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A matched pairs comparison of single- versus double-bundle anterior cruciate ligament reconstructions, clinical results and manual laxity testing

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Abstract

Purpose To compare the subjective clinical results as well as manual anterior and rotational stability in patients treated with either single- (SB) or double-bundle (DB) anterior cruciate ligament (ACL) reconstructions.

Methods Sixty-four patients who had undergone SB or DB hamstring ACL reconstruction with hamstrings were included in a retrospective matched pair analysis. At follow-up IKDC subjective, CKS, KOOS, CKS and a visual analogue satisfaction scale was assessed. A blinded surgeon examined the joint laxity and completed the objective IKDC. The KT-1000 was used to bilaterally test anterior tibial translation. Patients with confounding variables, which statistically influenced the clinical outcome (passive flexion and extension deficits, persistent quadriceps deficit, tibiofemoral osteoarthritis and non-repairable medial meniscus injury), were identified and excluded from the statistical analysis ($n = 10$).

Results For all subjective scores, DB patients reported increased scores compared with SB patients. While consistently higher scores were demonstrated, statistical significance was only achieved for the IKDC subjective ($P = 0.04$) and VAS satisfaction ($P = 0.02$). Graded stability results of the Lachman, anterior drawer and pivot-shift tests were significantly higher in the DB group and KT-1000 side-to-side difference was significantly better for DB ($P = 0.01$).

Conclusion DB ACL reconstruction appeared to more consistently result in significantly higher subjective outcome scores and manual tests of joint stability than SB ACL reconstruction. Besides the surgical technique, normal extension and quadriceps strength after surgery were identified to be an essential component in order to provide the patient with a successful outcome.

Level of evidence II.

Keywords Anterior cruciate ligament · Double-bundle · Single-bundle · Clinical outcome · Stability · Subjective outcome · Matched pair

Introduction

Great interest has been directed to the separate reconstruction of the anteromedial (AM) and the posterolateral (PL) bundles of the anterior cruciate ligament (ACL) in order to recreate the natural anatomy [12, 14–17, 22, 23, 44, 53–56, 63, 68] and to restore their biomechanical functions [4, 6, 9–11, 19, 32, 35, 36, 39–42, 45, 48, 50, 51, 59, 65–67, 69, 71, 72]. A precise reconstruction of the anatomical double-bundle (DB) structure of the ACL with its AM and PL insertions might theoretically be of significant clinical benefit for the patient.

According to their distinct insertions sites, each bundle contributes individually to the overall biomechanical function of the ACL. Biomechanical in vitro and in vivo studies suggest that both bundles improve anterior stability

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of the knee, and that both bundles, and especially the PL bundle, contribute to rotational stability of the knee close to extension [4, 11, 19, 39–41, 48, 50, 61, 65, 72]. Biomechanical studies have also demonstrated that DB reconstruction significantly reduced internal rotation when compared with single-bundle (SB) ACL reconstruction [7, 25, 50]. Clinical studies have supported these concepts, reconfirming superior anterior and rotational stability with DB compared with SB ACL reconstruction. [2, 3, 5, 8, 13, 18, 25–27, 29–31, 37–39, 47, 52, 60, 61, 67, 68, 70, 72, 73] Furthermore, clinical studies have also reported that DB reconstruction resulted in significantly better IKDC [2, 25, 52, 64], subjective Lysholm Score [25], Tegner Score [72] and visual analogue scale (VAS) [2] than SB ACL reconstruction.

However, the subjective clinical benefit of DB ACL reconstruction is still controversial, and the majority of clinical trials [1, 18, 21, 26, 29, 31, 33, 37, 38, 43, 47, 49, 52, 60, 62, 64, 67] as well as a clinical meta-analysis from Meredick et al. [33] have not shown any significant subjective clinical difference between patients treated with either technique. Patient-reported function has been determined to be influenced not only by the type of ACL reconstruction but also by pain and/or function of the non-operative limb [34, 57]. Concomitant injury or factors associated with postoperative rehabilitation such as range of motion and quadriceps strength may influence subjective scores. While providing useful information about patient's postoperative recovery, subjective scores may be too blunt of a tool to judge differences between two ACL reconstruction surgical techniques. Clinical studies including patients with either concomitant disease or insufficient rehabilitation may cloud the subjective comparison of SB to DB ACL reconstruction.

The purpose of this study was to evaluate the clinical outcomes, patient satisfaction and manual tests of knee stability of patients without concomitant disease or deficits in motion or strength treated with either DB or SB ACL reconstruction. It was hypothesized that when controlling for confounding variables, patients treated with a DB technique would demonstrate increased subjective outcome scores, patient satisfaction scores and manual stability testing.

