

Single-bundle versus double-bundle anterior cruciate ligament reconstruction

A comparative study with propensity score matching

Jeong-Ku Ha, Dhong-Won Lee¹, Jin-Goo Kim²

ABSTRACT

Background: Numerous studies have elucidated the functional anatomy and biomechanics of the anterior cruciate ligament (ACL), as a result, double-bundle (DB) ACL reconstruction has received much attention and has become a popular choice because it gives better rotational stability. Many other studies, however, found no differences with respect to stability, and/or other clinical outcomes between the DB and single-bundle (SB) techniques. There is still not enough evidence as to whether the anatomical DB anterior cruciate ligament reconstruction (ACL) is superior to anatomical SB reconstruction. The purpose of this study is to compare various clinical and functional outcomes between SB and DB ACLR at 2 years followup.

Materials and Methods: Medical records of patients with ACLR available for at least 2 years followup were reviewed retrospectively. 191 patients (164 males and 25 females) for SB and 48 patients (40 males and 8 females) for DB were selected using the inclusion and exclusion criteria. The mean age of SB and DB was 29.9 and 24.8 years, respectively. Propensity score (PS) was calculated based on age, sex and Tegner activity score and 48 patients in each group were matched by the PS. Lysholm score, International Knee Documentation Committee (IKDC) subjective knee score and Tegner activity score were investigated. Functional performance tests, isokinetic muscle strength test with Biodex system, pivot shift test and KT-2000 arthrometer test were performed.

Results: At 2 years followup, there were no significant differences between SB and DB group in Lysholm score (92.9 vs. 90.6, $P = 0.224$), IKDC subjective knee score (88.7 vs. 87.0, $P = 0.524$), Tegner activity score (7.3 vs. 8.0, $P = 0.059$). No significant differences were also found in all functional performance tests, isokinetic muscle strength tests in 60° and 180°/s, KT-2000 arthrometer test and pivot shift test ($P > 0.05$).

Conclusions: There were no significant differences of clinical and functional outcomes between SB and DB ACLR at 2 years followup.

Key words: Anatomical reconstruction, anterior cruciate ligament reconstruction, double-bundle reconstruction, functional performance tests, propensity score

MeSH terms: Anterior cruciate ligament, sports medicine, knee joint

INTRODUCTION

In recent years, numerous studies have elucidated the functional anatomy and biomechanics of the anterior cruciate ligament (ACL). As a result, double-bundle (DB)

ACL reconstruction has received much attention and has become a popular choice, which exhibits better rotational stability and pivot resistance than the single-bundle (SB) method.^{1,4} A recent review article about the clinical results of randomized controlled trials reported that 71% (10 of 14) showed better results for the DB technique, where the following factors were shown to be superior for DB over SB; rotational stability, anterior stability, objective knee score, subjective knee score, and/or less graft failure.⁵ Controlled laboratory studies

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have reported that DB ACL reconstruction showed better kinematics for restoring intact knee kinematics, including translations and rotations.⁶⁻⁸ *In vivo* biomechanical studies showed patients that underwent DB had higher control of rotational stability.⁹⁻¹¹ Many other studies, however, found no differences with respect to anteroposterior laxity, rotational stability and/or other clinical outcomes between the DB and SB techniques.¹²⁻¹⁷

As for evaluation methods, many evaluation methods, such as subjective scale, physical examination, arthrometer, radiology and functional tests have been applied in the previous studies for comparison between SB and DB. However, few of these methods reflect the comprehensive functional ability. One-leg hop test has been used for functional evaluation; however, this reflects only the quadriceps power and the agonist-antagonist balance and does not reflect rotational stability.^{18,19} As for evaluation of rotational instability, it is more difficult to quantify in a standardized manner. The *in vivo* measurement of rotational knee stability remains technically demanding. Intraoperative navigation was reported to measure rotational stability for DB reconstruction, but this method only evaluates primary knee stability.⁹ For pivot-shift testing in a clinical followup situation, techniques with electromagnetic sensors or a mechanized pivot shifter are described, but they are not used in a standardized manner yet.^{10,11}

