Anatomic single-bundle versus anatomic double-bundle anterior cruciate ligament reconstruction: a comparative study based on midterm results

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Introduction

Reconstruction of the torn anterior cruciate ligament (ACL) is a common surgical procedure for orthopedic surgeons, especially who are interested in sports medicine. The nonanatomical conventional single-bundle reconstructive procedures fail to recreate the native anatomy of the knee. As a result of suboptimal outcomes following traditional single-bundle ACL reconstruction, there has been a growing interest in anatomic ACL reconstruction.

Aim of the study

The aim of the study was to compare the midterm clinical results of arthroscopic single-bundle versus double-bundle anatomical anterior cruciate reconstruction using hamstring tendons.

Patients and methods

From October 2006 to May 2010, arthroscopic anatomic ACL reconstruction was carried out on 152 patients with ACL, who were divided into two equal groups: group A included 76 patients who underwent arthroscopic anatomic single-bundle ACL reconstruction, and group B included 76 patients who underwent arthroscopic anatomic double-bundle ACL reconstruction.

Results

All patients were analyzed using the International Knee Documentation Committee evaluation form. At the end of follow-up period, which ranged from 5 to 7 years, with an average of 5.2 years (midterm follow up), the results of group A were rated as normal and nearly normal on the total subjective and objective levels in 65 (85%) patients, except in 11 (15%) patients, who were rated abnormal and severely abnormal, whereas the results of group B were rated as normal and nearly normal on the total subjective and objective levels in 69 (91%) patients, except in seven (9%) patients, who were rated abnormal and severely abnormal. The difference in the results between the two groups was statistically not significant. Regarding the complications, there have been four cases of superficial infection related to the medial wound of tendon harvest, one in group A and three in group B, which were treated with oral antibiotics with clearance of infection.

Conclusion

Our results have showed that the anatomical double-bundle ACL reconstruction technique can achieve better anteroposterior and rotational stability compared with the anatomical single-bundle ACL reconstruction, which is not statistically significant. Considering that the double-bundle technique is more complex, expensive, and lengthy, we recommend the single-bundle anatomical technique as the standard technique, and the double-bundle technique to be used in case of high-demand patients like elite athletes.

Keywords:
anatomical, anterior cruciate ligament, double bundle, single bundle

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Introduction

Reconstruction of the torn anterior cruciate ligament (ACL) is a common surgical procedure for orthopedic surgeons, especially who are interested in sports medicine. Although some patients who are not involved in sports can function without complaint with an ACL-deficient knee, most patients experience pain and recurrent episodes of instability [1].

The goal of any ACL reconstruction is to restore normal anterior knee stability to approximate normal knee kinematics. The fact that so many different methods have been described for reconstruction of

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ACL in patients with chronic functional instability indicates that the ideal solution to this problem has not yet been found [2,3].

Although ACL reconstruction with standard single-bundle techniques provides satisfactory subjective results and restores anteroposterior (AP) stability in the vast majority of patients, some authors have clinically detected residual minimal rotatory instability (pivot shift or increased tibial internal rotation) in 20% of cases independent of the graft, surgical technique, and choice of fixation device [4,5].

The ACL native bundles show load-sharing behavior. Neither of the two bundles alone can reproduce the mechanical properties of the intact ACL. The anteromedial bundle (AMB) becomes tense in flexion controlling mainly the AP translation. During extension, the effect of the posterolateral bundle (PLB) is more evident mainly on rotation. Therefore, to address residual rotatory instability after ACL reconstruction, it seems reasonable to reconstruct both bundles [6,7].

It is difficult to reproduce the anatomy and kinematics of the native ACL with the single-bundle technique [8]. Standard single-bundle ACL reconstructions are successful in restoring anterior stability to the knee, but not the rotational stability, the deficit of which is seen as a pivot-shift phenomenon [9]. It has been shown in a cadaver model that anatomic double-bundle reconstructions are able to more closely restore the normal kinematics of the knee when compared with the single-bundle technique [10].

