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Research Article

Clinical outcomes of single-bundle versus double-bundle ACL reconstruction in adolescent elite athletes: A retrospective comparative study

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ABSTRACT

Objective: The aim of the study was to evaluate the single bundle (SB) and double bundle (DB) anterior cruciate ligament (ACL) reconstruction in terms of graft survival, complications, and patient reported functional outcomes in adolescent athletes.

Methods: In this retrospective study, 89 elite adolescent athletes who underwent either SB or DB ACL reconstruction were included. All patients were then divided into two groups: group 1 including 51 patients with SB ACL reconstruction (31 male, 20 female; mean age = 15.4 ± 1.03 years) and group 2 including 38 patients with DB ACL (30 male, 8 female; mean age = 15.7 ± 1.3 years). Clinical data were obtained, comprising skeletal maturity, sports type, ACL reconstruction technique, Lachman scores, KT-1000™ arthrometer measurement, additional meniscal procedures as well as International Knee Documentation Committee (IKDC) score, Cincinnati score, and graft size.

Results: The mean follow-up period was 53.1 ± 8.6 months in group 1 and 46.4± 9.1 months in group 2 ($P = 0.61$). The type of ACL reconstruction technique (SB or DB), gender, skeletal maturity, sports type, additional meniscal procedures and Lachman scores were not associated with the re-rupture of the ACL ($P > 0.05$). Moreover, ACL reconstruction technique did not effect the rate of re-rupture of an ACL. There were 21 re-ruptures (23.5%) and 11 (12.3%) contralateral ACL ruptures in total. Among 21 re-ruptures, 12 of them were in the DB group while nine of them in the SB group ($P > 0.05$). The groups did not differ with respect to age, the injured side, the time from injury to surgery, the postoperative follow-up time, or the preoperative physical examination results KT-1000 device (SSD), Cincinnati score, IKDC objective and subjective score,Lachman test and pivot-shift test).

Conclusion: There are no differences in the re-rupture of an ACL, patient reported outcomes, and complications in adolescent elite players, when either an SB or DB technique is performed.

Level of Evidence: Level III, Therapeuthic Study

Introduction

Anterior Cruciate Ligament (ACL) injuries are more common than before,[1] this is most likely due to increased participation in sports, earlier sport specialization, and increased recognition of ACL injuries.[2] The ACL injury rate is highest in younger athletes participating in high-risk sports involving cutting and pivoting, such as basketball, football, skiing, and soccer.[3] The rate of graft failure has been reported to be two to three-fold higher in adolescents than in adults.[4-6] Moreover, a return to the operating room after an ACL Reconstruction (ACLR) due to any cause of injury has been reported at a rate of up to 38%.[7-9] Anatomical factors, hormonal changes, and skeletal immaturity are displayed to clarify the cause of failure.[10,11] With regards to these potential risk factors, there have been numerous studies on the effects of surgical methods on ACLR failure.[12,13]

Surgical methods have evolved over the years. Transtibial ACLR technique, which was popular in the early 2000s, had been replaced with anatomic ACLR in the following years.[14] Thereinafter, Double-Bundle (DB) ACLR started to be used after 2003 when first described by Marcacci[15] with the claim of better knee kinematics and function. However, there is still no consensus in the literature about the superiority of DB ACLR.[16]

In this study, we aim to evaluate the Single Bundle (SB) and DB ACLR techniques in terms of survival of reconstruction, complications, and patient-reported outcomes in adolescent sports participants. Our hypothesis was that patients who had undergone DB ACLR would have lower re-rupture rate and better clinical outcomes.

Materials and Methods

This study was approved by the Institutional Review Board (2020-06/2020) and the informed consent was obtained from each patient. Medical records of 161 adolescent patients who underwent ACL reconstruction surgery between 2002 and 2017 were retrospectively evaluated. A group of 89 patients who were elite athletes with a complete medical history and a follow-

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up period of more than 2 years were included in this study. Patients who were Tanner 1 and 2, underwent revision ACL, had previous knee surgery history, a multi-ligamentous knee injury, any chondral lesions, avulsion fracture, and a follow-up time of less than 2 years were excluded from this study (Figure 1).