We conducted a comprehensive evaluation of the patients using the subjective scores, functional performance test, isokinetic muscle strength test and static laxity test scores to compare the outcomes of SB and DB ACL reconstruction. Matching analysis with the propensity scores (PSs) was performed to eliminate baseline difference in some factors during comparison. PS was used for matching analysis to decrease data loss during the matching procedure. The purpose of this study is to compare the clinical results and functional performance between the anatomical SB and DB ACL reconstruction methods after at least a 2-year followup. We hypothesized that there are no differences between the clinical results and functional performance of patients who have undergone SB and DB ACL reconstruction after 2 years postsurgery.

MATERIALS AND METHODS

From November 2010 to January 2013, patients who were available for a 2-year work-up, involving clinical, functional, and muscle strength tests, after an ACL reconstruction surgery, were recruited and investigated retrospectively. The criteria for inclusion in this trial were (1) a normal contralateral knee on clinical examination (2) no associated ligamentous injury (3) no history of prior knee surgery

and finally (4) participation of all the evaluation records. The exclusion criteria for were (1) combined ligament injury, (2) fracture (3) revision surgery (4) subtotal or total meniscectomy (5) contralateral knee ligament injury and (6) grade 3 or 4 arthritis. All patients who fulfilled the above criteria were subjected to the study data. Finally, 191 patients for SB and 48 patients for DB were selected using the inclusion and exclusion criteria. Table 1 shows demographic data.

Operative procedure

Single-bundle reconstruction

The ACL reconstructions were done 4–8 weeks after injury once the patient was capable of full range of motions without any signs of joint swelling. All the surgical methods were arthroscopically performed by an experienced surgeon using an autogenous hamstring tendon. Prior to the ACL reconstruction, arthroscopic examinations of patients were achieved and the meniscal resections or repairs and cartilage lesion treatments were carried out. To carry out the ACL reconstruction, the ipsilateral hamstring was harvested and the four stranded gracilis-semitendinosus autografts were prepared by suturing the folded end and the looped end with No. 2 Ethibond (Ethicon, Somerville, NJ, USA) and No. 2 Vicryl (Ethicon), respectively. A transtibial technique was used to create the femoral tunnel. The ACL tibial guide (Linvatec, Largo, FL, USA) was set at a 45–50° angle. The starting point of the tibial tunnel was superior to the pes anserinus and the anterior margin of medial collateral ligament. The intraarticular site was positioned at the center of the tibial footprint of the ligament. The femoral tunnel was made in the same way as the previous article.²⁰ The femoral tunnel was made to a depth of 30–35 mm. The tunnel was dilated using serial tunnel dilators (DePuy Mitek, Raynham, MA, USA) by 0.5-mm increments to make a press-fit fixation between the hamstring graft and femoral tunnel. The graft was inserted once the insertion location was confirmed by RIGIDFIX (DePuy Mitek, Raynham, MA, USA) cross pin by arthroscopically viewing the reconstruction site through the tibial tunnel. Femoral fixation was performed with Endobutton fixation

Table 1: Demographic data before and after propensity score matching

Demography	Before matching		P	After matching		P
	Single (n=191)	Double (n=48)		Single (n=48)	Double (n=48)	
Age	29.9	24.8	0.005	25.1	24.8	0.886
Sex (n, male/female)	164/25	40/8		40/8	40/8	1.000
Tegner activity	7.2	8.1	0.003	8.1	8.1	0.996*
Lysholm				66.3	63.2	0.392
IKDC SKF				59.8	58.6	0.772

Values are mean, except sex. Independent t-test; *Mann-Whitney U-test. IKDC SKF=International Knee Documentation Committee Subjective Knee Form

system (Smith and Nephew, Andover, MA, USA) and one cross pin (RigidFix System, Mitek, Johnson and Johnson, Norwood, MA, USA). If femoral tunnel was short, the graft was press fitted with only Endobutton. Then, 20 lbs was applied to the fully extended graft, where the tension was applied using a tensiometer before final tibial bioabsorbable interference screw fixation with staple or cortical screw [Figure 1].