Few decades ago, most conventional ACL reconstruction procedures have focused only on replacing the AMB, which is insufficient in restoring the rotational stability of the knee; the other functional bundle, the PLB, has not received sufficient attention. Recently, many studies have been published to describe the techniques and outcomes of more anatomically correct ACL reconstructions designed to reconstruct both bundles of the ACL [11].

The nonanatomical conventional single-bundle reconstructive procedures fail to recreate the native anatomy of the knee, and therefore, the natural kinematics of the knee [12]. As a result of suboptimal outcomes following traditional single-bundle ACL reconstruction, there has been a growing interest in anatomic ACL reconstruction.

It is clear that the restoration of normal anatomy is required to restore normal function of the knee. Double-bundle ACL reconstruction is one application of the anatomic reconstruction concept. A number of biomechanical and clinical studies have demonstrated that double-bundle ACL reconstruction provides superior knee anterior and rotatory stability in comparison with nonanatomical single-bundle ACL reconstruction [13–15].

On the contrary, the anterior tibial translation after anatomic double-bundle ACL reconstruction was 24% less than that after traditional single-bundle ACL reconstruction [16]. In addition, the in-situ force in the ACL graft was 93% of the intact ACL as compared with only 68% for single-bundle ACL reconstruction [17]. These research studies have confirmed the impossibility of a single nonanatomical bundle reconstruction to completely reproduce the performance of the normal ACL and have increased the interest in anatomical reconstruction with double-bundle technique with the aim to reproduce as much as possible the original load distribution and kinematic behavior of an intact knee [18].

Anatomic ACL reconstruction intends to replicate normal anatomy, restore normal kinematics, and protect long-term knee health. Although double-bundle ACL reconstruction has been shown to result in better rotational stability in both biomechanical and clinical studies [19], it is vital to differentiate between anatomic and double-bundle ACL reconstruction. A double-bundle ACL reconstruction is not the same as an 'anatomic' ACL reconstruction: double-bundle reconstruction indicates that the ACL was restored by the use of two separate bundles and does not necessarily specify the location of the tunnels as it can still be done nonanatomically [20].

An 'anatomic' ACL reconstruction suggests that the tunnels were placed in the center of the native femoral and tibial insertion sites, which is independent of whether a single or double bundle was used [21]. This difference in terms is therefore of major importance because 'anatomic' and 'double-bundle' are not interchangeable. Anatomic ACL reconstruction can be applied to both single-bundle and double-bundle reconstructions [22].

Recently, several biomechanical studies showed that the single-bundle ACL grafts placed in the center of their anatomic insertions can provide nearly normal knee kinematics comparable to double-bundle reconstruction [23,24].

Aim of the study

The aim of the study was to compare the midterm clinical results of arthroscopic single-bundle versus double-bundle anatomical anterior cruciate reconstruction using hamstring tendons.

Patients and methods

From October 2006 to May 2010, arthroscopic anatomic ACL reconstruction was carried out on 152 patients with torn ACL. Institutional review board approval was granted from Alexandria Faculty of Medicine ethical committee and informed consent was obtained from all study participants. The patients were divided into two equal groups: group A included 76 patients who underwent arthroscopic anatomic single-bundle ACL reconstruction, and group B included 76 patients who underwent arthroscopic anatomic double-bundle ACL reconstruction.

The inclusion criteria included symptomatic male patients with torn ACL complaining of knee instability, who are active and wish to continue participating in sports; patients working in heavy labors who need a stable knee; and patients experiencing instability with activities of daily life. We excluded from this study patients with degenerative changes evidenced radiologically (joint space narrowing), patients with combined ligamentous injuries, patients with clinical evidence of mal-alignment (varus or valgus), and patients with previous ACL reconstruction.

The age of the patients of group A ranged from 20 to 37 years with a mean of 29.2 years. The age of the patients of group B ranged from 25 to 42 years with a mean of 33.1 years. Left knee was affected in 59 patients of group A and in 62 patients of group B. The original knee injury was during football playing in most cases. The time interval between injury and operation ranged between 2 and 19 months. All patients had no previous knee surgeries (Table 1).