Data reviewed included demographic data of the patients such as age and sex, surgical technique (SB or DB ACL reconstruction), sport type (football, basketball, others), cause of the injury, associated injuries, postoperative clinical outcomes (Lachman scores), preoperative and postoperative International Knee Documentation Committee (IKDC) scores, Cincinnati Knee Score, time to return to sports, re-rupture, complications, additional meniscal procedures (partial meniscectomy or repair), and graft size.

Although we excluded Tanner 1 and 2 patients, we divided the patients as approaching maturity and mature according to preoperative left-hand X-Rays.[17] As the expansion of approaching maturity, we included the remaining patients with limited growth (males > 13 and females > 12 years old).

All the failures were evaluated by clinical assessment (Lachman test and KT1000) and MRI findings. The result of the Lachman test had scores of 0 (< 3 mm), 1 (≥ 3 and < 5 mm), 2 (≥ 5 and < 10 mm), or 3 (≥ 10 mm), while the pivot-shift test had scores of normal (0), subluxation (1), jump (2), or transient lock (3). To evaluate anterior stability, a KT-1000 arthrometer (MED metric, San Diego, California) was used in 30° of knee flexion with an applied force of 134 N. Failure is defined as the revision of the re-ruptured ACL graft with a surgery.

Fifty-one patients and 38 patients underwent SB and DB ACL reconstruction surgery, respectively (Table 1). Except for four patients, hamstring tendons were used in all patients. In four cases that were runners, allograft was used to avoid explosive hamstring muscle force.

Detailed surgical procedures

Review of the data regarding the ACL reconstruction surgeries revealed that operations were performed by a single experienced senior surgeon in sports surgery. Semitendinosus and Gracilis tendon grafts were harvested using traditional surgical incisions, and these were either doubled, tripled, or quadrupled according to the technique used and thickness of each graft. After a diagnostic arthroscopy, repairable meniscus tears especially in the red zone were repaired mainly with all-inside sutures and only in some cases with inside-out sutures, while a meniscectomy was performed on the non-repairable ones. Before the ACL reconstruction, ACL remnants were removed. Tunnel placement preference was made according to the ACL reconstruction technique (SB or DB).

SB anterior cruciate ligament reconstruction procedure: Between 2002 and 2008, the patients underwent SB ACL reconstruction with the TransFix femoral fixation system (Arthrex, Naples, FL). The femoral tunnel was located between the resident's ridge (lateral to the intercondylar ridge) and the posterior cartilage of the lateral femoral condyle. The femoral tunnel was opened with a transtibial guide. The tibial footprint was located by placing a tibial guide in the centre of the ACL footprint. The tibial fixation was performed with a bioabsorbable screw comprised of 30% biphasic calcium phosphate and 70% PLDLA (Arthrex, Naples, FL). Additional stability was achieved with a staple. After 2009, the TightRope RT (Arthrex, Naples, FL) device was used for femoral fixation in SB ACL reconstruction cases. Between 2008 and 2017, the SB ACL reconstruction technique was also performed on patients with an approaching skeletal maturity (Tanner 3) with femoral fixation, by using the TightRope RT (Arthrex, Naples, FL). In these patients, routine X-ray imaging was used while opening the tunnels perioperatively. The femoral tunnel was opened with an additional anteromedial portal to achieve a better angle.

DB anterior cruciate ligament reconstruction procedure: Between 2009 and 2017, the DB ACL reconstruction technique was widely preferred. A double endobutton fixation was achieved by using the TightRope RT (Arthrex, Naples, FL) device for femoral fixation and a bioabsorbable screw fixation for tibial fixation. The locations of the femoral and tibial tunnels were evaluated and determined by using posterolateral and anteromedial bundle footprints. The femoral posterolateral bundle was aimed to be on the anterior side of the lateral bifurcate ridge and the anteromedial bundle on the posterior of the lateral bifurcate ridge. The tibial footprint of the posterolateral bundle was centred to the posterior border of the medial to the lateral meniscus, and the anteromedial bundle was centred to the anterior to the posterolateral bundle. It is always important to be meticulous about providing the bony bridge between the anteromedial (AM) and the posterolateral PM bundles.

