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Single-bundle versus double-bundle arthroscopic reconstruction of the anterior cruciate ligament: what does the available evidence suggest?

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Abstract The introduction of the double-bundle technique as a surgical option for primary anterior cruciate ligament (ACL) surgery stems from the hypothesis that replicating the double-bundle anatomy of the native ACL improves knee kinematics by supplying better rotational control. We performed a systematic review of the literature comparing double-bundle with standard single-bundle reconstruction methods. One RCT and three quasi-RCTs with a one- to two-year follow-up were included in this review. On the basis of these studies, ACL reconstruction with a double-bundle technique leads to less residual pivot-shift as assessed on manual and instrumented tests. Conflicting results exist as to whether the double-bundle technique leads to less side-to-side anterior tibial translation, and no significant differences were found regarding proprioception, flexor-extensor peak torque and knee function as assessed with the International Knee Documentation Committee score. On the other hand, better subjective knee function was found in one quasi-RCT. However, there is a lack of correlation between these kinematic differences and an as yet unproven clinical effect. Uncertainties also exist regarding the mid- and long-term performances of the ACL reconstructed with a double-bundle technique. Comparison between the single-bundle and double-bundle techniques should be expanded to cover unresolved issues such as the rate of complications from a more challenging surgical technique, the risk of complicating revision surgery due to the presence of two tunnels, and the cost-effectiveness of a procedure with a higher consumption of fixation devices. The double-bundle technique should be further investigated by experienced knee surgeons in studies with higher methodological quality.

Key words Anterior cruciate ligament • Reconstruction • Surgery • Single bundle • Double bundle

Introduction

Arthroscopic reconstruction of the anterior cruciate ligament (ACL) is a widely performed surgical procedure that is recommended to recreational and professional athletes when conservative treatment fails to prevent recurrent instability. Currently, more than 100 000 ACL reconstructions are performed yearly in the United States [1]. The success rate assessed on both physician- and patient-oriented outcome tools ranges from 80% to 90%, with a 10%–20% rate less favourable results following surgery [2].

A large amount of research has been conducted over the past decade to assess the viability of different types of autografts and the effectiveness of fixation devices in order to improve success rates. Both bone-patellar tendon-bone (BPTP) and hamstring tendon (HT) autografts provide satisfactory outcomes when used for ACL reconstruction [3]. Conversely, conflicting conclusions have been reached regarding the effectiveness of cortical versus interference fixation devices. A meta-analysis concluded that four-strand HT autografts using femoral fixation with second-generation tibial fixation yielded greater stability than other graft-fixation constructs [4]. A randomised controlled trial (RCT) found that fixation devices placed closer to the joint line reduced tunnel widening [5], which might affect graft performance in the middle and long terms.

On the basis of a biomechanical study, Yamamoto et al. [6] concluded that ACL reconstruction with a single bundle (SB) could not restore the complex two-bundle anatomy and related function of the native ACL. It has been accordingly assumed that the success rate of ACL reconstructive surgery would be improved by a surgical technique that more closely reproduced the configuration and function of the native ACL. This has led to a reappraisal of the two-bundle anatomy and biomechanics of the ACL focusing on its application to surgical practice [7, 8]. Two studies have further expanded our knowledge of the biomechanical behaviour of the two-bundle graft, allowing for a number of variables including the number and orientation of tunnels, the amount of graft tensioning and the type of fixation [9, 10]. The relevant stresses acting on each bundle as a function of the joint angle at which graft fixation is set have also been investigated [10]. Several studies have evaluated the 1- to 2-year clinical outcomes of patients undergoing double-bundle (DB) ACL reconstruction, albeit with conflicting results [11–14].

The introduction of the DB reconstruction technique into surgical practice has elicited enthusiasm in the orthopaedic community owing to the theoretical advantage of restoring native ACL anatomy and function. However, an editorial published in 2004 by Harner and Poehling warned against the potential short- and long-term risks associated with a more challenging surgical technique and also underlined the necessity for basic science, biomechanical and evidence-based medicine (EBM) studies benchmarking the DB approach against the SB reconstruction technique [2]. The authors' conclusion was that until such information is available, orthopaedic surgeons should continue to master SB reconstruction before embracing the DB technique. In addition, once evidence is available, health economics analyses should be conducted to determine if DB reconstruction is more cost-effective than the SB technique.

