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Original Article

Isokinetic Quadriceps and Hamstring Muscle Strength After Anterior Cruciate Ligament Reconstruction: Comparison Between Single-bundle and Double-bundle Reconstruction

前十字韌帶重建手術後股四頭肌和腿後肌羣(膕繩肌)的等速肌力：單束和雙束前十字韌帶重建術之比較

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ABSTRACT

Introduction: Clinical studies have not yet proven whether single-bundle (SB) or double-bundle (DB) anterior cruciate ligament (ACL) reconstruction is superior. Nonetheless, quadriceps and hamstring muscle deficit is common after ACL reconstruction and it may affect the final outcome. The purpose of this study was to compare the isokinetic quadriceps and hamstring muscle strength after SB-ACL and DB-ACL reconstruction.
Materials and methods: We recruited 40 patients with ACL reconstruction (20 SB and 20 DB) by the same team of surgeons from 2006 to 2009. Demographic data of both groups were comparable. Lower extremity concentric isokinetic peak extension and flexion torques were assessed at angular velocities of 60°/second, 180°/second, and 300°/second preoperatively and at least 1 year postoperatively. Clinical evaluation was performed, including anterior stability with an arthrometer (model KT-1000), Lysholm score, Tegner activity score, single leg hop test, and International Knee Documentation Committee score. Data were analysed statistically.
Results: The isokinetic quadriceps and hamstring peak torque values in both the SB and DB groups did not show any significant difference. The maximum displacement upon KT-1000 arthrometer measurement appeared lower in the DB group but the difference was not significant. The side-to-side percentage deficits in quadriceps and hamstring peak torque at postoperative assessment were comparable in both groups.
Conclusion: Isokinetic quadriceps and hamstring muscle strength after SB-ACL or DB-ACL reconstruction was comparable.

中文摘要

簡介： 現有的臨床研究尚未能證明單束或雙束前十字韌帶重建手術的相對優越性。儘管如此，股四頭肌和腿後肌羣(膕繩肌)力量不足是前十字韌帶重建手術後的普遍現象，它可能會影響術後的成果。本研究之目的是比較單束和雙束前十字韌帶重建後股四頭肌和腿後肌羣(膕繩肌)的等速肌力。
方法： 於2006至2009年間，有40名前十字韌帶重建手術病人(分別為20名單束重建和20名雙束重建患者) 被納入這個研究，手術都是由同一組骨科醫生所做的。這兩個組別的人口統計數據並無分別。於術前和手術後至少1年，我們量度下肢分別於角速度每秒60度，180度和300度的同心等速伸長和屈曲最大扭力值。另進行了多項臨床評估，包括關節動度計測試 (型號KT-1000)，Lysholm評分，Tegner活動評分，單腿跳測試，國際膝關節文獻委員會(IKDC)評分，並對數據進行統計分析。
結果： 比較單束重建和雙束重建組別，發現股四頭肌和腿後肌羣(膕繩肌)的等速最大扭力值沒有顯著的差別。 KT-1000關節動度計顯示雙束重建組別有較少的脛骨前移差值，但這差異於統計學上並無分別。於手術後的評估中，比較股四頭肌和腿後肌羣(膕繩肌)的最大扭力值較對側腿之差別百分比，並無分別。
結論： 單束和雙束前十字韌帶重建後的股四頭肌和腿後肌羣(**膕繩肌)**等速肌力比較，兩者相約。

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Introduction

Double-bundle (DB) anterior cruciate ligament (ACL) reconstruction has become more commonly practiced in recent years. The principle of DB-ACL reconstruction is based on restoration of the original anatomical structure of the ACL, which consists of the anteromedial (AM) and posterolateral (PL) bundles. Anatomical studies have shown that the AM bundle contributes mainly to anteroposterior stability of the knee, whereas the PL bundle contributes more to rotational stability, such as twisting, pivoting, jumping, and running motions.[1,2] By reconstructing the two grafts into the anatomical position of the native ACL, the aim is to restore the normal kinematics of the knee, hence this new technique will result in better biomechanical outcome of knee performance.