Postoperative rehabilitation: The postoperative rehabilitation procedure was the same for both groups. Immediate full weight-bearing without a brace was permitted. Closed kinetic chain exercises were started on the postoperative day one. Crutches were used until the quadriceps muscle control was established. Between eight and 10 weeks, running was allowed. Patients were permitted to return to sports after an isokinetic muscle test when a minimal difference with the contralateral leg was achieved. In the patients who had a meniscus repair, the first six to eight weeks of the rehabilitation schedule was modified. The range of motion was limited to 90° in the first six weeks with partial weight bearing. For at least six to eight weeks, Crutches were used for at least six to eight weeks, the rehabilitation schedule was continued as above with the exception that these patients who underwent a meniscus repair were permitted to run after 3 months.

Statistical analysis

The statistical analyses were performed using SPSS, version 22 (IBM SPSS Statistics for Windows, Armonk, NY, USA; IBM Corp., Released 2013). First, a Kolmogorov–Smirnov test was used to determine the variables to be included in the data analysis and whether the data for the variables were normally distributed; however, the data were not normally distributed. Therefore, non-parametric tests were used. The Mann–Whitney *U*-test was used to compare continuous variables across the groups. The Wilcoxon Signed Rank test was used to compare continuous variables between the groups. The chi-square test and Fisher's exact test were used to compare categorical variables between the two groups. The median (Q1 (1st quartile)-Q3 (3rd quartile)), mean ± standard deviation, frequency, and percentage were reported as descriptive statistics.

HIGHLIGHTS

- To our knowledge, this study is significant and valuable to display one of the most troublesome issues in orthopaedics. Adolescent ACL reconstruction is one of the nightmares of most sports medicine surgeons. Over the years, numerous surgical techniques have been introduced to minimize the failure rates. Our single surgeon long-term experience found no difference between the SB and the DB ACLR in the adolescent period.

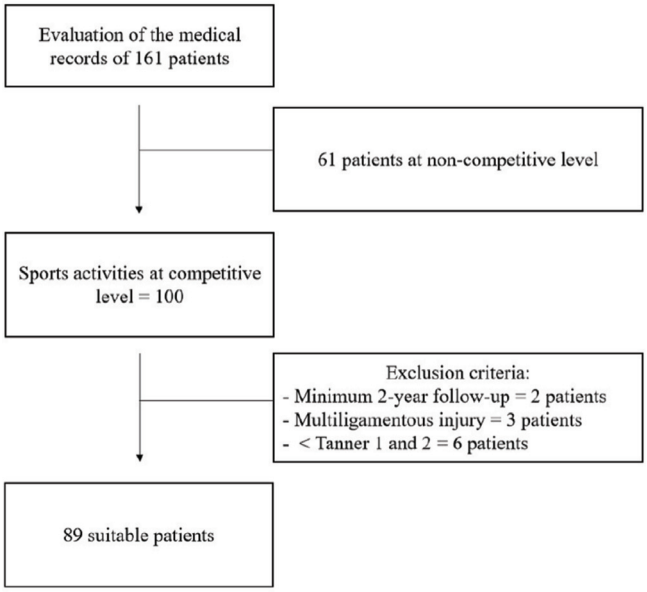

Figure 1. Participant flowchart.

Results

Of the 89 patients who underwent primary ACL reconstruction, 28 were females (31.5%) and 61 were males (68.5%) (Table 1). The mean follow-up period was 53.1 ± 8.6 months for group 1 and 46.4 ± 9.1 months for group 2 (p = 0.61). Most of the patients had an ACL injury due to non-contact injuries (Table 1) and all the patients who were participating in other sports including volleyball (four patients), running (four patients), wrestling (two patients), handball (one patient), and skiing (one patient) had non-contact injuries.