In order to provide orthopaedic surgeons with an updated appraisal of the current evidence, we carried out a systematic review of the literature regarding the outcomes of arthroscopic ACL reconstruction performed with the SB and DB approaches.

Materials and methods

We conducted a literature search for meta-analyses, systematic reviews, RCTs and quasi-RCTs on SB and DB reconstructions of the ACL. The following databases were searched: Cochrane Musculoskeletal Injuries Group Specialised Register, Cochrane Register of Controlled Trials, Health Technology Assessment (HTA), PEDro, Medline, EMBASE, CINAHL, AMED, DARE, TRIP, and UK National Research Register. The search was completed on 30 April 2007. The search strategy employed the following terms selected from the US National Library of Medicine's Medical Subject Headings (MESH): arthroscopy; anterior cruciate ligament; reconstruction; single-bundle; double bundle. Two of the authors (SL and GR) appraised the quality of the retrieved articles according to accepted standards [15]. Only articles reporting on clinical outcomes were included in the present analysis. The articles were reviewed chronologically to detect any changes over the years.

Results

Our literature search for studies comparing single-bundle and double-bundle approaches to ACL reconstruction identified one RCT and three quasi-RCTs (Table 1).

The RCT by Adachi and associates compared 55 patients who underwent ACL reconstruction with SB to 53 patients who received a DB graft [11]. The purpose of the study was to investigate whether the two techniques differed in terms of joint stability and proprioception. The method of randomization was not detailed by the authors. Baseline variables did not differ between the groups. Multistranded autogeneic HTs were used as grafts. In the SB group, the femoral tunnel was located 5 mm anteriorly to the posterior margin of the intercondylar notch at the 10:00 o'clock (right knee) or 2:00 o'clock (left knee) position. In the DB group, the two femoral tunnels were drilled at a distance of at least 1 mm to avoid overlapping and their relevant positions were 11:00 and 9:30 o'clock (right knee) or 1:00 and 2:30 o'clock (left knee) for the anteromedial and posterolateral bundles, respectively. Cortical fixation was used at the femoral level (Endobutton CL; Acufex, Smith & Nephew, Mansfield, MA, USA) whereas tibial fixation was achieved with Endobutton Tape (Acufex, Smith & Nephew) and two staples. A tensile force of 50 N was

Table 1 Randomised controlled trials (RCTs) and quasi-RCTs comparing single-bundle (SB) and double-bundle (DB) approaches to primary anterior cruciate ligament (ACL) reconstruction.

Reference	Study design	Follow-up	Study groups	Outcome measures	
				Physician oriented	Patient oriented
Adachi et al. [11]	RCT	2 years	SB (*n*=55) DB (*n*=53)	Side-to-side ATT (KT-2000) Proprioception (Cybex II)	None
Yasuda et al. [12]	Quasi-RCT	2 years	SB (*n*=24) N-AD (*n*=24) AD (*n*=24)	Side-to-side ATT (KT-2000) Peak torque (Cybex II) Pivot-shift (manual) IKDC score	None
Aglietti et al. [13]	Quasi-RCT	2 years	Single incision SB (*n*=25) Single incision DB (*n*=25) Double incision DB (*n*=25)	Side-to-side ATT (KT-2000) Pivot-shift (manual) IKDC score	KOOS IKDC subjective score
Yagi et al. [14]	Quasi-RCT	1 year	Anteromedial SB (*n*=24) Posterolateral SB (*n*=24) DB (*n*=24)	Side-to-side ATT (KT-2000) Peak torque (Cybex II) Pivot-shift (instrumented) IKDC score	None

N-AD, non-anatomical DB; *AD*, anatomical DB; *ATT*, anterior tibial translation; *IKDC*, International Knee Documentation Committee; *KOOS*, Knee Injury and Osteoarthritis Outcome score

exerted at the distal end of the SB autograft, which was secured with the knee at 90° of flexion. The distal ends of the DB autografts exiting through two distinct tibial tunnels were tensioned by applying a force of 25 N and were fixed at 90° of knee flexion. Joint stability (anterior laxity) and proprioception (position sense at different angles of knee flexion) were assessed at a minimum two-year follow-up by an independent observer using the KT-2000 knee arthrometer (MedMetric, San Diego, CA, USA) and the Cybex II dynamometer (Lumex, Ronkonkoma, NY, USA), respectively. The study did not find any significant difference in joint stability and proprioception between the SB and DB groups.

