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Original Article

Functional outcome of double-bundle anterior cruciate ligament reconstruction

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ABSTRACT

Background/Purpose: The anterior cruciate ligament (ACL) is one of the most frequently injured ligaments in the knee joint and is generally treated by surgical reconstruction. A possible reason for the unsatisfactory nature of this reconstruction is that the complex function of the ACL is not reproduced by the traditional ACL reconstruction procedure, which replicates only a single bundle rather than the two separate bundles that form the original ACL. It has been suggested that re-establishment of the double-bundle anatomy of the ACL is crucial for obtaining a better restoration of the normal biomechanics of the knee and improving the knee's rotatory stability. The purpose of this study was to evaluate the authors' current double-bundle ACL reconstruction technique and assess the various functions of the anteromedial and posterolateral bundles.

Methods: Patients were assessed for instability and laxity after a mean follow-up of 16 months (range, 12–26 months). The range of motion was measured and compared with the opposite normal knee. Clinical evaluation was performed using the modified Lysholm scoring scale, the Tegner activity scale, and the International Knee Documentation Committee (IKDC) rating system.

Results: The study included 20 patients, 15 males and five females, with a mean age of 22.7 years (range, 18–29 years) at the time of surgery. Following the procedure described by Yasuda et al, double-bundle ACL reconstruction, which anatomically reproduces the anteromedial and posterolateral bundles using hamstring tendon grafts, was performed on patients under general anesthesia. The clinical results for the Lysholm rating system were good to excellent, being 71 points preoperatively and 94 postoperatively. The IKDC rating was 65% preoperatively and 92% postoperatively. All patients showed a negative pivot shifting test.

Conclusion: The ACL not only is the primary restraint on anterior tibial translation but also contributes considerably to normal knee kinematics. Our study showed that the four-tunnel double-bundle ACL reconstruction provides significant advantages in terms of anterior and rotational stability as well as objective IKDC. The subjective measurement of postoperative functional results using either the Lysholm or the IKDC rating system revealed a promising outcome after a short follow-up period.

1. Introduction

The anterior cruciate ligament (ACL) consists of dense connective tissue enveloped in a synovial membrane; this places the ligament in an intra-articular but extrasynovial position.[1,2] It is attached proximally to the posterior aspect of the lateral femoral condyle, and runs in an oblique course distally through the intercondylar ridge to insert between the medial and lateral tibial spines. Hence, the ACL consists of two bundles: a slightly larger anteromedial bundle and a smaller posterolateral bundle, named according to their relative tibial insertion sites.[3] The two-bundle anatomy has been verified in fetal[4] (Fig. 1), cadaveric, and arthroscopic studies.[4] Both bundles are crucial to knee stability.[5]

Functionality has been shown to be split between the anteromedial and posterolateral bundles, and varies in proportion to changes in the knee flexion angle.[6,7] The posterolateral bundle carries the majority of load when the knee is at near extension, whereas the anteromedial bundle carries the majority of load at high flexion angles. Study[8] has shown that anatomical double-bundle ACL reconstruction, which places femoral tunnels at the insertion of both the anteromedial bundle and the posterolateral bundle of the ACL with separate grafts, has biomechanical advantages over single-bundle procedures in terms of both knee kinematics and restoring normal ACL function.

ACL is one of the most frequently injured ligaments in the knee joint and is generally treated by surgical reconstruction.[9] However, 15–25% of patients report unsatisfactory postsurgical results in

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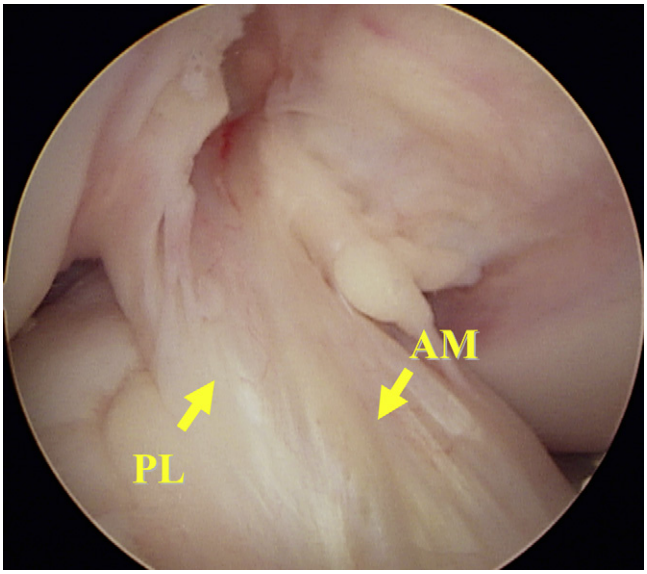