The groups did not differ with respect to age (P = 0.068), sex (P = 0.068), the injured side (P = 0.82), the time from injury to surgery (P = 0.60), the postoperative follow-up time (P = 0.61), or the preoperative physical examination results (P = 0.298 for the KT-1000 device (SSD), P = 0.225 for the Cincinnati score, P = 0.317 for the IKDC objective value, P = 0.379 for the IKDC subjective score, P = 0.775 for the Lachman test, and P = 0.351 for the pivot-shift test) (Table 2).

Twenty-one patients encountered an ACL re-rupture. Among these patients, nine patients underwent SB ACL reconstruction surgery and 12 underwent DB ACL reconstruction surgery (Table 1). Among the patients who had a re-rupture, 13 were males and 8 were females. No significant association was detected between the type of reconstruction surgery and the re-rupture of the ACL (P = 0.98).

The patients in both groups showed similar postoperative clinical anteroposterior stability, as evaluated by KT-1000 arthrometry (SSD) (P = 0.669), pivot-shift test (P= 0.507), Lachman test (P = 0.823), graft failure rate (P = 0.126), and similar postoperative physical examination results (Table 3). In group 1, 5.8% of the patients presented a positive pivot-shift which was 2.6% in group 2.

The mean time required to return to sports was 7 months (min-max: 6-8.5 months). For patients who underwent either SB or DB ACL reconstruction, the mean time required to return to sports was 6.8 and 7.2 months, respectively.

In SB group 2, different implants were used in femoral fixation. In 23 patients, transfix cross-pin system was used while 28 patients were operated with tightrope suspensatuary system. In the subgroup analysis, no statistical difference is found regarding re-rupture rates.

When binary logistic regression analysis was performed, it was seen that the variables like type of reconstruction (P = 0.64), gender (P = 0.63), skeletal maturity (P = 0.99), sports type (P = 0.41), and meniscal procedures (P = 0.59) were not risk factors for re-rupture.

Discussion

In this study, we focused on the effect of the ACL reconstruction technique (SB or DB) on survival and overall outcomes. We could not verify our thesis that DB ACLR had lower re-rupture rates than SB ACLR.

ACL reconstruction is the major reconstructive surgery performed in the knee.[18] Both SB and DB techniques are frequently used in ACL reconstruction surgeries.[19,20] However, there is no consensus on whether one technique is superior to the other.[21] In this study, there were no significant associations between the preference of ACL surgery, the mechanism of injury, the re-rupture of the ACL, or postoperative Lachman and IKDC scores. Moreover, postoperative IKDC scores did not differ between the SB ACL reconstruction and the DB ACL reconstruction groups.

The parameters for the comparison of the SB and the DB ACL reconstruction results vary among the studies conducted. In a study conducted by Zhang et al., the SB ACL and the DB ACL results were compared in terms of patient satisfaction, anterior stability, and rotational stability.[22] They reported that all patients were satisfied with the results and had satisfactory anterior stability in both groups; however, rotational stability was significantly higher in the DB ACL reconstruction compared to the SB ACL reconstruction.[22] In another study comparing several other parameters including clinical examination, KT-1000™ arthrometry, Tegner knee score, modified Cincinnati score, Knee Injury and Osteoarthritis Outcome Scale, and IKDC score, there were no differences between the SB ACL reconstruction or the DB ACL reconstruction, with an improvement in all parameters in both groups.[23] In a meta-analysis evaluating 17 randomized clinical trials, Lysholm score, knee extensor/flexor peak torques, and objective IKDC scores did not differ between the SB ACL reconstruction or the DB ACL reconstruction, while the arthroscopic DB reconstruction was found to be associated with a lower graft failure and KT-1000™ arthrometry measurements and higher subjective IKDC scores.[24] They concluded that the arthroscopic DB reconstruction should be acknowledged as the primary intervention in an ACL reconstruction.[24] A more recent randomized controlled trial investigated the SB ACL and the DB ACL reconstruction results in terms of clinical examination, KT-1000™ arthrometry measurements, IKDC and Lysholm scores, and radiographic examinations.[25] Although they found a lower graft failure in the patients who underwent the DB ACL reconstruction, knee stability, KT-1000™ arthrometry measurements, and knee scores did not differ between the groups.[25] In contrast to the literature, in our study, we found a lower graft failure in the SB ACLR, but it was not statistically significant.

