Comparison of Rotatory and Sagittal Laxity After Single-Bundle Versus Double-Bundle ACL Reconstruction

Outcomes at 7-Year Follow-up

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Background: Biomechanical studies have shown excellent anteroposterior and rotatory laxity control after double-bundle (DB) anterior cruciate ligament (ACL) reconstruction, but no clinical studies have compared midterm (>5-year) residual laxity between the DB and single-bundle (SB) techniques.

Purpose: To clinically compare sagittal and rotatory laxities and residual sagittal laxity on the KT-1000 arthrometer between patients treated with an SB ACL reconstruction and those treated with a DB ACL reconstruction at the 7-year follow-up.

Study Design: Cohort study; Level of evidence, 3.

Methods: A total of 110 patients were included between January 2006 and December 2007. The patients were randomly assigned into 2 groups: those treated with SB ACL reconstruction (n = 63) and those treated with the DB technique (n = 47). All patients were then reviewed at a minimum of 7 years of follow-up; patients with ACL rerupture (n = 3 in the SB group and n = 2 in the DB group) were excluded from the postoperative comparative analysis. Residual anterior laxity (Lachman test), rotatory laxity (pivot-shift test), and sagittal laxity (KT-1000 arthrometer side-to-side difference) were measured and compared between the 2 groups.

Results: The mean age at surgery was 23.0 ± 5.1 years for the DB group and 28.1 ± 7.0 years for the SB group, and the mean follow-up was 7.4 ± 0.8 years. No statistically significant differences were found between the 2 groups in terms of age, sex, preoperative laxity on KT-1000, preoperative Tegner score, or concomitant meniscal lesions. Residual postoperative laxity via Lachman testing ($P < .01$), pivot-shift testing ($P = .042$), and the KT-1000 arthrometer ($P < .01$) was statistically significantly in favor of DB reconstruction.

Conclusion: DB ACL reconstruction allowed better control of anterior stability during the evaluation via the Lachman test and via objective measurement on the KT-1000, as well as rotatory stability at a minimum of 7 years of follow-up.

Keywords: ACL reconstruction; double-bundle; residual laxity; KT-1000

Anterior cruciate ligament (ACL) reconstruction using the single-bundle (SB) technique with autologous grafting remains the most widely used treatment for ACL tear.[33] However, the imperfect objective results regarding the residual postoperative laxity of these reconstructions[3] and more precise knowledge of the anatomy of the ACL over the past 20 years have led to the creation of the double-bundle (DB) or "anatomic" reconstruction technique,[37] which aims to reproduce the anatomy and physiology of a native ACL during surgical reconstruction.

While biomechanical studies have shown superior control of anterior and rotatory laxity of DB ACL reconstructions,[30] few clinical studies have compared midterm (>5-year) residual laxity between these 2 surgical techniques. Our aim in the current study was to clinically compare sagittal laxity and rotatory instability, as well as residual sagittal laxity on the KT-1000 arthrometer, between patients who underwent SB ACL reconstruction and those who underwent DB ACL reconstruction with a minimum of 7 years of follow-up. Our hypothesis was that DB ACL reconstruction would provide better results on stability compared with SB ACL reconstruction.

METHODS

Study Population

The study protocol was approved by the French national agency regulating data protection and the ethical

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committee of our institution (IRB Approval). This was a monocentric retrospective comparative clinical study in which initial patient inclusion was conducted between January 1, 2006, and December 31, 2007. The study inclusion criteria were adult patients (age ≥18 years at the time of surgery) with an acute ACL rupture (<6 months) and without peripheral ligament injury. Exclusion criteria were patients aged <18 years, those with associated ligament or bone lesions, and those with a history of knee surgery. Two patient cohorts, for whom an SB (semitendinosus/gracilis) or DB (semitendinosus/gracilis) ACL reconstruction was performed, were initially established. The surgical technique was determined from a computer-based randomization program for all patients at inclusion. All patients were operated on by the same surgeon (S.P.). Ultimately, a total of 110 patients were included: 47 patients (42.73%) who underwent DB ACL reconstruction and 63 patients (57.27%) who underwent SB ACL reconstruction.

