The role of lateral extra-articular tenodesis in revision anterior cruciate ligament reconstruction

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DOCTORAL THESIS

“The role of lateral extra-articular tenodesis in revision anterior cruciate ligament reconstruction”

Doctoral thesis presented to obtain the title of Doctor of Philosophy by the

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A Agnello, Márcia e Rafael,

pelo seu apoyo incondicional.

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Doctors Nayana Joshi Jubert, Joan Minguell Monyart and Maria Mercedes Revertè-Vinaixa from the Knee Unit of the Orthopaedic and Traumatology Surgery Department of the Vall d'Hebron University Hospital in Barcelona,

CERTIFY:

Felipe Moreira Borim has completed an impactful original research project titled "The Role of Lateral Extra-Articular Tenodesis in Revision Anterior Cruciate Ligament Reconstruction". Under our guidance, this research aligns with the high methodological and scientific standards required for the Doctoral Program in Surgery and Morphological Sciences.

The core studies of this research were developed through a detailed follow-up of patients in external consultations at both the Vall d'Hebron University Hospital and the Corachan Clinic, in effective collaboration with the Knee Orthopaedic Surgery Unit.

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Nayana Joshi Jubert Joan Minguell Monyart Maria Mercedes Revertè-Vinaixa

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ABBREVIATIONS

ACL: Anterior Cruciate Ligament

ACLR: Anterior Cruciate Ligament Reconstruction

ALC: Anterolateral Complex

ALL: Anterolateral Ligament

BPTB: Bone Patellar-Tendon Bone

HS: Hamstrings Tendon

HUVH: Hospital Universitari Vall d'Hebron

IKDC: International Knee Documentation Committee

ITB: Iliotibial Band

LET: Lateral Extra-Articular Tenodesis

Lysholm: Lysholm Knee Scoring System

MARS: Multicenter ACL Revision Study

MOON: Multicenter Orthopaedic Outcomes Network

QT: Quadriceps Tendon

RTS: Return to Sport

SD: Standard Deviation

SF-12: Short Form (12) Health Survey

TAS: Tegner Activity Scale

UAB: Universitat Autònoma de Barcelona

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SUMMARY

Introduction:

This thesis explores the crucial question of whether a combination of modified Lemaire lateral extra-articular tenodesis (LET) can deliver favorable outcomes and minimal complications in revision anterior cruciate ligament reconstruction (ACLR). The research concentrates on two distinct demographics. First, it analyses the influence of LET and allografts on a general population, focusing on improving rotational stability. Second, it evaluates the potential for a successful return to sports in young athletes following the procedure with autografts and LET. These studies employ a prospective design, with follow-up periods of one and two years, respectively.

Scientific Justification:

Revision ACLR can be challenging due to chronic instability and associated chondral and meniscal lesions. The incorporation of LET might add extra risks without substantial advantages. Consequently, assessing outcomes is crucial to advancing clinical practice and enhancing patients' quality of life.

Hypothesis and Objectives:

The hypothesis suggests that combining LET with revision ACLR using allografts or autografts can achieve favorable functional outcomes with minimal complications. The objectives include evaluating functional scores, assessing knee stability, examining complication rates, and determining the ability of patients to return to sports post-procedure.

Study Design

- Intervention: Observational
- Time: Prospective
- Comparison: Non-comparative

- Laboratory: Does not involve laboratory experimentation with animals or cadavers.
- International Study Registry: Not registered in an international study registry.
- Sample Calculation: n = 36(46) and n = 19(19), respectively
- Single-center/Multicenter: Single-center (HUVH and Clínica Corachan, respectively)

Results

In summary, the combined results of both articles indicate that revision ACLR with the addition of LET can lead to improvements in patient-reported functional outcomes. Specifically, significant enhancements were observed in IKDC, Lysholm, and SF-12 scores in both allograft and autograft cases. Stability tests (Lachman and pivot shift) also demonstrated improvements, hinting at enhanced rotational knee joint stability with LET.

However, revision ACLR with LET isn't without challenges and limitations. Notably, a significant number of patients developed concurrent lesions, highlighting the intricate nature of revision procedures. Complications, including anteroposterior instability, knee pain, and graft re-rupture, were observed in a subset of patients.

When it comes to resuming sports activities, the results varied between the two studies. In both groups, the percentage of patients who managed to return to their pre-injury sports performance level was reduced when compared to those same patients after their primary ACLR. In the allograft group, there was a lower rate of patients able to return to any level of sport participation. Conversely, in the autograft group, all athletes succeeded in resuming sports activities, albeit not necessarily at their original performance level.

Conclusions

The thesis demonstrates that augmenting revision ACLR with LET can lead to encouraging mid-term functional outcomes and enhanced knee joint stability. Both allografts and autografts, when used alongside LET, present potential for these positive results. Allografts emerge as a viable option for patients with less physically demanding lifestyles or when autografts are not feasible. Active, younger patients choosing autografts may anticipate a

higher chance of returning to their pre-injury sports level, though this is influenced by associated injuries, the nature of the sport, and initial performance level. However, the existence of simultaneous lesions and possible complications emphasize the complexity and constraints of this approach. Therefore, a comprehensive evaluation of patient attributes, expectations, and possible complications becomes vital when contemplating revision ACLR with LET. These insights provide useful direction for clinical decision-making and subsequent patient care.

RESUMEN

Introducción:

Esta tesis explora la pregunta crucial de si la combinación de la tenodesis extra-articular lateral modificada de Lemaire (LET, por sus siglas en inglés) puede ofrecer resultados favorables y mínimas complicaciones en la reconstrucción de ligamento cruzado anterior (ACLR, por sus siglas en inglés). Se investigan dos poblaciones distintas. Primero, se analiza la influencia de LET y los aloinjertos en una población general, centrada en mejorar la estabilidad rotacional. En segundo lugar, se evalúa la posibilidad de un regreso al deporte en atletas jóvenes tras el procedimiento con autoinjertos y LET. Estos estudios emplean un diseño prospectivo, con periodos de seguimiento de uno y dos años, respectivamente.

Justificación científica:

La ACLR de revisión puede ser desafiante debido a la inestabilidad crónica y las lesiones condrales y meniscales asociadas. La incorporación de LET podría añadir riesgos adicionales sin ventajas sustanciales. Por lo tanto, evaluar los resultados es crucial para avanzar en la práctica clínica y mejorar la calidad de vida de los pacientes.

Hipótesis y objetivos:

La hipótesis sugiere que combinar LET con ACLR de revisión usando aloinjertos o autoinjertos puede lograr resultados funcionales favorables con mínimas complicaciones. Los objetivos incluyen evaluar escalas funcionales, comprobar la estabilidad de la rodilla, examinar las tasas de complicaciones y determinar la capacidad de los pacientes para regresar al deporte después del procedimiento.