Fig. 1. The ACL consists of two bundles: a slightly larger AM bundle and a smaller PL bundle, which are named according to their relative tibial insertion sites. ACL = anterior cruciate ligament; AM = anteromedial; PL = posterolateral.

short- and long-term clinical studies.[10,11] A possible reason for these unsatisfactory results is that the complex function of the ACL is not reproduced by the traditional ACL reconstruction procedure, which replicates only a single bundle rather than the two separate bundles of the ACL.[12] Another reason for unsatisfying results may be the surgical technique used for tunnel placement in the tibia and femur.[13]

It has been suggested that re-establishment of the double-bundle anatomy of the ACL is crucial for obtaining a better restoration of the normal biomechanics of the knee and improving rotatory laxity.[8,14] Such techniques aim to reconstruct both bundles and, theoretically, should provide a superior construct that is able to reduce the failure rate, improve the functional outcome, and provide better rotatory stability.[10] However, these techniques have not been shown to be associated with an improved functional outcome over a 2-year follow-up.[8,14]

The purpose of this study was to evaluate the authors' current double-bundle ACL reconstruction technique and assess the functional outcome of this approach. The hypothesis was that double-bundle ACL-reconstructed patients have a superior functional outcome compared to single-bundle ACL-reconstructed patients in selective cases. The authors further hypothesized that double-bundle ACL reconstruction improves knee stability more than single-bundle ACL reconstruction during whole knee flexion angle.

2. Materials and methods

From 2008 to 2009, a total of 23 consecutive and selected patients underwent double-bundle ACL reconstruction using hamstring autografts in our hospital. The study included 20 patients, who returned for the follow-up evaluation; out of these, 15 were males and five females, with a mean age 22.7 years (range, 18 to 29) at the time of surgery. Three of the patients were excluded because they were lost to follow-up or they followed up for less than 2 years. Although the final outcomes in these three patients are uncertain, they recovered as well as other patients in the first postoperative year. Most of the injuries resulted from playing basketball or traffic accidents. The main mechanism of injury was a valgus-external rotational force. All individuals needed to serve in the armed forces or be a team member at a high school or college. Prior to surgery, all patients complained of recurrent giving way of the knee during activities that required pivoting. The preoperative physical examination found positive results for the Lachman test and pivot shift test in all patients. The Lachman score was graded as follows: normal (0–2 mm), nearly normal (3–5 mm), abnormal (6–10 mm), and severely abnormal (>10 mm). Furthermore, the pivot shift score was graded as follows: normal (equal), nearly normal (glide), abnormal (clunk), and severely abnormal (gross; subluxation). The reproducibility of the KT-1000 arthrometer (Medmetric, San Diego, CA, USA) laxity examination was assessed by comparing measured anterior tibial displacement at 30-pound testing of the normal knee, as measured preoperatively and on follow-up. No patient exhibited associated posterior tibial translation or posterolateral rotatory instability. Preoperatively, the diagnosis of each patient was confirmed by magnetic resonance imaging (MRI) and arthroscopic examination.

Postoperatively, patients were assessed for clinical instability and laxity after a mean follow-up of 16 months (range, 12–26 months). The range of motion was measured and compared with the opposite normal knee. Flexion loss, as the angular difference in maximal active flexion, was measured with the patient in the supine position. At the same time, extension loss was measured in a similar way, but with the patient in the prone position. Clinical evaluation was performed using the modified Lysholm scoring scale and the International Knee Documentation Committee (IKDC) rating system. The IKDC assessment was based on eight groupings, each of which is assigned one of four grades. The eight groups are as follows: (1) patient subjective assessment, (2) symptoms, (3) range of motion, (4) ligament examination, (5) compartment finding, (6) harvest site pathology, (7) X-ray finding, and (8) functional test. To assess muscle force evaluation, quadriceps strength was measured using a Tricone Isokinetic Dynamometer (Lumex Inc., Ronkonkoma, NY, USA). Quadriceps peak torque was tested for both the involved and the uninvolved limbs using standard stabilization, with the patients seated. The peak torque was measured at velocities of both 60 and 240°/s. Peak torque was defined as the highest torque produced during a given isokinetic contraction, thus being a measure of muscle strength (force). The quadriceps index was calculated as the ratio of the peak torque in the involved knee to the peak torque in the uninvolved knee. Informed consent was obtained from each participant prior to the study.

