Double-bundle revision anterior cruciate ligament reconstruction is effective in rescuing failed primary reconstruction and re-introducing patients to physical exercise

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Abstract. The anterior cruciate ligament (ACL) is one of a pair of cruciate ligaments in the human knee and is critical for knee stability, as it limits anterior tibial translation on the femur, restrains rotation and resists varus and valgus joint forces. The present study aimed to assess the effect of double-bundle revision anterior cruciate ligament (ACL) reconstruction in improving the subjective and objective functions and re-introducing patients to physical activity after primary ACL reconstruction had failed. A total of 34 patients who underwent double-bundle ACL revision surgeries were included in the present retrospective study. Lysholm, Tegner and IKDC scores as well as KT-2000 arthrometry measures were obtained pre- and post-operatively. The follow-up time was at least 2 years. The results indicated that the IKDC, Lysholm and Tegner scores as well as KT-2000 flexion scores were significantly improved after revision ACL reconstruction. All patients resumed to performing physical exercise activities after revision surgeries, 65% of whom reached pre-injury levels. In conclusion, these results demonstrated that double-bundle revision ACL reconstruction was consistently effective in rescuing failed primary ACL reconstruction and re-introducing patients to physical exercise.

Introduction

The anterior cruciate ligament (ACL) is one of a pair of cruciate ligaments in the human knee and is critical for knee stability, as it limits anterior tibial translation on the femur, restrains rotation and resists varus and valgus joint forces (1,2). ACL tears are one of the most common types of knee injury and ACL reconstruction is often performed with the purpose of re-introducing patients to this type of physical activity (3,4). However, even with the advances in ACL reconstructive surgery made in previous years, grafting failure keeps occurring at a substantial rate of ~2% within 2 years (5), 11.9% within 10 years (6) and an alarming 36% within 20 years (7) of operation. Re-injuries may occur due to high-level physical exercise activity, prior meniscectomy or surgical errors, including improper graft placement, tensioning and fixation (3). Failed graft results in a devastating situation for ACL reconstruction patients, who normally require to undergo revision ACL reconstruction to restore joint stability and knee function.

With the growing number of ACL reconstructions performed, the number of revision ACL reconstruction surgeries has been continuously increasing (8,9), which is technically more challenging than primary ACL reconstruction due to the difficulties in tunnel placement, limitation of graft sources and the complexity of the challenge to acquire stable graft fixation (8). Consequently, inferior outcomes to primary ACL reconstructions were reported, although significant improvements have been demonstrated after revision reconstruction (10-14). Of note, most revision ACL constructions were performed using a single-bundle technique (15); however, a vast amount of evidence has demonstrated that the double-bundle technique is superior to the single-bundle technique for primary ACL reconstruction (16-24). Compared with single-bundle ACL reconstruction, the double-bundle technique produced better Lachman and pivot-shift test results, KT arthrometry results and Tegner score after 3-12 years post operation (19). In most cases, double-bundle ACL reconstruction yielded significantly favorable results on KT arthrometry, pivot shift test and Lachman test (16-24), as well as reduced graft failure (22-24) and improved International Knee Documentation Committee (IKDC) objective score (18,23,24) compared with single-bundle ACL reconstruction. Therefore, double-bundle ACL reconstruction is indicated to be superior to single-bundle ACL reconstruction. However, to the best of our knowledge, no systematic analysis on the feasibility and efficacy of the double-bundle technique to rescue failed primary ACL reconstruction performed using the double- and single-bundle technique has been performed. The present study aimed to evaluate the clinical and functional outcomes of a series of patients who underwent a double-bundle revision

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ACL reconstruction procedure. It was hypothesized that double-bundle ACL reconstruction is technically feasible to rescue failed single-bundle as well as double-bundle primary ACL reconstructions and results in better clinical outcomes compared with those of single-bundle revision surgeries. In case the primary ACL reconstruction was a single-bundle operation, additional bone tunnels were established in addition to the corrected ones to replace misplaced original bone tunnels. If the primary surgery was performed using the double-bundle technique, a new bone tunnel was established only if any original bone tunnel was misplaced.