Materials and methods

Patients

Sixty-eight patients following arthroscopic SB and DB hamstring ACL reconstruction were included in this retrospective matched pair analysis in order to compare the clinical outcomes, patient satisfaction, and knee stability of the two procedures. All patients were examined carefully during pre- and postoperative evaluation and during surgery. Pre- and postoperative evaluation included history, examination, standardized radiographs (anteroposterior and lateral view), and preoperative MRI. Patients were excluded from the study if they had any injury to the contralateral knee, or if they demonstrated a severe injury to involved knee, e.g. additional knee ligament injuries, previous knee ligament surgery, arthritic changes grade 3 or 4 according to Outerbridge, subtotal or total meniscectomy, malalignment or patellar pathology.

Patients were selected to participate in the current investigation from the patient populations of two participating surgeons, provided they met the inclusion criteria, matching was possible and they were willing to attend the clinical follow-up for testing. Prior to participation, patients provided informed consent for the IRB-approved protocol. At the time of testing, 3 patients were identified as having an injured opposite extremity and 1 patient did not attend the follow-up, leaving an active sample of 64 patients. The groups were well matched, as there were no differences in age, sex, height, weight or follow-up.

Surgical techniques and rehabilitation

Skin incisions were identical for both groups. The semitendinosus and gracilis tendons were harvested through an anteromedial tibial incision at the pes anserine with a tendon stripper. For the four tunnel DB ACL reconstruction, the semitendinosus tendon (for the AM bundle) and the gracilis tendon (for the PL bundle) were looped over a 20 mm EndoButton CL (Smith and Nephew Endoscopy, Mansfield, Mass., USA). The SB ACL reconstruction utilized a double loop semitendinosus and gracilis graft; therefore, both tendons were looped over one 20 mm EndoButton CL. For both techniques, the distal free ends of the tendons were armed with two No. 2 vicryl sutures using a whip-stitch technique and the grafts were pretensioned on a suture board. The tibial and femoral ACL footprints and the intercondylar notch were cleaned from soft tissue as much as necessary to have an exact arthroscopic view of the insertion sites. No notchplasty was performed. All graft diameters were measured in 0.5 mm steps and the tibial and femoral bone tunnels were drilled accordingly in 0.5 mm steps with a conventional reamer on the tibia and with a headed reamer on the femur.

In SB ACL reconstruction, the tibial bone tunnel was drilled in a 50–55° angle to the tibial plateau. It was positioned in the centre of the native tibial ACL footprint. The femoral bone tunnel was drilled transtibially approximately 4–5 mm inferior to the "over the top position" at the 10:30 h for a right knee and at the 1:30 h position for a left knee at the femoral ACL footprint. The tibial bone tunnel was positioned according to Jackson et al. [28] and Goble et al. [20], and the femoral bone tunnel according to Bernard et al. [7]. A tight press-fit of the two grafts in the bone tunnels was aimed for in all patients. After positioning of the graft, the femoral EndoButton CL was flipped and a 30-mm tibial biodegradable interference screw (Smith and Nephew Endoscopy, Mansfield, Mass., USA) with the same diameter as the tibial bone tunnel or 1 mm larger was inserted.

In four tunnel DB ACL reconstruction, the tibial AM bone tunnel was drilled in a 55° angle and the PL bone tunnel in a 60° angle to the tibial plateau and approximately 1.5 cm (AM bundle) and 3.5 cm (PL bundle) medial to the tibial tuberosity in the coronal plane. Both tibial bone tunnels were positioned in the area intercondylaris anterior respecting the natural border of the tibial ACL footprint according to previous anatomical studies [54]. The femoral AM bone tunnel was drilled 4–5 mm inferior to the "over the top position" at the 10.30 h for a right knee and at the 1.30 h for left knee at the insertion site of the AM bundle [53]. The PL femoral tunnel was drilled at the insertion site of the PL bundle 5–7 mm deep in the notch measured from the shallow (anatomical: inferior) articular cartilage of the lateral femoral condyle. Both femoral bone tunnels were drilled through an accessorial anteromedial portal. We preserved a bone bridge of 1–2 mm between the AM and PL bone tunnels in all patients. After positioning of the two grafts, the two femoral EndoButton CL were flipped. Tibial AM bundle fixation was achieved by an 8 mm or 9 mm by 23 mm long biodegradable interference screw (Arthrex Inc, USA) having the same diameter as that of the AM bone tunnel and tibial PL bundle fixation was by means of a 7 × 23-mm biodegradable interference screw (Arthrex Inc., USA) for all patients. The screws were placed in the most distal part of the bone tunnel keeping a distal cortical contact. The AM bundle was fixed in 60° and the PL bundle in 10° of knee flexion. The postoperative rehabilitation was similar for both groups and was similar to a previous clinical study [52].