The role of the PL bundle was illustrated in a biomechanical study by Zantop et al,[3] in which the PL bundle exerted more load at 30° of knee flexion and a significantly increased load with combined rotation at 0° and 30°. A cadaveric knee study by Yagi et al demonstrated better biomechanical outcome of DB-ACL reconstructed knee in terms of combined rotational load than that with SB-ACL reconstruction.[4] In clinical studies, the advantage of rotational stability has been demonstrated using different measures including computer navigation systems and electromagnetic devices. [5,6]

Despite its theoretical biomechanical advantage, the clinical and functional outcome of DB-ACL reconstruction is variable and cannot be proven superior to SB-ACL reconstruction. A systematic review evaluating the biomechanical stability, kinematics, and clinical outcome could not reach a conclusion about the superiority of either SB-ACL or DB-ACL reconstruction.[7]

From the rehabilitation point of view, return to sports is one of the important goals for patients with ACL injury. However, quadriceps and hamstring muscle strength deficit of the ACL-deficient knee after ACL reconstruction is common, ranging from 22% to 28%, irrespective of the different choice of graft.[8,9] Muscle strength is correlated with better functional outcome of patients with ACL injury.[10] Studies of DB-ACL reconstruction have mostly focused on the outcome in terms of clinical evaluation and knee function scores, but rarely on the isokinetic quadriceps and hamstring muscle strength. Whether there is any muscle strength difference after DB-ACL reconstruction compared to SB-ACL reconstruction, and whether muscle strength correlates with the final outcome of patients, are yet to be answered.

The purpose of the present study was to compare the isokinetic quadriceps and hamstring muscle strength after SB-ACL and DB-ACL reconstruction, and correlate the findings with other clinical outcome parameters.

Materials and Methods

This was a retrospective cohort study of patients who had confirmed ACL deficiency, with ACL reconstruction performed by the same team of orthopaedic surgeons at our hospital from 2006 to 2009. A total of 23 patients had DB-ACL reconstruction performed during the study period. Those who had no preoperative isokinetic studies or arthrometric measurement, isolated AM-bundle or PL-bundle reconstruction, revision ACL surgery, contralateral knee injury, or contralateral knee ACL reconstruction performed were excluded. Three patients from the DB group did not have preoperative assessment and were excluded. The remaining 20 patients were included. Another 20 patients who underwent SB-ACL reconstruction and met the same criteria were recruited as the control group for comparison. Hence, a total of 40 patients (20 DB and 20 SB) were recruited.

Demographic data of both groups were comparable (Table 1). There were no significant differences between the SB-ACL and DB-ACL groups with respect to sex, age at surgery, side of injury, duration from time of injury to operation, and pre-injury activity level using the Tegner activity score. There were no significant differences in meniscal injury or collateral ligament tears in both groups.

All operations were performed by the same team of surgeons with a standard surgical technique. Standard knee portals were created for diagnostic arthroscopy. Any meniscus or articular pathologies were addressed. Both gracilis and semitendinosus autografts were harvested by a tendon stripper from the operated leg. The grafts were folded and tensioned using a tensioning board. For SB-ACL reconstruction, a femoral tunnel was made with reference to the mid-point of the AM bundle and PL bundle, using the transportal technique, whereas the tibial tunnel was created between the AM bundle and PL bundle footprint. The graft was fixed with interference screws (BIORCI; Smith & Nephew, Andover, MA, USA) at the femoral side, and tibial fixation was performed using tibial intrafix (Bio-INTRAFIX, DePuy, J&J, Raynham, MA, USA), with graft tensioning at 30° of knee flexion.

The technique of DB-ACL reconstruction followed the method proposed by the Department of Orthopaedic Surgery, University of Pittsburgh School of Medicine (Pittsburgh, PA, USA). The AM femoral tunnel was fixed with interference screws and the PL femoral tunnel was fixed with Endobutton CL (Smith & Nephew, Andover, MA, USA), with 15 mm for the closed loop Endobutton and at least 15 mm for graft incorporation. Tibial tunnels were created with reference to the original ACL footprint and the two bundles were fixed with interference screws, with AM bundle tensioning at 45° knee flexion and PL bundle tensioning at 0° knee flexion.