Table 1 Characteristic features of the two studied patient groups

	Group A (N=76)	Group B (N=76)	P
Age			
Range	20–37	25–42	0.132
Mean	29.3	33.1	
SD	29.3±8.23	33.1±7.12	
Side [n (%)]			
Right knee	59 (77.6)	62 (81.6)	
Left knee	17 (22.4)	14 (18.4)	0.412
Original knee injury [n (%)]			
Pivoting noncontact sport	50 (65.8)	58 (76.3)	
Contact sport	9 (11.8)	9 (11.8)	
Traffic	5 (6.6)	3 (3.9)	0.107
Work	7 (9.2)	4 (5.3)	
Activity of daily living	5 (6.6)	2 (2.6)	
Time interval between injury and operation (months)			
Range	4–15	2–19	
Mean	7.65	8.65	0.112
SD	2.68	5.12	

Statistical analysis

Statistical analysis was undertaken using the statistical program for the social sciences, version 20.0 (IBM, Armonk, New York, USA). Paired t tests and comparing means were used to analyze the relations between the obtained results in both groups. χ^2 test was used to compare between two groups' categorized data. Statistical significance was set at P value equal to 0.05.

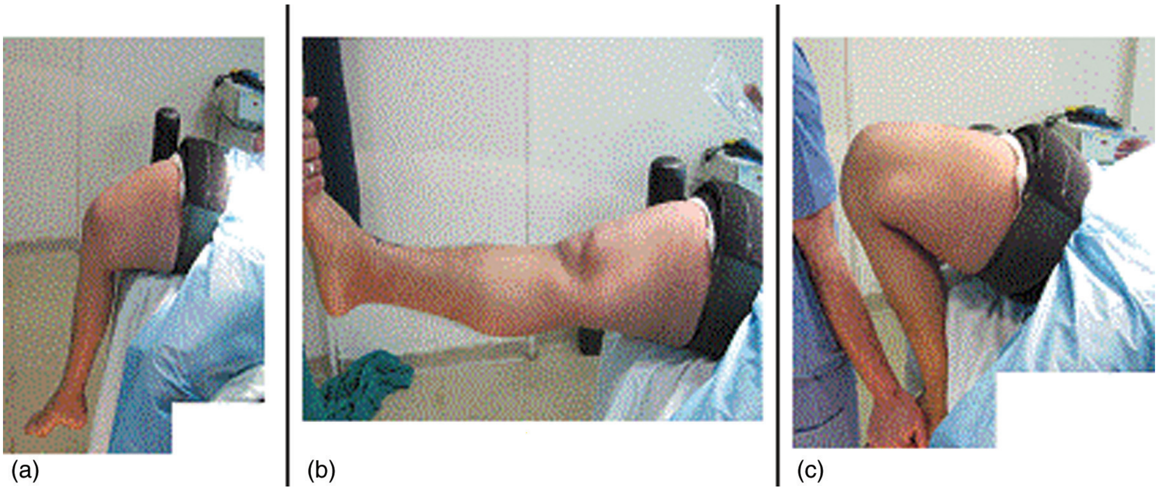
Preoperative assessment included history and clinical tests, including anterior drawer test, Lachman test, and Pivot shift test. Radiological evaluation included plain radiography and MRI study for evaluation of the ACL and any associated internal derangement of the knee.

All patients were given spinal anesthesia. Patients were laid supine with the affected knee flexed at the end of table, allowing knee flexion up to 120° (Fig. 1). All patients were examined under anesthesia to confirm the preoperative diagnosis. The hamstring tendons were harvested and prepared while preparation of tunnels was performed. Arthroscopy of the knee was performed to confirm the ACL tear and evaluate other knee pathological conditions.

Both femoral tunnels were created with a freehand technique without a guide. The femoral tunnels were typically drilled through the transportal approach [25].