Diseño del estudio

- Intervención: Observacional
- Tiempo: Prospectivo

- Comparación: No comparativo
- Laboratorio: No implica experimentación de laboratorio con animales o cadáveres.
- Registro de estudio internacional: No registrado en un registro de estudio internacional.
- Cálculo de muestra: n = 36(46) y n = 19(19), respectivamente
- Unicéntrico/Multicéntrico: Unicéntrico (HUVH y Clínica Corachan, respectivamente)

Resultados:

En resumen, los resultados de ambos artículos señalan que la ACLR de revisión complementada con LET, conduce a mejoras notables en los resultados funcionales. De manera específica, se apreciaron mejoras importantes en las puntuaciones de las escalas IKDC, Lysholm y SF-12, tanto en los casos que emplearon aloinjertos como en los que se utilizaron autoinjertos. Las pruebas de estabilidad (Lachman y pivot shift) también demostraron resultados superiores, sugiriendo una mejora en la estabilidad rotacional de la articulación de la rodilla con LET.

Sin embargo, la ACLR de revisión con LET no está exenta de desafíos y limitaciones. En particular, un número significativo de pacientes desarrolló lesiones concurrentes, destacando la complejidad inherente de los procedimientos de revisión. Se observaron complicaciones, incluyendo inestabilidad anteroposterior, dolor en la rodilla, y re-ruptura del injerto, en un subconjunto de pacientes.

En cuanto a la reanudación de las actividades deportivas, se vieron variaciones entre ambos estudios. En ambos grupos, el porcentaje de pacientes que lograron regresar a su nivel de rendimiento deportivo previo a la lesión se redujo en comparación con esos mismos pacientes después de su ACLR primaria. En el grupo de aloinjertos, hubo una menor tasa de pacientes capaces de regresar a cualquier nivel de práctica deportiva. Por el contrario, en el grupo de autoinjertos, todos los atletas lograron reanudar las actividades deportivas, aunque no necesariamente en su nivel de rendimiento previo.

Conclusiones:

La tesis demuestra que complementar la ACLR de revisión con LET puede llevar a resultados funcionales a medio plazo alentadores y mejorar la estabilidad de la articulación de la rodilla. Tanto los aloinjertos como los autoinjertos, cuando se aumentan con LET, presentan estos resultados positivos. Los aloinjertos emergen como una opción viable para pacientes con estilos de vida menos exigentes físicamente o cuando los autoinjertos no son factibles. Los pacientes jóvenes y activos que eligen autoinjertos pueden anticipar una mayor posibilidad de regresar a su nivel deportivo previo a la lesión, aunque esto está influenciado por lesiones asociadas, la modalidad del deporte y el nivel de rendimiento inicial. Sin embargo, la existencia de lesiones simultáneas y posibles complicaciones enfatiza la complejidad y las limitaciones del procedimiento. Por lo tanto, una evaluación exhaustiva de las características del paciente, las expectativas y las posibles complicaciones se vuelve vital al contemplar la ACLR de revisión con LET. Estos hallazgos proporcionan una dirección útil para la toma de decisiones clínicas y la atención al paciente posterior.

1. INTRODUCTION

1.1 Revision of the anterior cruciate ligament reconstruction

Anterior cruciate ligament reconstructions (ACLR) are one of the most common surgical procedures, with more than 200,000 anterior cruciate ligament (ACL) tears occurring annually. With modern arthroscopic techniques, good patient-reported outcomes have been typically reported[1,2], and the rate of failure after ACLR remains low, with a reported failure rate of 3–14%[3-9]. Failures include graft rupture, structural failure, and functional failure with residual instability and pivoting in the setting of an intact graft. Consequently, several thousand revision ACLR are performed annually and are unfortunately associated with inferior clinical outcomes, unplanned readmission, and surgical complications[10-12].

Patients undergoing revision ACLR are not only subject to increased failure rates but also present associated injuries with increased frequency. A recent prospective cohort study showed that after revision ACLR, 38% of patients met subjective failure criteria, while only 20% of patients undergoing primary ACLR met subjective failure criteria[13]. Data from the Multicenter Orthopaedic Outcomes Network (MOON) and Multicenter ACL Revision Study (MARS) groups demonstrated meniscal and cartilage injury in 90% of patients at the time of revision ACLR, and these patients had a 1.7 times greater risk of Outerbridge grade 3 or 4 cartilaginous lesions than patients undergoing primary ACLR[14,15]. Additionally, Chen et al. found that patients undergoing multiple revision ACLR had lower activity scores, increased risk of chondral injuries in the patellofemoral and medial compartments, and a high rate of non-traumatic, recurrent graft tears[16]. Various studies have demonstrated that patient-reported outcomes, activity levels, and return to sport (RTS) rates are worse after revision ACLR when compared to primary procedures[17,18].

While both primary and revision ACLR surgery with modern techniques improve functional outcomes in many patients, there is still a margin for improvement and much to be learned. Moreover, there appear to exist subgroups of patients in whom addressing rotational laxity may be indicated in order to improve clinical results further.

1.2 The anterolateral complex: anatomic and biomechanical considerations

One contributing reason for inferior outcomes of revisions ACLR could be the inability of the conventional revision and reconstruction to restore normal knee rotational kinematics reliably. Few anatomic regions in the orthopaedic world have been as highly debated as the anterolateral side of the knee. In 1879, Segond was the first to describe the eponymous fracture associated with injury to these structures[19]. He described a pearly band remaining attached to the fracture fragment. Kaplan detailed the layers and attachments of the iliotibial band (ITB) to the femur, further enhancing our understanding of this complex area[20]. He was also the first to coin the term anterolateral ligament (ALL); however, he had instead attributed it to a segment of the ITB[20]. The subsequent literature is fraught with overlapping nomenclature for various structures to add to the perplexity of this inherently complicated anatomical site[21-25]. Vieira et al. were the first to describe the anterolateral ligament (ALL) as a separate entity[25]. The rediscovery of the ALL by Claes et al. reignited much controversy and research into this topic[26]. They identified the ligament in 40 of the 41 dissected specimens and thoroughly described its structure. Interestingly, they found that it lacked connections to the overlying ITB but had a robust meniscal attachment[26]. Dodds et al. and Kennedy et al. have since published further descriptions of the ALL, describing the femoral attachment to be proximal and posterior to the FCL origin[27,28]. Helito et al., in their histological study, demonstrated the ALL to have a well-organized and dense collagenous structure similar to ligaments[29].

The recent International ALC Consensus Group Meeting[30] yielded several important conclusions regarding the anatomy and function of the ALC. It was determined that the ALC consists of the superficial and deep aspects of the iliotibial tract, along with its Kaplan fiber attachments on the distal femur, and the anterior arm of the short head of the biceps. Additionally, the ALC includes the ALL, which is a capsular structure within the anterolateral capsule. Thus, it is understood that the ALC plays a crucial role in providing anterolateral rotatory stability as a secondary stabilizer to the ACL.

