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Review article

Do lateral extra-articular tenodeses play a role in the control of sagittal knee laxity in short hamstring tendon graft ACL reconstruction? A retrospective study of 80 cases with and without tenodesis

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ABSTRACT

Introduction: Lateral extra-articular tenodesis (LET) associated with an intra-articular anterior cruciate ligament reconstruction (ACLR) provides better rotational control, especially in knees with injuries to the anterolateral structures that are characterized by the presence of a gross pivot shift. However, the role of LET in the control of sagittal knee laxity remains debated. We hypothesized that LET plays a role in the control of sagittal knee laxity.
Patients and methods: This was a retrospective, single-center, single-surgeon study of 80 patients operated on between January 2014 and December 2016 for a complete primary ACL tear. We compared 43 patients who underwent an isolated short hamstring tendon graft ACLR with 37 patients who underwent an ACLR using intra- and extra-articular grafts. Knee laxity measurements were taken with a GNRB® arthrometer preoperatively, at 1, 3, 6, and 9 months (M1–M9), 1 year, and at the last follow-up. The side-to-side differences (healthy vs. operated knees) in graft laxity (ΔL in mm) and compliance (ΔC in μm/N) were calculated for each patient from the generated force-displacement curves.
Results: No differences were found between the 2 groups in terms of the ΔL and ΔC evolvement profiles. All laxity parameters decreased significantly between the preoperative assessment and M1. ΔL and ΔC increased at low forces between M1 and M9. ΔL and ΔC stabilized after M9.
Discussion: Sagittal control remains the primary function of the ACL. The anterolateral ligament (ALL) reconstruction and LET do not improve sagittal postoperative laxity.
Conclusion: Sagittal laxity measurements recorded during the postoperative period did not show that adding LET to short hamstring tendon graft ACLRs improved either graft laxity or compliance.
Level of evidence: IV, retrospective study.

1. Introduction

Although anterior cruciate ligament reconstruction (ACLR) generally results in satisfactory outcomes, rotational instability has been reported in up to 30% of cases [1]. Residual instability is caused by frequently associated lesions of the lateral structures identified several decades ago [2]. Several anatomical and biomechanical studies, carried out over the past 10 years, have demonstrated that the anterolateral structures (iliotibial band and anterolateral joint capsule and ligament) contribute to rotatory knee stability, functioning in synergy with the ACL and menisci [3–5].

While the literature acknowledges the role of lateral extra-articular tenodesis (LET) in rotatory knee control, disagreement around its role in the control of sagittal stability exists. Furthermore, few laboratory or clinical studies have highlighted a sagittal control function that complements the anterolateral structures' rotatory control [4–6].

We hypothesized that LET plays a mechanical role in sagittal control of knee laxity and compliance when added to an ACLR.

The purpose of this study was to assess the possible role of LET in the sagittal stability of ACLR with short hamstring tendon graft

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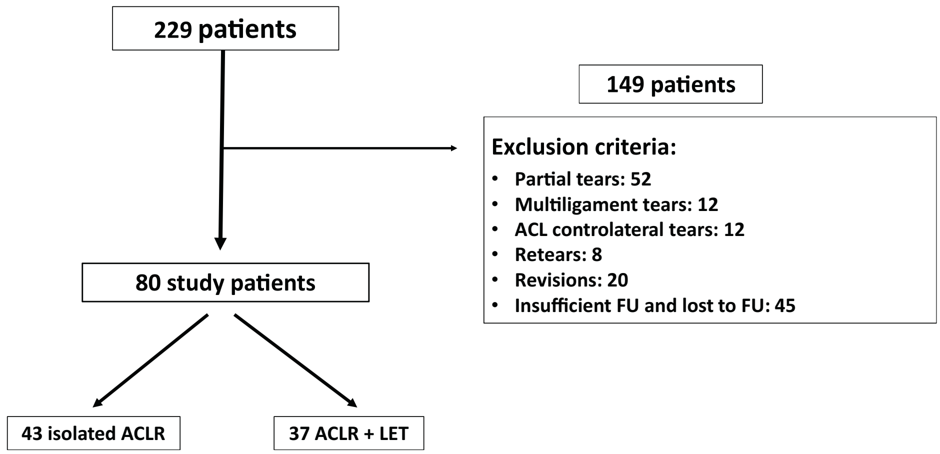

Fig. 1. Study flowchart.

using knee laxity measurements (laximetry) recorded periodically after surgery.