3. Surgical technique

Following the procedure described by Yasuda et al,[15] a double-bundle ACL reconstruction, which anatomically reproduces the anteromedial and posterolateral bundles using hamstring tendon grafts, was performed on patients under general anesthesia. Both the semitendinosus and the gracillis tendons were harvested using a tendon stripper. The semitendinosus tendon was cut in half, and the gracillis tendon was resected so that the thickest portion could be used for the graft. The proximal halves of the semitendinosus tendon and the gracillis tendon were doubled and used for anteromedial bundle reconstruction. The distal half of the semitendinosus tendon was doubled and used for posterolateral bundle reconstruction. An EndoButton CL (Smith & Nephew Endoscopy, Mansfield, MA, USA) was attached to the proximal end of each graft using No. 5 Fiberwire (Arthrex, Naples, FL, USA), and the length of the suture loop was matched to the femoral tunnel as measured during reconstruction. The distal end of each graft was connected with No. 2 Ethibond (Ethicon Inc., Somerville, NJ, USA) using an appropriate size of biodegradable interference screw. The metal staples (screw + washer) were attached to the proximal tibia by advancing the distal graft fixation. The diameters of these grafts were measured using a sizing system, which were, on average,

7.3 ± 0.8 mm (6–8.5 mm) for the anteromedial bundle and 6.1 ± 0.6 mm (5–6.5 mm) for the posterolateral bundle.

After arthroscopic treatment of the meniscal injury, the ACL remnant was removed, and the footprints of the anteromedial and the posterolateral bundles were identified. No notch plasty was performed. The tibial and femoral tunnels (sockets) were then created using arthroscopic visualization. First, a tibial tunnel and femoral socket for the posterolateral bundle were created. The center of the tibial attachment and femoral attachment of the posterolateral bundle (defined as the posterolateral point) was confirmed by Yasuda's methods. Next, a tibial tunnel and a femoral socket for the anteromedial bundle were created. The tibial drill guide was positioned in the center of the tibial footprint of the anteromedial bundle and directed to the femoral footprint of the anteromedial bundle. The guide pin was drilled into the tibial sleeve, and the tibial tunnel was made with a cannulated drill corresponding to the measured diameter of the prepared graft. For the femoral socket of the anteromedial bundle, a 5 or 6 mm step-off guide confirmed the center of the femoral attachment of the anteromedial bundle (defined as the anteromedial point), and the guide pin was drilled at an 1:30 orientation for the left knee and at a 10:30 orientation for the right knee.

After creating the two tibial tunnels and two femoral sockets, the graft for the posterolateral bundle was introduced through the tibial tunnel to the femoral socket using a passing pin. The endobutton was flipped onto the femoral cortical surface. The graft for the anteromedial bundle was then placed in the same manner. The knee was flexed and extended 20–30 times to precondition the grafts. Finally, the posterolateral and anteromedial bundles were fixed simultaneously at 15° of knee flexion by screw and washer (Fig. 2).

Upon completing the procedure, a cold compression cryocuff (Aircast Inc., Summit, NJ, USA) was applied to the knee and the operative leg was put in a long-leg hinged knee brace that was locked at full extension. The initial postoperative management following ACL reconstruction was designed to control inflammation and swelling, restore rapidly full extension (equal to that in the uninjured knee), re-establish quadriceps control and range of motion, and restore a normal gait. Closed-chain exercises, including stationary bicycling and up-and-down stair climbing, were prescribed to strengthen the patient's muscles. Jogging was allowed at 8 weeks and noncontact pivoting at 10 weeks. If the patient could not achieve the IKDC objectives listed in the protocol, more aggressive physical therapy was ordered to improve muscle force and to provide proprioceptive balance training.