Postoperative follow-up, rehabilitation protocol, and return-to-sports criteria were the same regardless of surgical technique. At the 7-year follow-up, patients with an ACL rerupture were excluded from the postoperative comparative analysis. Five of 110 patients (4.55%) experienced rerupture: 2 of 47 patients (4.3%) in the DB group and 3 of 63 patients (4.8%) in the SB group. All of these reruptures were the result of a new sports injury and occurred >5 months after the initial ACL reconstruction (5 months, 9 months [2 patients], 2 years, and 6 years). Thus, a total of 105 patients (45 in the DB group and 60 in the SB group) were assessed at 7-year follow-up (Figure 1).

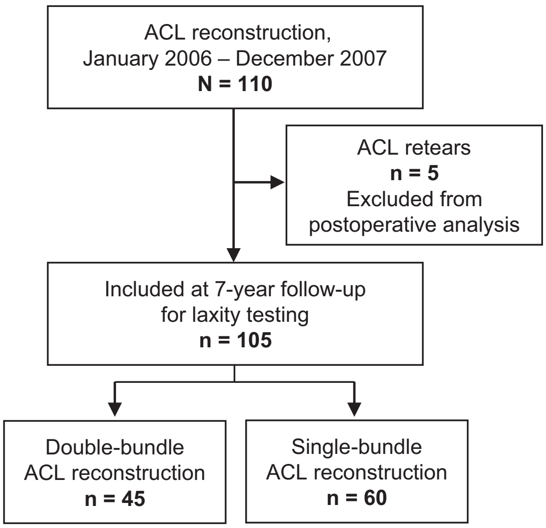

Figure 1. Flowchart of patient enrollment. ACL, anterior cruciate ligament.

Surgical Procedure

SB Reconstruction Technique. Reconstruction was conducted using the standard anatomic SB method. The semitendinosus and the gracilis were harvested (minimum length, 26 cm) via a 2.5 cm–long incision centered 1 cm medial and 1 cm distal to the medial margin of the tibial tubercle and prepared into a 4-strand closed loop, with a mean diameter of 8.25 ± 0.9 mm (range, 7-9.5 mm).

For the tibial bone tunnel, the tibial drill guide was set to 60°. The intra-articular tip was positioned in the anteromedial (AM) part of the tibial ACL footprint. Tibial remnants of the ACL stump were preserved as much as possible during tunnel preparation. A guide wire was overdrilled using a conventional reamer according to the size of the semitendinosus/gracilis graft. The center of the femoral bone tunnel was marked using a microfracture awl in 110° to 120° of knee flexion. Based on the modified lateral clock wall model, the average center was at the 11-o'clock position for the right knee and at the 1-o'clock position for the left knee in the same knee flexion. A guide wire was then positioned at the center of the femoral insertion, the knee was flexed to a maximum of 130°, and the femoral bone tunnel was established via a low AM accessory portal using a headed reamer. The drill system for an EndoButton Continuous Loop fixation (Smith & Nephew Endoscopy) was then used to create a femoral tunnel. The graft was then passed, and the EndoButton was inverted in standard fashion for femoral fixation. Afterward, the knee was cycled from 0° to 120° approximately 25 times for preconditioning of the graft. Then, tibial graft fixation was performed using the Biosure screw (Smith & Nephew Endoscopy), which was 7 to 10 mm, via manual tensioning in the counter-Lachman position.

DB Reconstruction Technique. DB ACL reconstruction was defined according to Yasuda et al[37] via the creation of 2 different bone tunnels on the femoral side and the tibial side, the objective being to get closer to the ACL anatomy. Each semitendinosus and gracilis was harvested and prepared in 2 strands. The mean diameter of the semitendinosus graft was 7.7 ± 1.1 mm (range, 6-9 mm), and the mean diameter of the gracilis graft was 6.0 ± 1.0 mm (range, 5-7 mm). Each bundle was to be anatomically positioned while ensuring good bone tunnel divergence: semitendinosus for the AM bundle and gracilis for the posterolateral (PL) bundle. The femoral tunnels consisted of the AM portal, starting with the AM bundle tunnel.