All patients underwent the same rehabilitation programme after the operation. The patients were assessed before ACL reconstruction and at least 1 year after the operation. For the SB-ACL group, mean follow-up was 19.0 months (standard deviation: 5.5 months, range: 12–30 months), and for the DB-ACL group, mean follow-up was 18.4 months (standard deviation: 5.5 months, range: 12–29 months). Clinical assessment included visual analogue scale (VAS), anterior stability using a KT-1000 arthrometer, single-leg hop test, Tegner activity score, Lysholm score, and International Knee Documentation Committee (IKDC) score. Anterior laxity was assessed quantitatively in terms of the difference between the injured and uninjured knees at 133 Newton stress and manual

Table 1
Patient characteristics

Variables	Single-bundle group ($n = 20$)	Double-bundle group ($n = 20$)	p value	Statistical test
Female/male	3/17	1/19	0.605	Fisher's exact test
Age at surgery (y)	27.8 ± 8.21	26.6 ± 7.88	0.640	Unpaired t test
Duration from injury to operation (mo)	14.2 ± 8.82	17.3 ± 13.89	0.405	Unpaired t test
Side (right/left)	11/9	10/10	0.752	χ^2 test
Meniscus injury (yes/no)	17/3	14/6	0.451	Fisher's exact test
Collateral ligament injury (yes/no)	4/16	7/13	0.288	χ^2 test

Table 2
Isokinetic peak torques of quadriceps and hamstring muscles of ACL-reconstructed knee at ≥1 year postoperatively

Peak torque	Velocity	Single-bundle ACLR	Double-bundle ACLR	*p* value	Statistical significance
		Mean (Nm) ± SD	Mean (Nm) ± SD		
Quadriceps	60°/s	139.8 ± 41.2	145.2 ± 39.6	*0.675*	N/S
	180°/s	99.8 ± 29.6	108.0 ± 26.3	*0.359*	N/S
	300°/s	73.6 ± 17.3	78.2 ± 15.7	*0.381*	N/S
Hamstring	60°/s	60.2 ± 22.7	63.5 ± 14.1	*0.584*	N/S
	180°/s	47.5 ± 17.4	53.2 ± 18.2	*0.318*	N/S
	300°/s	44.2 ± 13.2	47.5 ± 14.4	*0.447*	N/S

ACLR = anterior cruciate ligament reconstruction; SD = standard deviation; N/S = not significant.

maximal stress using the KT-1000 arthrometer. The single-leg hop test was recorded as the percentage difference between the injured and uninjured knees. The patients jumped three times on each leg and the average value of the three trials was used for calculation. Functional scores and clinical results were recorded by the same group of physiotherapists.

Lower extremity concentric isokinetic peak extension torque (quadriceps strength) and peak flexion torque (hamstring strength) were assessed at angular velocities of 60°/second, 180°/second, and 300°/second with a dynamometer (Biodex System 3, Shirley, New York, USA). Isokinetic peak torque was the maximal force recorded by the machine on quadriceps or hamstring muscle contraction during knee motion at a constant velocity, and it was indicative of muscle strength. A standardised application of the equipment, data recording system, and procedure for warm-up were applied. Both knees were assessed, with the uninjured knee first. During testing, the patients sat with their pelvis stabilised by straps, with the thigh bolster set over their thighs and ankle cuff just proximal to the malleolus. The rotational axis was aligned with the axis of the knee joint. The range of motion was set between 0° and 90° flexion upon testing. Five maximal extension–flexion concentric efforts were performed; first at a velocity of 60°/second, then 15 repetitions at a velocity of 180°/second, followed by 300°/second, with 20 seconds rest between the tests. Tests on different velocities were conducted because maximal muscle strength was reflected more on testing at low velocity, while muscle endurance was more related to the high velocity test. Patients were encouraged to make a maximal effort at each test. Both injured and uninjured knees were assessed for isokinetic peak torque, and the percentage deficit in peak torque value compared with the contralateral (uninjured) knee at postoperative assessment was generated by the computer programme in the dynamometer.

