.37 preoperatively to 90.2±1.44 at the 24-month follow-up in the SB group and from 71.9±2.01 to 91.3±1.08 in the TB group ($p>0.05$) (Table 3).

Mean postoperative ROM was 132.6±3.1° in the SB group and 131.3±3.7° in the TB group ($p>0.05$) (Table 3). No significant difference was detected in postoperative side-to-side difference in mid-thigh circumference between the two groups; with 1.4±0.03 cm in the SB and 1.5±0.09 cm in the TB group (Table 3). Preoperative maximal manual muscle test and AP instability were 5.43±0.42 mm and 5.78±1.01 mm, respectively, in the SB group; and 5.42±0.55 mm and 5.64±0.09 mm, respectively, in the TB group. Residual AP laxity assessed at the 24-month follow-up using the KT-2000 arthrometer and Telos device was 1.67±0.33 mm and 1.81±0.07 mm, respectively, in the SB group and 1.75±0.12 mm and 1.79±0.13 mm, respectively, in the TB group ($p>0.05$) (Table 3).

Discussion

Traditional arthroscopic ACL reconstruction has focused on reconstructing the anteromedial bundle.[1,22] As progress in anatomic studies has suggested that the ACL is composed of three functional bundles, it is reasonable to restore the ACL footprint anatomy. Thus, reconstruction of native ACL anatomy and normal knee kinematics is currently established as the basic goal in all ACL reconstruction techniques.[5,8,9,18,20] In the current study, rotational stability, as evaluated by the pivot shift test, was significantly superior in the group that underwent TB reconstruction than SB reconstruction. We hypothesize that the better rotational stability of the knee in TB ACL reconstruction patients will minimize the occurrence of new knee traumas.

The development of osteoarthritis and failure of the graft, both dependent on joint laxity, have been established as the most common long-term failure mechanisms after ACL reconstruction.[1,22,23] Increased laxity can lead to damage to the articular cartilage and menisci, contributing to the further progression of osteoarthritis.[23,24] While increased laxity in each of the three planes of motion has been individually implicated in the development of osteoarthritis,[24] excessive tibial rotation has been specifically suggested to be involved with the progression of knee osteoarthritis.[25] Moreover, 20 to 25% of poor outcomes after ACL reconstruction have been considered to result from rotational instability.[15] The potential improvement in rotational control is suspected to be important for a better outcome and patient satisfaction. Zaffagnini et al. stated a significant relationship between the pivot shift test and patient satisfaction, while anteroposterior laxity failed to show influence on patient subjective assessment.[26] This is in line with the results published by Lopomo et al., who suggested a positive pivot shift test to be a predictor of later osteoarthritis based on the results of a long-term radiographic evaluation.[27] Therefore, one of the main aims of this type of surgery should be control of rotatory stability in the joint. The most important result obtained in our study confirms the superiority of TB ACL reconstruction in terms of rotatory stability as compared to SB reconstruction. However, our study failed to show a significant difference in clinical scores (IKDC and OAK) between the TB and SB groups, which may be due to the low power value. In the current study, the power for pre-IKDC score between the two groups was <0.80. To obtain a power of 0.80, larger samples are needed.

Similar to other studies,[2,5-7,9] we investigated isokinetic muscle torque. The quadriceps muscle dynamically stabilizes the knee joint in most functional activities,[28] while the hamstrings play an important role in terms of shear forces by preventing the tibia from sliding anteriorly relative to the femur.[29] In our series, the muscle strength between the injured and uninjured knees concerning total flexion work was comparable in both groups at the 24-month follow-up. The reserved hamstring strength in both groups appears to have not affected the function of the knee and minimized vulnerability to new traumas. This is one possible explanation as to why no significant difference was detected in the two groups regarding subsequent knee surgery. There was no significant difference in terms of peak flexion torque between the TB and SB groups at the 24-month follow-up. It has been suggested that hamstring weakness might be due to inadequate rehabilitation after ACL reconstruction.[30] In the present study, we did not find significant difference between the groups with regard to extension work. Some authors reported that postoperative mobilization without bracing is preferable.[31] Additionally, a recent review also concluded that postoperative mobilization without bracing is preferable.[32] Based on these studies and the clinical experience of the senior authors, bracing was not found beneficial and was therefore not used postoperatively.

In conclusion, both the TB and SB technique are safe and effective techniques for ACL reconstruction. Moreover, TB ACL reconstruction can produce better rotational stability of the knee than arthroscopic SB ACL reconstruction.

Conflicts of Interest: No conflicts declared.

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