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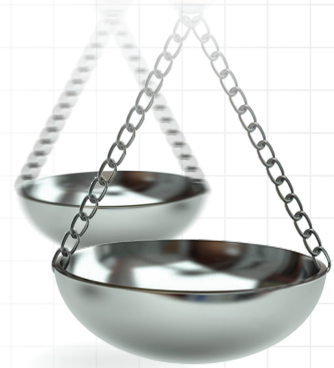

Journal of Comparative Effectiveness Research

Restoring rotational stability following anterior cruciate ligament surgery: single-bundle reconstruction combined with lateral extra-articular tenodesis versus double-bundle reconstruction

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Aim: To compare the outcomes of patients who underwent single-bundle (SB) anterior cruciate ligament (ACL) reconstruction combined with lateral extra-articular tenodesis (LET) with the outcomes of those who underwent double-bundle (DB) ACL reconstruction. **Methods:** 16 patients who underwent ACL hamstring SB reconstruction combined with LET (Coker–Arnold modification of the MacIntosh procedure) were retrospectively compared with 20 patients who underwent hamstring DB reconstruction at an average follow-up of 6.2 years. Assessment included Lysholm and International Knee Documentation Committee scores, objective examination and instrumented laxity test. **Results:** No complications were reported. Mean Lysholm and International Knee Documentation Committee scores significantly increased from preoperatively ($p < 0.05$). No differences were reported between the two groups with regard to point scales, anterior tibial translation and pivot-shift test (p = not significant). **Conclusions:** Both DB ACL reconstruction and combined LET and autologous hamstring SB ACL reconstruction are effective at providing satisfying functional outcomes and restoring rotational stability.

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Keywords: ACL reconstruction • anterior cruciate ligament • double bundle • lateral tenodesis • rotational stability

Traditional single-bundle (SB) anterior cruciate ligament (ACL) reconstruction has been shown to produce good to excellent results in most cases [1]. However, many studies have outlined poor rates in terms of return to sport and a significant percentage of re-tear, especially in young patients practicing high-risk sports [2–4]. Furthermore, although adequate anteroposterior stability can be achieved with this technique, studies have shown that many patients continue to exhibit persistent anterolateral rotatory laxity following ACL reconstruction, with a residual pivot-shift rate ranging from 10% to 20% [5,6]. Therefore, in an attempt to increase return to sport rate, improve rotational control and reduce the incidence of re-tear, other surgical strategies have been proposed as viable options to address these issues.

In the past years, double-bundle (DB) ACL reconstruction, which aims to reconstruct both the anteromedial (AM) and posterolateral (PL) bundles of the ACL, has been proposed to better restore the anatomy and biomechanics of the native ligament, improve rotational control and ultimately reduce failure compared with SB reconstruction. However, outcomes between the two procedures are controversial, and there is still a lack of objective data documenting a difference between the two reconstructive methods [7–12]. In fact, although reduced occurrence of rotational instability and tunnel widening has been reported compared with SB reconstruction [7–10], clinical results of DB reconstruction did not show any significant improvement over the conventional procedure, and the disadvantages of increased technical complexity, surgical time and cost may not be justified [11,12].

Recently, studies on the role of the knee anterolateral complex of the knee have led to the development of new reconstruction techniques of the anterolateral ligament (ALL) and a resurgence of interest in lateral extra-articular tenodesis (LET) procedures, which are currently recommended as adjuvant procedures to existing ACL reconstructive strategies. Previous studies demonstrated that both additional ALL reconstruction and LET improve

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Table 1. Patient demographics and anthropometric data.

	DB ACL reconstruction	SB ACL reconstruction combined with LET	p-value
n of patients	20	16	
Gender			
Male	11	11	
Female	9	5	
BMI (SD)	23.5 (1.9)	22.9 (1.7)	ns
Time from injury to surgery (SD) (months)	6.5 (0.9)	5.8 (1.1)	ns
Age at surgery (SD) (years)	28.3 (9.2)	26.8 (8.7)	ns

ACL: Anterior cruciate ligament; DB: Double-bundle; LET: Lateral extra-articular tenodesis; ns: Not significant; SB: Single-bundle; SD: Standard deviation.

patient-related outcomes and reduce the risks of graft failures, especially in high-demanding patients or to improve revision surgery outcomes [13–23].