Clinical evaluation

At clinical follow-up, all patients were examined by a single experienced orthopaedic surgeon who was not a member of the hospital, nor the operative surgeon for any of the study patients and was blinded to both surgical techniques. The patients themselves were not blinded to the type of procedure.

Bilateral knee extension and flexion ranges of knee motion were measured using standard goniometry, and graded manual muscle tests were performed to assess quadriceps strength by the blinded orthopaedic surgeon. Side-to-side deficits in knee extension, knee flexion, and quadriceps strength were then calculated and used for all analyses. Bilateral knee stability was assessed manually using the Lachman, anterior drawer, and pivot-shift tests. Instrumented side-to-side anterior knee laxity was assessed using the KT-1000, with an anteriorly directed force of 134 N. The objective IKDC was completed by this blinded orthopaedic surgeon. Seated separately, all patients completed the questionnaires necessary to calculate the Cincinnati Knee Score (CKS), Knee Injury and Osteoarthritis Outcome Score (KOOS), International Knee Documentation Committee (IKDC) Subjective Score, and Visual Analogue Scale (VAS) for patient satisfaction.

Statistical analyses

Pearson's product moment correlation coefficients (r) were calculated to evaluate the relationships between subjective outcome scores and the presence of confounding variables (side-to-side deficits in quadriceps strength, passive knee flexion, passive knee extension, tibiofemoral osteoarthritis, patellofemoral osteoarthritis, unrepairable medial or lateral meniscus injury and concomitant medial collateral ligament injury). Once it was determined which confounding factors significantly influenced outcome scores, patients exhibiting these factors were excluded from the comparison of subjective outcome scores in an attempt to make a more clear comparison of the two reconstruction techniques. After applying the additional exclusion criteria, two-tailed, independent t-tests were used to compare side-to-side passive knee flexion and extension deficits between groups. Mann–Whitney U-tests were used to compare subjective IKDC scores, CKS, KOOS, VAS satisfaction scores. Subjective laxity testing (Lachman, anterior drawer, and pivot-shift tests) and objective IKDC scores were compared between groups using Chi^2 tests. All analyses were performed using Statistical Package for the Social Sciences v 17.0 (SPSS Inc., Chicago, IL), and an α-level of $P \leq 0.05$ was considered significant.

Results

The five factors that significantly correlated with subjective outcome scores were side-to-side passive knee flexion and extension deficits, persistent quadriceps deficit, tibiofemoral osteoarthritis, and non-repairable medial meniscus injury (Table 1). All patients with persistent quadriceps deficits greater than grade 2, side-to-side extension deficits of $\geq 5°$, side-to-side flexion deficits of $\geq 15°$, tibiofemoral arthritis, or non-repairable medial meniscus injury were then excluded. The remaining 54 patients (28 SB, 26 DB) were then used to compare the two surgical techniques (Table 2).

Table 1 Correlations between confounding factors and subjective outcome scores

Subjective evaluation scores	Persistent quadriceps deficit	Passive extension loss	Passive flexion loss	Tibiofemoral joint osteoarthritis	Medial menisectomy	Lateral menisectomy	MCL injury	Patellofemoral joint osteoarthritis
Cincinnati knee	−0.31*	0.30*	−0.30*	−0.26*	−0.24	−0.01	−0.07	0.12
IKDC subjective	−0.25*	0.30*	−0.23	−0.29*	−0.26*	−0.01	−0.07	0.09
KOOS pain	−0.34**	0.40**	−0.28*	−0.28*	−0.15	0.07	−0.08	0.12
KOOS symptom	−0.30*	0.38**	−0.28*	−0.11	−0.11	0.05	0.03	0.06
KOOS ADL	−0.30*	0.39**	−0.23	−0.28*	−0.10	0.06	−0.11	0.08
KOOS sport/rec	−0.28*	0.42**	−0.33**	−0.22	−0.16	0	−0.04	0.07
KOOS QOL	−0.24	0.26*	−0.30*	−0.25*	−0.09	−0.06	−0.01	0.06

* $P < 0.05$, ** $P < 0.01$

Table 2 Patient demographics (mean ± standard deviation) of the single bundle (SB) and double bundle (DB) reconstruction groups

	SB	DB	*P*-value
Sample size	28	26	–
Age at surgery	31.8 ± 11.9 years	32.2 ± 11.6 years	n.s.
Gender (male/female)	19/9	19/7	n.s.
Side (right/left)	17/11	14/12	n.s.
Height (cm)	175.9 ± 8.6	177.3 ± 6.8	n.s.
Weight (kg)	73.0 ± 12.6	79.5 ± 10.1	n.s.
Follow-up interval (days)	515 ± 147	466 ± 94	n.s.

