Anatomic anterior cruciate ligament double-bundle reconstruction

Khaled M. Abu-Elnasr

Department of Orthopaedic Surgery, Faculty of Medicine, Suez Canal University, Ismailia, Egypt

Correspondence to Khaled M. Abu-Elnasr, MD, Assistant Professor, Department of Orthopaedic Surgery, Faculty of Medicine, Suez Canal University, 42111 Ismailia, Egypt
Tel: +20 100 683 2778; fax: +20 66 3324500;
e-mail: khaboelnasr@gmail.com

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Background

Many techniques for reconstruction of the anterior cruciate ligament (ACL) have been described. There is a trend towards the use of double-bundle techniques for the reconstruction of the ACL. Such techniques aim to reconstruct both bundles, and, theoretically, should provide a superior construct that would reduce rates of failure and improve the functional anatomy. In this study, the clinical results of double-bundle ACL reconstruction have been reported.

Patients and methods

Between 2008 and 2010, 19 patients suffering from ACL tear were treated using double-bundle ACL reconstruction.

Results

The objective International Knee Documentation Committee score and the modified Cincinnati subjective score were significantly higher in the double-bundle technique. The pivot-shift test was negative in 97% of the patients.

Conclusion

The main advantage of double-bundle rather than single-bundle reconstruction is its better rotational stability.

Keywords:

Arthroscopy, anterior curriciate ligament reconstruction, double-bundle reconstruction

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Introduction

Anterior cruciate ligament (ACL) tear is a common injury in orthopedic sports medicine. Surgical reconstruction is the preferred choice in its management to restore knee stability and prevent intra-articular injuries [1]. Current techniques in ACL surgery have been associated with satisfactory long-term results in the majority of the patients; however, there remains a considerable subset of patients with unsatisfactory outcomes. Specifically, patients report difficulties relating to rotational instability and return to previous level of activity. The ACL consists of two major functional bundles, namely anteromedial (AM) and the posterolateral (PL). The former originates more proximally on the femur and inserts anteromedially on the tibia, whereas the latter originates more distally from the femoral site and inserts posterolaterally into the tibia. Both are nearly parallel when the knee is extended and twist around each other as the knee flexes. The anatomic ACL double-bundle reconstruction aims to restore the original anatomy and footprints of the ACL by reconstructing the AM and the PL bundles to achieve a better functional outcome, to obtain a better restoration of the normal biomechanics of the knee, and to improve the rotator laxity [2]. Such techniques aim to reconstruct both bundles, and theoretically should provide a superior construct that would reduce the rate of failure and improve the functional outcome, with better rotator stability, which is in contrast to single-bundle reconstruction, which attempts to restore the fibers of the AM bundle. The indications for the reconstruction of a torn ACL by applying the anatomic ACL double-bundle reconstruction are similar to the traditional single-bundle reconstruction and are influenced by several factors [3]. Universally accepted indications for ACL reconstruction are heavy work occupation, a high-risk lifestyle, a demanding level of sports activity, instability despite rehabilitation, and associated injuries such as meniscal tears or severe injuries to other ligament structures in the knee. Age is also an important parameter to take into account; however, it is not so much the biologic age, but the status of the knee and the individual lifestyle that have to be considered [4,5].

Patients and methods

The study included 19 patients with an average age of 23 years (range, 16–33 years), a height of 1.7 m (range, 1.6–1.8 m), and a weight of 76.9 kg (range, 69.1–87.5 kg). Five patients had acute injuries (surgery within 6 weeks after the injury), and 14 patients had chronic injuries. There were five female and 15 male patients. The study was conducted between January 2008 and April 2010. The patients were selected if they met the following criteria:

(a) They had a unilateral, isolated ACL injury without an injury of the contralateral knee;
(b) They had no history of surgery involving the lower extremity;
(c) They had no articular cartilage erosion of more than grade, II, III [fissuring and fragmentation <0.5 (13 mm) in diameter]; and
(d) A meniscectomy, when performed, had involved less than one-third of the entire meniscus.