3.1. Statistical analysis

The Wilcoxon test was used to compare IKDC scores, modified Lysholm scores, Tegner scale scores, and anteroposterior stability obtained using the KT-1000. Significance was reported at the 95% confidence level ($p < 0.05$). We used SPSS Version 17.0 software (SPSS Inc., Chicago, IL, USA) for all analysis.

4. Results

Twenty patients returned for follow-up evaluation (Table 1). The clinical results for the Lysholm rating system were good to excellent, being 71% preoperatively and 94% postoperatively, while the IKDC rating was 65% preoperatively and 92% postoperatively. Analysis of the results of IKDC rating scale revealed that the patients rated their satisfaction with the response of their knee following surgery as normal in 10 cases (50%) and as near normal in eight cases (40%). Evaluation of symptoms using the IKDC form revealed no pain, swelling, or feelings of giving way in 19 of 20 cases (>90%). The results of the Lachman and pivot shift tests between the preoperative assessment and postoperative follow-up revealed a statistically significant difference ($p < 0.05$). Eighteen of the 20 knees surveyed achieved a full range of motion postoperatively. The remaining two patients displayed a 5° loss of full

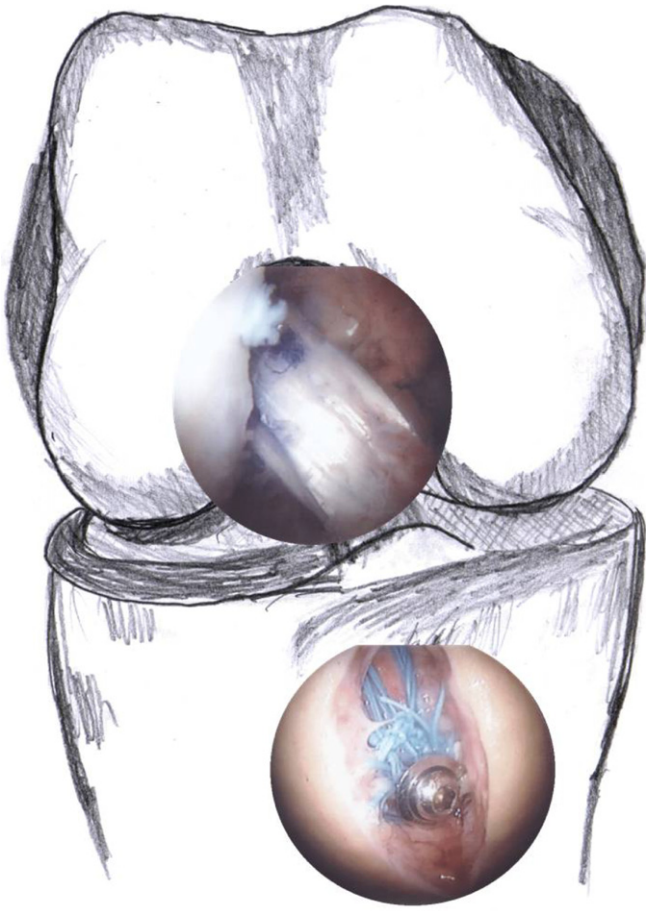

Fig. 2. The posterolateral bundle and anteromedial bundle were fixed simultaneously at full extension and 15° of knee flexion by screw and washer.

Table 1
General patient information.

Case	Age	Gender	Lysholm score [a]	Lysholm score [b]	IDKC score [a]	IKDC score [b]
1	18	M	68	93	73	95
2	25	F	63	93	69	94
3	23	F	68	91	75	95
4	20	M	69	94	77	96
5	27	F	64	92	71	95
6	21	M	63	92	70	94
7	22	M	68	93	75	95
8	18	M	60	89	66	90
9	23	M	57	88	63	89
10	19	M	69	92	73	94
11	26	F	75	95	78	98
12	18	M	62	90	65	90
13	18	M	70	94	75	96
14	23	M	68	91	72	94
15	22	M	69	94	74	96
16	24	M	65	90	69	93
17	29	M	60	89	65	92
18	25	M	63	91	70	93
19	29	F	61	90	66	91
20	24	M	64	94	72	95

IKDC = International Knee Documentation Committee.
[a] Prior to surgery.
[b] After surgery.

Table 2
Comparison of the pre- and postoperative results obtained with anatomical double ACL reconstruction using a hamstring graft.