2. Patients and methods

2.1. Patients

This was a retrospective, single-center, single-surgeon study of 80 enrolled patients with an ACL complete tear operated on by an experienced surgeon (HR) between January 2014 and December 2016. Two cohorts were compared: 43 patients who underwent an isolated short hamstring tendon graft ACLR (group 1) and 37 patients who underwent an ACLR and LET (group 2). The enrollment criteria were a unilateral complete ACL tear and regular laximetry follow-ups for at least 1 year. Patients enrolled in group 2 had a grade 2 or 3 pivot shift and/or a high functional demand (high performance or contact/pivoting sports), regardless of their level. Enrollment in the groups was carried out either preoperatively based on the sports criterion or intraoperatively based on the results of the pivot shift test, which was performed under general anesthesia (grades 1 to 3). Only patients with a high-grade (≥ 2) pivot shift underwent ACLR and LET. Group 2 had more young patients, grade 2/3 pivot shifts, and meniscal sutures (20 in group 2 [14 medial and 6 lateral] vs. 14 in group 1 [11 medial and 3 lateral]). Patients with partial (52 cases), bilateral (12 cases), or multiligament injuries (12 cases); revision ligament reconstructions (20 cases); retears (8 cases); who were lost to follow-up or had missing data (45 cases) were excluded. Consequently, 149 patients were excluded from this study (Fig. 1). Population characteristics are described in Table 1.

This study was approved by the Institutional Review Board of the University Hospital Center of Angers (No. 2013/07). Each patient consented to be enrolled in this study and undergo regular follow-ups.

2.2. Methods

The knee was tested under general anesthesia to grade the pivot shift (1 to 3) and decide whether to add a LET to the ACLR. A diagnostic arthroscopy was performed first to assess the menisci and treat any tears.

All patients underwent an arthroscopic ACLR with a short 4-strand semitendinosus graft (ST4) using the Tape Locking Screw (TLS®) technique (FH Orthopedics, Mulhouse, France) [7]. If the diameter of the semitendinosus (ST) was considered too small, the gracilis tendon was added to create a 4-strand tendon graft (ST-G).

Two different techniques were used to perform LET in group 2, depending on the availability of the gracilis tendon. When the

Table 1
Population characteristics.

Population characteristics	Group 1: isolated ACLR	Group 2: ACLR + LET	*p*-value
Age at surgery			
< 25 years	**13 (30.2%)**	**25 (67.6%)**	**0.001**[a]
≥ 25 years	**30 (69.8%)**	**12 (32.4%)**	
Sex			
Male	31 (72.1%)	29 (78.4%)	0.5[a]
Female	12 (27.9%)	8 (21.6%)	
Side			
Left	25 (58.1%)	25 (67.6%)	0.4[a]
Right	18 (41.9%)	12 (32.4%)	
BMI (kg/m^2)			
< 25	28 (65.1%)	29 (78.4%)	0.3[a]
25–30	10 (23.3%)	7 (18.9%)	
≥ 30	5 (11.6%)	1 (2.7%)	
Pivot shift test in internal rotation			
Negative	**5 (11.6%)**	**2 (5.4%)**	**< 0.001**[a]
Grade 1	**38 (88.4%)**	**21 (56.8%)**	
Grades 2 and 3	**0 (0.0%)**	**14 (37.8%)**	
Types of intra-articular grafts			
ST4	**33 (76.7%)**	**14 (37.8%)**	**< 0.001**[a]
ST-G	**10 (23.3%)**	**23 (62.2%)**	
Graft diameters at the femur			
≤ 8 mm	22 (51.2%)	11 (29.7%)	0.1[a]
[8–9 mm]	13 (30.2%)	14 (37.8%)	
> 9 mm	8 (18.6%)	12 (32.4%)	
Graft diameters at the tibia			
≤ 8 mm	6 (14.0%)	4 (10.8%)	0.3[a]
[8–9 mm]	25 (58.1%)	16 (43.2%)	
> 9 mm	12 (27.9%)	17 (45.9%)	
Types of tenodeses			
Lemaire		22 (59.5%)	
Double-bundle gracilis		15 (40.5%)	
Associated meniscal tears			
No	15 (34.9%)	8 (21.6%)	0.4[a]
Yes	28 (65.1%)	29 (78.4%)	
Meniscal procedure(s) undertaken			
Suturing	14 (50.0%)	20 (69%)	0.3[a]
Partial resection	9 (32.1%)	7 (24.1%)	
None	5 (17.9%)	2 (6.9%)	
Initial differential laxity: ΔL > 4 mm	15 (34.9%)	12 (32.4%)	0.8[a]
Final differential laxity: ΔL > 3 mm	3 (7.0%)	3 (8.1%)	1[a]
Final differential compliance: ΔC > 10 μm/N	3 (7.0%)	4 (10.8%)	0.7[a]
Follow-up in months (interval)	28 (12–60)	26 (12–58)	0.4[b]

significant, p-value <0,05.
[a] Chi^2 or Fisher's exact tests.
[b] Independent *t*-test.