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Ethical approval for this study was obtained from the University Hospital of Martinique (study No. 2021/143).

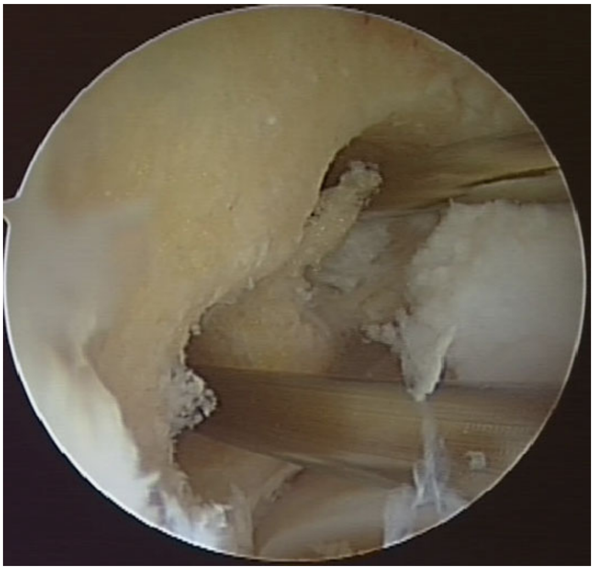

Figure 2. Arthroscopic view of bone tunnel preparation during double-bundle anterior cruciate ligament reconstruction. The anteromedial femoral tunnel was drilled first and placed as posterior as possible in the posterior part of the intercondylar area. The posterolateral femoral tunnel was located anterior and inferior to the anteromedial femoral tunnel in the flexion position.

The AM femoral tunnel was drilled first using the AM portal and a freehand technique without a guide. The AM femoral tunnel was placed as posterior as possible, without breaking the posterior wall of the femoral condyle, in the posterior part of the intercondylar notch on the lateral wall of the notch. The tunnel was drilled using a guide pin through the femoral condyle at 120° of knee flexion. A 5 mm–diameter cannulated drill was used for the first drilling of the tunnel. The final drilling of the tunnel was made after harvesting and measuring the diameter of the hamstring autografts. The PL femoral tunnel was drilled using the AM portal and a freehand technique. The anatomic femoral footprint of the PL bundle was identified arthroscopically and marked using a 30° awl. If the PL femoral footprint was difficult to identify, the PL femoral tunnel was placed as close as possible to the AM femoral tunnel, without breaking the wall between the 2 tunnels. The PL femoral tunnel was anterior and inferior to the AM femoral tunnel in the flexion position. The drilling of the PL femoral tunnel was performed with the knee at 110° of flexion. The diameter of the PL femoral tunnel was 6 mm, and the depth of the tunnel was 20 mm. The wall between these 2 tunnels (AM and PL) in the femoral side had to be at least 1 to 2 mm (Figure 2).

On the tibial side, the tibial guide was used when creating the tibial tunnels. An ACL tibial drill guide was placed on the AM aspect of the ACL tibial footprint. The starting point of the AM tibial tunnel was the same as that in the standard SB ACL technique. After acceptable placement of the AM tibial pin was obtained (no impingement with knee extension), the PL tibial guide wire was placed on the PL aspect of the ACL tibial footprint. The PL tibial tunnel had a more medial starting point on the tibial cortex than did the standard ACL tibial tunnel. An osseous bridge of 1 to 2 cm remained on the tibial cortex between these tunnels. The AM tibial tunnel was drilled first, followed by the PL tunnel. The diameter of the AM tibial tunnel was typically 7.5 mm, and that of the PL tunnel was 6 mm (Figure 3).

