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Isolated lateral extra-articular tenodesis in ACL-deficient knees: in vivo knee kinematics and clinical outcomes

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Abstract

Purpose To carry out an in vivo kinematic analysis of isolated modified Lemaire lateral extra-articular tenodesis (LET) to explore its ability to modify the stability of anterior cruciate ligament (ACL) deficient knees. The secondary aim was to look at the clinical outcomes of the isolated LET to analyze whether biomechanical changes have an influence on clinical improvement or not.

Methods A total of 52 patients who underwent an isolated modified Lemaire LET were prospectively studied. Twenty-two were over 55-year-old patients with ACL rupture and subjective instability (group 1). They were followed up for 2 years postoperatively. Thirty were patients underwent a two-stage ACL revision (group 2). They were followed up for 4 months postoperatively (up to the second stage of the ACL revision). Preoperative, intraoperative, and postoperative kinematic analyses were carried out using the KiRA accelerometer and KT1000 arthrometer to look for residual anterolateral rotational instability and residual anteroposterior instability. Functional outcomes were measured with the single-leg vertical jump test (SLVJT) and the single-leg hop test (SLHT). Clinical outcomes were evaluated using the IKDC 2000, Lysholm, and Tegner scores.

Results A significant reduction of both rotational and anteroposterior instability was detected. It was present both with the patient under anesthesia ($p<0.001$ and $p=0.007$ respectively) as well as with the patient awake ($p=0.008$ and $p=0.018$ respectively). Postoperative analysis of knee laxity did not show any significant variation from the first to the last follow-up. Both the SLVJT and SLHT improved significantly at the last follow-up ($p<0.001$ and $p=0.011$ respectively). The mean values of both the IKDC and Lysholm and Tegner scores showed an improvement ($p=0.008$; $p=0.012$; $p<0.001$).

Conclusion The modified Lemaire LET improves the kinematics of ACL-deficient knees. The improvement in the kinematics leads to an improvement in subjective stability as well as in the function of the knee and in the clinical outcomes. At the 2-year follow-up, these improvements were maintained in a cohort of patients over 55 years. Following our findings, to reduce knee instability, an isolated LET in ACL-deficient knees may be used when ACL reconstruction in patients over 55 years is not indicated.

Level of evidence Level IV

Keywords ACL · Anterolateral tenodesis · Isolated tenodesis · KiRA

Introduction

The use of lateral extra-articular procedures in association with anterior cruciate ligament (ACL) reconstruction has increased over recent years. Biomechanical, cadaveric, and clinical studies have investigated the advantages, disadvantages, and clinical results of these combined procedures [27, 31, 40, 47]. Some studies have analyzed the kinematic effect of lateral extra-articular tenodesis (LET) in vivo [6, 34, 42, 49]. All those investigations were carried out with a focus on the effects of the combined LET and ACL procedures and described contrary results. Thus, few in vivo data are available on the role of an isolated anterolateral procedure in ACL-deficient knees from a biomechanical point of view.

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Extra-articular techniques were originally thought to mechanically act on the lateral periphery of the joint to prevent subluxation of the tibial plateau and thereby reduce rotational instability of the knee [12, 14]. Therefore, its use can be theoretically indicated in case of subjective instability of ACL-deficient knees when it is not indicated to carry out an intra-articular ACL reconstruction even though isolated extra-articular reconstructions are rarely performed in contemporary practice [50].

The most recent clinical reports on the use of an isolated LET were published more than 25 years ago. They were small retrospective non-controlled studies mostly using the MacIntosh procedure [1–3, 11, 13, 15, 21, 25, 30, 32, 39, 52].

Most of those studies described good outcomes in terms of patient-reported outcome measures and the ability of LET to provide rotational control. However, they reported persistent anterior laxity in the operated knees and early degenerative changes in the lateral compartment [13, 21, 30, 39, 52]. Many authors have attributed these problems to numerous factors including the non-anatomic nature of the techniques used and the slow rehabilitation with a prolonged period of cast immobilization [8, 10, 35, 43, 44]. For those reasons and due to the spread of intra-articular reconstruction of the ACL, the use of isolated extra-articular tenodesis has been abandoned over time and no recent clinical data about isolated use of LET are available.