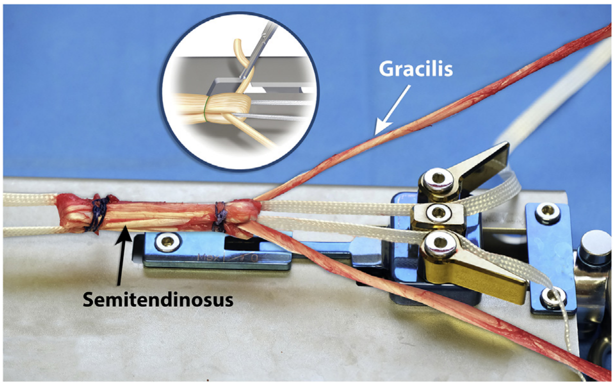

Fig. 2. Preparation of the articular anterior cruciate ligament reconstruction (ACLR) + lateral extra-articular tenodesis (LET) grafts with the gracilis tendon.

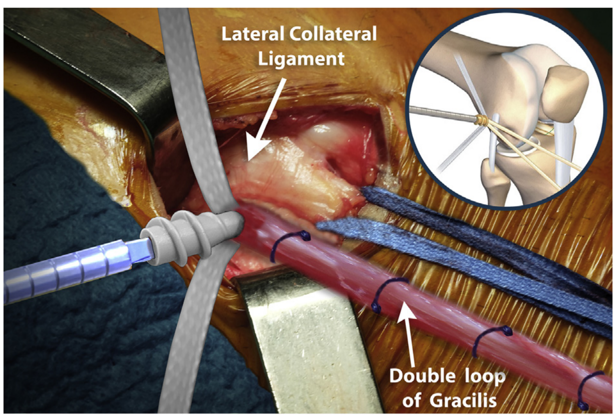

Fig. 3. Femoral fixation in mixed grafts with lateral extra-articular tenodesis (LET) using the gracilis tendon (G2).

harvested ST was the correct diameter for a 4-strand graft, a double-strand gracilis tendon graft (G2) was created and passed through the femoral loop of the ST4 (ST4 + G2) (Fig. 2). The anteromedial approach was used to introduce the G2 of the LET into the knee and through the femoral tunnel. After exiting the tunnel, the G2 loop was passed under the lateral collateral ligament (LCL) and fixed in a tunnel drilled between Gerdy's tubercle and the fibular head with an interference screw (the isometric tibial point was determined with a compass) (Figs. 3 and 4) [8]. When the gracilis was no longer available because it was used for the ST-G, the LET was performed using the modified Lemaire procedure described by Christel and Djian. A strip of fascia lata (1 × 10 cm), left pedicled to the tibia, was passed under the LCL and fixed to the femur with an interference screw [9]. The isometric femoral point, determined with a compass, was located posterior and proximal to the femoral tunnel of the 4-strand graft at 90° of flexion. Screw fixations were carried out with the knee at 20° of flexion and the foot in neutral rotation [10].

The postoperative rehabilitation was the same for both groups.

2.3. Assessment methods

The measurements were taken with the GNRB® (Genourob, Laval, France), an automated dynamic arthrometer that enables continuous recording of the anterior translation of the anterior tibial tubercle [11]. The data processing method used was previously described in the study conducted by Pouderoux et al. [12]. Side-to-side graft laxity (ΔL) was defined as the difference between the operated and healthy knee at a given force (30 N, 60 N, 90 N, 134 N). The local graft compliance or elasticity (μm/N) was calculated from a force-displacement curve. Side-to-side graft compliance (ΔC)