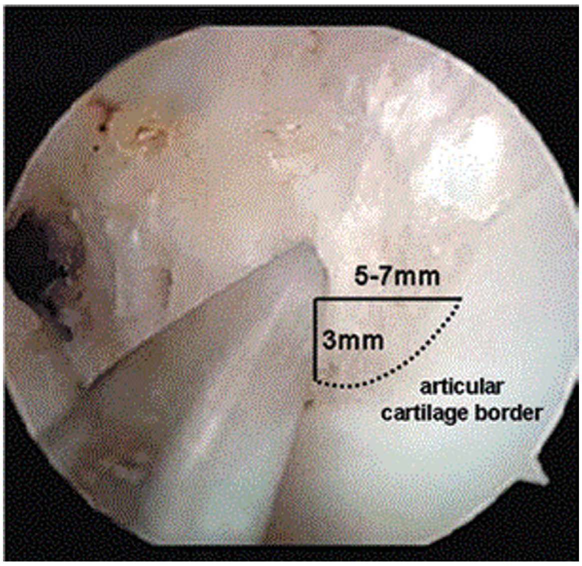
After correct identification of the femoral footprints, we prepared the PL femoral tunnel first. A 2.4-mm guide wire placement is located 5–7 mm behind and 3 mm above the anterior articular cartilage border of the lateral femoral condyle (Fig. 2). With the knee held in 120° of hyperflexion and the arthroscope in the AM portal, a guide wire was introduced through the accessory anteromedial (AAM) portal and advanced through the PL footprint until it passes the lateral femoral cortex [26]. The tunnel was drilled with a 5-mm diameter cannulated reamer inserted along the guide wire through the AAM portal under arthroscopic visualization through the AM portal (the same diameter of doubled gracilis tendon graft size) to a depth of 30 mm (Fig. 3).

Figure 1



(a) A knee holder was used to keep the affected knee stable during the surgery. It also allows a good range of motion, both extension (b) and hyperflexion (c), during the surgery.

Figure 2



Landmarks for the placement of the PL femoral guide wire. The knee is held in 120° of hyperflexion for wire positioning and tunnel drilling. Flexion angle of the knee is essential for proper tunnel location. PL, posterolateral.

A femoral targeted point for AM bundle is determined at the point 5–6 mm from the posterior articular cartilage of the lateral femoral condyle [27]. The femoral AM tunnel is then prepared also through the AAM portal. The AM tunnel is drilled in a similar fashion that the PL femoral tunnel was drilled. With the knee hyperflexed to 120°, a 7-mm drill bit is inserted over the guide wire and the AM femoral tunnel is drilled to a depth of 30 mm and a diameter 7 mm (the same diameter of doubled semitendinosus tendon graft size).

Care was taken to leave a bony bridge of at least 1–2 mm between the two tunnels (AM and PL) to avoid tunnel confluence [28].

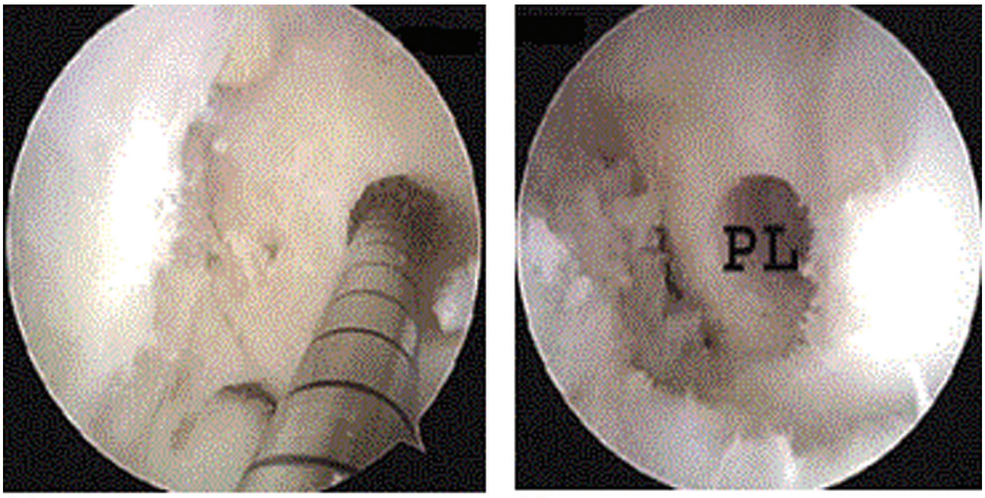
As for the anatomic single bundle, the femoral footprint lies midway between the previously mentioned PL and AM footprints.