The purpose of the present study was to carry out an in vivo kinematic analysis of isolated modified Lemaire LET to explore its ability to modify the stability of ACL-deficient knees. The secondary aim was to look at the clinical outcomes of the isolated LET to analyze whether biomechanical changes have an influence on clinical improvement or not. Our hypothesis was that both knee instability and clinical outcomes can be improved performing isolated LET in ACL-deficient knees.

Materials and methods

A prospective observational single-center study that adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines was carried out [53]. All the procedures described in this study were performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments [54], and ethics committee approval was obtained (Protocol LCA-2017–01, Approved by ethics committee of Grupo Hospitalario Quiron en Barcelona). All the patients signed an informed consent form before recruitment. No external funding was received for the initiation or completion of this study.

All the patients who had undergone an isolated LET to treat instability of an ACL-deficient knee were considered for the study. Patients were recruited between November 2017 and February 2020 and prospectively followed up for two years. The isolated LET was considered an indication for two groups of patients: (1) complete ACL rupture in active patients over 55 years old, (2) patients undergoing the first step of two-stage revision ACL reconstruction.

Exclusion criteria for both groups were skeletally immature patients, knee osteoarthritis superior to stage 2 of the Kellgren–Lawrence classification, a multiligament knee injury or previous ligament reconstruction, the need for cartilage lesion surgery at the time of LET, patients with contralateral ACL injuries, those with excessive (> 5°) varus/valgus deformity, excessive (> 12º) tibial slope or associated severe meniscal damage (root tears, ramp lesions, bucket handle tears). Finally, patients not willing to participate in the study or unable to sign written informed consent were excluded.

All the surgical procedures were performed by two of the senior authors.

Sixty-seven patients were assessed for eligibility. After application of the exclusion criteria, fifty-two patients were prospectively included in the study. Three patients were excluded because of a medial collateral ligament lesion and 2 other patients because of the presence of advanced medial compartment osteoarthritis. Four were excluded because of a root tear, 4 because of a ramp lesion and 2 underwent a bucket handle suture of the medial meniscus.

The patients in group 1 were encouraged to go through a 6-month rehabilitation and strengthening program before they would be considered suitable for the surgical approach. Only patients who presented instability that limited their activity level at the end of this program were proposed for an isolated LET. Subjective instability was described as the feeling of giving way during daily life and/or sport and work activities and the lack of confidence in the knee joint. In all cases, the subjective instability of the patients was confirmed by a quantitative evaluation of the degree of anteroposterior and rotational laxity. Only patients with both objective and subjective instability were included.

The patients in group 2 were treated with 2 stage revision ACL surgery when either the position or the enlargement of the tunnels used for previous ACL reconstruction prevented a revision in one-stage. Subsequently, the patients underwent the second step of the revision at 4 months after the first step. We usually perform LET during the first step of the two-stage approach to prevent the patient from excessive instability during the months between the first and second step of the revision.

Lateral extra-articular tenodesis

Before starting the LET, an arthroscopic review of all the joint compartments was always done to confirm the presence of an ACL lesion and to rule out associated injuries. All meniscal procedures were performed before the LET. In all cases in group 2, debridement of the ACL graft remnant was performed in association with allogenic bone impaction grafting in the previously used tunnels. A modified Lemaire tenodesis was carried out in all cases using an interference screw to fix the fascia lata into the femur as previously described [41]. During fixation, care was taken to avoid extreme graft tensioning given that a previous biomechanical study has suggested that tension over 20N may overconstrain knee kinematics [16].

Starting from the first postoperative day, the patients were encouraged to perform active motion and weightbearing as tolerated. The crutches are usually completely abandoned at between 2 and 3 weeks and soft treadmill running was performed between 4 and 6 weeks postoperatively.

Clinical assessments and follow-up

The same preoperative magnetic resonance imaging (MRI) and X-ray protocols were used in every case to detect ACL graft rupture, cartilage and meniscal injuries, lower limb malalignment and radiological signs of osteoarthritis.