Data were analyzed statistically using SPSS software version 19. The differences between the numerical variables of the SB-ACL and DB-ACL groups were determined by two sample *t* test. The relationships between the categorical variables were determined by the Pearson χ^2 test or Fisher's exact test if the criteria for the χ^2 test were not met. Nonparametric data including VAS and Tegner activity scores were analysed using the Mann–Whitney *U* test. Statistical significance was defined at $p < 0.05$.

Results

Muscle Strength

The concentric isokinetic peak extension torque (quadriceps strength) and peak flexion torque (hamstring strength) of the ACL-reconstructed knee recorded at angular velocities of 60°/second, 180°/second, and 300°/second in the DB and SB groups are shown in Table 2. The maximum muscle strength of the quadriceps and hamstring muscles at postoperative assessment did not show significant differences between the two groups. Both treatment groups showed a deficit in quadriceps and hamstring muscle strength in the injured knee compared to the uninjured knee, with a mean deficit of 4.4–11.55% in the SB group and 3.75–14.15% in the DB group (Table 3). Comparing the percentage difference in peak torque value with that in the contralateral knee, there were no significant differences between the groups at the three preset angular velocities.

The hamstring-to-quadriceps (H/Q) muscle strength ratio did not improve significantly after SB-ACL and DB-ACL reconstruction compared to that before the operation. The postoperative H/Q ratio remained at 45.5–47.8% in the SB group and 46.1–49.1% in the DB group (Table 4).

Anterior Stability

The results of KT-1000 arthrometry using 133 Newton force and maximal manual force are shown in Table 5. Both groups showed significant improvement in anterior stability using maximal manual stress, with the KT-1000 arthrometer measurement comparing preoperative and postoperative results (SB, $p = 0.012$; DB, $p < 0.001$). The side-to-side difference in tibiofemoral displacement with maximal stress was 1.27 ± 0.70 mm lower in the DB-ACL group (DB 1.98 ± 1.82 mm; SB 3.25 ± 2.53 mm), although it did not reach a significant level ($p = 0.075$).

Clinical and Functional Outcome

The single-leg hop test, VAS, Tegner activity score, Lysholm knee score, and IKDC score were compared and the results are shown in

Table 3
Side-to-side percentage difference of peak torque of injured limb compared to uninjured limb at ≥1 year postoperatively

Side-to-side percentage difference	Velocity	Single-bundle ACLR	Double-bundle ACLR	*p* value	Statistical significance
		Deficit (%) ± SD	Deficit (%) ± SD		
Quadriceps	60°/s	4.20 ± 15.1	12.9 ± 18.9	*0.116*	N/S
	180°/s	8.65 ± 16.7	6.15 ± 16.3	*0.635*	N/S
	300°/s	9.55 ± 14.0	8.80 ± 12.5	*0.859*	N/S
Hamstring	60°/s	10.35 ± 20.2	12.25 ± 18.7	*0.759*	N/S
	180°/s	11.55 ± 20.4	3.75 ± 15.7	*0.185*	N/S
	300°/s	5.95 ± 20.5	4.0 ± 25.5	*0.791*	N/S

ACLR = anterior cruciate ligament reconstruction; N/S = not significant; SD = standard deviation.

Table 4
H/Q muscle strength ratio of SB and DB groups at preoperative and ≥1 year postoperative assessments

H/Q muscle strength ratio		SB ACLR	DB ACLR	*p* value (DB vs. SB)	Statistical significance
		Mean ± SD	Mean ± SD		
Velocity 60°/s	Preoperatively	40.74 ± 15.36	41.00 ± 9.84	*0.948*	N/S
	Postoperatively	43.53 ± 13.46	46.08 ± 11.85	*0.529*	N/S
	Significance of improvement	*p = 0.384*	*p = 0.167*		
Velocity 180°/s	Preoperatively	47.12 ± 15.50	46.94 ± 13.03	*0.969*	N/S
	Postoperatively	47.77 ± 12.39	49.08 ± 13.03	*0.767*	N/S
	Significance of improvement	*p = 0.824*	*p = 0.651*		

ACLR = anterior cruciate ligament reconstruction; DB = double bundle; H/Q = hamstring to quadriceps; N/S = not significant; SB = single bundle; SD = standard deviation.