	Mean IKDC score	Mean Lysholm score	Mean Tegner score	KT-1000 for anterior translation at 30° knee flexion (mean)
Preoperative	65 ± 7	71 ± 5	3.4	All >3 mm
Postoperative	92 ± 5	94 ± 3	6.1	All <3 mm (1.27 mm)
p	<0.05	<0.05	<0.05	<0.05

ACL = anterior cruciate ligament; IKDC = International Knee Documentation Committee.

extension as compared to uninvolved knees. Pivot shift was graded as 0 (absent), grade I (slight), grade II (definite subluxation), and grade III (subluxation and momentary locking). Of all the 20 patients, six patients (30%) had grade II instability and 14 (70%) had grade III instability preoperatively; two patients (10%) improved to grade I and 18 patients (90%) improved to grade 0 postoperatively. The anterior tibial displacement was measured using a KT-1000 arthrometer at 30 pounds of force, and the results were compared preoperatively and postoperatively; this revealed a significant difference ($p < 0.05$) (Table 2). The roentgenographic studies performed at follow-up indicated no degenerative changes and no malpositioning of the patella (Fig. 3). Six of the patients have received MRI after four-tunnel double-bundle ACL reconstruction 6 months postoperatively (Fig. 4). There were no bone tunnel communication on the femoral side and tibial side in these cases. Moreover, results of the postoperative isokinetic quadriceps strength testing, comparing the involved and uninvolved knees, showed no significant difference ($p > 0.05$). Additionally, peak torque did not differ significantly at either 60°/s or 240°/s between the involved and uninvolved knees. Finally, the quadriceps index indicated no significant difference between the knees (Table 3).

5. Discussion

The ACL is not only the primary restraint on anterior tibial translation, but also a significant contributor to normal knee kinematics. The purpose of ACL reconstruction is to prevent recurrent injury and enable patients to resume preinjury levels of work and activity. Surgery is frequently recommended for patients with combined injuries, those who are unwilling to modify their activities, and those who experience symptoms such as painful giving way during their regular daily activities. Our clinical study selected younger and more active individuals, patients with more severe pivot shift and lateral joint opening, and cases that were more chronic, in order to be able to detect improvement after the operation.

In our previous series study,[16] 90 consecutive patients with a primary diagnosis of anterior cruciate deficiency underwent arthroscopically assisted single-bundle ACL reconstruction using autogenous quadrupled hamstring tendons. The clinical results over a 5–8-year follow-up (mean, 6.7 years) using the Lysholm rating system were that 91% of the patients had a good to excellent rating, while, using the IKDC rating system, 85% of the patients had a good to excellent rating. These findings should be compared to the present study (the double-bundle reconstruction group), where the Lysholm rating system gave 94% and the IKDC rating system gave 92% good to excellent ratings, using a 2-year follow-up. Although double-bundle reconstruction group has an overall better clinical result than single-bundle group on average, there is no statistical significance between them. One possible reason for this is the different follow-up periods and the differences in patient's selection.

It has been suggested that re-establishing the double-bundle anatomy of the ACL is crucial for obtaining a better restoration of the normal biomechanics of the knee and improving rotatory laxity.[14,17–19] The objective of such is to reconstruct both bundles with the aim of reducing the rate of failure, improving the functional outcome,[20–23] and restoring better rotatory stability.[18] However, these techniques have not been shown to be associated with an improved functional outcome at a follow-up of 2 years.[14,17–19]

Radford and Amis[24] first described the mechanical results of double-bundle reconstruction in cadaver knees, showing restoration of anterior laxity to nearly normal levels at 20° and 90° of flexion. The force distribution between the anteromedial and posterolateral bundles in the reconstruction was similar to that found in the normal ACL. There was a higher *in situ* force in the posterolateral bundle at 0° and 15° of flexion, whereas in the anteromedial bundle this force was higher at 90° of flexion.

Yagi et al[8] used a robotic/universal force–moment sensor-testing system to study 10 cadaver knees subjected to external loading with an anterior load and a combined rotatory load. This showed superior restoration of the biomechanics in double- than in single-bundle reconstructions, especially with respect to rotatory loads.