During the outpatient clinic visit, anteroposterior knee laxity was measured using the Kinematic Rapid Assessment (KiRA) triaxial accelerometer (Orthokey, Italia Srl, Firenze, Italy) and the KT-1000 arthrometer (MEDmetric, San Diego, California) while performing the manual maximum test at 30º of flexion as previously described [9, 45]. Quantitative assessment of the pivot shift (QPS) phenomenon to detect the values of rotational acceleration was performed using the KiRA accelerometer. All the measurements were recorded following the indications previously described, allowing 2 decimals [29, 45]. Each measurement was performed five times. Then, the maximum and minimum values were excluded, and the three remaining values were averaged and used for the analyses. Both knees were evaluated to analyze the difference in rotational acceleration. It is defined as residual anterolateral rotational instability (ALRI). ALRI was calculated by subtracting the value of the laxity of the healthy joint from the one acquired on the involved joint. In the same way, the residual anteroposterior instability (API) was calculated with both the KT1000 and KiRA.

To prevent a technical bias, preoperative and postoperative assessments were always performed by the same senior surgeon trained on the KiRA system and KT1000 arthrometer. A single trained observer approach was adopted to mitigate the broad inter-observer reliability of the test. The examiner was not blinded to the state of the knee but was blinded to the results of the KiRA analyses during the execution of the tests. The observer was not one of the treating surgeons.

To evaluate knee function and subjective instability, the Single-leg vertical jump test (SLVJT) and the Single-leg hop test (SLHT) were used, as originally described [28, 33, 46].

Subjective outcomes were assessed using the IKDC 2000 subjective knee evaluation form and the Lysholm score [5, 22]. Finally, the patients from group 1 were asked to complete the Tegner activity scale [5]. None of the patients from group 2 were asked to complete Tegner scale since they were not allowed to participate in sport activities before the second step of the ACL revision.

The Patient-Reported Outcomes (PRO) measures, SLHT, SLVJT, KT-1000 and KiRA evaluations were collected during the last visit before surgery and at 4 months. At 2 years after surgery, the collection was only carried out with group 1. Furthermore, the SLVJT was also evaluated at 6 weeks postoperatively. Patients were prospectively followed up, and the occurrence of any complications, further surgery, persisting symptoms of instability or meniscal lesions were noted.

Time zero kinematic assessment

On the day of surgery, the patient was evaluated to obtain quantitative anterior and rotational laxity values using the KiRA system. Both knees were evaluated on two occasions following the same preoperative protocol: (1) after the administration of general anesthesia but before the application of the tourniquet and (2) just after the end of the surgery after the removal of the tourniquet (still under anesthesia).

Statistical analysis

Continuous variables are presented as mean and standard deviations (SD). Categorical variables are presented as percentages and frequencies. The Shapiro–Wilk test was used to confirm the normality of the variables. The inference in continuous variables was calculated with the paired samples *t* test and the results are presented with their 95% confidence interval (95% CI). The inference for categorical variables was studied with the chi-squared test or Fisher's exact test, depending on what corresponded. To compare repetitive variables, the ANOVA test was used. The level of significance was set at 5% ($\alpha = 0.05$), the bilateral approximation. The sample size calculation was carried out both for the kinematic and the clinical part of the study. The difference in rotational acceleration was considered for the kinematic evaluation. The calculation factored in previous published data [24, 38] that showed that a reduction of the side-to-side difference under anesthesia of 1.5 ± 0.4 m/s^2 in rotational acceleration was considered clinically relevant. Based on these data, the estimated effect size was calculated using Cohen's D statistic, resulting in $d = 3.00$. Thus, using a two-sided alpha value of 0.05 in a formula for the difference of means in two dependent populations, a total of 15 participants would give us 80% power with 95% confidence. Using the same formula, the power analysis was performed with the IKDC. The minimal clinically significant difference (MCID) was used to identify true clinically meaningful changes in the measures that were not the result of measurement error. The MCID for the IKDC has been reported as 11.5 point [7, 18, 22, 23]. Then, it was used to identify a meaningful difference. A minimum of 20 patients were determined to be necessary to adequately identify a clinically meaningful difference. Considering a possible 10% drop-out rate, a minimum of 22 patients were considered adequate. All the analyses were performed with the SPSS version 19 (SPSS Inc., Chicago, Illinois).