The aim of this study is to compare the clinical outcome of patients who underwent DB ACL reconstruction with that of those who underwent SB ACL reconstruction combined with LET, with regard to patient satisfaction, return to preinjury activity level and functional outcomes, specifically investigating rotational knee stability. The authors hypothesized that the rotational stability acquired following DB ACL reconstruction was comparable to the one acquired following ACL SB reconstruction combined with LET in the setting of primary ACL surgery.

Materials & methods

Patient recruitment

This retrospective comparative case series examined 36 patients who underwent ACL reconstruction surgery between 2011 and 2018. Average follow-up was 6.2 years (range: 2–9 years). All were competitive or recreational athletes. All patients met the following inclusion criteria: aged 18–45 years; primary ACL reconstruction; absence of concomitant cartilage, ligament or meniscal pathology requiring surgery; and pivot-shift test greater than or equal to grade 2. All the operations were performed by the same well-experienced senior surgeon. 16 patients who underwent ACL SB reconstruction combined with LET were matched for age and BMI to a control group of 20 consecutive patients who underwent autologous hamstring DB reconstruction taken from the senior author's database. The surgical technique was chosen depending on the surgeon's preference. Table 1 shows complete demographic and anthropometric data. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Ethical approval was not required for the retrospective follow-up of this cohort, as the patient-reported outcomes used are part of routine follow-up at the authors' institution (observational analytic study with a retrospective design on well-established surgical procedures). Informed consent was obtained from all individual participants included in the study.

Surgical technique of autologous hamstring DB reconstruction

Patients in this group underwent an arthroscopically assisted reconstruction using harvested doubled semitendinosus tendon for the AM bundle and doubled gracilis tendon for the PL bundle. A 50° guide (Acufex; Smith & Nephew, MD, USA) placed in the native PL bundle footprint was used to drill the tibial tunnel for the PL, while the AM tunnel was drilled using a 55° angle, leaving a bone bridge of at least 5 mm between the guidewires. The femoral half-tunnels were drilled using either a transtibial or an anteromedial technique. In case satisfactory graft positioning could not be achieved with the transtibial approach, an anteromedial technique was preferred. Then, after passing the grafts through the tibial tunnels, fixation was achieved using a supension fixation device (Tightrope; Arthrex, FL, USA). Two bioabsorbable interference screws (Arthrex), each 1 mm larger than the graft, fixed the graft distally by putting the knee fully extended for the PL bundle and flexed at 20° for the AM bundle under maximal manual tension.

Surgical technique of autologous hamstring SB reconstruction combined with LET

SB ACL reconstruction was performed with a traditional technique, using a transtibial or an anteromedial approach and drilling the tunnels similarly to way described for the AM bundle in the DB technique. In addition to ACL reconstruction, a Coker–Arnold modification of the MacIntosh procedure was performed: a strip of the central

Table 2. Overview of the results of clinical assessment in the double-bundle anterior cruciate ligament reconstruction group.

	Preoperative	Postoperative	p-value
Lysholm score (mean, SD)	65.2 (SD: 8.1)	85.4 (SD: 7.8)	$p < 0.001$
IKDC score (mean, SD)	44.8 (SD: 9.6)	82.2 (SD: 8.6)	$p < 0.001$
Lachman sign (positivity)	20/20 (100%)	1/20 (5%)	$p < 0.001$
Pivot-shift sign (positivity)	20/20 (100%)	2/20 (10%)	$p < 0.001$
Mean side-to-side anterior laxity in mm (mean, SD)	6.2 (SD: 1.1)	1.8 (SD: 0.9)	$p < 0.001$

IKDC: International Knee Documentation Committee; SD: Standard deviation.