Aglietti et al[18] carried out a prospective, comparative cohort study to evaluate whether the technique for double-bundle

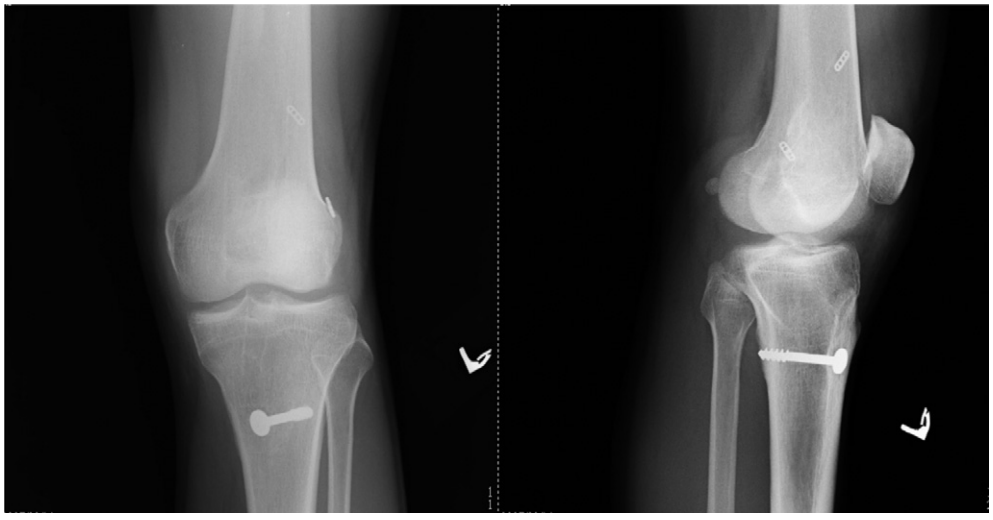

Fig. 3. Postoperative X-ray film of the anteroposterior (AP) and lateral.

Fig. 4. Postoperative magnetic resonance imaging.

reconstruction was superior to a single-bundle procedure in terms of controlling anterior tibial translation and reducing pivot shift. The first 25 patients (group I) had a single-bundle transtibial ACL reconstruction, the next 25 (group II) a double-bundle single-incision transtibial procedure, and a further 25 (group III) a double-bundle two-incision outside-in operation. The mean side-to-side anterior laxity, the amount of residual pivot shift, and the mean IKDC subjective evaluation score were significantly better in group III than in group I ($p < 0.05$). No significant differences were observed between groups II and III.

Järvelä[25] conducted a prospective, randomized clinical study to compare the outcome of ACL reconstruction using either double- or single-bundle techniques. He randomized 65 patients into either double-bundle ($n = 35$) or single-bundle ($n = 30$) groups using hamstring tendons and bioabsorbable screw fixation. The double-bundle reconstruction group resulted in better restoration of rotational laxity than the single-bundle ACL reconstruction when assessed by the pivot shift test ($p < 0.002$). In addition, the single-bundle groups had six graft failures leading to revision ACL surgery, whereas the double-bundle group had only one graft failure.

Table 3
Postoperative quadriceps strength.

[Nm]	Uninvolved	Involved	*p*
Peak torque at 60°/s	159.6 ± 23.1	147.9 ± 18.5	>0.05
Peak torque at 240°/s	126.2 ± 12.1	117.8 ± 8.7	>0.05

Nm = Newton meter.

In a recent review of clinical results of double-bundle ACL reconstruction,[26] 14 randomized controlled trials published in the literature were included. Of these studies, 10 (71%) reported significantly better results with the double-bundle technique than with the single-bundle technique, of which seven (50%) reported better rotational stability, six (43%) reported better anterior stability, three (21%) reported better objective knee scores, three (21%) reported better subjective knee scores, two (14%) reported fewer graft failures, and one (7%) reported less degenerative changes of the knee. In addition, none of the trials found that the single-bundle technique provided better results, by any of these evaluations, when compared with the double-bundle technique. However, 13 (93%) of the 14 trials had only short-term follow-ups (1–3 years).