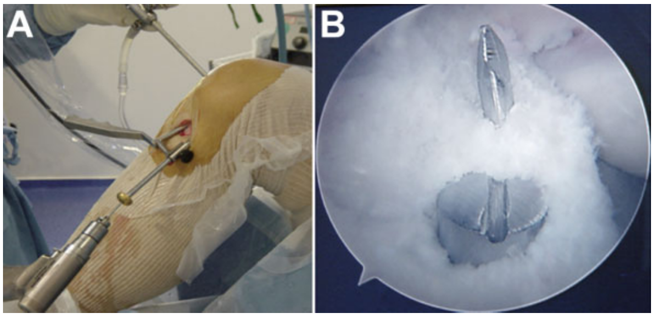

Figure 3. (A) Tibial drilling during double-bundle anterior cruciate ligament (ACL) reconstruction. (B) The first ACL tibial drill guide was placed on the anteromedial tibial footprint. The posterolateral tibial guide wire was placed on the posterolateral tibial footprint. An osseous bridge of 1 to 2 cm remained on the tibial cortex between these tunnels.

Grafts were inserted in a retrograde manner through the tibial tunnels and then past the distal end of the femoral tunnel, and the EndoButton Continuous Loop was inserted in the standard fashion. The PL graft was passed first and fixed using the aforementioned bioabsorbable screw. Then the graft for AM bundle (doubled semitendinosus tendon autograft) was passed and fixed using the same technique as described above. On the tibial side, the PL bundle was manually tensioned at 90° of flexion by pulling with one hand then fixed in full extension. In a second time, the AM bundle was fixed at 20° of flexion of the knee via manual tensioning in the counter-Lachman position.

The diameter of the screw was typically 7 mm in the PL tunnel and 8 mm in the AM tunnel, and the length of the screw was 30 mm. On the tibial side, the graft was fixed using bioabsorbable interference screws (Biosure; Smith & Nephew Endoscopy) in an outside-in manner in the tibia (Figure 4).

Postoperative Rehabilitation

The rehabilitation protocol was standardized and given to the patient and the physiologist. Full weightbearing was immediately authorized, and the recovery of passive and active motions and passive strengthening were started the next day with the physiologist. Return to sports was allowed after 6 months in cases in which performance of the isokinetic test resulted in an operated/healthy knee ratio >85% in flexion and extension. In the absence of the isokinetic test, return to sports was not suggested before 1 year postoperatively.

Assessment Criteria

Epidemiological data were collected during initial inclusion. The preoperative activity level was evaluated using the Tegner activity scale, and preoperative anterior laxity was measured as the KT-1000 arthrometer side-to-side difference at 89 N. During surgery, the presence of concomitant meniscal lesions was noted. All patients were then independently evaluated at 7 years postoperatively by 2 blinded senior surgeons (M.S. and S.P.) in a surgical consultation as part of the care protocol. A Lachman test was performed at 20° of flexion, and anterior laxity was noted as absent, delayed stop, or strictly positive. Rotatory laxity (pivot-shift test) was clinically noted as negative or residual. Residual sagittal laxity was also measured using the KT-1000 arthrometer (89 N) and was noted as absent ($\leq$3 mm) or present (>3 mm).[4] Finally, the patients were evaluated using the International Knee Documentation Committee examination form. Profile and anteroposterior radiographs obtained at the last follow-up were analyzed by the 2 observers, and osteoarthritis was classified using the Ahlbäck scoring system.

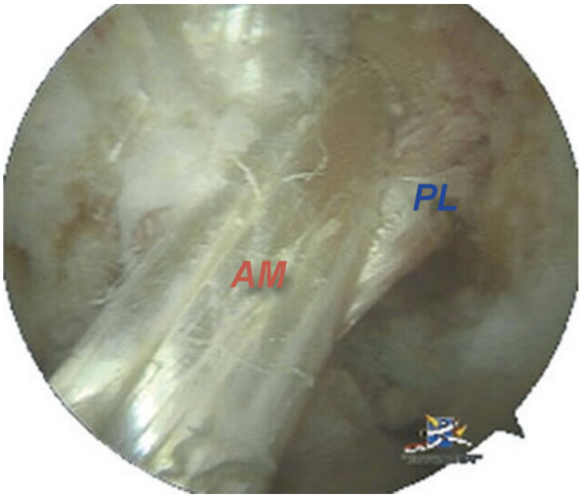

Figure 4. Final arthroscopic appearance of a double-bundle anterior cruciate ligament reconstruction. AM, anteromedial bundle; PL, posterolateral bundle.