Table 1. Demographic data

	SB (n = 51)	DB (n = 38)	*P*
Gender (M/F)	31/20	30/8	0.11
Age (years)	15.4 ± 1.03	15.7 ± 1.3	0.68
Side (right/left)	34/17	28/10	–
Time from injury to surgery (mo)	1.2 ± 0.9	1.4 ± 0.9	0.60
Skeletal maturity (n (%))			
Approaching	10 (19.6)	2 (5.3)	0.34
Mature	41(80.4)	36 (94.7)	
Sports (n (%))			
Football	36 (70.6)	25 (65.8)	0.26
Basketball	7 (13.7)	8 (21.1)	
Others	8 (15.7)	5 (13.1)	
Mean follow-up (mo)	53.1 ± 8.6	46.4 ± 9.1	0.61
Graft size (n (%))			
<7.5 mm	14 (27.5)	11 (28.9)	0.21
≥7.5 mm	37 (72.5)	27 (71.1)	
Mechanism of injury			
Contact	13 (25.4)	14 (36.8)	0.24
Non-contact	38 (74.5)	24 (63.2)	
Contralateral injury	4	7	0.13
Re-rupture	9 (17.6)	12 (31.5)	0.12
Additional meniscus injury			
Meniscectomy	2 (3.9)	1 (2.6)	0.10
Repair	0	2 (5.2)	
Deep joint infection	0	2 (5.2)	-

DB, Double Bundle; IKDC, International Knee Documentation Committee; SB, Single Bundle.

Table 2. Preoperative clinical data of enrolled patients

	Group 1 (SB)	Group 2 (DB)
Lachman test [number (%)]		
I	25 (49%)	16 (42.1%)
II	21 (41.2%)	17 (44.7%)
III	5 (9.8%)	5 (13.2%)
Pivot shift test [number (%)]		
I	47 (92.1%)	33 (86.8%)
II	3 (5.9%)	5 (13.2%)
III	1 (2%)	0
Objective IKDC score [number (%)]		
A	%0	%0
B	%0	%0
C	44 (86.3%)	30 (78.9%)
D	7 (13.7%)	8 (21.1%)
Subjective IKDC [median (Q1-Q3)]	55.2 (48.3-56.3)	54.0 (49.4-58.3)
Side-to-side difference [median (Q1-Q3)]	8 (7-9 mm)	7.5 (7-9 mm)
Cincinnati Knee Score [median (Q1-Q3)]	54 (48-58)	56 (52-60)

A better kinematics restoration was also indicated after the DB ACL reconstruction than with the SB ACL reconstruction.[26] However, no differences in the risk of revision were observed between the DB ACL reconstruction and SB ACL reconstruction.[27,28] In the present study, although we did not examine the kinematic properties of the knee after reconstruction surgeries, we also could not find any associations between the reconstruction technique and the risk of revision.

We did not reveal any difference associated with additional meniscus surgery. Our results were inconsistent with the study of DeFrancesco et al., in which they found lower rates of failure in patients who

Table 3. Postoperative clinical data of enrolled patients

Re-rupture [number (%)]	Group 1 (SB) 9 (17.6%)	Group 2 (DB) 12 (31.6%)	*P value* 0.12
Lachman test [number (%)]			
0	43 (84.3%)	31 (81.6%)	0.82
I	6 (11.8%)	6 (15.8%)	
II	2 (3.9%)	1 (2.6%)	
III	0	0	
Pivot shift test [number (%)]			0.50
0	48 (94.2%)	37 (97.4%)	
I	3 (5.8%)	1 (2.6%)	
II	0	0	
III	0	0	
Objective IKDC score [number (%)]			0.44
A	42 (82.4%)	34 (89.5%)	
B	7 (13.7%)	3 (7.9%)	
C	2 (3.9%)	1 (2.6%)	
D	0	0	
Subjective IKDC [median (Q1-Q3)]	88.5 (85.1-94.3)	88.2(85.1-92.2)	0.39
Side-to-side difference [median (Q1-Q3)]	2 (1-3 mm)	2 (1-3 mm)	0.41
Cincinnati Knee Score [median (Q1-Q3)]	90 (84-91)	91.0 (87.5-92.2)	0.62

underwent an additional meniscal procedure.[9] Our partial meniscectomy number was higher than meniscus repair which is expected to be far from their study. This could be explained by the innovation of an all-inside suture implant that was available after 2007.