Measurements of laxity and the IKDC ratings are incapable of distinguishing the functional status of the ACL-deficient patients.[27] Alternatively, the Lysholm, Knee Outcome Survey (KOS)-Sport,

KOS-ADL, and the global knee function rating scores seem to be able to discriminate between symptomatic and asymptomatic deficiency.[28,29] No single measurement tool is sufficient in itself and measurements of anterior laxity does not correlate with functional outcome scores. Assessments that are based partially on measures of joint laxity, such as the IKDC score, may artificially overestimate the disability after rupture of the ACL.[29,30]

The main advantage of double-bundle reconstruction compared with single-bundle reconstruction should be better rotational stability, but the validity and accuracy of the measurement systems for rotational stability have not been established[14,19] and this remains the major weakness when evaluating the results of double-bundle reconstruction. The most pronounced biomechanical benefit of double-bundle reconstruction appears to be associated with resisting combined rotator loads, and it is in this area that objective assessment of the clinical differences in rotational stability between these two techniques must be developed and validated.[31] In addition, there are potential risks associated with the double-bundle technique, such as osteonecrosis of lateral femoral condyle, bone tunnel communication, difficulty in revision, and a longer operative time. These make the double-bundle ACL reconstruction a very technically demanding procedure, which, together with the procedure's potential complications, creates a steep learning curve for the surgeon.

6. Conclusions

Our study showed that four-tunnel double-bundle ACL reconstruction had a significant advantage in terms of anterior and rotational stability as well as objective IKDC compared to single-bundle reconstruction. The subjective measurement of post-operative functional results, using either the Lysholm or the IKDC rating systems, revealed a promising outcome over a short follow-up period.