Statistical Analysis

Descriptive data consisted of means, medians, and standard deviations. Data were collected in an Excel spreadsheet (Microsoft Corp) and analyzed using Stata software (StataCorp). Normal distribution of the measured variables was verified using the Shapiro-Wilk test, and the homogeneity of variances was verified using the Fisher *F* test and Levene test to ensure that conditions had been met for parametric testing. A comparative analysis was performed using the paired *t* test or chi-square test. The significance threshold was set at $P < .05$.

RESULTS

Epidemiological Characteristics

The mean follow-up for all 110 patients was 7.4 ± 0.8 years. The overall incidence of initial meniscal tears was 40% (44 of 110 patients), with a predominance of medial meniscal lesions (26.36%) compared with lateral meniscal lesions (13.63%). No statistically significant differences between the DB and SB groups were found in terms of sex, concomitant meniscal lesions, preoperative laxity, or preoperative Tegner score.[32] The interval between the trauma and the ACL reconstruction was not significantly different between the 2 groups. Table 1 summarizes the epidemiological characteristics of the study population and their distribution between the 2 groups. The distribution of graft sizes by reconstruction technique is shown in Figure 5.

Residual Anterior Laxity

At the 7-year follow-up, 44 of the 45 patients (97.8%) who underwent a DB ACL reconstruction had a Lachman test that was absent, and 1 (2.2%) had a delayed stop. In the SB group, 40 of the 60 patients (66.7%) had a Lachman test noted absent, 19 patients (31.7%) had a delayed stop, and only 1 patient (1.7%) had a strictly positive test. This

TABLE 1
Epidemiological Characteristics of the Study Population (N = 110)[a]

	DB Group (n = 47)	SB Group (n = 63)	*P*
Age, y	23.0 ± 5.1	28.1 ± 7.0	.41
Body mass index	22.1 ± 2.0	24.0 ± 3.1	.54
Sex ratio, % male	87.5	66.7	.19
Preoperative Tegner score	7.9 ± 1.0	7.8 ± 0.4	.84
Preoperative laxity, mm[b]	9.1 ± 2.7	7.9 ± 2.9	.13
Time from injury to surgery, mo	4.8 ± 0.5	3.8 ± 1.0	.17
Meniscal lesions, n (%)	18 (38.3)	26 (41.3)	.16
Lateral	5 (10.6)	10 (15.9)	
Medial	13 (27.7)	16 (25.4)	
Follow-up period, y	7.1 ± 0.4	7.6 ± 0.5	.36

[a]Data are reported as mean ± SD unless otherwise indicated. DB, double bundle; SB, single bundle.
[b]KT-1000 arthrometer side-to-side difference.