Double-bundle reconstruction

We used the Achilles tendon allograft without the bone block as the anteromedial (AM) bundle and the mitendinosus autograft for posterolateral (PL) bundle. The bone block removed Achilles tendon allograft was whipstitched at both ends to be used as the AM graft. The semitendinosus autograft was also whipstitched at both ends and folded through Endobutton loop. The femoral tunnels for AM bundle and PL bundle were made at the anatomical footprints of both bundles, which lied under the intercondylar notch and each tunnel inlet was divided by the bifurcate ridge. The AM tunnel was created at slightly posterior position to the tunnel of the SB reconstruction in the same manner and PL tunnel was formed at just anterior to the AM and dilated through the accessory AM arthroscopic portal. For the AM bundle, Rigidfix was applied for the femoral side, whereas the bioabsorbable interference screw was used for the tibial side. For the PL bundle, Endobutton for the femoral side and interference screw with staple or cortical screw were used for the tibial side [Figure 1].

There was no intraoperative complication. Complications after the operation were reported in 8 cases. Sensory changes at the donor site occurred in 7 cases (SB 3, DB 4) and superficial infection was reported in 1 case (DB). There was no deep infection.



Figure 1: Anteroposterior view of the knee after single-bundle reconstruction (a) and double bundle reconstruction (b)

Evaluation methods

The clinical results were evaluated by the Lysholm score, International knee documentation Committee (IKDC) subjective knee score, Tegner activity score, and KT-2000 side-to-side difference, isokinetic muscle strength test by Biodex III system (Biodex Medical Systems, Shirley, NY, USA), and the functional performance tests at 2 years after the surgery. The functional performance tests included the one-legged hop for distance reported by Noyes *et al.*²¹ and three types of functional evaluation tests: Co-contraction test, carioca test and shuttle run test, as reported by Lephart *et al.*,¹⁸ of which reliability, validity and responsiveness were validated.²²

The one-legged hop test was performed 3 times for each leg. The longest distance achieved out of the three trials for the involved and the uninvolved limb was used.

Co-contraction test

The co-contraction test was carried out to reproduce the rotational forces at the knee, necessitating the control of the tibial translation by the thigh musculature. First, a heavy Velcro belt was secured around the subject's waist, which was attached to a heavy 48-inch rubber tube with an outer diameter of one inch. The tube anchored to a metal loop was attached to the wall 60 inches above the floor. A semicircle was painted on the floor ($r = 96$ inches) with the metal loop situated at the center. The subject stood facing the wall with his/her toes on the semicircle, and this action caused the tube to stretch by 48 inches beyond its recoil length. The co-contraction test required each subject to complete a 5 wall-to-wall traverse of the 180° semicircle with tension applied to the overstretched rubber tubing. The subjects began on the right hand side of the semicircle, moving in a sidestep or a shuffle fashion to the other end, completing in total five lengths (three right-to-left lengths and two left-to-right) in the minimum amount of time possible [Figure 2].