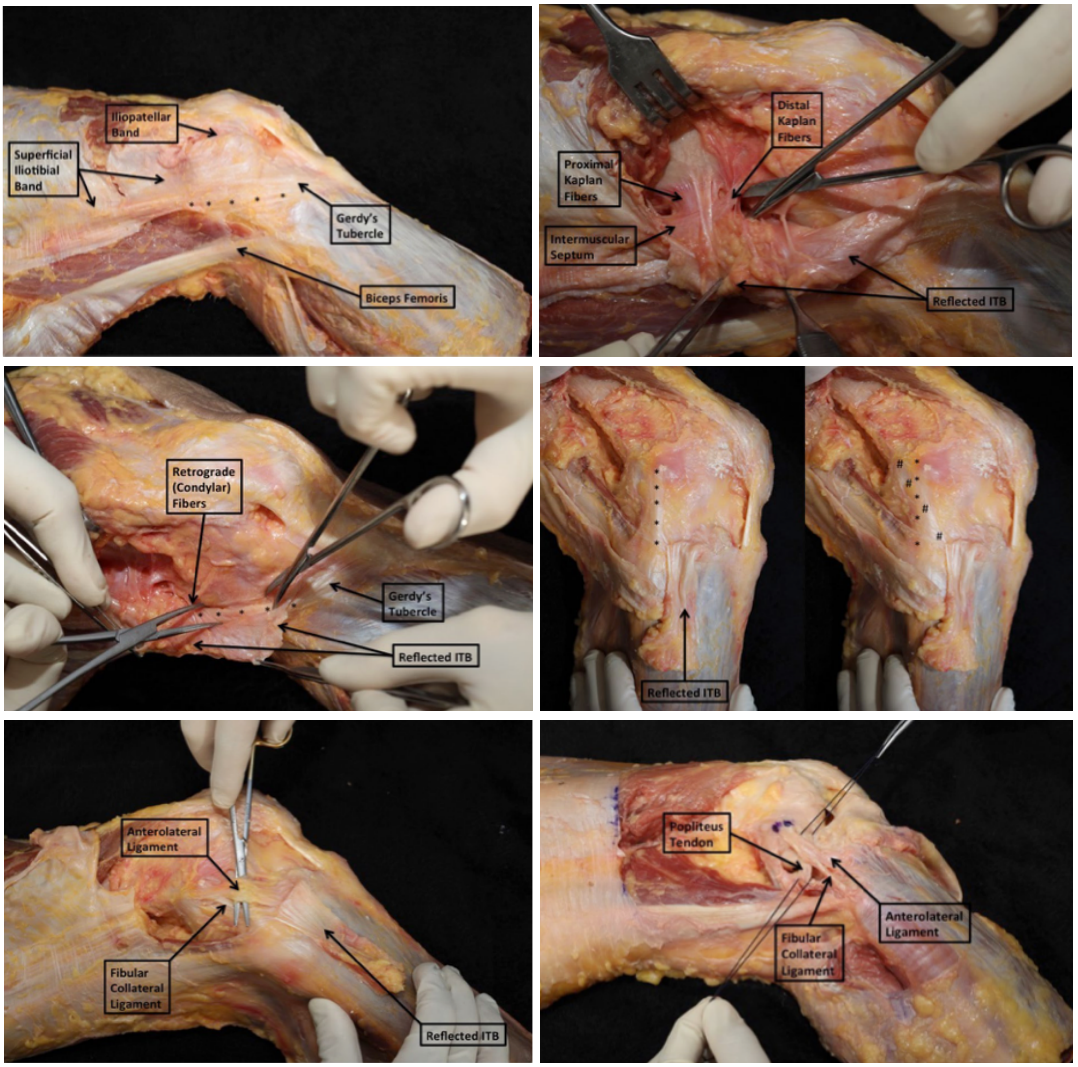

Figure 1. Anatomical dissection images highlighting key structures within the anterolateral complex of the knee. Adapted from "The anterolateral complex of the knee: results from the International ALC Consensus Group Meeting" authored by Getgood A, Brown C, Lording T, et al., published in 2019 Jan;27(1):166-176. Used with explicit permission from Springer Nature.

Cadaveric biomechanical studies have been published evaluating the kinematics of the knee following sectioning of the ALC structures. Transecting the ALL in ACL-deficient knees has significantly increased both anterior translation and internal rotation during the early phases of the pivot shift[31]. In addition, navigation studies evaluating dynamic pivot shift in ACL/ITB-deficient and ACL/LCL-deficient knees have shown significantly increased internal rotation laxity[32]. Thein et al. performed a serial sectioning study that demonstrated that the ALL only engaged in load sharing when the physiological limits of the ACL were surpassed. They concluded that the ALL acted as a secondary stabilizer only after the loss of the ACL[33].

Furthermore, Huser et al. performed a simulated pivot shift and showed that isolated ALL sectioning in ACL intact knees did not increase tibiofemoral compartment translation. They also concluded that the ALL is not a primary restraint to the pivot shift[34]. This same group subsequently performed another study demonstrating that the ALL and ITB sectioning in ACL-deficient knees transformed 71% of the cadavers into a grade 3 pivot shift. Concluding that isolated ACLR cannot restore normal knee kinematics when combined ACL and ALL injuries are present[35]. In this scenario, only combined ACL and lateral extra-articular procedures could return kinematics to normal.

1.3 The rationale for lateral extra-articular tenodesis as an augmentation to an intra-articular revision of the anterior cruciate ligament reconstruction

Although the cause of rotational instability after ACLR is multifactorial, adding a lateral extra-articular procedure is based on its ability to restrict rotational instability[36]. Various lateral extra-articular tenodesis (LET) procedures were introduced over 40 years ago. These methods were developed as the biomechanical understanding of ACL injury improved, specifically the lack of anterolateral rotational stability in an ACL-deficient knee[37].

For the past few years, there has been a renewed growing interest in performing LET as an adjunct procedure to address rotational instability better and improve overall outcomes[38]. Augmenting with a LET in the case of revision ACLR is attractive, particularly if no causative factor for failure was identified. This would allow the surgeon to address residual rotational instability that may have been a cause of the failure. Furthermore, it allows the LET to shield the revision graft from excessive stress during the initial incorporation period[39] by reducing graft strain as much as 43%[40].

Herbst et al. evaluated the role of augmentation of ACLR with LET in knees with and without ALC deficiency. When an ACLR was performed, they found that adding a LET provided no further benefit in isolated ACL-deficient knees. Conversely, LET was required in the combined injuries to restore normal knee kinematics. Therefore, it can be deduced that it is vital to identify ACL deficiencies in which a combined ALC injury may have occurred[41].

Several studies have shown that an isolated ACL injury is mainly unlikely in a knee exhibiting high-grade laxity. Instead, coexisting meniscal and ALC injuries are usually encountered, supporting the need for a combined ACLR and ALL reconstruction[42].

Table 1. Indications for a lateral extra-articular tenodesis (LET) procedure in revision ACLR.