Table 6. There was no significant difference in any of these scores in both groups in the postoperative period. The injured knee achieved an average of 88.8% and 86.6% hopping power of the uninjured knee after SB-ACL and DB-ACL reconstruction respectively, and the two groups did not differ significantly. Significant improvement was noted for both SB and DB groups in terms of Lysholm knee score and IKDC score comparing preoperative and postoperative assessments. The pain level as recorded by VAS showed no difference before and ≥1 year after the operation.

Discussion

The main objective of ACL reconstruction is to restore the original anatomy, kinematics, and function of the ACL. The uniqueness of the human ACL is demonstrated by the AM and PL bundles; each with its own characteristic way in which it carries different loads at different knee positions, and they contribute unequally to anterior and rotational stability.[3,11] Our study investigated different outcome measures, including anterior stability, muscle strength, and clinical outcome of patients after DB-ACL reconstruction, and explored the applicability of this surgical technique in the Chinese population.

Many studies have reported better results for anterior stability after DB-ACL reconstruction.[12,13] Anterior stability in the DB-ACL group using KT-1000 arthrometer measurement in our study also demonstrated a mean of 1.27 ± 0.70 mm side-to-side difference compared to the SB-ACL group. Yet this difference did not reach statistical significance. This result was similar to the meta-analysis of Gadikota et al,[14] which reported that the overall mean difference calculated by the random-effects model between DB-ACL and SB-ACL reconstruction was 0.99 mm (95% confidence interval: −0.15 to 2.13) less anterior laxity at full extension, but no significant difference was noted between the two treatments at various flexion angles.

The theoretical advantage of DB-ACL reconstruction in rotational stability is supported by different biomechanical studies *in vitro* and *in vivo*.[4–6] A meta-analysis by Meredick et al recruited four randomised controlled trials for pivot shift testing to assess rotational stability with an overall log odds ratio of 0.24 between the DB and SB groups, but the difference was not statistically significant.[15] The difficulty in assessing rotational stability is the validity of the clinical pivot-shift test and the lack of more objective arthrometry measurements.

If there is an advantage with DB-ACL reconstruction in relation to anterior and rotational stability, knee stability may contribute to better neuromuscular control and postoperative rehabilitation for training of the quadriceps and hamstring muscle strength. Hence, these patients may benefit from better physical rehabilitation and functional outcome. Therefore, the quadriceps and hamstring muscle strength may be an objective and indicative method for assessment of ACL reconstruction. Fujita et al compared postoperative muscle strength in three groups of patients: DB, single AM bundle, and single PL bundle ACL reconstruction. Greater extension strength was found in patients after DB-ACL reconstruction compared to the AM-bundle group, but it did not differ significantly compared to the PL-bundle group.[16] However, in real-life surgical procedures, the position of tunnel placement in SB-ACL reconstruction should be anatomic, which means that the tunnels are placed in the centre of the native femoral and tibial insertion sites; neither the AM nor the PL position.[17] Comparison in our study was made between DB-ACL and SB-ACL reconstruction that was aimed at the anatomical position in both operations.

Our results comparing DB-ACL and SB-ACL reconstruction could not find any significant difference in the flexion and extension muscle strength. The clinical outcome and functional scores were all comparable. It signified that neither method of ACL reconstruction could be proven superior to the other. The percentage deficit of muscle strength after ACL reconstruction in our study ranged from 4.2% to 12.9% of the contralateral knee, with no significant difference between the DB and SB groups. The problem with postoperative muscle strength deficit was not affected by the choice of SB or DB reconstruction. Using the contralateral limb for comparison may also be a limiting factor because both knees undergo deconditioning after an injury.[10]