Carioca test

The carioca test required the subjects to move laterally using the crossover step. The subjects began moving laterally

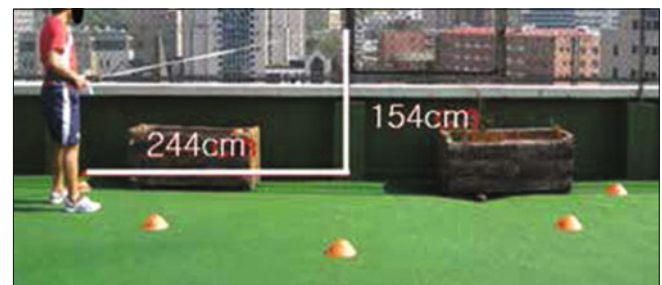


Figure 2: Photograph showing co-contraction test. The patient is required to complete 5 wall-to-wall traverses of the 180° semicircle with tension applied to the overstretched rubber tubing

from left to right until they reached a distance of 40 feet, then reversed direction to begin retracing their steps (still using the crossover step). All the subjects were timed to see how quickly they could cover the 80 feet distance. This test was used to reproduce the pivot shift phenomenon in the ACL-insufficient knee [Figure 3].

Shuttle run test

The subjects also performed the shuttle run test, where each subject had to run 20 feet, touch a line on the floor with his/her foot, reverse direction, return to the starting point, touch the line, and repeat this process once more. Therefore, the complete test covered 80 feet in total with three changes in direction. This test was designed to reproduce the acceleration and deceleration forces that are commonly encountered in athletic activity.

During the performance test, subjects with a dynamically unstable knee, especially those with an ACL insufficient knee, experience tibial subluxation or the sensation of subluxation, resulting in apprehension and slower performance [Figure 4].

Rehabilitation protocol

All patients underwent the same standardized rehabilitation protocol as at-home-based exercise. We regularly performed followups of the patients in the out-patient clinic and set up a protocol for rehabilitation. The patients were allowed tolerable weight bearing with a locked brace immediately after surgery and full weight bearing with an unlocked brace 2 weeks after surgery. Partial weight bearing with crutches for 6 weeks was mandated for patients who underwent meniscal repair. The goal for the patients was to gain a full range of motions at 2–6 weeks after surgery. A perturbation training program was started at 6 weeks after surgery. Running and side-cutting activities were allowed at 3 months, with a return to sports activities at 6 months after surgery.



Figure 3: Photograph showing carioca test. The patient is required to move laterally with crossover step

Statistical method

PS matching was used to minimize the potential confounding factors and treatment selection bias, and to make adjustments for significant differences in baseline covariates. We used multiple logistic regression analysis to determine the PS for SB and DB groups. Age, sex, and Tegner activity were included in creating this model. PS was the probability of multiple logistic regression analysis. Therefore, PS has the meaning of propensity that the PS-matched pairs were created into a 1:1 match, where each DB patient was matched to a SB patient who had a PS that was identical to five digits. If this could not be done, we then proceeded sequentially to the next highest digit PS match to create the best possible matches. After all PS matches had been set, we compared baseline covariates and 2-year followup results between the two groups using the independent *t*-test for the continuous variables and the Mann–Whitney test for the ordinal variables. Paired *t*-test was used for comparison between preoperation and postoperation in each group. SPSS, version 18.0 (SPSS, Chicago, IL, USA) was used for statistics.

RESULTS

For this study, 191 patients for SB and 48 patients for DB were selected using the inclusion and exclusion criteria. The 48 patients in each group were allocated into PS matched sets as described above. There were no differences in meniscal injury and chondral pathology between two groups after matching. When the standard deviation of Lysholm was set to 15, the mean differences which the author aimed to present being 10, and significant value as 0.05, the SB and DB groups containing 48 patients each was shown to have a statistical power of 89.8%.