The intra-articular exit of the tibial tunnels should reproduce the footprint of the native bundles (Fig. 4), leaving a bony bridge between the two tunnels, which should limit tunnel confluence and ensure graft independence [29].

The arthroscope is then placed in the AL portal for preparation of the tibial side. The PL footprint is just anteromedial to the posterior root of the lateral meniscus, posterolateral to the AM bundle, and adjacent to the PCL forming an anatomic triangle. The starting point for the PL tibial tunnel is slightly anterior to the superficial medial collateral ligament (MCL), with the tip centered on the native footprint [30]. A 2.4-mm guide wire was inserted using the ACL C-guide system (Fig. 5). The C-guide was inserted into the joint through the AM arthroscopic portal. The guide wire was drilled from the anteromedial aspect of the proximal tibia through the graft harvest incision and advanced intra-articularly. The angle of the C-guide was 55°. The guide wire was overdrilled with a cannulated reamer of the same diameter for the PL bundle (5 mm).

For the AM tunnel, the starting point is anterior to the PL tunnel such that a 1–2 mm bone bridge exists. The angle of the C-guide was 55°. With the ACL guide

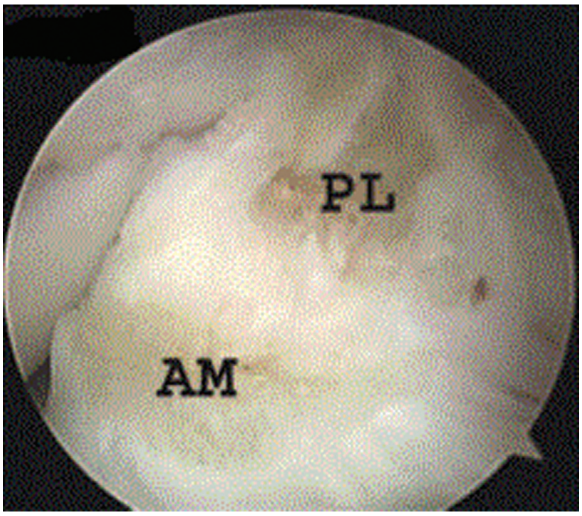
Figure 3



(a) (b)

(a) The PL femoral tunnel is drilled through the AAM portal using a 5-mm drill bit over a 2.4-mm guide wire. (b) The finished PL femoral tunnel of 30 mm in depth is shown. AAM, accessory anteromedial; PL, posterolateral.

Figure 4



The tibial insertion sites of AM and PL bundles are shown. AM, anteromedial; PL, posterolateral.

centered within the AM footprint, a 2.4-mm guide wire was inserted. After removal of the C-guide, the knee was extended to check roof impingement. It was overdrilled to the same diameter for the AM bundle (7 mm) [31].

For the anatomic single bundle, the tibial footprint lies midway between the previously mentioned PL and AM footprints.

The graft for the PL bundle (doubled gracilis tendon autograft) was passed first and then the graft for the AM bundle (doubled semitendinosus tendon autograft) was passed. Graft fixation of each bundle was obtained after tensioning of the grafts was performed using transverse cross-pin for the femur and interference screw for the tibia.