For all subjective scores, the DB patients reported increased scores compared to the SB patients (Table 3). While consistently higher scores were reported, statistical significance was only achieved for the IKDC subjective score ($P = 0.04$) and VAS satisfaction ($P = 0.02$). The mean arc of motion did not differ between the SB group (−1.3–131.4°) and the DB group (−2.1–129.1°), nor did side-to-side knee flexion or extension deficits.

Graded laxity results from the Lachman, anterior drawer, and pivots-shift tests were significantly lower for DB than for SB (Fig. 1) as were the side-to-side differences of anterior translation measured with the KT-1000 (DB group = 1.1 ± 1.0 mm and SB group = 2.2 ± 1.4 mm, $P = 0.01$) The objective IKDC was normal or nearly normal in 92.0% patients in group SB and 96.2% in group DB (Table 3).

Discussion

The most important finding of the present study was that patients following DB ACL reconstruction demonstrated significantly reduced anterior and rotational laxity with significantly improved subjective IKDC and patient VAS satisfaction scores. The other scoring systems assessed in this study did not demonstrate differences between the two surgical techniques.

A second part of our clinical study was to compare rotational laxity with these same groups of patients using a robotic testing system [7]. When comparing the reconstructed knee to the intact contralateral knee, Branch et al. [7] found that side-to-side differences in internal rotation difference were significantly lower with DB (2°) compared to SB reconstruction (5°). A significantly greater percentage of DB patients (81%) also had both anterior tibial translation and internal rotation similar to the normal contralateral knee, compared to 34% of the SB patients [7]. We concluded that the DB technique more consistently reproduced the biomechanical profile of the uninjured limb.

In recent years, several clinical trials demonstrated improved knee stability with DB ACL reconstruction compared to SB [2, 3, 5, 8, 13, 18, 25–27, 29–31, 37–39, 47, 52, 60, 61, 67, 68, 70, 72, 73]. Aglietti et al. [2] performed a randomized, controlled clinical trial including 70 patients with a minimum follow-up of 2 years and found significantly improved VAS, significantly greater number of "normal knees" according to the objective IKDC final scores, and significantly improved KT-1000 and pivot shift test results with DB compared to SB reconstruction. Significantly improved anterior and rotational stability were also described by Kondo et al. [31], including 328 patients with a minimum follow-up of 2 years and by Yasuda et al. [67] in a comparison of "anatomic" DB reconstruction to "non-anatomic" SB reconstruction including 72 patients

Table 3 Clinical outcomes scores, patient satisfaction, and range of motion (mean ± standard deviation) for the single bundle (SB) and double bundle (DB) groups

	SB	DB	*P*-value
Cincinnati knee score (/100)	81.8 ± 17.4	89.2 ± 9.6	n.s.
Subjective IKDC score (/100)	80.3 ± 15.1	87.7 ± 9.8	0.04
Knee osteoarthritis & injury outcome score			
Pain subscale (/100)	88.0 ± 11.6	90.6 ± 9.1	n.s.
Symptom subscale (/100)	81.6 ± 16.0	86.8 ± 11.0	n.s.
Activities of daily living subscale (/100)	92.4 ± 9.0	96.0 ± 7.3	n.s.
Sport/recreation subscale (/100)	77.4 ± 20.0	85.6 ± 15.8	n.s.
Quality of life subscale (/100)	70.6 ± 23.8	75.7 ± 18.1	n.s.
Patient satisfaction (/10 cm)	7.8 ± 1.8	8.8 ± 1.2	0.02
Objective IKDC grade			
A (normal)	1	5	n.s.
B (nearly normal)	25	20	n.s.
C (abnormal)	2	1	n.s.
D (severely abnormal)	0	0	n.s.
Knee extension deficit (°)	−1.0 ± 1.2°	−1.7 ± 1.3°	n.s.
Knee flexion deficit (°)	2.9 ± 2.9°	3.2 ± 3.1°	n.s.