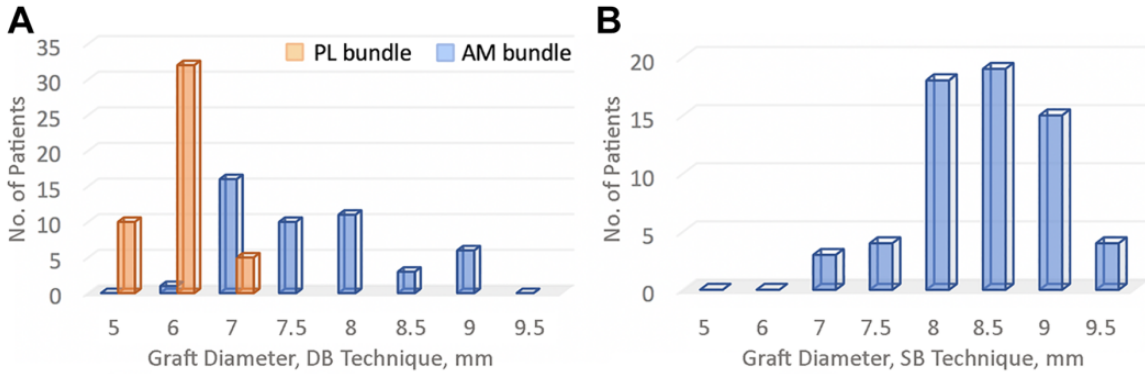

Figure 5. Diagram of graft sizes with the (A) double-bundle and (B) single-bundle techniques. AM, anteromedial; DB, double bundle; PL, posterolateral; SB, single bundle.

TABLE 2
Comparison of Residual Laxity and IKDC Scores at 7-Year Follow-up (n = 105)[a]

	DB Group (n = 45)	SB Group (n = 60)	*P*
KT-1000 arthrometer laxity			
≤3 mm	44 (97.8)	41 (68.3)	**<.01**
>3 mm	1 (2.2)	19 (31.7)	
Mean ± SD	0.8 ± 0.3	1.6 ± 1	**<.01**
IKDC score			**<.01**
A	44 (97.8)	40 (66.6)	
B	1 (2.2)	19 (31.7)	
C	0 (0)	1 (1.7)	
Lachman test			**<.01**
Absent	44 (97.8)	40 (66.6)	
Delayed stop	1 (2.2)	19 (31.7)	
Strictly positive	0 (0)	1 (1.7)	
Pivot-shift test			**.042**
Residual	1 (2.2)	9 (15)	
Negative	44 (97.8)	51 (85)	

[a]Data are reported as n (%) unless otherwise indicated. Boldface *P* values indicate a statistically significant difference between groups ($P < .05$). DB, double bundle; IKDC, International Knee Documentation Committee; SB, single bundle.

difference was statistically significant ($P = .0007$). All data on residual laxity between the 2 groups are summarized in Table 2.

Residual Rotatory Laxity

A positive pivot shift was found in 1 patient (2.2%) operated on with a DB technique, whereas it was absent for the 44 others (97.8%). In the SB group, 9 (15%) had a residual pivot shift and 51 (85%) had negative pivot shift. A statistically significant difference was found in favor of DB ACL reconstruction ($P = .042$).

Residual Sagittal Laxity

Of the 45 patients in the DB group, only 1 (2.2%) had a residual sagittal laxity on the KT-1000 arthrometer >3 mm. However, in the SB group, 19 of the 60 patients (31.7%) had residual laxity >3 mm. SB ACL reconstruction was statistically significantly associated with greater residual laxity (1.6 ± 1 mm [SB] vs 0.8 ± 0.3 mm [DB]; $P < .01$) (Table 2).

Osteoarthritic Degeneration

At the 7-year follow-up, the overall incidence of osteoarthritis (Ahlbäck grade, ≥1) was 15.7% for the medial femorotibial compartment and 6.9% for the lateral femorotibial compartment. For the medial femorotibial compartment, this rate was 12.2% in the DB group versus 18.0% in the SB group, without a statistically significant difference ($P = .43$). For the lateral femorotibial compartment, this rate was 12.2% in the DB group versus 3.3% in the SB group, without a statistically significant difference ($P = .09$).

DISCUSSION

The main finding of this study was that DB ACL reconstruction enables better control of anterior stability during evaluation via the Lachman test and KT-1000 arthrometer, as well as rotatory stability, at a minimum of 7 years of follow-up. In the literature, rotational stability has been reported as significantly better in patients with anatomic DB ACL reconstruction compared with patients with the SB procedure.[17,18]