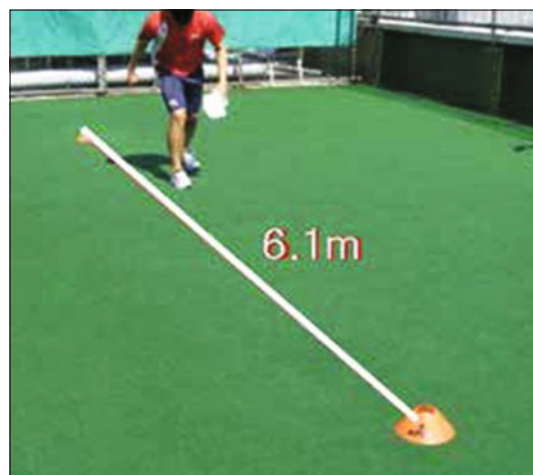


Figure 4: Photograph showing shuttle run test. The patient runs 20 ft, touches a line on the floor with his/her foot, reverses direction, returns to the starting point, touches the line, and repeats the process

Before PS matching, baseline demographic data such as age and Tegner activity score were significantly different between two groups. Age was older and Tegner activity level was lower in SB reconstruction group. After matching, the demographic variables, i.e., age, sex, Tegner activity score, Lysholm and IKDC score, showed no statistical differences ($P > 0.05$) [Table 1]. Meniscus tear was observed in 10 of SB group and in 11 of DB group. Two of SB group and 3 of DB group received meniscus repair. The Lysholm score significantly improved from 66.3 to 92.9 after 2 years in SB and from 63.2 to 90.6 in DB ($P = 0.000$). The IKDC score also showed significant improvement from 59.8 to 88.7 in SB and from 58.6 to 87.0 ($P = 0.000$). The 2 years followup results showed no statistical differences in all the variables between the SB and DB groups: Lysholm score (SB 92.9 vs. DB 90.6, $P = 0.224$), IKDC subjective knee score (88.7 vs. 87.0, $P = 0.524$), Tegner activity score (7.3 vs. 8.0, $P = 0.059$), KT-2000 arthrometer (1.93 vs. 1.87, $P = 0.844$), isokinetic muscle strength test (60°/s extension deficit, 18.2 vs. 18.1, $P = 0.986$), pivot shift test ($P = 0.679$), and functional performance tests (carioca, shuttle run, co-contraction, one-leg hop test) ($P > 0.05$) [Tables 2 and 3].

DISCUSSION

This study shows that there are no significant clinical differences between the outcomes of the SB and the

DB ACL reconstruction, in terms of the subjective score, static instability measured by KT-2000 and pivot shift test, isokinetic muscle strength, and functional performance test at a 2-year followup.

Several recent clinical trials showed superior results in DB method compared to SB method. Zaffagnini *et al.*²³ performed a randomized controlled trial with 35 patients in each group. They reported better results of anterior instability, rotational stability, and objective IKDC in DB group.²³ In a randomized controlled trial by Suomalainen *et al.*, they reported the result of 3 different groups; 30 patients with DB, 30 patients of SB with bioabsorbable screw fixation, and 30 patients of SB with a metallic screw. DB showed less graft failure rate and less revision surgery in 5 years followup.²⁴ In contrast, there are also several researches that revealed no difference between SB and DB group. Sastre *et al.*¹⁶ reported a randomized controlled study with 40 patients. In a 2 years followup, there were no significant differences in the pivot-shift test, anterior-posterior laxity, and IKDC scores.¹⁶ Streich *et al.*¹⁷ also reported that both techniques showed equal results in subjective and clinical evaluation.¹⁷

Different grafts, different fixation methods, different tunnel creating technique, and different fixation position were used in those studies.^{16,17,23,24} Many graft options are available for ACL reconstruction, including different autografts and allografts. In recent studies dealing with graft choice, allografts proved its durability and strength in SB and DB techniques and through comparison with autografts.^{25,26} However, there were no clear results of interaction between autograft and allograft in DB reconstruction; we could not assume the types of additional effects. In terms of femoral tunnel position, some of them used 10 o'clock position and others used 10 and a half o'clock position, whereas other researchers placed the tunnel at an anatomical position or over the top position. Our method was anatomical position for SB and DB reconstruction, which was similar to previous articles.^{20,27} Kondo *et al.*⁴ showed that there do not seem to be a biomechanical difference between the outcomes of the anatomical SB and DB reconstruction. In addition, the standard procedure for anatomical ACL reconstruction and the most common technique used in the United States is the SB technique. In our study, SB reconstruction by a transtibial technique revealed similar clinical results compared to DB reconstruction.