Materials and methods

General information. The protocols of the present study were approved by the Institutional Review Committee of Peking University Shenzhen Hospital (Shenzhen, China). A signed informed consent form was obtained from each participant. Records of 34 cases of revision ACL reconstruction performed at the Department of Sports Medicine of Peking University Shenzhen Hospital (Shenzhen, China) between June 2009 and July 2013 were reviewed. Data included pre- and postoperative magnetic resonance imaging (MRI) and three-dimensional computed tomography (3D CT) radiographies, endoscopic images prior to surgery, pre- and post-operative KT-2000 flexion scores as well as the IKDC, Tegner and Lysholm scores (17-23). The time interval between primary ACL reconstruction and the first occurrence of instability was 7-35 months (average, 17.0±2.3 months). The patients were positive for anterior drawer test, Lachman test and pivot shift test. The cohort included 24 males and 10 female patients aged 19-38 years (mean age, 29 years; Table I). The follow-up time was at least 24 months.

Pre-and post-operative diagnoses. All patients underwent diagnostic MRI to examine knee injury and pre-operative 3-D CT to assess the position of existing bone tunnels. Post-operative 3-D CT was performed to assess reconstructed bone tunnels and MRI was performed at follow-up to monitor recovery.

Operation procedure. All patients were subjected to arthroscopic revision double-bundle anterior cruciate ligament reconstruction. The patients were in a supine position with epidural anesthesia. The arthroscope was inserted prepatellar laterally. Concomitant cartilage and/or meniscal injuries were treated during the reconstruction surgeries. Cartilage damages were treated by microfracture surgery, while meniscus injuries were treated by suturing or partial meniscectomy.

For bone tunnel management, additional tunnels were added for patients with primary single-bundle ACL reconstruction. In the cases of original tibial bone tunnels positioned too anterior (Fig. 1), too high (Fig. 2) or over the top (Fig. 3), new bone tunnels were generated at the correct positions. If the existing tunnels from primary reconstruction were correctly positioned, they were used in the revision reconstruction, several of which were expanded to the required size (Fig. 4).

Out of the 34 surgeries, allogeneic tendons were used in 8 cases, a mix of allogeneic and autologous tendons in 20 cases and autologous tendons in 6 cases.

The anteromedial bundle was located at the junction of the ridge and femoral condyles, and the entering site of the posterolateral bundle was located 8 mm from the anterior edge and 6 mm from the posterior edge of condyles. The ligaments were fixed using endo-button, absorbable interface screws.

Post-operative rehabilitation. The patients started the ankle pump and straight leg raising training 1 day after the operation, knee exercise at 4 days post-surgery, weight-bearing walking without crutches half a month after the operation, and commenced exercises to strengthen the muscles, jogging and training for leg flexibility at 3 months post-operation.

Statistical analysis. Values are expressed as the mean ± standard deviation. Differences between pre- and post-operative functional scores were assessed by Student's t-test with SPSS 13.0 (SPSS, Inc., Chicago, IL, USA). $P<0.05$ was considered to indicate a statistically significant difference.

Results

Operative findings. Meniscal lesions were seen in 24 patients (70.6%). Cartilage lesions were identified in 26 patients (76.5%) during revision surgery (trochlear cartilage injury in 15 patients and femoral condyle cartilage injury in 11 patients). ACL injuries included ACL absorption in 4 patients, ACL rupture in 10 patients and ACL laxity in 20 patients. Tunnel malposition of the primary reconstruction was identified in 28 patients (82.4%; Table II).

Overall clinical outcomes of double-bundle revision ACL reconstruction. Double-bundle revision ACL reconstruction was successful in all 34 active patients regarding strengthening of knee stability (decreases of KT-2000 flexion 30˚ and flexion 75˚ differences). All patients resumed to performing a physical exercise activity at a certain level, 23 (67.6%) of which were without concomitant severe cartilage injury or meniscus deficiency and resumed to performing the same type of physical exercise activity at their pre-injury level at the 2-year follow-up.

Double-bundle revision ACL reconstruction improves knee function. Double-bundle revision ACL reconstruction significantly improved the knee function (Table III). Average IKDC score improved from 47.73±6.85 prior to revision surgery to 79.6±4.79 at 2 years thereafter. Lysholm knee scores were significantly changed from pre-operatively poor (56.33±8.60) to post-operatively good (87.73±5.02). Furthermore, the average Tegner activity score was also substantially improved after double-bundle revision ACL reconstruction.

Double-bundle revision ACL reconstruction significantly improves knee laxity. The anteroposterior laxity was also significantly improved, as the KT-2000 flexion 30˚ difference was reduced from 6.8±0.77 to 2.00±0.32 mm and the KT-2000 flexion 75˚ difference from 5.9±1.0 to 2.1±0.89 mm after revision reconstruction.

Discussion

The present study demonstrated that double-bundle revision ACL reconstruction was feasible and effective to rescue failed

Table I. Patient data at baseline.