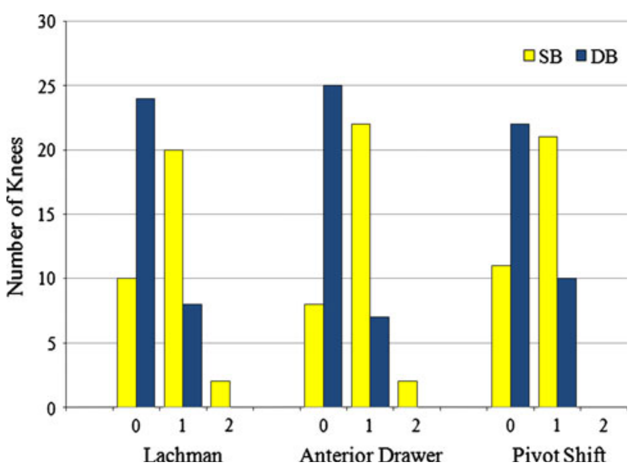

Fig. 1 Results of manual laxity tests for the single bundle (SB) and double bundle (DB) groups

with hamstring tendon graft. These findings were reconfirmed by Muneta et al. [37] in a randomized clinical trial including 68 patients. In that report, DB ACL reconstruction using a 4-strand semitendinosus graft demonstrated superior anterior and rotational stability, but no subjective differences were noted between the two techniques.

Significantly better objective IKDC results were observed by Siebold et al. [52] in a randomized clinical trial of SB versus DB ACL reconstruction in 2008 including 70 patients. In addition, anterior and rotational stability were superior with DB compared to SB. Hofbauer et al. [25] reconfirmed these findings and demonstrated significantly higher IKDC and Lysholm scores and a significant greater reduction in internal rotation in the DB patients (16°) compared to SB patients (7°). Similar results were reported by Volpi et al. [64] comparing transtibial SB bone-patellar tendon-bone reconstruction (BPTB) to transtibial DB semitendinosus/gracilis (ST/G) reconstruction in sportive patients. IKDC scores were significantly higher with the DB technique, and only DB patients were able to return to sports at a pre-injury level. A significantly higher Tegner activity level, higher passive range of motion recovery, faster sport resumption and lower pivot-shift was seen by Zaffagnini et al. [72] in a long-term study comparing SB BPTB to non-anatomical DB ST/G ACL reconstruction. They also assessed a lower reintervention rate for DB, similar to the findings of Järvelä et al. [29] in their cohort.

However, a recent meta-analysis comparing the overall outcomes of SB to DB ACL reconstruction performed by Meredick et al. [33] did not find any significant difference between SB and DB techniques. They included four randomized controlled trials. KT-1000 arthrometer side-to-side difference was 0.52 mm closer to normal in patients with DB, but the difference was not significant. In addition, there was no difference in rotational stability evaluated with the pivot-shift test. Similar results between SB and DB ACL reconstruction were also reported by several other authors [1, 21, 24, 29, 43, 49, 58, 62].

On the contrary, when controlling for concomitant disease and factors related to postoperative rehabilitation, our current results demonstrate a difference in the subjective scores between the two ACL reconstruction techniques. Despite only the subjective IKDC and VAS satisfaction scores being statistically significant between the groups, all other subjective scores (KOOS, CKS) were consistently higher in the DB group. In addition to consistent patient-reported subjective results, the three manual tests of anterior and rotational knee stability as well as the KT 1000 demonstrated significantly increased stability with the DB reconstruction.

However, the statistical analyses show that attaining proper motion and strength after surgery is very important in order to provide the patient with a successful outcome. Of the potential confounding variables that were evaluated in the present study, loss of extension significantly correlated with all subjective scores. An inability to full extend the knee may result in quadriceps weakness, fatigue, and patellofemoral pain [46]. This is further supported by the significant correlations between postoperative quadriceps deficit and the CKS, IKDC subjective score, and four of the five subcomponents of the KOOS.

This study is not without limitations. While we attempted to control for confounding variables that may influence subjective scores by applying secondary exclusion criteria, our sample size was reduced. It is unclear if a larger sample size would have resulted in statistical differences for a greater proportion of the subjective scoring systems. Also, this study utilized manual tests and the KT1000 for assessing joint stability, which may also limit our ability to truly gauge potential differences between ACL reconstruction techniques. Furthermore, transtibial drilling was used in the SB group compared to an anteromedial portal approach in DB, which might have influenced femoral bone tunnel positioning.

Conclusion

DB ACL reconstruction resulted in significantly higher subjective outcome scores and manual tests of joint stability than SB ACL reconstruction. Normal extension and quadriceps strength after surgery were identified to be essential components in order to provide the patient with a successful outcome. Therefore, it is clinically relevant to not only to focus on the type of ACL reconstruction (SB/DB) but also on regaining a full range of motion and quadriceps strength.

Conflict of interest The authors declare that they have no conflict of interest.

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