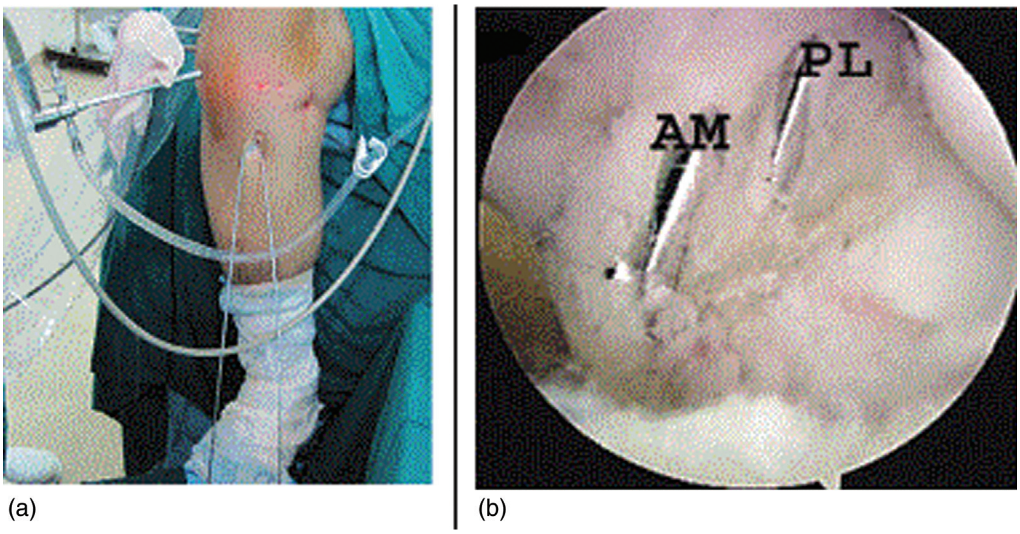
For the anatomic single bundle, the quadrupled semitendinosus and gracilis tendons autograft was passed. Graft fixation was obtained after tensioning of the graft was performed using endbutton suspensory loop for the femur and interference screw for the tibia.

Finally, arthroscopic inspection and probing of the graft was performed to confirm the status of the graft, the absence of anterior impingement, and PCL impingement. An intra-articular drain is inserted through anterolateral portal, and another one is inserted through anteromedial portal but passed subcutaneously to graft incision. The medial fascia over the pes anserinus is closed. Subcutaneous tissue and skin are closed in a standard fashion. Cold therapy and compression were applied postoperatively [32,33].

Results

All patients were analyzed using the International Knee Documentation Committee evaluation form. Preoperatively, all patients of group A were rated as severely abnormal on the total subjective and objective levels (71 patients – 93%), except five (7%) patients, who were rated abnormal, whereas all patients of group B were rated as severely abnormal on the total subjective and objective levels (74 patients – 97%), except two (3%) patients, who were rated abnormal.

Figure 5



(a) Both the PL and AM guide wires are inserted at 55°. (b) The arthroscopic view of the tibial guide wires before the tibial tunnels was created using a cannulated reamer of the same diameter for the PLB (5 mm) and the AMB (7 mm). AM, anteromedial; AMB, anteromedial bundle; PL, posterolateral; PLB, posterolateral bundle.

Table 2 Postoperative overall assessment of the two studied groups

Postoperative final rating	Group A (*N*=76) [*n* (%)]	Group B (*N*=76) [*n* (%)]
Normal	50 (65.8)	55 (72.4)
Nearly normal	15 (19.7)	14 (18.4)
Abnormal	8 (10.5)	5 (6.6)
Severely abnormal	3 (3.9)	2 (2.6)
χ^2	1.16	
P	0.761	

The average operative time of group A was 90 min compared with 112 min in group B (*P*=0.034). This difference was statistically significant.

At the end of follow-up period which ranged from 5 to 7 years with an average of 5.2 years (midterm follow up), the results of group A were rated as normal and nearly normal on the total subjective and objective levels in 65 (85%) patients, except 11 (15%) patients, who were rated abnormal and severely abnormal, whereas the results of group B were rated as normal and nearly normal on the total subjective and objective levels in 69 (91%) patients, except seven (9%) patients, who were rated abnormal and severely abnormal. The difference in the results between the two groups was statistically not significant. The subjective and the objective parameters of the final results are detailed in Tables 2–5.

Overall, 35% of group A and 40% of group B had associated meniscal tear. The presence of meniscal tear was associated with worse results, and this association was statistically significant in group A and group B (*P*=0.003 and 0.001, respectively).