Patients with evidence of an unstable knee with acute multiple ligament injuries, a chronic ACL tear that had not responded to nonoperative treatment, or a chronic combined injury of the ACL were enrolled. Patients were excluded if they had arthritic changes of greater than grade 2, were on corticosteroids, had severe arthrofibrosis, or had an infection. All patients had anteroposterior, lateral, and long leg alignment radiographs.

Preoperative planning

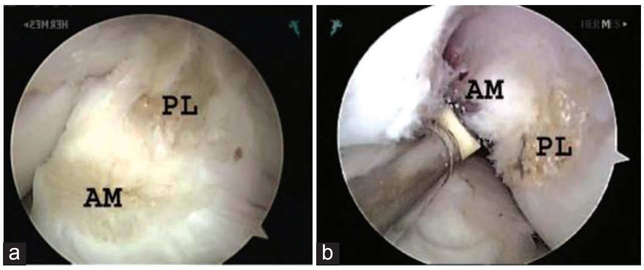
Planning the surgical procedure includes obtaining the patient's history as well as physical examination. For outcome evaluation, clinical parameters such as the range of motion, the Lachman grade, the anterior drawer grade, and the pivot-shift grade were evaluated. Imaging of the knee was performed with routine radiographs to determine fractures, osteoarthritis, and the alignment of the lower extremity. MRI was performed to assess further intra-articular and extra-articular injury and to confirm the rupture of the ACL.

Surgery

Arthroscopy was performed for the diagnosis and the treatment of associated injuries. The anterolateral approach and AM portal; an accessory anteromedial (AAM) portal was used. To establish the AAM portal, the arthroscope was placed into the standard anterolateral or AM portal and an 18-G spinal needle was inserted medially and distally to this portal just above the meniscus to reach the center of the femoral footprint of the PL bundle. Once the needle was placed correctly, the AAM portal was performed with a #11 blade. First the tendon semitendinosus and gracilis were trimmed and the diameters of the grafts were adjusted. To maintain the morphometric ratio of the AM and the PL bundles, the AM graft was made slightly larger than the PL graft. For the AM bundle, the double semitendinosus graft was used. For the PL bundle, the doubled gracilis graft was used. The ends of the grafts were sutured with 2-0 vicryl sutures. An EndoButton was used to loop each graft and obtain a double-stranded graft. The length of the EndoButton loop was chosen according to the measured length of the femoral tunnels. While the arthroscopy was being performed, the grafts were being prepared in a back table by another surgeon. During the arthroscopy, it was important to observe the rupture pattern of the ACL. This step definitively diagnoses the total tear of the ACL and shows the original footprint of the AM and the PL bundles on the lateral wall of the intercondylar notch and on the tibial side. When identified, the footprints of each bundle were marked by a thermal device (Fig. 1). A small hole in the center of the femoral AM and PL footprints was created by awl to facilitate further guidewire placement to create the femoral tunnels. After marked by a thermal device, the remaining tibial footprint fibers were left intact due to their proprioceptive and vascular contributions. The PL femoral tunnel was the first tunnel to be drilled. The PL femoral tunnel was drilled through the AAM portal, and a 3.2-mm guidewire was inserted through the portal. The tip of the guidewire was placed on the small hole created previously by awl on the center of the femoral footprint of the PL bundle. Once the tip of the guidewire was malleted in the correct position, the femoral PL tunnel was drilled. The PL femoral tunnel was drilled to a depth of 25–30 mm. The far cortex was breached with a 4.5-mm EndoButton drill and the depth gauge was used to measure the distance to the far cortex. During the drilling of the PL bundle tunnel, the arthroscope was placed through the AM portal and the tunnel was drilled through the AAM portal. It was also important that during the entire procedure to create a PL femoral tunnel, the knee was positioned at 110° of flexion, which brings the PL bundle footprint anteriorly.