Characteristic	Males, n=24 (%)	Females, n=10 (%)
Age (years)	31.2±1.1	29.6±1.3
Weight (kg)	71.6±11.3	52.3±10.7
Height (m)	1.75±0.08	1.61±0.05
Body mass index (kg/m^2)	25.1±3.2	22.5±3.2
Meniscus injury	18 (75.00)	6 (25.00)
Cartilage damage	19 (79.17)	7 (20.83)
Autologous tendon used	16 (66.67)	5 (33.33)
Allogeneic tendon used	8 (33.33)	5 (66.67)
Single bundle	17 (70.83)	6 (29.17)
Double bundle	7 (29.17)	4 (70.83)
Single-bundle tendon diameter <8 mm	4 (16.67)	2 (83.33)
Bone tunnel position error	21 (87.50)	7 (12.50)
Interval between primary and revision reconstruction (days)	192±926	287±861

Values are expressed as the mean ± standard deviation.

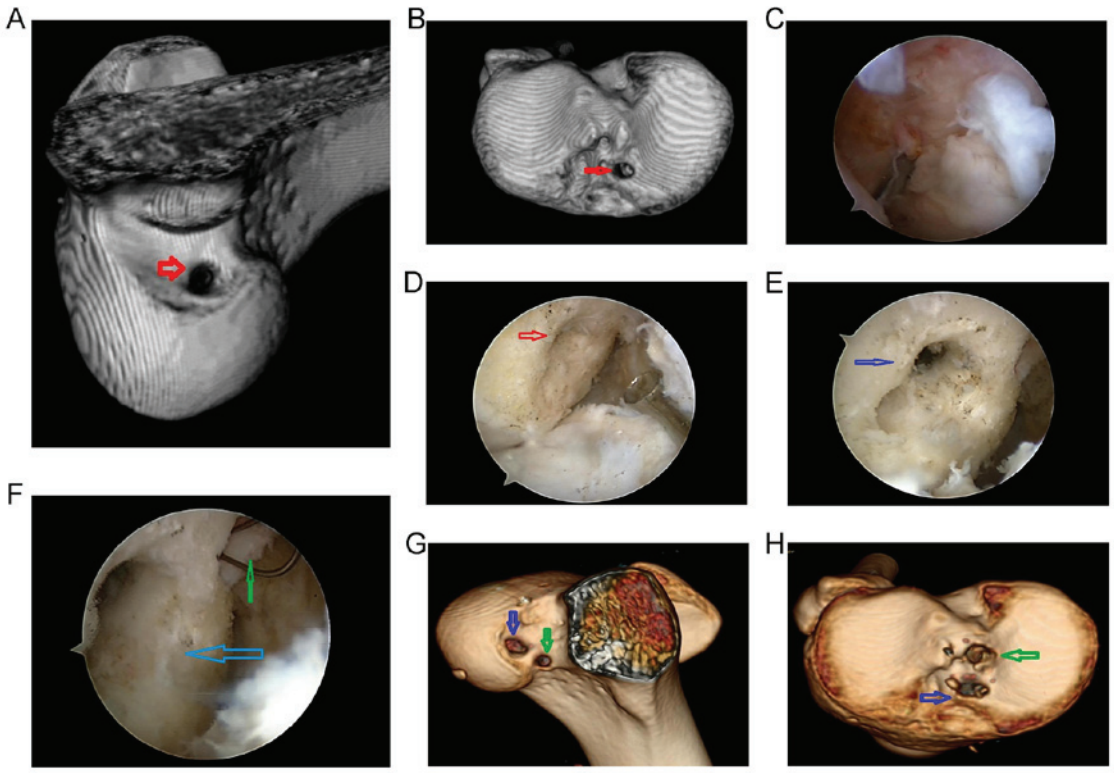

Figure 1. Revision surgery to rescue a failed single-bundle ACL reconstruction. (A-C) The original bone tunnel was too anterior with a narrow diameter. (D) The repaired ACL ligaments were missing during revision operation. (E) The original bone tunnel was expanded into an oval and used for the posterolateral bundle. (F) A new bone tunnel for the anteromedial bundle was constructed (green arrow). (G and H) Post-operative 3-dimensional computed tomography scan displaying the bone tunnels. Blue arrows indicate that the original femoral tunnel was used for the posterolateral bundle and the tibial tunnel for the anteromedial bundle, and green arrows indicate that the added femoral tunnel was used for the anteromedial bundle and the added tibial tunnel for the posterolateral bundle. The red arrows represent the original bone tunnel. ACL, anterior cruciate ligament.

primary single-bundle or double-bundle ACL reconstruction. The post-operative IKDC, Tegner and Lysholm score as well as the KT-2000 30˚ and 75˚ flexion scores were significantly improved compared with the pre-operative ones, indicating the recovery of the subjective function and knee stability. Furthermore, all patients were able to resume to performing physical exercise and the majority of them reached pre-injury levels.