Results

Twenty-two subjects were included in group 1 and 30 subjects were included in group 2.

The baseline characteristics of the patients are summarized in Table 1. A meniscal procedure was undertaken on 11 patients during the LET surgery (Table 1).

Kinematic analysis

The mean side-to-side difference in rotational acceleration of the tibia during pivot shift test measured with KiRA (ALRI) decreased significantly under anesthesia ($p < 0.001$) as well as without the effect of the anesthesia at last FU ($p = 0.008$). The mean side-to-side difference in anterior tibial translation measured with KiRA (API) decreased significantly under anesthesia ($p = 0.007$) and without the effect of the anesthesia at last follow-up ($p = 0.018$). The mean side-to-side difference measured with KT1000 turned out to be significant at last follow-up ($p = 0.024$). All the postoperative analyses made from the first to the last FU showed no significant

Table 1 Baseline characteristics of the cohort and meniscal surgery at the time of LET

	Age (years)	Male	Female	Meniscectomy	Meniscal suture
Group 1	57.7 ± 1.4	13	9	4 (M)	0
Group 2	25.4 ± 6.9	16	14	2 (M), 1 (L)	2 (M), 2(L)

Age is expressed as mean and standard deviations

M medial, *L* lateral

Table 2 Summary of the mean kinematic values under anesthesia measured with KiRA

	Pre API	Post API	*P value*	Pre ALRI	Post ALRI	*P value*
Group 1	3.72 ± 1.93	2.56 ± 1.84	*0.008*	3.25 ± 2.50	1.61 ± 1.66	*0.004*
Group 2	4.60 ± 2.25	3.12 ± 2.14	*0.003*	3.91 ± 3.14	1.94 ± 2.12	*< 0.001*
Group 1 + 2	3.98 ± 2.87	2.61 ± 2.19	*0.007*	3.63 ± 3.81	1.87 ± 2.89	*< 0.001*

Measures are expressed as mean and standard deviations

Pre Preoperative, *Post* Postoperative, *API* anteroposterior instability (mm), *ALRI* anterolateral rotational instability (m/s^2)

Table 3 Summary of the mean kinematic values without anesthesia measured with KiRA

	Pre API	4 M API	2Y API	*P value*	Pre ALRI	4 M ALRI	2Y ALRI	*P value*
Group 1	3.03 ± 3.95	1.98 ± 1.79	1.89 ± 2.15	*0.021*	2.39 ± 3.68	0.82 ± 1.95	0.91 ± 2.11	*0.009*
Group 2	3.84 ± 3.67	2.68 ± 2.52		*0.008*	2.65 ± 4.02	0.86 ± 1.87		*0.008*
Group 1 + 2	3.49 ± 3.39	2.41 ± 1.96		*0.018*	2.51 ± 3.98	0.87 ± 2.13		*0.008*

Measures are expressed as mean and standard deviation

Pre Preoperative, *4 M* 4 months of follow-up, *2 Y* 2 years of follow-up, *API* anteroposterior instability (mm), *ALRI* anterolateral rotational instability (m/s^2)

variation in neither rotational acceleration or anterior tibial translation ($p = 0.002$ and $p = 0.004$, respectively). A summary of the mean kinematic values is presented in Tables 2 and 3.

Clinical and functional findings

All 52 patients complained of subjective instability preoperatively. At the 4-month follow-up, this feeling disappeared in all 22 (100%) cases from group 1, and in 23 (76.7%) patients from group 2. A significant improvement was detected in the SLVJT ($p = 0.001$) as 11 (21.1%) patients were able to perform SLVJT before the operation, 29 (55.7%) were able at 6 weeks postoperatively, 37 (71.1%) at 4 months of FU, 22 (100%) of the patients evaluated at the 2-year FU. Moreover, a significative improvement was found for the SLHT in the postoperative evaluation (Table 4).

For both IKDC and Lysholm score, we detected a significant improvement ($p = 0.008$ and $p = 0.012$, respectively) between the pre and postoperative evaluations (Table 5). No significant variation was seen from the first to the last follow-up ($p < 0.001$). The median preinjury Tegner activity score in group 1 was 6 (range 4–6). That median dropped to 3 (range 1–4) preoperatively (post injury), and the postoperative median at the last follow-up rose to 6 (range 3–6, $p < 0.001$).