To create the two tibial tunnels, a 4-cm skin incision was made over the AM surface of the tibia at the level of the tibial tubercle. The PL tibial tunnel was the first one to be drilled. The elbow ACL tibial drill guide was set up at 45°, and the tip of the drill guide was placed intra-articularly on the tibial footprint of

Figure 1



The insertion sites of anteromedial (AM) and posterolateral (PL) bundle on both the tibial side (a) and the femoral side (b) were marked by a thermal device.

the PL bundle. Once the tibial drill guide was set up intra-articularly and on the tibial cortex, a 3.2-mm guidewire was passed into the stump of the PL tibial footprint. The AM tibial tunnel was drilled with the elbow ACL tibial drill guide set at 45°, and the tip of the drill guide was placed on the tibial footprint of the AM tunnel already marked with the thermal device, and AM to the PL guidewire. On the tibial cortex, the starting point for the AM bundle was placed anterior, central, and proximal to the PL starting point. Once the elbow ACL tibial drill guide was placed in the desired position, a 3.2-mm guidewire was passed into the stump of the AM tibial footprint. After passing the tibial guidewire into an adequate position, the two tibial tunnels were drilled using a cannulated drill. The femoral AM tunnel was the last tunnel to be drilled. A transtibial AM technique similar to single-bundle ACL reconstruction was chosen to create the AM femoral tunnel. If the center of the AM femoral footprint was not reached through the PL tibial tunnel, the AAM portal was used to reach the center of the AM bundle. The AM tunnel was drilled in a manner similar to the way the PL femoral tunnel was drilled. Once the tip of the guidewire was placed in the correct position, the guidewire was malleted, and the AM femoral tunnel was drilled to a depth of 35–40 mm when it was performed transtibially either through the AM tibial tunnel or the PL tibial tunnel. If the AM femoral tunnel was performed through the AAM portal, it was drilled to a depth of 30 mm to avoid breaking the cortex. The far cortex of the AM femoral tunnel was breached with a 4.5-mm EndoButton drill, and the depth gauge was used to measure the distance to the far cortex. The first graft to be passed was the PL graft. A pin with a long looped suture attached to the eyelet was passed through the AAM portal and out through the PL femoral tunnel. The looped suture was visualized within the joint and retrieved with an arthroscopic suture grasper through the PL tibial tunnel.

A crossing pattern of the AM and the PL grafts was clearly seen after passing both looped sutures through the tunnels. The graft was passed and the EndoButton was flipped to establish cortex fixation of the PL bundle graft. The AM bundle graft was passed using the transtibial technique, using the same technique as in the PL bundle graft passage. The EndoButton was flipped in a standard manner for AM bundle graft to establish AM bundle femoral cortex fixation. Preconditioning of the grafts was performed by flexing and extending the knee through a range of motion from 0 to 120° ~20–30 times. The graft fixation is important for the tensioning of the grafts. The tensioning was performed manually and fixed during tibial fixation. The PL graft was fixed at 0–10° of flexion. The AM graft was fixed at 60° of flexion. After tibial fixation, a final arthroscopic inspection was performed to confirm the status of the graft and the absence of anterior impingement and posterior cruciate ligament impingement (Fig. 2). Subcutaneous tissue and skin were closed in the standard manner.

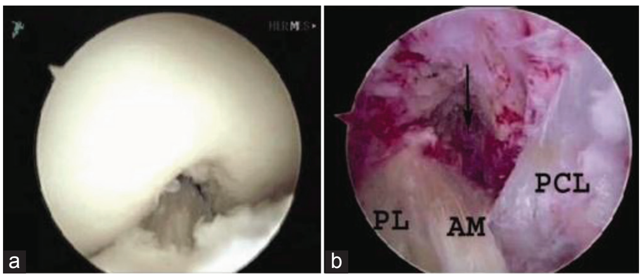
Postoperative rehabilitation

Postoperatively, the knee was placed in a knee brace in full extension. All patients were nonweight bearing for 6 weeks. Physical therapy emphasizing on quadriceps muscle activation was applied postoperatively. Six weeks postoperatively, patients initiated weight-bearing exercises. Additional increases in low-impact knee exercises were also allowed as tolerated. Removal of the brace and return to daily activities were allowed by the end of the second month. Follow-up of the patients was carried out every 3 months. Subjective evaluations with the modified Cincinnati [6] and International Knee Documentation Committee (IKDC) [7] knee surveys were completed by all patients both preoperatively and at the time of the final follow-up. Ligament stability was assessed using the Lachman and the pivot-shift tests. The Lachman test was graded on a scale of 0 (<3 mm), 1+ (3–5 mm), 2+ (6–10 mm), or 3+ (>10 mm). The pivot-shift test was performed with the hip in abduction and the tibia in internal rotation. The pivot-shift phenomenon was graded on a scale of 0 (absent), 1+ (subluxation), 2+ (jump), or 3+ (transient lock).