With the growing number of ACL reconstructions performed, the number of patients undergoing revision ACL reconstruction has also been on the rise, as the graft may fail due to mechanical, technical and biological factors (25).

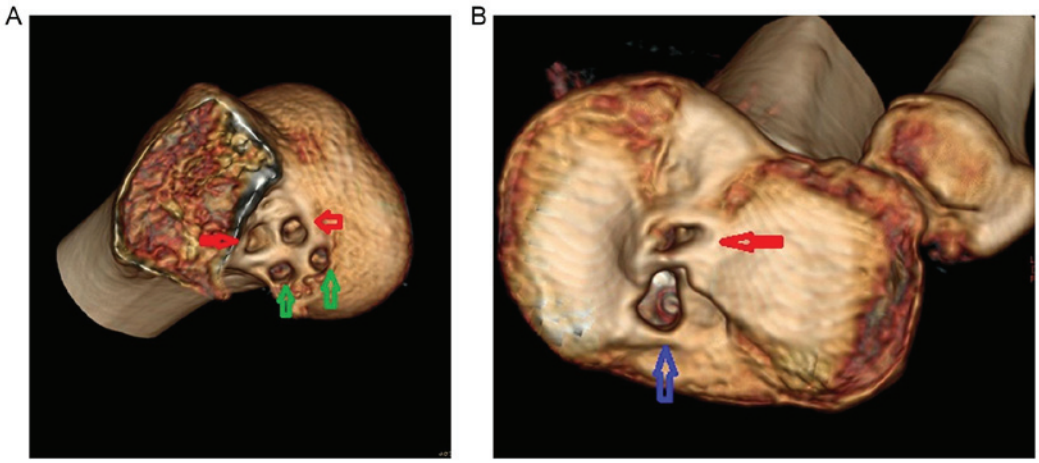

Figure 2. Revision surgery to rescue a failed anterior cruciate ligament reconstruction with misplaced bone tunnels. (A) The original femoral bone tunnels were too high (red arrows) and a major cause of reconstruction failure, which were repositioned during revision surgery (green arrows). (B) The original tibial tunnels were kept in the revision surgery and only the tunnel for the anteromedial bundle was expanded (blue arrow).