The DB ACL reconstruction had higher rates of postoperative joint infections.[29] This could be understandable when considering the longer operation times, bigger tunnel sizes, and higher hematoma risk. Also, in the present study, the infection rate in the DB group was 5.2%, which was slightly higher than usual. Moreover, no infection was observed in the SB group. However, due to the small sample size of both groups, it would be hasty to suggest that a SB technique is much safer in the terms of infection.

In adolescent patients, growth disturbances can be seen especially in the skeletally immature patients.[30,31] In the present study, the medium age was 15 and most of the patients were detected as skeletally mature or approaching skeletal maturity (Tanner 3-5) who had limited growth capacity. This may be the reason that we did not observe any growth disturbance and leg length discrepancy in the rest of the study group.

There is no consensus on the timing to return to sports after the ACL reconstruction. Zaffagnini et al. reported a period of around 6 months for the return to play in official games for a professional soccer player,[32] which is similar to the present study. However, in recent years, delaying the period for as long as possible has been the inclination. Beischer et al. reported that returning to the sports before 9 months increases the risk of a new injury by as much as seven-fold.[33] The reason that we have encountered patients who experienced a re-rupture may be due to returning to the sports too early (before seven months) and this is separate to any surgical technique. Paterno et al. emphasized that younger athletes returned to sports more rapidly than older ones[34]; however, it is really difficult to prove this scientifically. Numerous factors determine the time to return to sports in adolescent athletes. Even though many of the parameters we evaluated seem to be insignificant, there may be other essential factors such as psychological readiness that might affect the results. Kostyun et al. reported that female athletes had

lower psychological readiness than male athletes.[35] They used the anterior cruciate ligament return to sports after injury (ACL-RSI) scale to evaluate the psychological readiness[35]; however, in our opinion, it is also very difficult to determine the confidence of the player by using ACL-RSI.

It is also noteworthy that we used two different techniques in the SB ACL reconstruction. However, the difference in the ACL reconstruction technique had no effect on the survival of the graft in the patients. This can be interpreted that proper positioning of the femoral and tibial tunnels is crucially important, but they are not superior when cortical buttons are used.

There were several limitations in our study. First of all, our study was a retrospective study and therefore, we could not reveal some predisposed factors such as generalized ligamentous laxity and valgus deformity that commonly affect the results of the ACL reconstruction. Second, we did not analyse the positions of the tunnels. Thus, we cannot claim that all of the reconstruction cases were free of any kind of technical errors. However, performing the ACL reconstruction surgeries by one senior surgeon strengthens our study. We only reported the timing of the athletes' return to their sports, but it is more valuable to identify the level of the athlete when he/she returns. As this study covers a 20-year period retrospectively, we could not evaluate this, which presents a weakness in our study.

In conclusion, our results suggest that there are no significant differences in the reported outcomes, complications, and re-ruptures between the two ACL reconstruction techniques. Scanning an important number of adolescent patients over a long period with a single surgeon experience makes the present study valuable. Even though there are innovations in orthopaedic surgery technology, the most significant dilemma in sports medicine has yet to be solved.

Ethics Committee Approval: Ethics Committee approval was received for this study from the Institutional Review Board of Acıbadem University (2020-06/2020).

Informed Consent: Written informed consents were obtained from the patients who participated in this study.

Author Contributions: Concept - B.T.; Design - T.E., V.E.O.; Data Collection and/or Processing - G.F.; Analysis and/or Interpretation - G.D.; Supervision - O.T.; Writing - B.T.

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