Statistical analysis

Subjective and objective measures were analyzed preoperatively and at a minimum 1-year follow-up. Comparisons of preoperative and postoperative outcomes were carried out with the paired *t*-test. Analysis of covariance was used to compare pain and function scores between the preoperative and the

Figure 2



Using anatomic double-bundle reconstruction, anterior (a) and PCL (b) impingements are usually avoided. AM, anteromedial; PCL, posterior cruciate ligament; PL, posterolateral.

postoperative results. The Fisher exact test was used to analyze variables related to the results after surgery.

Results

Outcome measurements included the Lachman and the pivot-shift tests, the range of motion, the overall IKDC rating (Appendix I), and the modified Cincinnati subjective score (Appendix II). Patients have been followed for an average of nearly 2 years. The Lachman test, the pivot-shift test, and the IKDC rating results demonstrated that the anteroposterior stability was effectively restored by double-bundle ACL reconstruction. Approximately 94% of the patients had an excellent or good IKDC rating. The rotational stability should be an important part of outcome evaluation after ACL reconstruction.

Subjective outcome analysis

The mean modified Cincinnati subjective score was 24.5 preoperatively and improved to 83.2 postoperatively ($P < 0.0001$). A similar significant increase in the postoperative IKDC subjective score was observed. The average IKDC subjective score increased from 31.6

Appendix I: The objective IKDC score

Your Full Name____

Today's Date: ______/_______/______ (Day Month Year)   Date of Injury: ______/_______/_____ (Day Month Year)

SYMPTOMS*:

*Grade symptoms at the highest activity level at which you think you could function without significant symptoms, even if you are not actually performing activities at this level.

1. What is the highest level of activity that you can perform without significant knee pain?

❑Very strenuous activities like jumping or pivoting as in basketball or soccer
❑Strenuous activities like heavy physical work, skiing or tennis
❑Moderate activities like moderate physical work, running or jogging
❑Light activities like walking, housework or yard work
❑Unable to perform any of the above activities due to knee pain

2. During the past 4 weeks, or since your injury, how often have you had pain?

	0	1	2	3	4	5	6	7	8	9	10	
Never	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	Constant

3. If you have pain, how severe is it?

	0	1	2	3	4	5	6	7	8	9	10	
No pain	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	Worst pain imaginable

4. During the past 4 weeks, or since your injury, how stiff or swollen was your knee?

❑Not at all
❑Mildly
❑Moderately
❑Very
❑Extremely

5. What is the highest level of activity you can perform without significant swelling in your knee?

❑Very strenuous activities like jumping or pivoting as in basketball or soccer
❑Strenuous activities like heavy physical work, skiing or tennis
❑Moderate activities like moderate physical work, running or jogging
❑Light activities like walking, housework, or yard work
❑Unable to perform any of the above activities due to knee swelling

6. During the past 4 weeks, or since your injury, did your knee lock or catch?

❑Yes ❑No

7. What is the highest level of activity you can perform without significant giving way in your knee?

❑Very strenuous activities like jumping or pivoting as in basketball or soccer
❑Strenuous activities like heavy physical work, skiing or tennis
❑Moderate activities like moderate physical work, running or jogging
❑Light activities like walking, housework or yard work
❑Unable to perform any of the above activities due to giving way of the knee

Appendix II: Modified Cincinnati subjective score

Points	Scale
100	Normal knee, able to do strenuous work/sports with jumping; hard pivoting
80	Able to do moderate work/sports with running/turning/twisting; symptoms with strenuous work/sports
60	Able to do light work/sports with no unning/twisting/jumping: symptoms with moderate work/sports
40	Able to do activities of daily living alone; symptoms with light work/sports
20	Moderate symptoms (frequent, limiting) with ADL
0	Severe symptoms (constant, not relived) with ADL

preoperatively to 81.1 postoperatively ($P < 0.0001$). Data were also analyzed according to the sex. Male patients had a significant increase in the average Cincinnati score from 24.8 preoperatively to 79.0 postoperatively ($P < 0.001$).