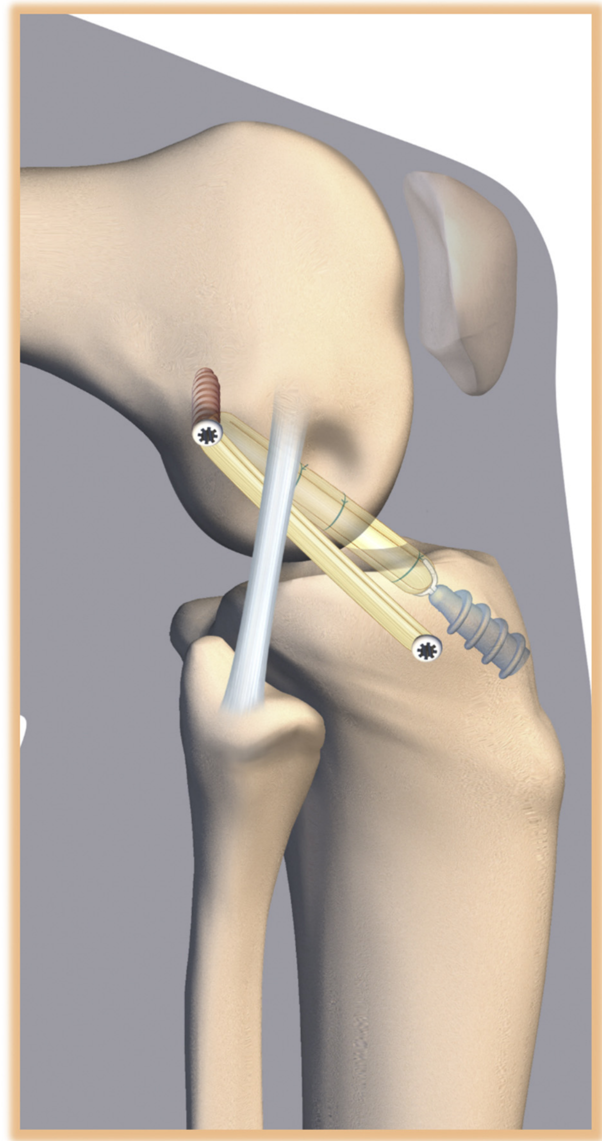

Fig. 4. Orientations of the articular anterior cruciate ligament reconstruction (ACLR) and lateral extra-articular tenodesis (LET) (sagittal view).

was defined as the difference between the operated and healthy knee at a given force. ΔL and ΔC were calculated at 30 N and 60 N the first month after surgery (M1), then at 90 N at 3 months (M3), and 134 N at 6 months (M6) to avoid excessive strain on the graft during the ligamentization process. These measurements were also recorded at 9 months (M9), 1 year, and the last follow-up. All patients were clinically assessed, and the graft was evaluated by an independent examiner during the follow-ups.

2.4. Statistical analysis

The statistical analyses were performed using IBM SPSS Statistics, version 23 (IBM Corp., Armonk, NY). A repeated measures analysis of variance (ANOVA) was carried out to look for intragroup changes over time and intergroup differences. The significance level was set at $p < 0.05$. A post-hoc analysis with a paired *t*-test was carried out in each group to analyze graft laxity and compliance profiles over time. Independent *t*-tests were performed to compare the 2 groups at a given point in time. The Chi^2 or Fisher's exact tests were used to compare the characteristics of the 2 populations when

Table 2
Comparisons between the side-to-side graft laxities (ΔL) and compliances (ΔC) of groups 1 and 2 preoperatively, 1 month, 3 months, 9 months, 1 year, and the last follow-up (repeated ANOVA measurements).

	Group	Preoperatively	1 month	3 months	6 months	9 months	1 year	Last follow-up	*p*-value
ΔL at 30 N	1	1.0	0.4	0.5	0.6	0.6	0.5	0.5	**0.37**
	2	0.9	0.5	0.5	0.6	0.7	0.5	0.5	
Δ at 60 N	1	2.1	0.6	1.1	1.1	1.1	1.0	1.1	**0.73**
	2	2.0	1.0	1.0	1.1	1.3	0.9	0.9	
ΔL at 90 N	1	2.9		1.3	1.3	1.4	1.3	1.4	**0.19**
	2	2.9		1.2	1.3	1.8	1.2	1.2	
ΔL at 134 N	1	3.4			1.5	1.4	1.4	1.5	**0.07**
	2	3.7			1.4	2.0	1.3	1.4	
ΔC at 30 N	1	35.0	13.3	20.7	20.1	21.5	18.6	20.1	**0.77**
	2	35.5	16.0	17.6	19.0	25.3	18.3	20.3	
ΔC at 60 N	1	37.1	16.8	23.5	25.4	25.7	23.4	22.6	**0.58**
	2	40.3	16.4	21.1	22.0	25.0	17.3	18.1	
ΔC at 90 N	1	20.0		6.9	6.0	7.7	7.9	7.9	**0.16**
	2	22.8		6.7	5.9	11.4	6.3	8.2	
ΔC at 134 N	1	15.6			5.9	3.6	2.7	3.6	**0.44**
	2	18.2			5.2	5.5	2.5	3.5	

significant, p-value <0,05.

the cohorts were small (number of patients < 5). Subgroup analyses were performed according to age at surgery, sex, body mass index (BMI), initial laxity at 134 N, meniscal tears, presence of a high-grade (≥ 2) pivot shift, tibial and femoral graft diameter, and the type of LET (modified Lemaire or G2). An ANOVA was performed for each subgroup.

3. Results

A total of 80 patients underwent surgery: 43 isolated ACLRs (group 1) and 37 mixed reconstructions (group 2). Both groups were comparable except for age, pivot shift grade, and distribution of ST4 and ST-G (Table 1). The minimum follow-up was 1 year, and the mean follow-up was 28 months for group 1 and 26 months for group 2. This may seem short, but no side-to-side graft laxity or compliance changes were recorded after 1 year [12,13]. Three patients in each group had laxity failure with a final side-to-side graft laxity > 3 mm ($p > 0.05$). Only one patient in each group underwent revision.