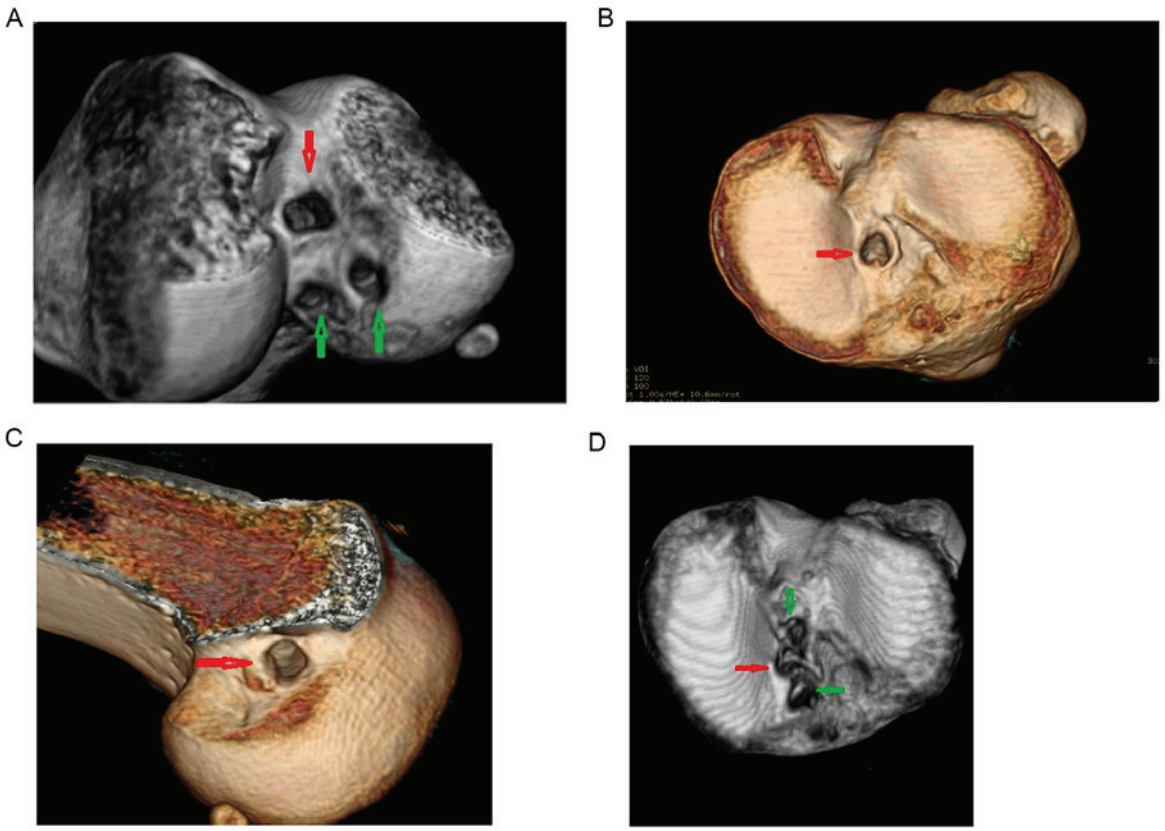

Figure 3. Revision surgery to rescue an over-the-top single-bundle anterior cruciate ligament reconstruction. The original bone tunnel (red arrow) (A) in the femur had an over-the-top position and (B) that in the tibia was too posterior, which did not affect the repositioning of new bone tunnels (green arrows) in (C) femur or (D) tibia.

Although revision ACL reconstruction is promising, the outcome is generally inferior to that of successful primary ACL reconstruction (9,26). Despite double-bundle ACL reconstruction producing superior clinical outcomes to those of single-bundle ACL reconstruction (16-24), the double-bundle technique has rarely been used in revision ACL reconstruction due to it being technically more challenging (27).

Tunnel placement errors, particularly femoral tunnel misplacement, are the most common causes for primary graft failure (28). In the present study, tunnel positioning in the primary ACL reconstruction was correct in only 6 out of 34 patients (17.6%). Malposition of the femoral tunnel accounted for primary graft failure in 28 cases (82.4%), which was at the high end of the previously reported range (37-85%) (28-31). The lesions of the anterior cruciate ligament identified intra-operatively in the present study included graft absorption (n=4, 11.8%), ACL rupture (n=10, 29.4%) and ACL laxity (n=20, 58.8%). Most of the cases had

Table II. Tunnel position of primary anterior cruciate ligament reconstruction.

Parameter	Single bundle placed too anterior on femur	Single bundle placed too high on femur	Single bundle placed too anterior on tibia	Double bundle placed too high on femur	Tunnel placed correctly
Patients (n)	16	10	6	2	6

Table III. Pre- and post-operative functional scores of patients subjected to revision double-bundle anterior cruciate ligament reconstruction.

Time-point	IKDC	Tegner	Lysholm	KT-2000 flexion 30˚ difference (mm)	KT-2000 flexion 75˚ difference (mm)
Pre-operative	47.73±6.85	2.80±0.56	56.33±8.60	6.80±0.77	5.9±1.0
Post-operative	79.60±4.79	6.13±0.74	87.73±5.02	2.00±0.32	2.1±0.89
P-value	0.007	0.026	0.006	0.003	0.017

Values are expressed as the mean ± standard deviation. Post-operative follow-up was performed ≥2 years following the revision surgery. IKDC, International Knee Documentation Committee score.