Our results also revealed that there was still a significant deficit in the H/Q muscle strength ratio after the operation, regardless of using SB or DB grafts (H/Q ratio in the SB group: 45.5–47.8%; DB group: 46.1–49.1%). The hamstring is a dynamic stabiliser for

Table 5
Anterior stability of SB and DB groups using the KT-1000 Arthrometer at preoperative and ≥1 year postoperative assessments

KT-1000 Arthrometer (side-to-side difference)		SB ACLR	DB ACLR	*p* value (DB vs. SB)	Statistical significance
		Mean ± SD	Mean ± SD		
133 Newton force (mm)	Preoperatively	5.14 ± 3.71	4.45 ± 2.59	*0.499*	N/S
	Postoperatively	*2.88* ± 2.76	*1.93* ± 2.19	*0.235*	N/S
	Significance of improvement	*p = 0.066*	*p = 0.001*		
Maximum displacement (mm)	Preoperatively	*6.43* ± 4.07	5.68 ± 2.98	*0.510*	N/S
	Postoperatively	*3.25* ± 2.53	*1.98* ± 1.82	*0.075*	N/S
	Significance of improvement	*p = 0.012*	*p < 0.001*		

ACLR = anterior cruciate ligament reconstruction; DB = double bundle; N/S = not significant; SB = single bundle; SD = standard deviation.

Table 6
Evaluation of clinical and functional outcomes of SB and DB groups at preoperative and ≥1 year postoperative assessments

Variable		SB ACLR	DB ACLR	*p* value	Statistical test
		Mean ± SD	Mean ± SD		
Single-leg hop test (% of uninjured limb)	Pre-op	67.25 ± 29.22	75.50 ± 22.72	*0.325*	Unpaired *t* test
	Post-op	88.75 ± 14.61	86.59 ± 14.39	*0.714*	Unpaired *t* test
Visual analogue scale	Pre-op	1.20 ± 1.28	1.68 ± 1.54	*0.329*	Mann–Whitney *U* test
	Post-op	0.75 ± 1.59	0.32 ± 0.48	*0.400*	Mann–Whitney *U* test
Tegner activity score	Pre-op	2.50 ± 1.28	5.65 ± 11.48	*0.106*	Mann–Whitney *U* test
	Post-op	5.50 ± 1.85	6.00 ± 2.05	*0.851*	Mann–Whitney *U* test
Lysholm knee score	Pre-op	83.15 ± 15.01	81.90 ± 13.20	*0.781*	Unpaired *t* test
	Post-op	94.90 ± 5.11	94.26 ± 6.72	*0.740*	Unpaired *t* test
IKDC score	Pre-op	67.65 ± 12.45	68.80 ± 15.63	*0.798*	Unpaired *t* test
	Post-op	87.14 ± 8.91	85.37 ± 9.99	*0.563*	Unpaired t-test

ACLR = anterior cruciate ligament reconstruction; DB = double bundle; IKDC = International Knee Documentation Committee; N/S = not significant; Pre-op = preoperative; Post-op = postoperative; SB = single bundle; SD = standard deviation.

preventing anterior tibial translation during knee joint movement, in addition to ligamentous constraint, therefore, the coactivation of the hamstring muscle significantly contributes to counterbalance tibial shear and rotation.[18] A greater variance between the H/Q ratio of the injured and uninjured leg is associated with less successful recovery. The effect of hamstring autograft may have a greater effect on muscle strength rather than the choice of DB or SB reconstruction technique. Therefore, modification of muscle strength training with attention to hamstring deficit may improve the outcome of ACL reconstruction.

The postoperative muscle strength deficit can also be explained by the altered mechanics of the musculotendinous unit of the knee. We used the same autograft from both groups (gracilis and semitendinosus of the ipsilateral limb), thus, the same effect on donor site morbidity led to weakening of the hamstrings. This may have contributed to the ultimate muscle strength, particularly of knee flexion. The study by Lautamies et al demonstrated that a different choice of graft affected the quadriceps and hamstring muscle strength, whereas the deficit compared to that in the uninjured limb was significant despite the choice of graft.[19] According to our results, when comparing the improvement of muscle strength pre- and postoperatively, both groups demonstrated significant improvement in quadriceps and hamstring muscle strength at a velocity of 60°/second, 180°/second, and 300°/second. Therefore, the choice of autograft may be a cofactor affecting muscle strength and clinical outcome.