ΔL and ΔC results for group 1 (isolated ACLR) and group 2 (ACLR and LET) are shown in Figs. 5–8.

When comparing both groups, no interindividual differences were found between the laxity evolvement profiles and the side-to-side graft compliances (Table 2). No significant differences were found between groups in terms of graft laxity and compliance (30 N, 60 N, 90 N, and 134 N) measured preoperatively and at the last follow-up.

Both groups showed a significant decrease in ΔL between the preoperative and last follow-up measurements. There was a significant decrease in ΔL at low forces (30 N and 60 N) between the preoperative and M1 measurements. Between M1 and M9, the increase in ΔL was significant in group 1 but not significant in group 2. ΔL stabilized after M9 (Figs. 5 and 6 and Table 3).

Both groups had a significant decrease in ΔC between the preoperative and last follow-up measurements. There was also a significant decrease in ΔC at low forces between the preoperative and M1 measurements. Between M1 and M9, the increase in ΔC was significant at 30 N and 60 N in group 1 and significant at 30 N and not significant at 60 N in group 2. ΔC stabilized after M9 (Figs. 7 and 8 and Table 4).

No differences were found in the subgroup analyses in terms of age at surgery, sex, BMI, initial laxity at 134 N (laxity > 4 mm), meniscal tears, type of LET, and graft diameters (tibial and femoral).

4. Discussion

The main finding of this study was that the addition of LET did not improve side-to-side sagittal graft laxity and compliance during the 1st postoperative year, with no significant differences found between the 2 types of LET at 30 N, 60 N, 90 N, and 134 N. The 3-phase evolvement profiles of both groups, with or without LET, were similar to those reported in the study by Pouderoux et al. [12]. At the last follow-up, the mean elongation of the ACLRs at 134 N was 1.5 ± 1.1 mm in group 1 and 1.4 ± 1 mm in group 2. These findings were consistent with other studies using the isolated ST4 technique [7,12,14]. There was no decrease in residual tibial translation in group 2 compared to group 1. Adding LET did not change the ΔL in group 2 compared to the ΔL in group 1. These findings do not support the hypothesis that LET might provide better laxity sagittal stability.

Several biomechanical studies have demonstrated that the ACL is the primary sagittal restraint of the knee, with the fascia lata acting as the secondary restraint, and that the anterolateral structures only play a minor role [6,15,16]. They also showed that performing a LET could lead to lateral compartment over-constraint (early onset of lateral compartment osteoarthritis) and abnormal knee kinematics (reduced internal rotation) [17].

A recent meta-analysis of 7 randomized studies showed no significant differences in residual positive Lachman test between isolated ACLR and ACLR + LET [18]. Moreover, it has been demonstrated that intra- and extra-articular reconstructions should be combined to ensure normal control of anterior laxity after ACL and ALL tears [16].

LET does not play a direct mechanical role in sagittal control. Still, it seems to protect the ACLR by reducing strain on the ACLR during the ligamentization process if the anterolateral structures do not heal. Adding LET to ACLR significantly reduces the in situ strain by 43%, regardless of the flexion angle (0 to 90°) [19]. The strain distribution across the ACLR and LET grafts could be explained by their oblique direction from back to front and from top to bottom and by the relatively parallel orientation of the 2 grafts in the sagittal plane (Fig. 4). Strain reductions must remain moderate to maintain the quality of the ligamentization process. A balance must be obtained between significant stress shielding and excessive over-constraining for each graft [20].

The protective function of LET on ACLR was clinically found in associated anterolateral injuries. Sonnery-Cottet et al. confirmed the benefit of an ALL reconstruction in their study comparing bone-patellar tendon-bone graft, hamstring tendon graft, and hamstring tendon graft combined with the ALL (gracilis). The rate of graft