Female patients had a significant increase in the average Cincinnati score from 32.3 preoperatively to 79.3 at the time of the final follow-up ($P < 0.001$). No significant difference was detected in the preoperative or the postoperative modified Cincinnati scores between the sexes. For male patients, the average IKDC subjective scores improved significantly from 43.0 preoperatively to 81.2 postoperatively ($P < 0.001$). Female patients also showed a significant increase in the average IKDC scores from 29.9 preoperatively to 75.9 postoperatively ($P < 0.001$). The age of the patients was normally distributed and had no association with their sex. Data were also analyzed on the basis of whether injuries were acute or chronic. In the five patients with acute injury, the average Cincinnati score was 26.6 preoperatively and improved significantly to 81.9 at the time of the final follow-up ($P < 0.0001$). In the 15 patients with chronic injury, the average Cincinnati scores increased significantly from 30.3 preoperatively to 78.4 at the time of the final follow-up ($P < 0.001$). A significant difference was detected between the acute and the chronic groups with respect to the preoperative Cincinnati ($P < 0.04$) and the IKDC subjective scores ($P < 0.003$), but no significant difference was found between the groups with respect to the postoperative outcome scores. Two years postoperatively, 17 patients were negative for the Lachman test; the other two patients had an anterior tibial translation between 3 and 5 mm (Table 1). Sixteen patients were negative for the pivot-shift test: two patients were grade I and one patient was grade II (Table 2). In this study, there was significant improvement in the rotational stability postoperatively.

Table 1 Preoperative and postoperative Lachman test grades

	Grades				Total
	0	1	2	3	
Time					
Preoperative	–	–	7	12	19
Postoperative	17	2	–	–	19

Table 2 Preoperative and postoperative pivot shift

	Grades				Total
	0	1	2	3	
Time					
Preoperative	–	–	5	14	19
Postoperative	16	2	1	–	19