Yasuda and coworkers conducted a quasi-RCT (prospective comparative cohort study) to compare clinical outcomes among patients who underwent ACL reconstruction with SB or DB autografts [12]. The DB reconstruction procedure was performed according to either a non-anatomical technique (N-AD) consisting of double femoral tunnels and a single tibial tunnel or an anatomical technique (AD) consisting of two femoral and tibial tunnels. A randomization method consecutively assigning three batches of patients to each study group was used. A total of 72 patients was enrolled in the study and 24 patients were allocated to each group. Baseline variables were not different among the SB, N-AD and AD groups. Reconstruction was performed using multistranded autogeneic HTs. The femoral tunnel was positioned at 10.30 o'clock (right knee) and 1:30 o'clock (left knee) in the SB group. In the N-AD and AD groups, the two femoral tunnels were drilled at the 11:30 and 10:30 o'clock positions (right knee) or at the 12:30 and 1:30 o'clock positions (left knee) for the anteromedial and posterolateral bundles, respectively. The proximal ends of the autografts were secured with an Endobutton CL and polyester tape (Neoligament, Leeds, UK). The distal ends were fixed with polyester tape and two spiked staples. An 80-N tension was applied to the tibial ends of the graft, which was fixed at 30° of knee flexion in the SB group. In the N-AD and AD groups, the distal ends were fixed respectively at 30° and 20° of knee flexion, and a 40-N tensile force was applied to each bundle. Independent observers assessed patients' outcomes at the two-year follow-up. Joint stability was evaluated by measuring the side-to-side anterior laxity using the KT-2000 knee arthrometer (MedMetric, San Diego, CA, USA); posterolateral instability was assessed on the manual pivot-shift test. Peak isokinetic torque of the quadriceps and hamstrings muscles was assessed using the Cybex II dynamometer. Knee function was assessed using the Internation Knee Documentation Committee (IKDC) Evaluation Form. The authors found that the side-to-side anterior laxity and the amount of residual pivot-shift were significantly less in the N-AD and AD groups than in the SB group. Conversely, no significant difference was observed among the three groups as to muscle torque, range of motion and IKDC score.

The quasi-RCT by Aglietti and associates compared the clinical outcomes in 75 patients who underwent ACL reconstruction by one of the following techniques: single-incision SB (Group 1); single-incision DB (Group 2); and double-incision DB (Group 3) [13]. Twenty-five patients were allocated to each group. Baseline variables were comparable among the three groups. Multistranded autogeneic HTs were harvested for reconstruction. In Group 1, the femoral tunnel was drilled at 70°–80° of flexion with a 5-mm femoral aimer that was externally rotated to achieve a more inferior and deeper position. The proximal end of the graft was fixed with an Endobutton CL while the distal end was secured with a Washerloc (Arthrotek, Warsaw, IN, USA), and a 40-N tension force was applied at 10° of knee flexion. In Group 2, the femoral tunnel for the anteromedial bundle was created in a manner similar to that of Group 1, while the second femoral tunnel for the posterolateral bundle was drilled with a 0- mm offset aimer with the knee set in internal rotation and posterior drawer and at 80° of flexion. The proximal ends of the graft were fixed with an Endobutton CL while the distal ends running through two distinct tibial tunnels were fixed with a Washerloc and a staple. A 20-N tension force was applied to the anteromedial and posteromedial bundles that were respectively fixed at 45° and 10° of knee flexion. In Group 3, the femoral tunnels were drilled according to an outside-in technique through an additional skin incision placed on the lateral aspect of the distal femur. The tunnel for the anteromedial bundle was created by drilling the guide wire with a rear-entry guide as deep as possible and close to the over-the-top position. The tunnel for the posteromedial bundle was created 9 mm more inferiorly to the anteromedial tunnel 5 mm from the inferior cartilage border. The posteromedial bundle was fixed at the femoral and tibial levels with a 6-mm rounded cannulated interference (RCI) screw (Smith & Nephew, Andover, MA, USA). The anteromedial bundle was secured to the femur by a 6-mm RCI screw while its distal end was fixed by availing of the bony bridge interposed between the two tibial tunnels and the previously inserted screw. Finally, both proximal ends were fixed to the femoral cortex by a staple. A 20-N tension force was applied to the anteromedial and posterolateral bundles that were respectively fixed at 45° and 10° of knee flexion. An independent observer evaluated patients' outcomes at the two-year follow-up. Joint stability was evaluated by measuring side-to-side anterior laxity using the KT-2000 knee arthrometer and posterolateral instability was assessed on the manual pivot-shift test. Knee function was assessed on the IKDC Evaluation Form. Patient-oriented knee function was assessed on the IKDC Subjective Evaluation Form and with the Knee Injury and Osteoarthritis Outcome Score (KOOS). The study found that side-to-side anterior laxity and the amount of residual pivot-shift were significantly lower in Group 3 than in Group 1 and that the IKDC Subjective Evaluation score was higher in Group 3 than in Group 1. No significant differences were observed between Groups 2 and 3.