Author	Year	High Grade Pivot Shift (2+ or 3+)	Revision without technical error	Collision or Pivot Sports	Combined ALC injuries
McGuire et al.[44]	2000	+	+		
Ferretti et al.[45]	2007	+	+		
Magnussen et al.[46]	2011	+	+	+	
Vadala et al.[47]	2013	+			
Saragaglia et al.[48]	2013	+		+	
Dejour et al.[49]	2013	+			
Trichine et al.[50]	2014	+			
Helito et al.[51]	2015	+	+		
Kernkamp et al.[52]	2015	+	+		
Hirahara et al.[53]	2016	+	+		+
Chala et al.[54]	2016	+	+		
Sonery-Cottet et al.[55]	2016	+		+	+

ALC Anterolateral capsule ACLR Anterior cruciate ligament reconstruction

Currently, no consensus exists for the addition of a LET to a revision ACLR; however, some commonalities are found in the literature[43], which include high-grade pivot shift (2+ or 3+), revision without a technical error, collision or pivot sports and combined ALC injuries (see Table 1). Other indications are Segond fracture, positive Dial Test, chronic ACL injury and lateral femoral notch sign[43,49,55].

1.4 Graft choice in revision of the anterior cruciate ligament reconstruction

The choice of graft for ACLR has since the start of ACL surgery been a key factor for both surgical technique and the expected clinical outcomes. The three categories of grafts are autograft, allograft, and synthetic graft. Autografts usually consist of either hamstrings tendon (HS), bone patella tendon-bone (BPTB), or quadriceps tendon (QT), but also iliotibial tract and peroneus longus autograft have seen limited usage. Allografts are varied but can

consist of tibialis posterior tendon, Achilles tendon, tibialis anterior tendon, BPTB, and peroneus longus tendon. Synthetic grafts were highly popular in the infancy of ACL reconstruction in the 1980s and 1990s. But catastrophic outcomes and severe adverse effects led to these grafts being completely abandoned two decades ago. However, recently new synthetic grafts have been introduced both as complete grafts as the Ligament Augmentation Reconstruction System (LARS®; Corin, Gloucestershire, England) or as augmentations to ACL reconstructions or repairs (Internal Brace®, Arthrex, Naples, USA)[56].

While autografts are largely the most commonly used grafts in primary ACLR, the use of allograft is appealing particularly due to the complete lack of donor site morbidity, good availability, and a range of graft sizes with the options of bone blocks attached to the graft[56]. Allografts become an excellent alternative in cases of second and third revision, being the selected choice in 20–51% of revision cases[57,58].

In a recent study, the Multicenter ACL Revision Study (MARS) group demonstrated that the surgeon is the most important factor in revision ACLR graft choice[59]. Other significant factors driving the choice for an allograft were: prior use of autograft, older age, concurrent MCL, posteromedial corner repair, non-traumatic failure, and the female gender[58,59].

Allograft material does come with its own unique risks including risk of microbiological disease transmission and is an expensive option compared to autografts. Other disadvantages with the use of an allograft include the immunogenic response of the host to the graft and delayed graft incorporation when compared to the autografts[60]. A histological study assessing allografts retrieved during autopsy at 2 years after implantation demonstrated poor vascularization in the center portion of the graft, which had remained acellular[61]. Thus, unlike previous reports of good incorporation of allograft at 18 months[62], this study shows that graft incorporation might take 3 years or more[61].

Revision rates with allograft used for primary ACLR reported in the USA in high patient volume registry studies from the MOON and MARS groups and the Kaiser Permanente ACL registry demonstrating crude revision rates from 3.6 to 10%[6,63]. Certain populations, specifically young patients under 21 years, were demonstrated to have an increased risk of

revision when reconstructed with an allograft with revision rates of 13%[63]. Similarly in the MOON cohort the revision rate for allograft in 20-year-old patients was found to be 10 times higher compared to BPTB autograft with revision rates of 2.5% and 25% for BPTB and allograft respectively[64,65]. In the MARS group, patients with allografts were 2.78 times more likely to sustain a subsequent graft rupture than patients treated with autograft[58].

Three categories of patients seem to emerge as the “best candidates” for allograft: (i) those needing ACL revision surgery, where further use of autografts could lead to high relevant donor site morbidity; (ii) those affected by complex instability, where there could be need of reconstructing other functional structures beyond the ACL[66]; (iii) those with clinical and radiologic signs of autologous tendon degeneration (i.e., patellar of hamstring tendinopathy) may face an increased risk of suboptimal outcomes if autografts are employed.

1.5 Return-to-sport in revision of the anterior cruciate ligament reconstruction

Most ACL injuries occur during sports participation[67]. Therefore, most athletes who undergo ACLR and revision surgery aim to return to their pre-injury sport at a similar level of performance and in the absence of further injury. However, it has become apparent that many athletes only sometimes attain these goals. Rates of RTS are often lower than expected, and younger athletes are at considerable risk of sustaining multiple ACL injuries[68].

An initial systematic review investigating RTS rates after ACLR surgery showed that 82% of patients returned to some form of sport, and only 63% participated at their pre-injury level at follow-up[67]. These return rates contrasted with the finding that 90% of patients rated normal or nearly normal on impairment-based measures. This review was subsequently updated, and similar rates were noted; 65% returned to the pre-injury level of sport, and 55% returned to competition sport[69]. Grassi et al. reported on revision ACLR and found that the rate of RTS at any level to be only slightly lower at 85.3%, while at pre-injury was achieved in 53.4% of cases. Not surprisingly, 93% had a normal or nearly normal rotatory laxity (normal or grade I pivot shift test). Grade II-III pivot shift only corresponded to 7% of patients, and the heterogeneity of the studies included can explain this, where many associated ALL

reconstruction or LET to RACLR[70]. Moreover, Glogovac et al. found similar RTS rates at any level, ranging from 56% to 100%. Pre-injury-level return to sport varied greatly from 13% to 69%. Lastly, the average time to return to sports ranged from 6.7 to 12 months[71]. Perhaps expected, elite-level athletes have the highest return rates, whereby 83% return to their pre-injury sport[72], followed by younger-aged athletes, in whom it has been reported that 81% return to competition sport[73]. Despite higher return rates in some select groups, the overall message is that a RTS is not guaranteed following ACLR and revision surgery.

Many factors influence an individual's RTS after primary and revision ACLR, including demographics, social characteristics, and surgical and rehabilitation factors[71,74]. Empirical data shows that males have a 10% higher return rate, and younger athletes can have up to 30% higher return rates[67,68]. A positive psychological response and higher motivation levels during rehabilitation have also been associated with higher pre-injury RTS[75-78]. It is also highly relevant to consider the role of patient expectations, and work in this area has shown that for a first ACL injury, over 80% of patients expect to be able to return to their previous level of the sport[79,80]. As this is higher than return rates, many athletes will not realize their goals and may need support and advice to readjust their expectations.

1.6 Introduction to compendium of publications

This doctoral thesis comprises two articles that investigates the use of LET (modified Lemaire), as a supplemental treatment for patients undergoing revision ACLR.

The first article examines the combined use of allografts and LET to enhance rotational stability and improve functional outcomes within a general patient population. The research evaluates the effectiveness of this treatment approach, aiming to contribute significantly to our understanding of its safety and potential benefits.

The second article, focusing on young athletes who have undergone revision ACLR using autografts and LET, investigates the rates of RTS. Recognizing the critical importance of RTS in this patient demographic, this part of the study aims to provide realistic expectations and a more comprehensive understanding of patient recovery following this procedure.