Discussion

Reconstruction of the ACL is a common procedure [8], with the reported clinical success ranging between 80 and 95% [9]. Many techniques for the reconstruction of the ACL have been described [10]. There is no true consensus as to the optimal positioning of the femoral tunnel or for determining the landmarks that best identify its true location. A single-bundle reconstruction is performed using one single femoral and one single tibial tunnel. It has been suggested that it is crucial to re-establish the double-bundle anatomy of the ACL to obtain a better restoration of the normal biomechanics of the knee, and to improve rotator laxity [11]. Such techniques aim to reconstruct both bundles, and, theoretically, should provide a superior reconstruction that would reduce rates of failure and improve the functional outcome, with better rotator stability; however, these techniques have not been shown to be associated with an improved functional outcome [12]. Adachi *et al.* [13] prospectively randomized 108 patients with unilateral instability of the knee associated with rupture of the ACL for arthroscopic single-bundle or double-bundle reconstruction of the ligament using the hamstring tendon. The patients were followed up for a mean of 32 months (range, 24–36 months), and no significant difference was found between the two groups with regard to the mean anterior laxity or with regard to proprioception. Yasuda *et al.* [14] carried out a prospective, comparative cohort study to compare the clinical outcomes in patients who had reconstruction to ACL with single-bundle or double-bundle hamstring autograft. The patients had been assigned to one of the three techniques of reconstruction: single-bundle, nonanatomical double-bundle, and anatomical double-bundle. They underwent clinical examination before surgery and 2 years after surgery. There were no significant differences in the three groups with regard to the muscle torque, the range of movement, and the IKDC score, although the side-to-side anterior laxity of the anatomical double-bundle reconstruction was better than that of the single-bundle reconstruction. Aglietti *et al.* [15] carried out a prospective, comparative cohort study to evaluate whether one of the two techniques of the double-bundle reconstruction was superior to a single-incision single-bundle procedure in controlling anterior tibial translation and in reducing pivot shift. The mean side-to-side anterior laxity and the amount of residual pivot shift were significantly lower in the group with double-bundle anatomical ACL reconstruction than in the group with single-bundle ACL reconstruction. Yagi *et al*. [16] carried out a quasi-randomized trial to evaluate whether the rotational stability differed in the three techniques, namely AM single bundle and PL single bundle and double bundle. A total of 60 patients were allocated in the three groups. There were no significant differences in the three groups with respect to the mean values of their side-to-side anterior laxity, the peak isokinetic torque, or the IKDC score. Patients in whom ACL had been reconstructed with the double-bundle technique had significantly better control of pivot shift. Muneta *et al*. [17] conducted a quasi-randomized trial on 64 patients with unilateral ACL deficiency to compare the outcome between single-bundle and double-bundle ACL reconstruction with a four-strand semitendinosus tendon. There were no significant differences between the two groups with regard to the mean range of movement, the girth of the thigh, the muscle strength, and the Lysholm score. Manual testing showed that positive Lachman and pivot-shift tests were less common in the double-bundle group. Statistical analysis showed that there was no significant difference regarding all of the modified IKDC categorized data between the two groups. The authors concluded that double-bundle reconstruction was superior to the single-bundle technique with regard to anterior and rotational stability, but they failed to show any difference between the two techniques when considering subjective variables. Jarvela [18] conducted a prospective, randomized clinical study to compare the outcome of ACL reconstruction using either the double-bundle or the single-bundle technique with a similar regimen of rehabilitation. He randomized 65 patients into either the double-bundle or the single-bundle group using hamstring tendons and bioabsorbable screw fixation. Double-bundle reconstruction results in better restoration of rotational laxity of the knee than single-bundle ACL reconstruction, when measured by the pivot-shift test ($P < 0.002$). Streich *et al*. [19] carried out a randomized trial in male athletes to compare the clinical results of a single-bundle reconstruction with that of a double-bundle reconstruction using an autologous semitendinosus tendon graft with extracortical fixation. After 2 years, there was no significant difference in the side-to-side measurements of anterior laxity. As evaluated by the pivot-shift test, no significant correlation was noted between rotational stability and the use of either technique. Statistical analysis showed a significant increase in the IKDC and the Lysholm scores at the final follow-up. Siebold *et al*. [20] compared both techniques of ACL reconstruction in 70 patients. Fixation was by means of a femoral EndoButton and tibial biodegradable interference screw. The subjective results were similar in both groups. The objective IKDC score was significantly higher in the double-bundle technique compared with the single-bundle technique; and the pivot-shift test was negative in 97% of the patients with double bundle and in 71% with single bundle. Jarvela *et al*. [21] compare the clinical results of a double-bundle technique using doubled semitendinosus and doubled gracilis autografts with bioabsorbable interference screw fixation and two tunnels on both the femoral and the tibial sides, with a single-bundle, four-stranded hamstring autograft technique using interference screw fixation. The rotational stability of the knee, as evaluated by the pivot-shift test, was best in the patients in the double-bundle group ($P = 0.005$). Measurement of anterior stability of the knee showed no statistically significant difference in the groups; nor were there significant differences in the knee scores between the groups.

In this study, there were significant improvements in the rotatory instability after using double-bundle anatomic ACL reconstruction. The pivot-shift test was negative in 97% of the patients. I believe that the primary reason for the better stability with double-bundle reconstruction is closely related to the biomechanics of double-bundle reconstruction. Mae *et al*. [22] reported that, biomechanically, the double-bundle ACL reconstruction provided better stability compared with single-bundle reconstruction under an anterior tibial load of 100 N at smaller flexion angles. They also noted that the PL bundle acted dominantly in extension, whereas the AM bundle mainly resisted the anterior tibial load in flexion.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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