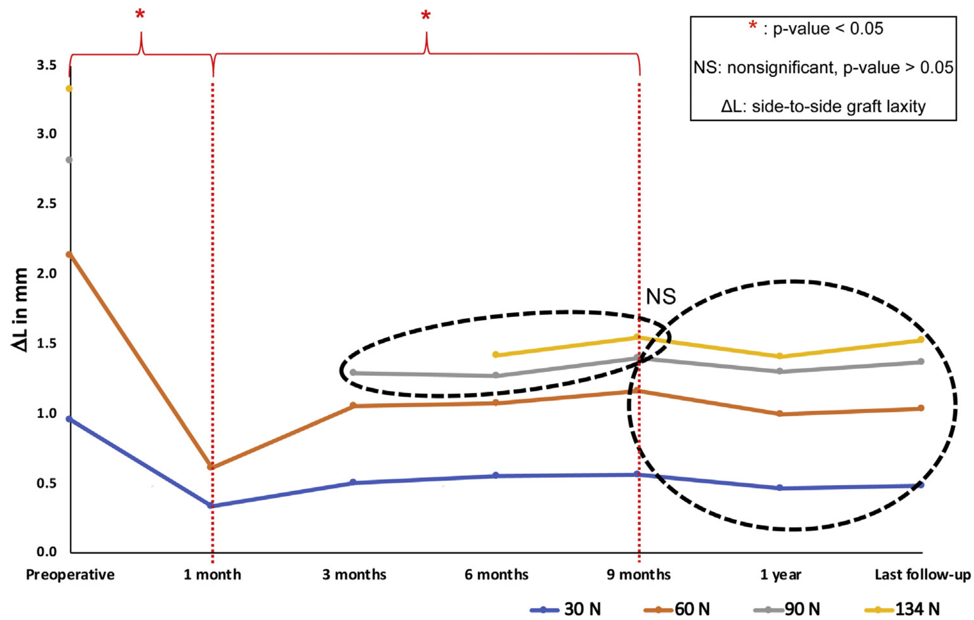

Fig. 5. Evolvement of the side-to-side graft laxity (ΔL) in group 1.

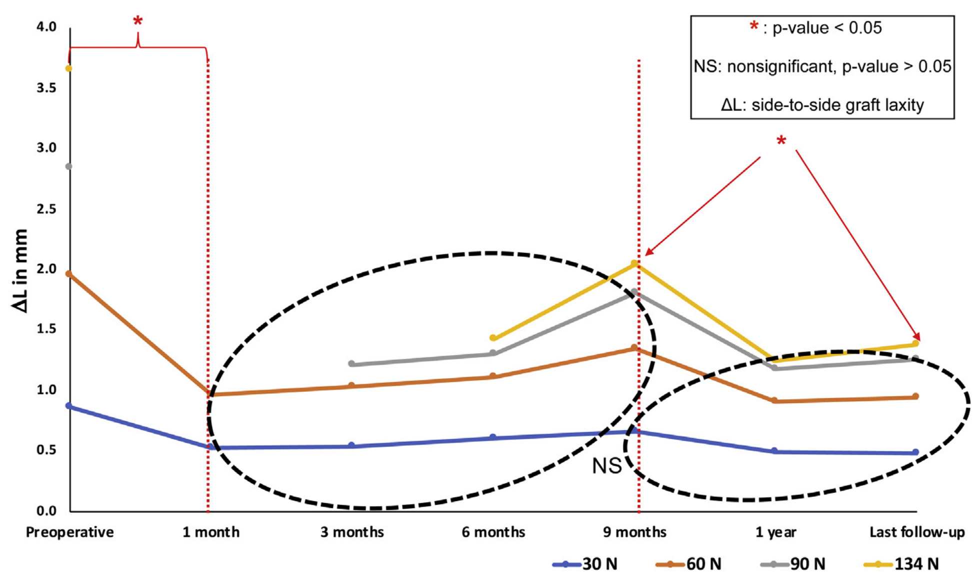

Fig. 6. Evolvement of the side-to-side graft laxity (ΔL) in group 2.

Table 3
Evolvement of the side-to-side graft laxities (ΔL) preoperatively, 1 month (M1) and 9 months (M9), and the last follow-up (FU) (paired *t*-tests).

Force (N)	Group	Preoperative ΔL (mm)	ΔL at M1 (mm)	Difference (mm)	*p*-value	ΔL at M1 (mm)	ΔL at M9 (mm)	Difference (mm)	*p*-value	ΔL at M9 (mm)	ΔL at last FU (mm)	Difference (mm)	*p*-value
30	1	1.0	0.4	0.6	**<0.0001**	0.4	0.6	−0.2	**0.03**	0.6	0.5	0.1	0.8
	2	0.9	0.5	0.4	**<0.01**	0.5	0.7	−0.2	0.07	0.7	0.5	0.2	0.5
60	1	2.1	0.6	1.5	**<0.0001**	0.6	1.1	−0.5	**0.01**	1.1	1.1	0.0	0.9
	2	2.0	1.0	1.0	**<0.0001**	1.0	1.3	−0.3	0.09	1.3	0.9	0.4	0.3
Force (N)	Group	Preoperative ΔL (mm)	ΔL at M3 (mm)	Difference (mm)	*p*-value	ΔL at M3 (mm)	ΔL at M9 (mm)	Difference (mm)	*p*-value	ΔL at M9 (mm)	ΔL at last FU (mm)	Difference (mm)	*p*-value
90	1	2.9	1.3	1.6	**<0.0001**	1.3	1.4	−0.1	0.7	1.4	1.4	0.0	0.7
	2	2.9	1.2	1.7	**<0.0001**	1.2	1.8	−0.6	0.1	1.8	1.2	0.6	0.1
Force (N)	Group	Preoperative ΔL (mm)	ΔL at M6 (mm)	Difference (mm)	*p*-value	ΔL at M6 (mm)	ΔL at M9 (mm)	Difference (mm)	*p*-value	ΔL at M9 (mm)	ΔL at last FU (mm)	Difference (mm)	*p*-value
134	1	3.4	1.5	1.9	**<0.0001**	1.5	1.4	0.1	0.6	1.4	1.5	0.1	0.7
	2	3.7	1.4	2.3	**<0.0001**	1.4	2.0	−0.6	0.2	2.0	1.4	0.6	0.05