Regarding the complications, there have been four cases of superficial infection related to the medial wound of tendon harvest, one in group A and three in group B, which were treated with oral antibiotics with clearance of infection. There was no reported postoperative deep vein thrombosis in both groups. Moreover, no patient developed graft failure or significant restriction of knee motion to warrant either manipulation under anesthesia or arthrolysis.

Discussion

Several technical articles on double-bundle ACL reconstruction procedures were published in the 1980s and 1990s. However, concerning the clinical results of these double-bundle ACL reconstruction procedures, there were no clinical reports. In the early 2000s, only a few clinical articles were published to evaluate the double-bundle procedures.

Although Hamada *et al.* [34] and Adachi *et al.* [35] showed that there were no statistically significant differences in subjective results or measured knee stability between their single-bundle and double-bundle procedures, they did not describe how to identify the center of the normal PLB attachment on the lateral femoral condyle in a surgical visual field or how to anatomically reconstruct the PLB. Thus, the concept of double-bundle ACL reconstruction performed in the 1980s and 1990s did not include the concept of anatomic

Table 3 Postoperative subjective assessment of the two groups

	Group A (*N*=76)				Group B (*N*=76)				*P*
	A	B	C	D	A	B	C	D	
Postoperative knee function	54	16	3	3	56	16	3	1	0.421
Postoperative activity affection	54	15	4	3	56	15	4	1	0.443
Postoperative subjective assessment	54	15	4	3	56	15	4	1	0.685

Table 4 Postoperative assessment of symptoms of both groups

	Group A (*N*=76)				Group B (*N*=76)				*P*
	A	B	C	D	A	B	C	D	
Postoperative pain	50	15	8	3	55	14	5	2	0.078
Postoperative swelling	52	16	5	3	56	14	5	1	0.099
Postoperative giving way	55	15	4	2	58	16	2	0	0.265
Postoperative symptoms	50	15	8	3	55	14	5	2	0.081

Table 5 Postoperative assessment of knee examination of both groups

	Group A (*N*=76)				Group B (*N*=76)				*P*
	A	B	C	D	A	B	C	D	
Postoperative flexion deficit	53	15	5	3	58	14	4	2	0.122
Postoperative extension deficit	55	16	4	3	56	14	4	2	0.425
Postoperative ROM	55	15	5	3	56	14	4	2	0.658
Postoperative Lachman test	55	15	5	2	59	16	1	0	0.107
Postoperative pivot shift test	56	15	3	2	60	16	0	0	0.365
Postoperative ligament examination	55	15	5	2	59	16	1	0	0.147

reconstruction of the PLB but rather meant to reconstruct the AMB with two bundles. From the above, we should distinguish the double-bundle reconstruction performed in the 1980s and 1990s from the anatomic double-bundle reconstruction, in which the PLB is anatomically reconstructed.

In 2004, Yasuda *et al.* [36] reported on the first anatomic reconstruction procedure of the AM and PL bundles with 2-year follow-up results, in which the two bundles were reconstructed with four independent tunnels created at the center of the four normal midsubstance attachments, and called it 'anatomic' double-bundle ACL reconstruction. Since then, a number of anatomical and technical articles on the anatomic double-bundle ACL reconstruction have been published with very good results [37,38,39].

This was followed by many studies reporting better results with the anatomical double-bundle reconstruction compared with the nonanatomical single-bundle reconstruction [40].

Recently, the improved awareness of the anatomy of the ACL insertion associated with the technical difficulty of double-bundle reconstruction as well as the lack of significant better clinical outcome related to the double-bundle technique has led to a return in interest in single-bundle ACL reconstructed anatomically in the mid-bundle position.

In our study, we used the accessory medial portal in both groups to create the femoral tunnel in the anatomical position. Many studies have showed that the transtibial technique produces less favorable results than the two-incision techniques, because it can be difficult to create a low enough position for the femoral tunnel. A nonoptimal tibial tunnel can force the position of the femoral tunnel too high and anterior. This is why we used in our study anteromedial portals to create femoral tunnels. With anteromedial portal technique, femoral tunnels and tibial tunnels can be placed independently. This allows a more anatomic placement of the femoral tunnel on the ACL femoral insertion. It has been established that the true insertion site of the ACL on the femur is actually on the wall of the intercondylar notch and not on the roof [41].