Both articles strive to enrich our knowledge of revision ACLR treatment alternatives and recovery trajectories, emphasizing the potential role of LET and the use of different graft types.

2. HYPOTHESIS

I. The inclusion of LET, both in the allograft and autograft scenarios, should be frequently considered in revision ACLR due to the higher occurrence of concomitant lesions and chronic instability. Incorporating LET is anticipated to improve overall knee stability and functional outcomes in these patients, leading to improved postoperative results.

II. The combined use of allografts and LET (modified Lemaire) in revision ACLR is a safe and effective option, resulting in satisfactory patient-reported functional scores, improved rotational stability of the knee joint, a low complication rate, and a high rate of return to activity. Allografts supplemented with LET should be considered as a viable choice, particularly for patients with a history of multiple ACLR and rotational instability.

III. In a group of young and active athletes undergoing revision ACLR using autografts (BPTB) combined with LET (modified Lemaire), reasonable rates of RTS similar to those observed after primary ACLR can be expected. The addition of LET is anticipated to provide enhanced stability, reduce the risk of re-injury, and enable a larger number of athletes to resume their pre-injury level of sports performance. Moreover, satisfactory patient-reported functional scores and a low complication rate are also expected in this population.

These hypotheses provide valuable insights into the role of LET in revision ACLR, anticipating positive outcomes in terms of functional scores, RTS rates, and a reduced risk of complications. They support the augmentation with LET in appropriate patient populations.

3. OBJECTIVES

Main Objective:

I. Examine the efficacy of incorporating LET (modified Lemaire) in revision ACLR surgeries. The objective is to evaluate whether the integration of LET enhances knee stability and functional outcomes among patients undergoing revision ACLR, ultimately resulting in improved postoperative results.

Secondary Objectives:

II. Assess the effectiveness of allografts and LET (modified Lemaire) in enhancing rotational stability and functional outcomes in revision ACLR. This objective aims to determine the efficacy of these techniques in improving rotational stability and overall functional outcomes in patients undergoing revision ACLR.

III. Investigate the rate of return to sport for athletes who underwent revision ACLR using autografts (BPTB) in combination with LET (modified Lemaire). This objective aims to understand the impact of this procedure on the successful return to pre-injury sporting activities. It assesses the timeline and level of sports activities achieved after surgery and compares the RTS rate with that after the primary ACLR in the same group of patients. Furthermore, evaluate mid-term functional outcomes, subjective knee function, patient satisfaction, complication rates, and associated lesions in patients who underwent revision ACLR using autografts (BPTB) and LET.

4. COMPENDIUM OF PUBLICATIONS

4.1 First Article

Minguell Monyart J, Moreira Borim F, Revertè Vinaixa MM, Portas-Torres I, Pijoan Bueno J, Castellet Feliu E, Joshi Jubert N.

Allografts and lateral extra-articular tenodesis for revision anterior cruciate ligament reconstruction: enhanced rotational stability and improved functional outcomes.

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ORIGINAL ARTICLE

Allografts and lateral extra-articular tenodesis for revision anterior cruciate ligament reconstruction: enhanced rotational stability and improved functional outcomes

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Abstract

Purpose Multiple studies have shown higher failure rate and patient-reported outcomes to be significantly worse following revision anterior cruciate ligament reconstructive (ACLR) surgery, especially using allografts. One of the reasons being rotational instability. Because of this, augmentation with lateral extra-articular tenodesis (LET) is often considered. Good short-term results in regards to functional and perceived scores and low complication rate can be expected in revision ACLR using allografts in combination with LET.

Methods Between 2014 and 2021, 46 patients were registered for revision ACLR using allografts and extra-articular augmentation (modified Lemaire) and included in this prospective study. Patients' demographic and clinical data were collected preoperatively, postoperatively, and during the follow-up period of 12 months.

Results Patient-reported functional outcomes were statistically significant for IKDC, Lysholm, and SF-12 physical scale ($p < 0.05$). Tegner score showed a decreased number of patients who were able to return to sport at their previous level ($p = 0.001$). Stability examination tests (Lachman and pivot-shift) showed significant improvements. Concomitant lesions were present in 76.1% of patients. Ten patients (21.7%) presented major complications, including six cases of anteroposterior instability, three cases of knee pain and one graft re-rupture.

Conclusion Revision procedures are inherently challenging with a high number of associated chondral and meniscus lesions. However, good short-term functional outcomes and enhanced rotational stability with an acceptable complication rate can be expected in most cases where revision ACLR using allografts is augmented with LET.

Study design Prospective; Case series; Level of evidence IV.

Keywords Anterior cruciate ligament · Allografts · Tenodesis · Rupture · Knee

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Introduction

Reconstruction of the anterior cruciate ligament (ACLR) is one of the most common surgical procedures, with a reported failure rate of 3–14% [1]. Patient outcomes are less favorable when failures occur, and they undergo revision procedures. These procedures have higher failure rates, complications, and poor functional outcomes [2, 3]. Several factors, including recurrent instability, stiffness and pain, may lead to less-than-expected results [4].

Although the cause of rotational instability after revision ACLR is multifactorial, adding an extra-articular procedure is based on its ability to restrict rotational laxity [5]. Patient satisfaction, overall knee function, return to sports, and functional scores appear to correlate more with the restoration of

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rotational stability than with translational stability, making it a critical short-term to mid-term goal [6, 7]. The limited body of evidence has shown that adding soft tissue procedures may lower the risk of graft re-rupture rates and improve outcomes [8]. Additionally, graft choice for revision ACLR remains controversial. Autografts have been reported to have improved patient-reported outcomes and decreased graft re-rupture rate [3, 9]. Despite this, allografts are the selected choice in 20–51% of revision cases [3, 10], while several specific details of allografts in revision ACLR cases, such as type of tendon, sterilization method, and complications, are still missing in the literature [11].

In recent years, many studies [5, 7, 8, 12] have advocated for the critical role in rotational stability and possibly graft protection of concomitant revision ACLR and lateral extra-articular tenodesis (LET). Nevertheless, only some authors [13, 14] have prospectively evaluated and reported their results regarding objective and subjective outcomes, complications, and re-ruptures rates, none using allografts. Therefore, an analysis, specifically looking into those outcomes after combined revision ACLR using allografts and LET with a minimum follow-up of 12 months, is warranted. We hypothesized that the described combination leads to good short- to mid-term outcomes and does not have specific complications.

Material and methods

Patient recruitment and follow-up assessment

This study was approved by Hospital Universitari Vall d'Hebron's Ethics Committee, and patients signed informed consent before being included. All patients who underwent revision ACLR using allografts and modified Lemaire LET between November 2014 and November 2021 were screened for eligibility for this prospective study. Inclusion criteria were (1) age above 18 years and capable of giving consent for study participation; (2) patients with ACLR graft rupture diagnosed by clinical symptoms and physical exam, confirmed by magnetic resonance images (MRI). Exclusion criteria included (1) concomitant ligament injuries or coronal plane deformity; (2) incomplete follow-up and clinical data.