No postoperative complications or deficits in range-of-motion of the operated knees were observed.

Table 5 Summary of clinical scores

	Preoperative	4 M	2 Y (only group 1)	*p* value
IKDC	60.1 ± 14.3	76.9 ± 10.8	79.6 ± 11.2	*0.008*
LYSHOLM	65.8 ± 12.7	79.4 ± 14.7	80.8 ± 13.7	*0.012*

Discussion

The main finding of the present study was that isolated LET procedure improved the kinematics of ACL-deficient knees. More specifically, it reduced both rotatory and anteroposterior laxity. This improvement in kinematics did not decrease at the 2-year follow-up.

Several biomechanical and clinical studies have shown that LET can improve both the kinematics and the clinical results when associated with an ACL reconstruction [16, 17, 20, 37, 55]. Nevertheless, few of them have evaluated the capacity of LET itself to modify the mechanics of an ACL-deficient knee. Monaco et al. [34] tested 10 knees with navigation during a combined ACL and LET reconstruction performing the extra-articular procedure first. They concluded that LET itself can decrease the rotational instability but has little effect on reducing the anterior displacement of the tibia at 30° of flexion. In a cadaveric study, Tavlo et al. [51] stated that LET has only the capacity to reduce rotational laxity when the ACL is intact. Then again, it can bring about a decrease in both rotational and anterior tibial translation when the ACL is lacking. The present study confirmed these latter findings in an in vivo evaluation with the patient under anesthesia as well as with the patient awake. A triaxial accelerometer was used for an accurate quantitative analysis of laxity in the present study. The use of the triaxial accelerometer has been widely validated and found to be useful and easy to use to perform a kinematic analysis [28, 45]. According to the data from some previous studies, one clinically relevant grading difference in pivot-shift acceleration under anesthesia was 1.5 (± 0.4 m/s^2) [24, 38]. This suggests that the mean tibial acceleration reduction via LET in ACL-deficient knees in the present study (> 1.5 ± 0.4 m/s^2) was both clinically and statistically significant.

The second finding of the present study is that subjective stability, the functional and the clinical outcomes can be improved with an isolated LET in ACL-deficient knees even few months postoperatively. The primary complaint of a patient with ACL insufficiency after an injury is instability. These patients complain particularly of subjective rotational instability with pivoting or cutting activities [26]. In 86.5% of the patients in the present study, the LET was useful in resolving the subjective instability as early as at the 4-month follow-up. Moreover, an improvement in both the SLVJT and SLHT was seen, pointing to an improvement in terms of stability during functional tests, as well. The SLVJT has been reported to provide an assessment of strength, power, and patient willingness and confidence to accept weight on the involved side [28, 33, 46]. Only 21.1% of the patients were able to perform a

Table 4 measurements of Single-Leg Hop Test

SLHT	Preoperative	4 M	2 Y (only group 1)	*p* value
Length	103.2 ± 38.9 cm	117.4 ± 25.3 cm	123.8 ± 20.2 cm	*0.011*
Limb symmetry index	64.7 ± 11.8%	75.5 ± 29.5%	77.9 ± 23.6%	*0.017*

Measures are expressed as mean and standard deviation

SLHT Single-leg hop test, *M* 4 months of follow-up, *2 Y* 2 years of follow-up

SLVJT correctly preoperatively and 55.7% of the patients were able at 6 weeks postoperatively ($p < 0.001$). The improvement in subjective instability and in the functional test may explain the improvement seen in the patient-reported outcomes. The mean improvement in the IKDC values was of 17.1 ± 8.3 points at the 4-month follow-up ($p = 0.008$). Considering that the MCID for the IKDC has been reported as 11.5 points [7, 18, 22, 23], we can state that the difference is clinically significant. Furthermore, the patient acceptable symptom state (PASS) previously described for the IKDC after ACL reconstruction is 75.9 points [36]. All the patients in this study were out of the PASS range preoperatively, whereas 73% ($n = 38$) of the patients were in the PASS range at the 4-month follow-up. Those that were in the PASS at the 2-year follow-up came to 21 (95.5%) patients from group 1. The clinical significance of our results is confirmed by that number. Our data confirmed only in a population over 55 years.