References

1. S.P. Arnoczky. Anatomy of the anterior cruciate ligament. Clin Orthop Relat Res 172 (1983) 19–25.
2. M. Dienst, R.T. Burks, P.E. Greis. Anatomy and biomechanics of the anterior cruciate ligament. Orthop Clin North Am 33 (2002) 605–620.
3. A. Chhabra, J.S. Starman, M. Ferretti, A.F. Vidal, T. Zantop, F.H. Fu. Anatomic, radiographic, biomechanical, and kinematic evaluation of the anterior cruciate ligament and its two functional bundles. J Bone Joint Surg Am 88 (Suppl. 4) (2006) 2–10.
4. M. Ferretti, E.A. Levicoff, T.A. Macpherson, M.S. Moreland, M. Cohen, F.H. Fu. The fetal anterior cruciate ligament: an anatomic and histologic study. Arthroscopy 23 (2007) 278–283.
5. W. Shen, S. Jordan, F. Fu. J Orthop Surg 15 (2007) 216–221.
6. F.G. Girgis, J.L. Marshall, A. Monajem. The cruciate ligaments of the knee joint. Anatomical, functional and experimental analysis. Clin Orthop 106 (1975) 216–231.
7. M. Sakane, R.J. Fox, S.L. Woo, G.A. Livesay, G. Li, F.H. Fu. *In situ* forces in the anterior cruciate ligament and its bundles in response to anterior tibial loads. J Orthop Res 15 (1997) 285–293.
8. M. Yagi, E.K. Wong, A. Kanamori, R.E. Debski, F.H. Fu, S.L. Woo. Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. Am J Sports Med 30 (2002) 660–666.
9. K.C. Miyasaka, D.M. Daniel, M.L. Stone, P. Hirschmann. The incidence of knee ligament injuries in the general population. Am J Knee Surg 4 (1991) 3–8.
10. B.R. Bach Jr., S. Tradonsky, J. Bojchuk, M.E. Levy, C.A. Bush-Joseph, N.H. Khan. Arthroscopically assisted anterior cruciate ligament reconstruction using patellar tendon autograft: five- to nine-year follow-up evaluation. Am J Sports Med 26 (1998) 20–29.
11. J. Gillquist, K. Messner. Anterior cruciate ligament reconstruction and the long-term incidence of gonarthrosis. Sports Med 27 (1999) 143–156.
12. R.J. Johnson, B.D. Beynnon, C.E. Nichols, P.A. Renstrom. The treatment of injuries of the anterior cruciate ligament. J Bone Joint Surg Am 74 (1992) 140–151.
13. F. Picard, A.M. DiGioia, J. Moody, V. Martinek, F.H. Fu, M. Rytel, C. Nikou, et al. Accuracy in tunnel placement for ACL reconstruction. Comparison of traditional arthroscopic and computer-assisted navigation techniques. Comput Aided Surg 6 (2001) 279–289.
14. T. Muneta, H. Koga, T. Mochizuki, Y.J. Ju, K. Hara, A. Nimura, K. Yagishita, et al. A prospective randomized study of 4-strand semitendinosus tendon anterior cruciate ligament reconstruction comparing single-bundle and double-bundle techniques. Arthroscopy 23 (2007) 618–628.
15. K. Yasuda, E. Kondo, H. Ichiyama, Y. Tanabe, H. Tohyama. Clinical evaluation of anatomic double-bundle anterior cruciate ligament reconstruction procedure using hamstring tendon grafts: comparisons among 3 different procedures. Arthroscopy 22 (2006) 240–251.
16. H.M. Lee, K.C. Cheng, B.J. Lin, S.T. Hung, J.T. Shih, Y.T. Hao. Arthroscopic anterior cruciate ligament reconstruction using hamstring graft with endobutton fixation—results of follow-up. J Orthop Surg Taiwan 24 (2007) 80–92.
17. N. Adachi, M. Ochi, Y. Uchio, J. Iwasa, M. Kuriwaka, Y. Ito. Reconstruction of the anterior cruciate ligament: a single- versus double-bundle multistranded hamstring tendons. J Bone Joint Surg Br 86-B (2004) 515–520.
18. P. Aglietti, F. Giron, P. Cuomo, M. Losco, M. Mondanelli. Single- and double-incision double-bundle ACL reconstruction. Clin Orhop 454 (2007) 108–113.
19. M. Yagi, R. Kuroda, K. Nagamune, S. Yoshiya, M. Kurosaka. Double-bundle ACL reconstruction can improve rotational stability. Clin Orthop 454 (2007) 100–107.
20. T. Zantop, M. Herbort, M.J. Raschke, F.H. Fu, W. Petersen. The role of the anteromedial and posterolateral bundles of the anterior cruciate ligament in anterior tibial translation and internal rotation. Am J Sports Med 35 (2007) 223–227.
21. B.A. Zelle, P.U. Brucker, M.T. Feng, F.H. Fu. Anatomical double-bundle anterior cruciate ligament reconstruction. Sports Med 36 (2006) 99–108.
22. W. Petersen, H. Tretow, A. Weimann, M. Herbort, F.H. Fu, M. Raschke, T. Zantop. Biomechanical evaluation of two techniques for double-bundle anterior cruciate ligament reconstruction: one tibial tunnel versus two tibial tunnels. Am J Sports Med 35 (2007) 228–234.
23. W. Petersen, T. Zantop. Anatomy of the anterior cruciate ligament with regard to its two bundles. Clin Orthop 454 (2007) 35–47.
24. W.J. Radford, A.A. Amis. Biomechanics of a double prosthetic ligament in the anterior cruciate deficient knee. J Bone Joint Surg Br 72 (1990) 1038–1043.
25. T. Järvelä. Double-bundle versus single-bundle anterior cruciate ligament reconstruction: a prospective, randomized clinical study. Knee Surg Sports Traumatol Arthrosc 15 (2007) 500–507.
26. T. Jarvela, P. Suomalainen. ACL reconstruction with double-bundle technique: a review of clinical results. Phys Sportsmed 39 (2011) 85–92.
27. J.J. Irrgang, H. Ho, C.D. Harner, F.H. Fu. Use of the International Knee Documentation Committee guidelines to assess outcome following anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 6 (1998) 107–114.
28. J.J. Irrgang, L. Snyder-Mackler, R.S. Wainner, F.H. Fu, C.D. Harner. Development of a patient-reported measure of function of the knee. J Bone Joint Surg Am 80-A (1998) 1132–1145.
29. K.S. Rudolph, M.J. Axe, T.S. Buchanan, J.P. Scholz, L. Snyder-Mackler. Dynamic stability in the anterior cruciate ligament deficient knee. Knee Surg Sports Traumatol Arthrosc 9 (2001) 62–71.
30. J. Lysholm, J. Gillquist. Evaluation of knee ligament surgery results with special emphasis on use of a scoring scale. Am J Sports Med 10 (1982) 150–154.
31. B.A. Zelle, A.F. Vidal, P.U. Brucker, F.H. Fu. Double-bundle reconstruction of the anterior cruciate ligament: anatomic and biomechanical rationale. J Am Acad Orthop Surg 15 (2007) 87–96. Review.