Muscle strength deficit did not improve after more stable DB-ACL reconstruction. This implies that more effort should be made to improve neuromuscular control of the reconstructed knee and postoperative strengthening regime. A neurophysiological study has shown altered neuromuscular control of the knee after ACL reconstruction, with enhanced long latency responses in electromyographic testing to unexpected perturbations.[20] Preserving the neuro-mechanoreceptors of the ruptured ACL stump and reinnervation of the ACL autologous graft may further improve the outcome of ACL reconstruction.

The limitations of our study included inter-operator difference because the operations were performed by more than one surgeon. The position of the grafts based on various anatomical and biomechanical studies is also debatable.[21] This may have contributed a type II error to our study in demonstrating significant results. We presumed that the muscle strength would be static 1 year after the operation. However, we cannot speculate whether there will be further improvement in muscle power after longer follow-up assessment. The small number of cases was insufficient for more powerful analysis.

Our study recruited early DB-ACL reconstruction cases that were performed during our learning curve. Despite the comparable outcome of the two techniques, an orthopaedic surgeon needs adequate practice in converting from SB-ACL to DB-ACL reconstruction with relative accuracy.[22]

When considering the choice of SB-ACL or DB-ACL reconstruction for our patients, one should consider factors related to both the patients and the surgeons. Although a significant benefit for DB-ACL reconstruction cannot be proven by recent review, the technique could be justified as a treatment of choice for ACL deficiency,[23] particularly in sportspeople involved in high-demand contact sports, who require high knee joint stability. Nevertheless, for patients who have low demand in sport and work, or who are recreational sportspeople, as in our locality, anatomical SB-ACL reconstruction will yield a good clinical outcome. Additional DB procedures may not be of much benefit, especially considering the potential surgical complications, difficult tunnel position placement, and longer operation time. Another practical limitation for DB-ACL reconstruction is the surgical technique itself. If the footprint size is too small, or the hamstring graft size is too short or too small for tunnel placement, the DB technique cannot be used. A larger series of patients and longer prospective follow-up of DB-ACL reconstruction is suggested to establish the utility of the DB-ACL procedure in the Chinese population.

In conclusion, at >1 year follow-up, the isokinetic quadriceps and hamstring muscle strength after SB-ACL and DB-ACL reconstruction was comparable. The H/Q muscle strength ratio did not improve with either SB-ACL or DB-ACL reconstruction. DB-ACL reconstructed knees tend to have higher anteroposterior stability with smaller side-to-side differences of 1.27 ± 0.70 mm by maximal manual anterior stress using the KT-1000 arthrometer. The overall clinical outcomes as measured by Lysholm score, Tegner activity score, and IKDC score did not differ between the two groups.

References

1. Amis AA, Dawkins GP. Functional anatomy of the anterior cruciate ligament. Fibre bundle actions related to ligament replacements and injuries. *J Bone Joint Surg Br* 1991;**73**:260–7.
2. Lorbach O, Pape D, Maas S, et al. Influence of the anteromedial and posterolateral bundles of the anterior cruciate ligament on external and internal tibiofemoral rotation. *Am J Sports Med* 2010;**38**:721–7.
3. Zantop T, Herbort M, Raschke MJ, et al. The role of the anteromedial and posterolateral bundles of the anterior cruciate ligament in anterior tibial translation and internal rotation. *Am J Sports Med* 2007;**35**:223–7.
4. Yagi M, Wong EK, Kanamori A, et al. Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. *Am J Sports Med* 2002;**30**:660–6.
5. Hofbauer M, Valentin P, Kdolsky R, et al. Rotational and translational laxity after computer-navigated single- and double-bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2010;**18**:1201–7.
6. Araki D, Kuroda R, Kubo S, et al. A prospective randomised study of anatomical single-bundle versus double-bundle anterior cruciate ligament reconstruction: quantitative evaluation using an electromagnetic measurement system. *Int Orthop* 2011;**35**:439–46.