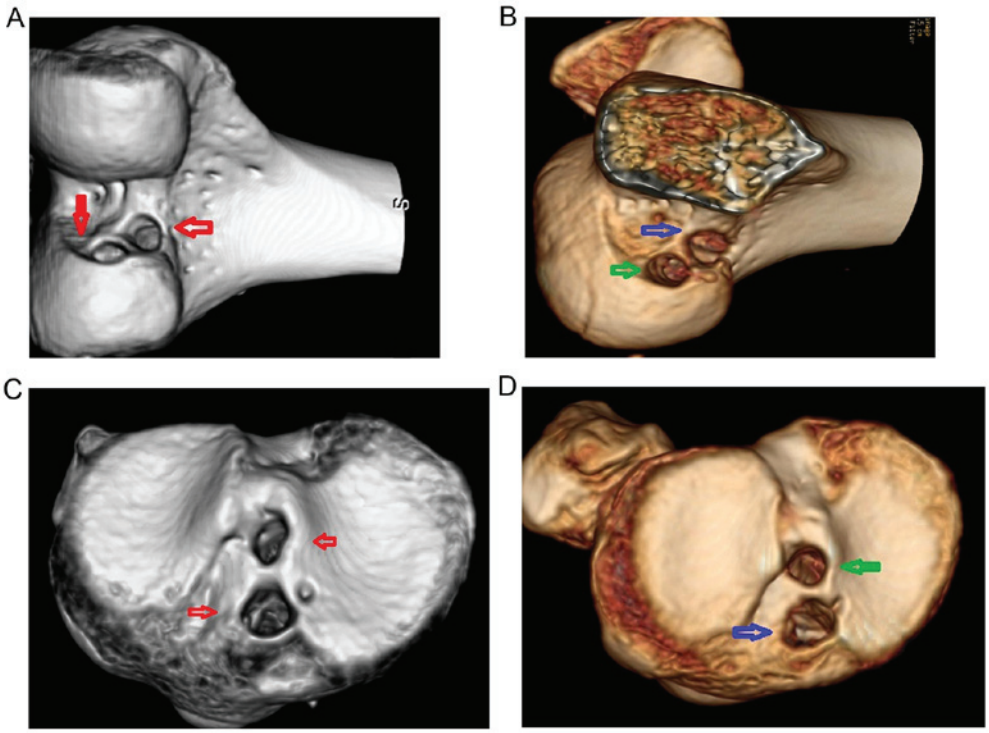

Figure 4. Revision surgery to rescue an anterior cruciate ligament rupture after double bundle reconstruction. Original (A) femoral and (B) tibial tunnels (red arrows), and (C and D) respective images following expansion by 1 mm each. Blue arrows indicate the anteromedial bundle and green arrows the posterolateral bundle.

concomitant cartilage and/or meniscal injuries. After revision double-bundle ACL reconstruction, whether a patient was able to resume to performing their physical exercise activity at the pre-injury level was dependent on concomitant cartilage damage and/or meniscal deficiency, which were also critical factors influencing the decision for primary (n=32) or repeated revision (n=8) ACL reconstruction patients to resume to performing their physical exercise activity. Andriolo *et al* (9) and Andernord *et al* (15) concluded that patients receiving revision ACL reconstruction patients were less able to resume to the same level of physical exercise activity compared with those receiving primary ACL reconstruction, which may also be associated with the increased concomitant cartilage and/or meniscal injuries.

To date, the effectiveness of double-bundle revision ACL reconstruction has not been systematically evaluated in spite

of the descriptions of aspects of double-bundle revision ACL reconstruction (27,32-34). The present study assessed the subjective and objective improvement of functions in 34 patients who received double-bundle revision ACL reconstruction, which included different causes for failure of primary ACL reconstruction. Double-bundle revision surgeries significantly improved Lysholm, Tegner and IKDC objective scores as well as KT-2000 flexion scores. At the last follow up, all patients without severe concomitant meniscal deficiency or serious cartilage injury resumed to performing their physical exercise activity at the pre-injury level, whereas others pursued less demanding types of physical exercise activity. Due to the lack of a single-bundle revision ACL reconstruction group for comparison, the present study did not provide any direct clues on whether double-bundle revision ACL reconstruction is superior to single-bundle revision ACL reconstruction. However, the present cohort subjected to double-bundle revision ACL reconstruction had an obviously higher level of physical exercise activity (Tegner score, 6.13 vs. 5.0) and better knee stability compared with that in other revision ACL reconstruction studies (9,13).

Certain limitations of the present study should be considered. First, patients with concomitant high-degree meniscus deficiency and/or cartilage injuries did not receive any double-bundle revision surgery, which poses a selection bias. Furthermore, due to the absence of a parallel single-bundle revision ACL reconstruction group, it was required to resort to historical data to compare the different outcomes between these two techniques. Finally, no comparison between the double-bundle ACL reconstruction and single-bundle ACL reconstruction in improving the subjective and objective functions was performed. In future studies, it may be worthwhile to collect clinical data for double-bundle and single-bundle methods.

In conclusion, double-bundle revision ACL reconstruction was indicated to be promising in improving the subjective and objective function and knee stability of patients regardless of whether the primary reconstruction was of the single- or double-bundle type. After double-bundle revision surgery, all patients resumed to performing a physical exercise activity, with certain patients reaching the pre-injury level.

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