We recognize that there are several limitations in the present study. The first limitation is the small cohort size. Thus, this study was not powered to detect differences between the baseline characteristics of the patients (i.e., Body mass index, sex, and meniscal lesions). Similar studies with a larger cohort would be better able to investigate whether baseline characteristics can influence the biomechanical changes brought on by the LET. The second limitation is the lack of a control group for the clinical part of the study. A second group of patients over 55 years treated by an ACL reconstruction would make the results more consistent about the capacity of LET surgery to improve the clinical outcomes. In the day practice of our health system, the long and hard rehabilitation protocol of an ACL reconstruction is hardly accepted by most of these patients. For this reason, an alternative to ACL reconstruction has been sought, in this specific kind of patients, in the case of persistent instability after an adequate rehabilitation protocol. Therefore, a control group cannot be provided for the clinical part of the study. Finally, our aim wasn't to demonstrate the superiority of LET surgery to the ACL reconstruction that, when possible, remain the gold standard in healthy and fit patients over 50 years. For the kinematic part of the study, which was the primary aim, the contralateral knee was considered the control group.

A further limitation is the single evaluator methodology. This obviously has an inherent weakness, but it was specifically adopted to minimize the error that would be introduced as a result of multiple observers as some authors claimed about the inter-rate reliability of KiRA, mainly to evaluate the anteroposterior stability [48]. Nevertheless, numerous studies have demonstrated that the KiRA device is both accurate and reliable at quantifying rotational acceleration and antero-posterior laxity [4, 19, 24]. At the same time, it has been shown that the reliability of the KiRA device is proportional to the experience of the user [4]. Finally, some could claim that the detected lower value for laxity of the involved knee collected at time-zero may also be related to the prudence required in postoperative measurements. For this reason, the decision was taken to re-evaluate the patients in the outpatient clinic for up to 2 years postoperatively to mitigate the influence of this bias.

Conclusions

The modified Lemaire LET improves the kinematics of ACL-deficient knees. The improvement in the kinematics leads to an improvement in subjective stability as well as in the function of the knee and in the clinical outcomes. At the 2-year follow-up, these improvements were maintained in a cohort of patients over 55 years.

Author contributions SP: Conception of the research idea, protocol design and drafting, obtaining, analyzing and interpreting the data, drafting the manuscript and approval of its final version as well as agreement with the other authors that all doubts or aspects of the manuscript were meticulously reviewed before being sent to publication. GPE-G: Concepcion of the research question, acquisition and analysis of the data, writing of a part of the manuscript and approval of its final version. RM-A: Conception of the research idea, protocol design and drafting, obtaining, analyzing and interpreting the data, drafting the manuscript, approval of the final version, search for current and ancient literature as well as agreement that all of the manuscript's minors were reviewed and it has validity and integrity. SR: Acquisition and analysis of data, intellectual advisor, write part of the manuscript and approval of its final version. RT-C: protocol design and drafting, obtaining, analyzing and interpreting the data, write part of the manuscript and approval of its final version. JE-M: Substantial contribution to the manuscript, proposal of the research idea, approval of the final version of the manuscript interpretation of the data, supervision of the study. JCM: One of the two main investigators of the study, editing of the manuscript before its final version, orthopedic adviser, proposal of the idea, proposal of the clinical relevance of the study, implementation of the protocol methodology, interpretation of results, approval of the final version, writing of part of the manuscript. Each one of the authors has contributed significantly to the execution of the manuscript, from the conception of the idea and the design of the protocol, the analysis and the interpretation of the results as well as in the writing and approval of the final version of the manuscript that is sent. All the authors significantly contributed to the execution and writing of the manuscript.

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Data availability The data that support the findings of this study are not openly available but are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no direct or indirect conflict of interest for the present study.

Ethical approval Ethics committee approval was obtained: Protocol No. LCA-2017-01

Informed consent All the patients signed an informed consent form before recruitment.

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