Patients' demographic, clinical and radiological data were collected preoperatively, postoperatively, and during the follow-up period until 12 months postoperatively. The assessment included International Knee Documentation Committee (IKDC) score, Lysholm Knee Score, Tegner activity scale (TAS), and Short-Form Health Survey (SF-12) physical and mental. In addition, range of motion and ligament instability was assessed using the Lachman and pivot-shift test, and concomitant lesions found in radiological and arthroscopic evaluation during the primary and revision surgery were recorded.

Surgical technique

Combined spinal anesthesia with regional nerve blockade was used. A preliminary arthroscopic inspection was performed to help diagnose and treat associated meniscal and chondral injuries. Furthermore, the size of the intercondylar fossa is evaluated, and notchplasty and osteophyte removal are done if needed to avoid impingement. Progressive drilling of the tibial and femoral tunnels with cannulated drills of different sizes until completing the debridement of the previous graft site was done. Fresh-frozen allografts were prepared; suspension systems were used for femoral fixation (TightRope® RT; Arthrex, Naples, FL); interferential screw (Biocomposite®; Arthrex, Naples, FL) and ligament staple were used for a hybrid fixation on the tibia. Lastly, a modified Lemaire LET was performed.

Patients were offered a two-stage surgery (1) if tunnel widening was so significant on both the tibia and femur that one-stage bone grafting is not feasible, usually enlarged over 14-16 mm; (2) malpositioned, which could result in tunnel overlapping; (3) arthrofibrosis; or (4) local infection. The two-stage procedure involved an initial bone grafting procedure, or in the case of infection, multiple debridements followed by bone grafting, and then an incorporation phase of 20–24 weeks, allowing the bone graft to fully heal before the subsequent second stage; CT scans at 5–6 months were performed to confirm correct incorporation.

Rehabilitation

For the first 4–6 weeks, walking with partial weight bearing was allowed using two crutches. Patients were encouraged to perform complete knee flexion and extension. Closed kinetic chain exercises and the use of a balance board to regain proprioception were performed for the first three months, and thereafter, open kinetic chain exercises were started. Noncontact sports were permitted after 3–4 months, and a return to contact sports was allowed after 5–6 months.

Statistical analysis

Statistical analysis was performed with statistics 26 (IBM SPSS® Statistics). Categorical variables were described with their absolute values and percentages. Quantitative variables were presented by their measures of central tendency (mean and standard deviation). Preoperative and postoperative tests were compared using paired *t* tests. Differences with p-values < 0.05 were considered statistically significant.

Table 1 Demographic and primary graft failure characteristics of the included patients

Patient data[1]	
Sex (female/male)	15 (32.6%)/31 (67.4%)
Side (right/left)	24 (52.2%)/22 (47.8%)
Average age (SD)	36.3 (9.72)
Number of Stages (one-stage/two-stages)	34 (73.9%)/12 (26.1%)
Primary graft failure	
Median time (in months)[2]	58 (14.3)
One-stage	55 (12.3)
Two-stage	69 (18.1)
Cause of primary ACLR failure	
Traumatic event	17 (36.9%)
Technical errors	5 (10.7%)
Unknown[3]	24 (52.2%)

[1]Expressed as the number of patients and (percentage). [2]Expressed in months and (SD). [3]Patient did not refer to any traumatic event, nor any technical reason for failure error was detected. ACLR: anterior cruciate ligament reconstruction

Results

Forty-six patients were registered for revision ACLR using allograft and LET (modified Lemaire) and prospectively followed. Demographic and primary graft failure characteristics are summarized in Table 1. Grafts used for the primary and revision surgery are registered in Figs. 1 and 2.

Concomitant lesions were present in 76.1% of patients and are summarized in Table 2. Partial meniscectomy was performed in sixteen cases (34.8%). Notchplasty was performed in thirteen cases (28.3%) due to intercondylar notch impingement.

Twelve months after the revision procedure, the functional improvement was statistically significant for Lysholm, IKDC, and SF-12 physical scales. There were no significant differences for SF-12 mental ($p=0.160$). Tegner Activity Scale (TAS) has shown a statistically significant reduction in the activity level ($p=0.001$). There were no professional athletes in this series, and two patients (4.3%) were associated

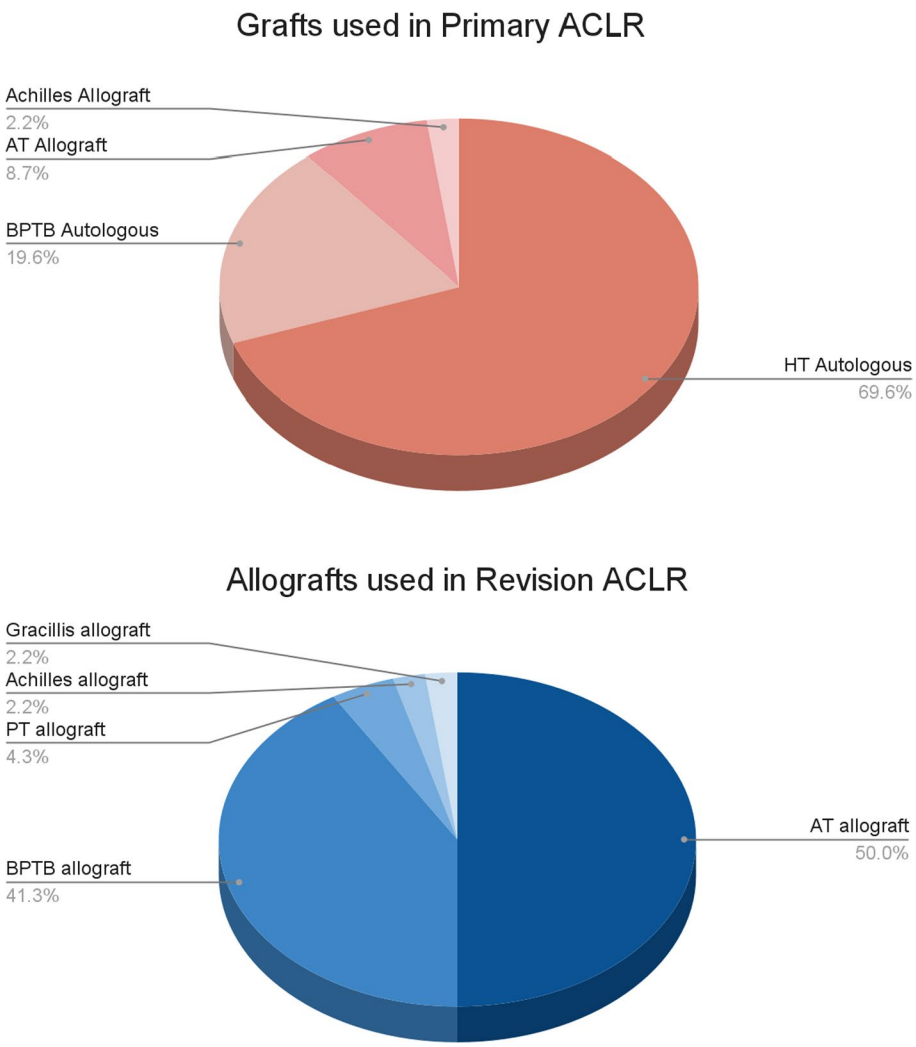

Fig. 1 and 2 Pie charts of the grafts used in primary and revision anterior cruciate ligament reconstructions (ACLR). AT: anterior tibialis; BPTB: bone-patellar tendon bone; HT: hamstrings; PT: posterior tibialis

Table 2 Table with intraoperative findings of concomitant lesions

Concomitant lesions	Number	Percentage (%)
Chondral lesion (medial, lateral and femoropatellar)	22	47.8
Meniscus lesion (medial, lateral)	28	60.9
Chondral and meniscal (both)	15	32.6
Chondral or meniscal (any lesion)	35	76.1
No chondral nor meniscus lesion	11	23.9

with a player's federation and played regularly on a weekend basis. Results are summarized in Table 3.