Table 3. Overview of the results of clinical assessment in the ingle-bundle anterior cruciate ligament reconstruction combined with lateral extra-articular tenodesis group.

	Preoperative	Postoperative	p-value
Lysholm score (mean, SD)	63.8 (SD: 7.7)	86.9 (SD: 9.1)	$p < 0.001$
IKDC subjective score (mean, SD)	41.7 (SD: 8.2)	84.8 (SD: 8.5)	$p < 0.001$
Lachman sign (positivity)	16/16 (100%)	1/16 (6%)	$p < 0.001$
Pivot-shift sign (positivity)	16/16 (100%)	1/16 (6%)	$p < 0.001$
Mean side-to-side anterior laxity in mm (mean, SD)	6.9 (SD: 1.2)	1.6 (SD: 0.6)	$p < 0.001$

IKDC: International Knee Documentation Committee; SD: Standard deviation.

portion of the iliotibial band was detached proximally, looped deeply under the lateral collateral ligament (LCL) and sutured distally on itself while keeping the knee mid-flexed in a neutral position.

Rehabilitation protocol

For patients who underwent DB ACL reconstruction, a brace-free routinary rehabilitation protocol was adopted, while a knee brace for 7 days was used during walking for pain control for patients who underwent SB reconstruction combined with LET. Walking with crutches with partial weight bearing was allowed for the first 4 weeks, together with swelling control, regaining of complete knee range of motion quadriceps activation and muscle strength recovery; after this period, proprioception exercises were started. Swimming and indoor cycling were allowed after 12 weeks, jogging after 5 months. Return to sport was allowed at 6 months for non-pivoting sports, at 7 months for pivoting sports.

Follow-up assessment

Patients were evaluated preoperatively and after an average follow-up of 6.2 years (range: 2–9 years). Assessment included Lysholm score [24], International Knee Documentation Committee (IKDC) score [25], objective examination including manual laxity testing (anterior drawer sign [26], Lachman test [27], pivot-shift test [28]) and instrumented laxity test with KT-1000 arthrometer (MEDmetric Corporation, CA, USA) under a 134-N anterior tibial load [29].

Statistical analysis

Data extracted were analyzed using the program IBM SPSS Statistics for Windows©, version 21.0 (IBM Corp, NY, USA). Wilcoxon signed-rank test for related samples was utilized to compare the preoperative and follow-up status, while the Mann–Whitney test for independent samples was used to compare the differences between the two groups. Differences with $p < 0.05$ were considered statistically significant.

Results

No major complications or graft failures were reported at follow-up. The mean overall Lysholm score increased from a preoperative mean of 64.5 (standard deviation [SD]: 7.9) to 86.1 (SD: 8.5), showing a statistically significant difference ($p < 0.001$). IKDC score improved from 43.2 (SD: 8.8) to 83.5 (SD: 8.6) ($p < 0.001$). The outcomes of clinical assessment regarding the Lachman test and pivot-shift sign were clearly improved when compared with preoperative status ($p < 0.001$). A detailed overview of the results of the clinical assessment of the two groups is shown in Tables 2 & 3.

The differences in the outcomes between the two groups are reported in Table 4. No statistically significant

Table 4. Overview of the results of clinical assessment at follow-up between the two groups.

	DB ACL reconstruction	SB ACL reconstruction combined with LET	p-value
Lysholm score (mean, SD)	85.4 (SD: 7.8)	86.9 (SD: 9.1)	ns
IKDC subjective score (mean, SD)	82.2 (SD: 8.6)	84.8 (SD: 8.5)	ns
Lachman sign (positivity)	1/20 (5%)	1/16 (6%)	ns
Pivot-shift sign (positivity)	2/20 (10%)	1/16 (6%)	ns
Mean side-to-side anterior laxity in mm (mean, SD)	1.8 (SD: 0.9)	1.6 (SD: 0.6)	ns

ACL: Anterior cruciate ligament; DB: Double-bundle; IKDC: International Knee Documentation Committee; LET: Lateral extra-articular tenodesis; ns: Not significant; SB: Single-bundle; SD: Standard deviation.