Yagi and coworkers investigated whether rotational stability differed in ACLs reconstructed with three different techniques: anteromedial SB, posterolateral SB and DB [14]. A total of 60 patients was allocated to three groups by a quasi-randomised procedure not described by the authors. Baseline variables were comparable among groups. Multistranded autogeneic HTs were used as autografts. In the anteromedial SB group the femoral tunnel was located at the 10:30 (right knee) or 13:30 (left knee) o'clock position, while in the posterolateral SB group the femoral tunnel was drilled at the center of the posterolateral bundle. The proximal and distal ends of the SB were respectively fixed with an Endobutton CL and a post screw. Manual tension was applied to the graft distal end with the knee flexed at 60° (anteromedial SB) and 15° (posterolateral SB). In the DB group, the femoral tunnel for the posterolateral bundle was located 5-8 mm from the cartilage margin on a line to the contact point between the femur and the tibia at 90° of knee flexion. The femoral tunnel for the anteromedial bundle was located at the 10:30 (right knee) or 13:30 (left knee) o'clock position. Proximal fixation used the Endobutton CL while tibial fixation was achieved with a 6.5-mm cancellous screw, a washer (Synthes, West Chester, PA, USA) and polyester sutures (Ethicon, Sommerville, NJ, USA). Manual tension was applied to the anteromedial and posterolateral bundles at 60° and 15° of knee flexion, respectively. Two independent observers assessed patients' outcomes at the one-year follow-up. Joint stability was evaluated by measuring side-to-side anterior laxity using the KT-1000 knee arthrometer and posterolateral instability was assessed using an instrumented pivot-shift test using electromagnetic sensors (Polhemus Fastrack, Colchester, VT, USA). Extensor and flexor peak isokinetic torques were measured using the Cybex II dynamometer. Knee function was evaluated on the IKDC Evaluation Form. The study found no significant differences among groups in side-to-side anterior laxity, peak isokinetic torque or IKDC score. On the other hand, patients who had the ACL reconstructed with the DB technique had significantly better pivot-shift control.

Discussion

The development of the DB reconstruction technique has been prompted by biomechanical studies and postoperative assessment of patients receiving SB reconstruction of the ACL. Each bundle of the native ACL behaves in a differential fashion during knee kinematics in that the anteromedial bundle is moderately lax in extension and becomes tauter during knee flexion whereas the opposite is true for the posterolateral bundle. A recent study on intact cadaver knees tested in a simulator found that isolated transection of the posterolateral bundle increases anterior tibial translation (ATT) and produces a combined rotatory instability at 30° of knee flexion [8]. On the other hand, a residual pivot-shift has been observed in a number of patients who underwent ACL reconstruction with the SB technique. It should be highlighted, however, that tunnel misplacement has been identified as the main cause of graft failure pertaining to ACL revision surgery [2]. Thus, interpretation of a residual pivot-shift following primary ACL surgery should consider the possibility of sub-optimal tunnel placement.