Many studies have reported an enhanced rotational stability when patients were treated with DB over SB.²⁸ However, the lack of reproducible methods to objectively measure and quantify the rotational stability *in vivo* is a main

Table 2: Comparisons of various results between single- and double-bundle ACLR at 2 years followup

Various results	Single (n=48)	Double (n=48)	P
Lysholm	92.9	90.6	0.224
IKDC SKF	88.7	87.0	0.524
Tegner	7.3	8.0	0.059
KT-2000 (difference)	1.93	1.87	0.844
Functional performance test			
Carioca	9.3	9.2	0.909
Co-contraction	14.8	16.1	0.291
Shuttle run	7.8	7.9	0.950
One leg hop	144.7	150.1	0.651
Isokinetic muscle strength test (deficit, %)			
60°/s extension	18.2	18.1	0.986
60°/s flex	11.8	15.5	0.305
180°/s extension	11.2	14.8	0.337
180°/s flex	8.8	11.9	0.413

Values are mean. Independent t-test, Mann-Whitney U-test. IKDC SKF=International Knee Documentation Committee Subjective Knee Form, ACLR=Anterior cruciate ligament reconstruction

Table 3: Pivot shift test in both groups

Grade	Preoperative		Postoperative	
	Single bundle	Double bundle	Single	Double
0	0	0	30	32
I slide	10	11	14	11
II clunk	13	15	4	5
III gross	25	22	0	0

disadvantage of such studies.¹⁶ The authors performed functional performance test as an alternative option that indirectly measures rotational dynamic stability *in vivo*. To our knowledge, there are no papers in literature that have used functional tests to compare the clinical results between the ACL SB and DB. The carioca test, shuttle run test, and the co-contraction test were designed to reproduce pivoting, cutting, accelerating, and decelerating motions of the knee. These motions are performed with relative difficulty by ACL injured patients, so these can be used to reflect the dynamic stability, as well as functional performance and recovery status in the ACL reconstructed knee. The authors had validated these tests and they were found to show good test retest reliability and good construct validity. These results were published in a domestic literature.²⁹

Evidence-based medicine clearly states that prospective randomized controlled trials are the highest level of medical research. As such, many prospective randomized controlled trials for the comparison between SB and DB ACL reconstruction surgeries have been held.^{5,30,31} However, these trials require a considerable amount of time, money, and effort, and often it is difficult to allocate the patients randomly according to the surgical procedures for the purpose of the academic research, especially for the elite athletes. Therefore, evaluating the clinical outcomes using prospective randomized trials without any bias is a challenging project. Matching analysis is a possible solution to overcome this problem in a comparison study. We conducted a matching analysis using the PS to minimize confounding factors and selection bias, which is an inherent drawback of retrospective studies. Age and Tegner activity differences between both groups could be adjusted after PS matching.

There are some limitations to our study design. First, there could be selection bias as not all the patients who underwent the ACL reconstruction were followed up at 2 years. Second, the 2 years followup period is not sufficient to show arthrosis changes of the knee joint and meniscal injury. Therefore, a long term followup study is needed to evaluate the chondro-protective effect and meniscal injury rate after ACL reconstruction. Third, the measurement instrument for rotational stability was only pivot shift test and functional performance tests, which showed less reproducibility and was difficult to be quantified. Finally, our modified transtibial technique was harder to make an anatomical femoral tunnel than independent drilling techniques.

CONCLUSIONS

There were no significant differences between the subjective knee scores, static stability, functional performance tests,

pivot shift test, and isokinetic muscle strengths in patients who received either the anatomical SB or the DB ACL reconstruction surgery at a 2 years followup.

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Conflicts of interest

There are no conflicts of interest.

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