differences were reported between the two groups with regard to point scales (p = not significant [ns]) and anterior tibial translation according to the Lachman test and as measured with KT-1000 arthrometer (p = ns). With regard to rotational instability, the results of the pivot-shift test were slightly in favor of patients who had undergone LET, with a lower percentage of subjects (6%) positive to the pivot-shift test postoperatively compared with the DB group (10%); however, the result was not statistically significant. No subjective or objective loss of motion was reported, neither postoperative stiffness nor donor-site morbidity.

Discussion

The findings demonstrate that both DB ACL reconstruction and combined LET and autologous contralateral hamstring SB ACL reconstruction are effective surgical methods, providing satisfying functional outcomes and conferring additional rotational stability control in selected patients in the setting of primary ACL reconstruction.

Residual rotational laxity has been reported in a significant percentage of patients following SB ACL reconstruction. To overcome this problem, DB reconstruction and more recently ALL reconstructive techniques, as well as LET procedures, have been proposed in order to improve knee stability, especially with regard to rotatory loads [7–19]. Their influence on rotational stability of the tibia is supposed to represent a protective element against the occurrence of new knee injuries and ACL rerupture, thus allowing a safer early rehabilitation phase and a more predictable return to sport [20]. Long-term follow-up studies have shown that the addition of a LET to intra-articular ACL reconstruction does not increase the rate of osteoarthritis in the presence of intact menisci [30].

In this case series after an average time of 6 years from surgery, overall mean Lysholm score improved to 86.1, while the IKDC score was 83.5. None of the patients reported knee instability. Subjective results are in line with those reported by other authors [13–18]. Dejour *et al.* reported increased stability in patients following SB patellar tendon ACL reconstruction combined with LET compared with SB patellar tendon ACL reconstruction and DB hamstring reconstruction as measured by Telos stress radiography at a mean follow-up of 25 months, and they suggested its use in patients involved in highly demanding sports [31]. The present authors reported satisfying outcomes in a cohort of active patients who had a preoperative grade 2 or 3+ pivot shift, supporting the concept of adding either a PL bundle or a LET as an augmentation in selected patients requiring increased stability.

In a comparative study on 35 patients with an isolated ACL injury (average age: 34.0 ± 8.7 years), Zaffagnini *et al.* reported superior results in terms of constraining the displacement of the lateral tibial compartment in patients who underwent LET, while DB reconstruction was more effective in controlling the pivot-shift stress test [32]. Grassi *et al.* reported improvement in internal-external tibial rotation following SB ACL reconstruction with associated LET compared with isolated SB or DB reconstruction [33]. Similarly, Branch *et al.* observed a reduction in internal tibial rotation in 18 patients aged 26–48 years who underwent SB ACL reconstruction with associated LET compared with intra-articular reconstruction alone, 9 years after surgery [34]. Ahn *et al.* retrospectively compared the results of 48 patients who underwent DB ACL reconstruction and 47 patients who underwent SB ACL reconstruction combined with LET after an average follow-up of 49.7 months. The second group reported significantly better results in pivot-shift grade, although no statistically significant difference could be seen regarding anterior tibial translation, subjective functional IKDC score or revision rate between the two groups [35].

With regard to subjective outcomes, in the authors' case series the two procedures did not show statistically significant differences. Anterior stability evaluated through manual test and with the KT-1000 arthrometer did not demonstrate a significant difference between the two groups. The results of the pivot-shift test were slightly in favor of LET, with a lower percentage of subjects positive to the pivot-shift test postoperatively compared with the DB

group. However, the limited study population may not have allowed for the detection of small differences between groups.

The DB procedure, by anatomically reconstructing both the AM and the PL bundles of the ACL, is advocated to mimic native ACL configuration more closely and therefore to restore knee biomechanics more accurately. However, limited evidence exists that DB ACL reconstruction may lead to improved clinical outcomes; in addition, its technical difficulty and increased costs led to its falling out of favor [11,12]. On the other hand, although LET may attract surgeons for its cost–effectiveness and its relatively easy reproducibility, it carries the disadvantages of being an open and non-anatomical procedure with risks of postoperative pain and increased stiffness [36].