significant, p-value <0,05.

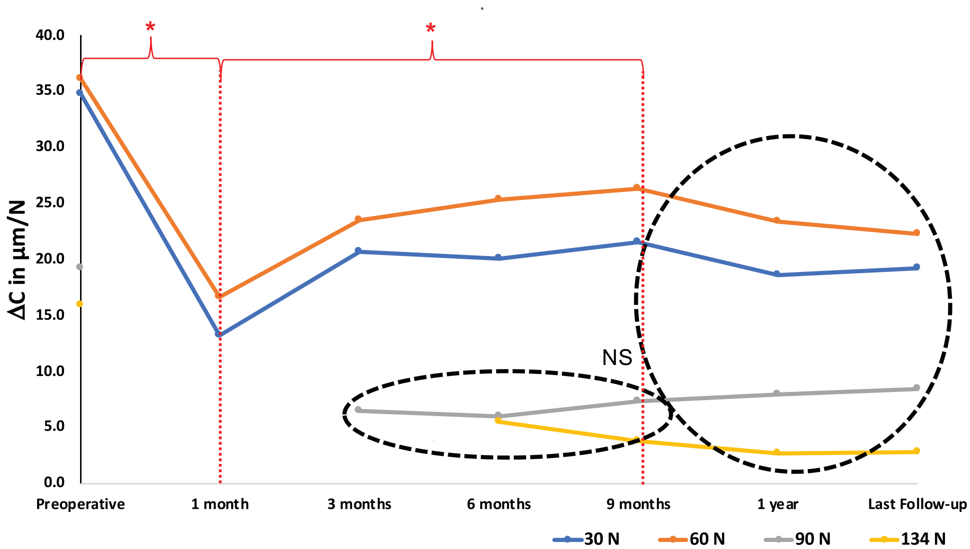

Fig. 7. Evolvement of the side-to-side graft compliance (ΔC) in group 1.

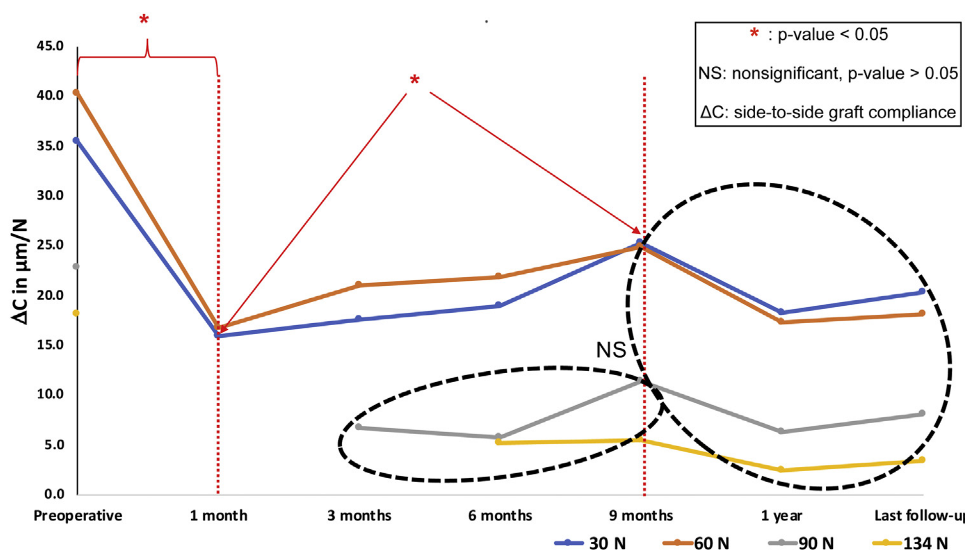

Fig. 8. Evolvement of the side-to-side graft compliance (ΔC) in group 2.