7. Steckel H, Starman JS, Baums MH, et al. The double-bundle technique for anterior cruciate ligament reconstruction: a systematic overview. *Scand J Med Sci Sports* 2007;**17**:99–108.
8. Lephart SM, Kocher MS, Harner CD, et al. Quadriceps strength and functional capacity after anterior cruciate ligament reconstruction. Patellar tendon autograft versus allograft. *Am J Sports Med* 1993;**21**:738–43.
9. Keays SL, Bullock-Saxton J, Keays AC. Strength and function before and after anterior cruciate ligament reconstruction. *Clin Orthop Relat Res* 2000;**373**:174–83.
10. Hiemstra LA, Webber S, MacDonald PB, et al. Knee strength deficits after hamstring tendon and patellar tendon anterior cruciate ligament reconstruction. *Med Sci Sports Exerc* 2000;**32**:1472–9.
11. Sakane M, Fox RJ, Woo SL, et al. *In situ* forces in the anterior cruciate ligament and its bundles in response to anterior tibial loads. *J Orthop Res* 1997;**15**:285–93.
12. Ho JY, Gardiner A, Shah V, et al. Equal kinematics between central anatomic single-bundle and double-bundle anterior cruciate ligament reconstructions. *Arthroscopy* 2009;**25**:464–72.
13. Siebold R, Dehler C, Ellert T. Prospective randomized comparison of double-bundle versus single-bundle anterior cruciate ligament reconstruction. *Arthroscopy* 2008;**24**:137–45.
14. Gadikota HR, Seon JK, Chen CH, et al. *In vitro* and intraoperative laxities after single-bundle and double-bundle anterior cruciate ligament reconstructions. *Arthroscopy* 2011;**27**:849–60.
15. Meredick RB, Vance KJ, Appleby D, et al. Outcome of single-bundle versus double-bundle reconstruction of the anterior cruciate ligament: a meta-analysis. *Am J Sports Med* 2008;**36**:1414–21.
16. Fujita N, Kuroda R, Matsumoto T, et al. Comparison of the clinical outcome of double-bundle, anteromedial single-bundle, and posterolateral single-bundle anterior cruciate ligament reconstruction using hamstring tendon graft with minimum 2-year follow-up. *Arthroscopy* 2011;**27**:906–13.
17. van Eck CF, Schreiber VM, Mejia HA, et al. "Anatomic" anterior cruciate ligament reconstruction: a systematic review of surgical techniques and reporting of surgical data. *Arthroscopy* 2010;**26**(9 Suppl):S2–12.
18. MacWilliams BA, Wilson DR, DesJardins JD, Romero J, Chao EY. Hamstrings cocontraction reduces internal rotation, anterior translation, and anterior cruciate ligament load in weight-bearing flexion. *Journal of Orthopaedic Research* 1999;**17**(6):817–22.
19. Lautamies R, Harilainen A, Kettunen J, et al. Isokinetic quadriceps and hamstring muscle strength and knee function 5 years after anterior cruciate ligament reconstruction: comparison between bone-patellar tendon-bone and hamstring tendon autografts. *Knee Surg Sports Traumatol Arthrosc* 2008;**16**:1009–16.
20. Madhavan S, Shields RK. Neuromuscular responses in individuals with anterior cruciate ligament repair. *Clin Neurophysiol* 2011;**122**:997–1004.
21. Crawford C, Nyland J, Landes S, et al. Anatomic double bundle ACL reconstruction: a literature review. *Knee Surg Sports Traumatol Arthrosc* 2007;**15**:946–64.
22. Snow M, Stanish WD. Double-bundle ACL reconstruction: how big is the learning curve? *Knee Surg Sports Traumatol Arthrosc* 2010;**18**:1195–200.
23. Yasuda K, Tanabe Y, Kondo E, et al. Anatomic double-bundle anterior cruciate ligament reconstruction. *Arthroscopy* 2010;**26**(9 Suppl):S21–34.