Several clinical studies showed the benefits of ALL reconstruction. Laboudie *et al.* reported reduced failure rates and less secondary meniscal lesions in young athletes who underwent combined ALL and ACL reconstruction compared with those who underwent ACL reconstruction alone [37]. Helito *et al.* compared the results of combined ACL and ALL reconstruction with hamstring grafts between acute and chronic cases and reported no differences in terms of knee stability, functional scores and failure rates after a minimum follow-up of 2 years [38]. Similarly, according to Rayes *et al.*, adding ALL reconstruction in the setting of revision ACL surgery was safe and effective [39].

Theoretically, it would appear reasonable that the most reliable reconstructive procedure able to restore knee anatomy and biomechanics as closely as possible to normal would be to address each injured structure, as demonstrated by a recent cadaveric study by Yasuma *et al.*, in which concomitant ALL and DB ACL reconstruction appeared to better control rotational instability [40]. However, before such an approach can be widely adopted in clinical practice, clinical trials are needed to substantiate if additional surgical time, morbidity and costs are justified by improvement in patient outcomes.

The limitations of the present study include its retrospective nature, the relatively small sample size and the fact that no power analysis was performed. A greater number of patients in each group could have enhanced the power of the results obtained. The findings suggest that these techniques have potential for improving rotational stability to add potential benefit to young, active patients involved in highly demanding sports. Studies with larger cohorts and longer-term outcomes as well as economic analyses are needed to better investigate the differences in the two surgical techniques, thus guiding surgeons and healthcare systems to the most appropriate treatment strategy.

Conclusion

Both DB ACL reconstruction and combined LET and autologous hamstring SB ACL reconstruction are effective surgical methods providing satisfying functional outcomes and restoring rotational stability control in selected patients in the setting of primary ACL reconstruction. Studies with larger cohorts are needed; given the small sample size, the present research might be underpowered to answer the study question.

Summary points

- Residual rotational laxity has been reported in a significant percentage of patients following single-bundle (SB) anterior cruciate ligament (ACL) reconstruction.
- To overcome this problem, double-bundle (DB) reconstruction and more recently lateral extra-articular tenodesis (LET) have been proposed in order to improve knee stability, especially with regard to rotatory loads.
- 16 patients who underwent SB ACL reconstruction combined with LET were compared with 20 patients who underwent hamstring DB reconstruction at an average follow-up of 6.2 years (range: 2–9 years).
- Assessments included Lysholm score, International Knee Documentation Committee score, manual laxity testing (Lachman test, pivot-shift test) and instrumented laxity test with KT-1000 arthrometer.
- No major complications were reported. The mean overall Lysholm score and International Knee Documentation Committee score increased from preoperatively, showing a statistically significant difference ($p < 0.05$).
- The outcomes of clinical assessment regarding the Lachman test and pivot-shift sign were clearly improved when compared with preoperative status ($p < 0.05$).
- With regard to rotational instability, the results of the pivot-shift test were slightly in favor of patients who underwent LET, with a lower percentage of subjects (6%) positive to the pivot-shift test postoperatively compared with the DB group (10%); however, the result was not statistically significant.
- The findings demonstrate that both DB ACL reconstruction and combined LET and autologous hamstring SB ACL reconstruction are effective surgical methods providing satisfying functional outcomes and conferring additional rotational stability control in selected patients in the setting of primary ACL reconstruction.
- These techniques could improve rotational stability to add potential benefit to young, active patients involved in highly demanding sports.

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Ethical conduct of research

The authors state that they have obtained appropriate institutional review board approval or have followed the principles outlined in the Declaration of Helsinki for all human or animal experimental investigations. In addition, for investigations involving human subjects, informed consent has been obtained from the participants involved.

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