Table 4
Evolvement of the side-to-side graft compliances (ΔC) preoperatively, 1 month (M1), 9 months (M9), and the last follow-up (FU) (paired *t*-tests).

Force (N)	Group	Preoperative ΔC (µm/N)	ΔC at M1 (µm/N)	Difference (mm)	*p*-value	ΔC at M1 (µm/N)	ΔC at M9 (µm/N)	Difference (mm)	*p*-value	ΔC at M9 (µm/N)	ΔC at last FU (µm/N)	Difference (mm)	*p*-value
30	1	35	13.3	21.7	**<0.001**	13.3	21.5	−7.2	**0.05**	21.5	20.1	1.4	0.9
	2	35.5	16.0	19.5	**<0.001**	16.0	25.3	−9.3	**<0.01**	25.3	20.3	5.0	0.5
60	1	37.1	16.8	20.3	**<0.001**	16.8	26.4	−9.6	**0.02**	25.7	22.6	3.1	0.6
	2	40.3	16.4	23.9	**<0.001**	16.4	25.0	−8.6	0.2	25.0	18.1	6.9	0.1

Force (N)	Group	Preoperative ΔC (µm/N)	ΔC at M3 (µm/N)	Difference (mm)	*p*-value	ΔC at M3 (µm/N)	ΔC at M9 (µm/N)	Difference (mm)	*p*-value	ΔC at M9 (µm/N)	ΔC at last FU (µm/N)	Difference (mm)	*p*-value
90	1	20.0	6.9	13.1	**<0.001**	6.9	7.7	−0.8	0.7	7.7	7.9	−0.2	0.5
	2	22.8	6.7	16.1	**<0.001**	6.7	11.4	−4.7	0.4	11.4	8.2	3.2	0.2

Force (N)	Group	Preoperative ΔC (µm/N)	ΔC at M6 (µm/N)	Difference (mm)	*p*-value	ΔC at M6 (µm/N)	ΔC at M9 (µm/N)	Difference (mm)	*p*-value	ΔC at M9 (µm/N)	ΔC at last FU (µm/N)	Difference (mm)	*p*-value
134	1	15.6	5.9	9.7	**<0.01**	5.9	3.6	2.3	0.1	3.6	3.6	0.0	0.9
	2	18.2	5.2	13.0	**<0.01**	5.2	5.5	−0.3	0.5	5.5	3.5	2.0	0.1

significant, p-value <0,05.

retears was 16.8%, 10.8%, and 4.1%, respectively, i.e., the incidence of rupture was 3 and 2.5 less with the addition of ALL [21]. Likewise, Laboudie et al. confirmed that performing an ALL reconstruction in conjunction with an ST graft reduced the rate of graft retears (5.8% versus 11.9%) [22]. Moreover, like our study, they found no significant differences between groups regarding the laxity measurements taken with a GNRB® 6 months after surgery.

This study confirmed a 3-phase evolvement of the side-to-side graft laxity and compliance [12]. ΔL and ΔC decreased significantly between preop and M1, then increased until M9. ΔL and ΔC did not change much after M9.

This study had several limitations. It was not randomized because the selection criteria for LET was the grade of pivot shift assessed under general anesthesia. The major limitation is that the groups were not comparable in terms of pivot shift, age, and graft type, but they were similar in terms of the preoperative laxity profile. The number of patients lost to follow-up or not followed regularly over 1 year (45 patients) is a shortcoming of this study. Still, several series studying young patients have reported the same issue, as it is challenging to motivate them to undergo regular laximetry testing during follow-ups. The results of the present study, which compared 2 types of LET, were not statistically conclusive because they only involved small populations (β risk). The study by Jacquet et al. found no differences between these 2 types of LET on high-grade pivot shifts [10]. The minimum follow-up was 1 year (mean of 28 months for group 1 and 26 months for group 2), which might seem short, but there was no change in side-to-side graft laxity after 1 year [12,13].

5. Conclusion

The sagittal laximetry follow-up of short hamstring tendon graft reconstructions showed that adding a LET did not reduce graft sagittal laxity and compliance at a mean 2-year follow-up. The magnitude of the preop side-to-side Lachman test, whether measured with an arthrometer or not, is insufficient to indicate a LET. However, in the literature, high-grade rotational pivot shift remains one of the key factors in deciding to perform an additional LET.

Disclosure of interest

H.R. developed the GNRB® but does not receive any royalties.

F.F., T.P., and C.V.-C. declare that they have no competing interest.

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None.

Author contributions

F.F.: analyzed data and drafted and edited the manuscript.

T.P.: analyzed data, proofread, and edited the manuscript.

C.V.-C.: proofread and edited the manuscript.

H.R.: surgeon, investigator, and supervisor of the study. Proofread the manuscript and validated the submitted version.

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