Analysis of objective rotational laxity is an important issue in characterizing possible differences in results between the different operating techniques.[5] While the results on residual sagittal and rotational laxity are well documented in the literature,[17] no demonstration has been made of the reliability of the pivot-shift test. One of the main reasons is the difficulty of carrying out this test and ensuring its reproducibility.[7,19] In 2008, Meredick et al[27] published the first meta-analysis on the DB technique versus the SB technique in a review of prospective comparative studies. The authors drew a conclusion on the superiority of the DB technique in terms of an anterior instrumental differential laxity of 0.52 mm. On the other hand, no difference was found in analysis of rotational control (pivot-shift test). However, better control of rotation after DB ACL reconstruction has been reported in analysis of the acceleration during the pivot-shift test[1] or robotic analyses.[5] Indeed, the assessments of preoperative and immediate postoperative laxity via computer-assisted navigation systems have shown better control of anterior and rotatory laxity using the DB technique.[12,16,24,31] It should be noted that all clinical studies report on the need for better assessment of rotatory laxity in vivo and could be improved by the use of an accelerometer.

Concerning sagittal laxity, there was a statistically significant difference in favor of the DB technique on the KT-1000 arthrometer (side-to-side difference, $\leq$3 mm) and also in the Lachman test. During the initial postoperative phase, correction of the anterior laxity represents the simplest and most reliably measurable element to assess the quality of the surgical procedure performed. It is now recognized that laxity is effectively corrected in 75% of cases but remains dependent on the quality of the initial surgical procedure and contingent on the possibility of a progressive degradation of the ACL reconstruction.[23] At the SOFCOT (French Orthopaedic Society) symposium, Curado et al[11] reported a 74% rate of residual laxity $\leq$3 mm with a minimum of 10 years of follow-up. Consequently, there does not appear to be any long-term distension of the grafts when the initial distension observed after the first postoperative months is reached. In 2014, Desai et al[12] focused on prospective studies with clinical kinematic data (Lachman test, pivot shift, instrumental laxity), carrying out a navigation analysis of anterior and rotatory stability. Meta-analyses[27,30] have highlighted the superiority of the DB technique over the SB technique in terms of anterior laxity, with an instrumental mean difference of 0.36 mm ($P < .001$) and navigation of 0.29 mm ($P = .042$). In our study, correction of anterior laxity was optimized using the DB technique. This seems to be confirmed by the various comparative studies published so far.[6,15] However, although the stability was improved with a side-to-side difference of 0.8 mm between the 2 groups, the clinical significance remains uncertain in terms of return to sports and osteoarthritic evolution.

The reason why the DB ACL reconstruction is stronger and more durable may be that it mimics the normal anatomy of the ACL more closely than does the SB technique.[9,13,14] In the DB technique, each bundle acts separately during the range of motion of the knee, creating a crossing pattern of these bundles, as is the case in the original ACL. This is something we cannot create using an SB technique. The DB graft could look thicker than the SB graft.[36] All of these factors could explain the superiority in terms of residual laxity of the DB ACL compared with the SB ACL, even at the 7-year follow-up. Despite the heterogeneity of prospective studies comparing the DB and SB techniques, the gain of DB ACL reconstruction regarding stability[20-22,29,34,35,38] and, consequently, on the risk of secondary osteoarthritis,[11] justifies its development. It is necessary to strictly respect the technical principles and their indications.[28]

Limitations

This study had limitations. First, we assessed a relatively small patient cohort that did not include SB with patellar tendon or quadriceps tendon grafts. No preoperative pivot-shift test, patient-reported outcome scores, or return-to-sports criteria were measured. However, the groups were homogeneous in terms of epidemiological data, preoperative laxity, and preoperative sports level. Second, the KT-1000 arthrometer, although it is well represented in the literature, may not be reliable. Recently, new systems have emerged, such as the GNRB arthrometer, which has higher intra- and interobserver reliability than does the KT-1000 arthrometer[4,8]; the KneeKG system, which allows dynamic evaluation during walking[25,26]; or computer-assisted navigation systems that can essentially be used during the intervention.[2,10]

CONCLUSION

Findings indicated that at a minimum of 7 years of follow-up, patients who had undergone DB ACL reconstruction had better control of anterior stability according to the Lachman test and KT-1000 arthrometer, as well as better rotatory stability, compared with those who had the SB hamstring technique.

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