Biomechanical studies have shown that the capacity of a laterally placed SB reconstruction to resist anterior and rotatory loads compares well with that of an anatomical DB reconstruction if the flexion angle does not exceed 60° [6]. Since the pivot-shift test is usually performed within 0°–30° of flexion, the residual pivot-shift in ACL-reconstructed knees may not necessarily express the inability of a SB to resist rotatory loads. In other words, a number of variables, including surgical ones, may account for a residual pivot-shift beside SB reconstruction per se. RCTs comparing the SB and DB reconstruction methods, conducted by high-volume knee arthroscopists experienced in ACL surgery, should help control for surgeon-related variables confounding the interpretation of clinical outcomes.

As with any other novel surgical technique, a number of basic science, biomechanical and EBM issues should be addressed before the DB technique may supersede the golden standard SB reconstruction of the ACL. First, since the long-term performance of the DB-reconstructed ACL and the associated complications are unknown, patients should be thoroughly informed that the evidence on long-term outcomes is lacking. Second, ACL reconstruction with the DB method is a challenging procedure and experienced knee surgeons have declared that the learning curve lasts at least one year [13]. Until evidence is available, we do not encourage implementation of the DB technique in low-volume surgical practices. Third, this review of the literature shows that the DB technique is characterised by a wide variability as to graft processing, tunnel placement, tension force applied at the tibial side, and joint angle of fixation of the anteromedial and posterolateral bundles. Each of these variables may affect the outcome. For example, biomechanical studies have demonstrated that the joint angle at which the anteromedail and posterolateral bundles are fixed affects the force distribution between the bundles and that overloading of either graft may occur [10]. Clearly, mid- and long-term follow-up studies are needed to determine which technical variant performs best.

What evidence is available in the literature and what does it suggest?

According to accepted standards of quality [15], studies included in the present review had level II evidence. The main methodological limitations of the reviewed papers are related either to the lack of information regarding the randomisation procedure [11] or to the use of a quasi-randomised method [12–14]. Moreover, the variability of the technical procedures used by the authors and the heterogeneity of the end-points chosen for evaluation make inter-study comparison difficult.

Allowing for these methodological limitations, no study detected any difference between the SB and DB procedures in proprioception, extensor and flexor peak torques and IKDC Form Evaluation score. Two quasi-RCTs [12, 13] found greater side-to-side ATT and a higher rate of residual pivot-shift (manual test) in patients who underwent SB reconstruction of the ACL. A higher rate of pivot-shift in SB reconstruction, as assessed with electromagnetic sensors, was observed in another quasi-RCT [14]. However, no significant difference in side-to-side ATT was detected in this study nor in the RCT by Adachi et al. [11]. No patient-oriented outcome measures were used in the included studies except in the one by Aglietti et al. [13], who reported a significantly higher IKDC subjective score in patients who underwent ACL reconstruction by a double-incision DB technique.

Currently available level II evidence from three studies specifically addressing the issue suggest that DB reconstruction of the ACL provides better rotational control at the one- or two-year follow-up [12–14]. Conversely, conflicting results have been reported as to the capacity of the DB procedure to reduce side-to-side ATT, which was measured in only two [12, 13] of the four studies herein reviewed.

Whether the reduced pivot-shift observed in patients who underwent ACL reconstruction with a DB technique may favourably affect the outcome in the midle and long terms remains to be clarified. Specifically, the clinical effect of differences observed for physician-oriented end-points, namely side-to-side ATT and pivot-shift, remains undetermined. Additionally, comparison between the SB and DB techniques should be extended to include other unresolved issues such as the rate of complications from a more challenging surgical technique, the risk of making revision surgery more complicated owing to the presence of two tunnels, and the cost-effectiveness of a procedure with a higher consumption of fixation devices.

In conclusion, primary ACL surgery with DB is theoretically appealing owing to its potential of restoring a better rotational control of the knee. Available level II evidence from quasi-RCTs supports the biomechanical hypothesis underlying the development of the DB technique, in that the residual manual and instrumented pivot-shift appears to be less in ACLs reconstructed with a DB. However, the lack of correlation between these kinematic differences and the relevant clinical effect as well as the uncertainties of the DB performance in the middle and long terms suggest that this technique should be further investigated by experienced knee surgeons in a research setting, with improved methodological quality of the studies.

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