Improvement in flexion was statistically significant ($p = 0.001$), but the differences in extension were not ($p = 0.058$). See Table 3. There was a clear improvement on all stability examination tests at the one-year follow-up. During the preoperative period, thirty-four patients (73.9%) had a Lachman ≥ 2; this was the case for only six patients (13%) one year down the line ($p = 0.024$). Forty (86.9%) patients had ≥ 1 preoperative pivot-shift, being the case for only four (8.7%) after one year ($p = 0.001$). See Fig. 2 for the comparison.

Twenty cases (43.5%) presented some complications. Ten patients (21.7%) presented major complications, including anteroposterior laxity, pain, and graft failure. Minor complications accounted for twelve cases (26.1%), including acute complications such as hemarthrosis, superficial infections, and material discomfort. Anteroposterior laxity (Lachman ≥ 2) was considered a failure. Despite this, patient satisfaction and functional outcomes remained reasonable, and no savage procedure was necessary. Pain was associated with chondral and meniscus lesions in all three cases, and osteoarthritis was also seen in these patients at follow-up. One of the cases of pain due to osteoarthritis was a patient who undertook a two-stage procedure with poor results and later went on to a conversion total knee arthroplasty. The one case of detected graft failure was attributed to an initially repaired multi-ligamentous injury, requiring a second revision procedure with modest results obtained after it. See Table 4.

Discussion

The most important findings of this study are that patients undergoing revision ACLR procedures using allografts and LET, after a one-year follow-up, had significant improvements on Lysholm, IKDC, and SF-12 physical scales. Improved residual rotatory laxity grants good short-term follow-up results with minimum re-rupture rates and acceptable rates of postoperative complications. Conversely, TAS showed a decreased level of activity. Residual anteroposterior laxity, detected by the Lachman test, appeared unrelated to poor outcomes and the need for revision (Fig. 3).

Table 4 Summarized major and minor complications

Major complications	
AP laxity (Lachman ≥ 2)	6 (13%)
Pain (Osteoarthritis)	3 (6.5%)
Graft failure and revision	1 (2.2%)
Minor complications	
Hemarthrosis	9 (19.6%)
Material discomfort	2 (4.3%)
Superficial Infection	1 (2.2%)

AP Anteroposterior

Table 3 Patient-reported outcomes summary and comparison preoperatively and after 12 months

	Preoperative	12 month follow-up	*p*
Patient-reported			
Lysholm[1]	27.26 (18.33)	81.57 (20.04)	0.001
TAS[2]	6.46 (1.88)	3.89 (1.73)	0.001
IKDC[3]	49.19 (13.63)	67 (18.11)	0.001
SF-12 physical[4]	43.5 (8.97)	47.81 (10.08)	0.034
SF-12 mental[4]	47.99 (11.35)	51.21 (10.31)	0.160
Clinical evaluation			
ROM[5]	131.56° (90°–150°)	120.54° (60°–140°)	0.001
Level of activity	Same sport, same level	Same sport, lower level	Another sport, lower level
	5 (10.87%)	25 (54.34%)	16 (34.78%)

Values for outcomes are expressed as mean and (SD). ROM is expressed as mean and (range). Level of Activity is expressed in numbers of patients and (percentages). [1]Lysholm Knee Scoring System. [2]Tegner Activity Scale. [3]International Knee Documentation Committee subjective knee form. [4]Short Form (12) Health Survey. [5]Range of Movement

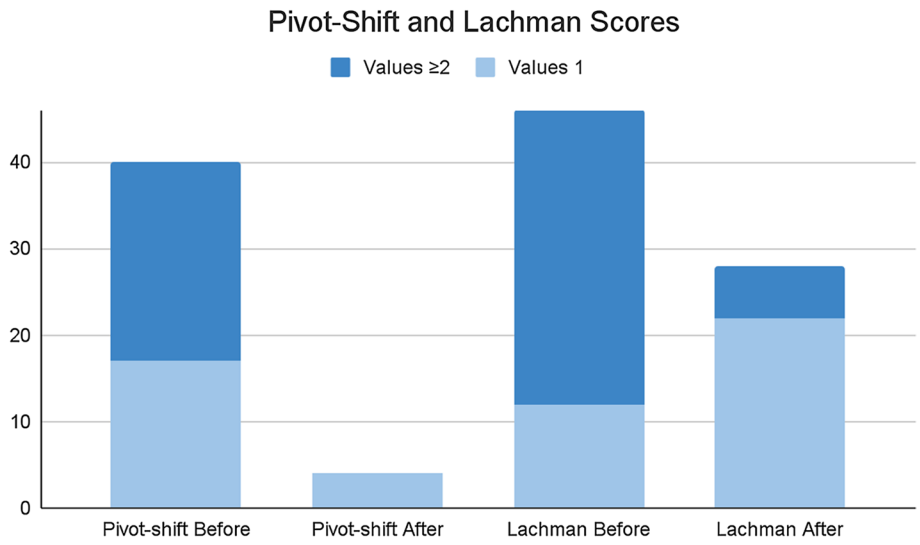

Fig. 3 Column chart comparing pivot-shift test Lachman test scores before and after 12 months from the intervention. Values of 0 for both Lachman and pivot-shift tests were excluded from the chart for clarity

Graft choice remains controversial and thought to be implicated among the causes of revision ACLR failure [11]. Autografts have been reported to have improved sports function, patient-reported outcome measures, and decreased graft re-rupture rate at 2-year follow-up [3, 9]. Despite this, allografts are still selected in 20–51% of revision cases [3, 10], with significant improvement rates reported [11, 15, 16]. Fresh-frozen allografts offer the advantages of decreased operative times and lower morbidity, addresses the problem of limited availability of donor tissue in multiple revision cases, and in the case of bone-patellar tendon-bone (BPTB) and Achilles tendon, a bone-block can be harvested, allowing initial bony fixation and addressing the void from the index tunnel. Possible disadvantages include the risk of disease transmission, immune rejection, delay in the remodeling, and prolonged integration process [17]. Legnani et al. reported similar subjective and objective outcomes at 5.2-year follow-up when autografts and allografts were compared [15]. Grassi et al. have found autografts to have better outcomes than allografts in revision ACLR, with lower postoperative laxity and rates of complications and re-operations. However, if only non-irradiated allografts were considered, the outcomes would be similar to autografts [7]. We advocate for fresh-frozen allografts and believe that graft choice is predominantly influenced by two factors: previous graft(s) used and surgeon preference. Moreover, it is also affected by other factors, including patient preference and tunnel dilatation. The mean age of our case series was 36. 30 years, donor-site morbidity was of concern, and there was an overall low physical activity demand and sports participation in this group of patients. Graft choice in our series has gone initially from BPTB allografts with its bone stock advantage. Later, after detecting this bone stock as insufficient, we opted for tibialis anterior (TA) allografts due to their technical ease when using suspension systems with the all-inside technique.