The two groups compared in our study were matching regarding the age, the side, and the time interval between injury and the surgery. All patients were males. We excluded females from this study because they are not suitable candidates for double-bundle ACL reconstruction for their inherently anatomical reasons in the form of narrow femoral intercondylar notch and small-sized hamstring graft.

The average operative time of group A was significantly less than group B. The double-bundle technique has a steep learning curve. It would be difficult for a general orthopedic surgeon who is not a professional arthroscopist to practice the technique. The operative time when we started this technique was ~2 h because of the difficulties we encountered during the procedure. This operative time decreased with increasing experience.

Our clinical results have showed that the double-bundle technique can lead to better rotational and AP stability than the single bundle. This difference was found to be nonsignificant. These results coincided with the reported results in the literature [42,43].

We think that the nonsignificant difference in the results between both groups was related to our adoption of the concept of ACL anatomical reconstruction, which is based on restoring the insertion sites, restoring the tensioning patterns, and individualizing surgery to the patient. This was helped by the soft-tissue remnants, the osseous landmarks, and the insertion-site anatomy, being now better defined. We agree that regardless of which surgical method is employed, the surgeon's foremost goal should be to achieve reconstruction in an anatomic fashion [44].

Kanaya *et al.* [45] found that a lower femoral tunnel-placed single-bundle reconstruction reproduced AP and rotational stability as well as double-bundle reconstruction intraoperatively. Accordingly, no significant differences were found between single-bundle or double-bundle ACL reconstruction in AP displacement and total range of tibial rotation. Based on these data, they stated that we may not need to persist with double-bundle reconstruction as long as the single-bundle reconstruction is performed with lower femoral tunnel placement.

Streich *et al.* [46] reported that no statistical differences were found in all the clinical evaluations, including anterior laxity or the pivot-shift test, between single-bundle and anatomic double-bundle reconstructions. In addition, Meredick *et al.* [47] performed a meta-analysis using four randomized clinical trials, to compare single-bundle and double-bundle reconstruction procedures. There was no statistical difference in patients treated with double-bundle versus single-bundle reconstruction.Yasuda *et al.* [48], Yamamoto *et al.* [49], Muneta *et al.* [50], and Zaffagnini *et al.* [51] have studied the importance of femoral tunnels location, most of all regarding the PLB, for which the correct positioning is extremely hard to achieve. In our technique, we simplify the procedure by the freehand technique without using a guide through the transportal approach as shown previously in the methodology. The risk of malpositioning the femoral tunnels is minimized by this method. Furthermore, this technique avoids the risk of PCL impingement that allows a better arthroscopic visualization of femoral tunnels placement.

Regarding the complications, there have been no significant intraoperative or postoperative complications in both groups. Delayed wound healing is a common complication, which has been reported by other surgeons [52].

From our results and other results in the literature, it is clear that the double-bundle ACL surgical technique is more demanding as the surgeon has to be perform a double femoral tunnel, and there could be an increased risk of intraoperative complications because of the higher technical difficulty of the procedure, making revision surgery even more difficult to perform [53]. Moreover, the anatomic double-bundle ACL reconstruction involves more surgical variables, which could affect the final outcome. One of the major concerns is the force distribution between the AM and PL grafts and the potential of overloading either one of the two grafts [54].

In conclusion, our results have showed that the anatomical double-bundle ACL reconstruction technique can achieve better AP and rotational stability compared with the anatomical single-bundle ACL reconstruction, which is not statistically significant. We recommend the single-bundle anatomical technique as a standard technique, which is expected to give satisfactory results. Considering that the double-bundle technique is more complex, expensive, and lengthy, we recommend it to be used in case of high-demand patients like elite athletes.

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Conflicts of interest
There are no conflicts of interest.

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