Persistent rotatory knee laxity is increasingly recognized as a common finding after ACLR (Musahl, 2017). While the reasons behind rotator knee laxity and graft failure are multifactorial, the impact of the anterolateral knee structures appears significant. More and more studies are finding lateral augmentation to be a common indication in this scenario, with good results showing low residual rotatory laxity, low complication rate, favorable results for Lysholm, IKDC, and KOOS scores, and lowering the risk of graft re-rupture rates [7, 8, 18]. Important insights regarding extra-articular-plasty in managing failed ACLR have been provided by a few studies, such as Trojani et al., who reported a significantly higher rate of negative pivot-shift when lateral tenodesis was performed compared to isolated revision surgery [19], something similar seen in our series. Lateral augmentation procedures have shown significant heterogeneity between studies [20]. Since results across the various series published have been similar, we believe that more important than the specific lateral augmentation technique is to correctly control rotational laxity while minimizing the chances of technical errors. We have opted for a modified Lemaire LET because it is a tried and tested technique that has demonstrated to reduce anterolateral rotatory laxity and to be graft-protective [14, 21, 22].

Three studies have explicitly looked into revision ACLR and LET using modified Lemaire LET [13, 14, 23], but none used allografts. Botto et al. retrospectively reviewed eight young patients who engaged in contact sports. They stated that adding a LET helps to control rotational stability decreasing the risk of graft overstretching and re-rupture rates [23]. Lefevre et al. prospectively compared the return-to-sport rate between primary ACL reconstruction and revision surgery (fifty-five patients in this second group). They

found a return-to-sport (RTS) rate of return of 87.3% for revisions. RTS at the same level showed much lower values at 12.7%. Comparatively, in our study, thirty-nine patients (84.8%) were able to RTS at a recreational level, and only five (10.9%) returned to the same sport and the same level [13]. Furthermore, Porter et al. reported that LET could neutralize persistent grade II or III rotatory laxity after isolate revision ACLR and reduce internal rotation and anterior translation using computer navigation [14]. Our results were similar; we noticed a clear improvement overall on all stability examination tests at the 12-month follow-up. During the preoperative period, forty patients had ≥ 1 preoperative pivot-shift, being the case for only four patients (8.7%) with an assessable pivot-shift of 1 after one year. Moreover, systematic reviews investigating extra-articular augmentation of ACLR have not demonstrated a reduction in rotatory laxity to be correlated with patient-reported outcome measures [21, 24]. In our case, we observed an overall improvement in stability examination tests and patient-reported scales. However, we cannot affirm it to be solely attributable to LET since correlation does not mean causation.

Since allografts have a prolonged integration process and delayed remodeling [11], LET can provide additional stability and protection against graft re-rupture during these first phases. The notion that LET may be graft-protective has previously been demonstrated by Engebretsen et al., who showed that the forces going through the ACL graft might be reduced by 43% in vitro [22]; we believe this to be crucial for the case of allograft integration in revision scenarios. Further clinical studies must be performed to understand this concept better. Only some studies have reported on allografts and LET. They advocate for the over-the-top technique, highlighting its advantage of avoiding the femoral tunnel altogether, permitting a one-stage surgery with improvements in objective and subjective scores, good RTS, and an acceptable rate of complication and failure [25, 26].

Revision ACLR procedures are known to be significantly more challenging and to present meniscal and cartilage injury in nearly 90% of patients [27]. In our case, 76.1% of all the patients had some concomitant lesions, including meniscus tears in twenty-nine patients (56.9%) and chondral lesions in twenty-four patients (47%). Surgeons must address this high prevalence of associated lesions, apprising patients of these issues before deciding on a revision procedure so that expectations can be realistic.

The complication rate in revision ACLR studies confirms the safety of combining an extra-articular procedure with intra-articular revision ACLR [7, 8]. In our series, the 21.7% complication rate was higher when compared to the 8–10% usually reported. Mainly because we considered anteroposterior laxity detected by Lachman's test ≥ 2 (13%) to be a major complication. Despite this, patient satisfaction and functional outcomes remained favorable for these patients.

This study presents some limitations. First, it is non-comparative, with the inherent biases of this type of study. Second, our cohort is small with consistent losses, which limits its statistical power and, therefore, the generalizability of the results. Third, the outcomes are not evaluated with objective measurements, with subjective tests and scales, with 12-month follow-up. However, our study provides information on using allografts combined with LET for revision ACLR, while most studies use autografts.

Conclusions

The use of allografts for ACL revision surgery is a safe and valid option, yielding satisfactory results regarding functional patient-reported outcomes with acceptable rates of complications. Allografts should be considered, especially in patients with low physical activity demand and when autografts cannot be safely chosen. The association of LET does not seem to increase complication rate while improving rotational stability and may be graft-protective.

Author contributions JMM, MRV, JPB, ECF, and NJJ were responsible for surgical operations and for the revision of the final manuscript for publication. FMB and IPT were responsible for maintaining the database, compiling information, writing and revising the manuscript. MRV and JPB were also responsible for the statistical analysis. All authors read and approved the final manuscript.

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Declarations

Conflict of interest Authors declare no conflicts of interest.

Consent to participate Every patient has signed an informed consent to participate in this study.

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4.2 Second Article

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Good rates of return-to-sport in athletes after revision anterior cruciate ligament reconstruction using autologous patellar tendon and lateral extra-articular tenodesis: a 2-year follow-up prospective study.

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ORIGINAL ARTICLE

Good rates of return-to-sport in athletes after revision anterior cruciate ligament reconstruction using autologous patellar tendon and lateral extra-articular tenodesis: a 2-year follow-up prospective study

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Abstract

Background Most athletes who undergo revision of the anterior cruciate ligament reconstruction (ACLR) aim to return to their preinjury sport at a similar level of performance while minimizing the risk for reinjury. Additional lateral extra-articular tenodesis (LET) has recently been correlated with improved outcomes and low complication rate. Yet, there are few series evaluating return-to-sport (RTS) and clinical outcomes after revision ACLR using bone-patellar tendon-bone (BPTB) and LET in athletes.

Methods The study cohort consisted of 19 eligible athletes who had undergone their first revision ACLR using BPTB and LET (modified Lemaire) between January 2019 and 2020. Patients were prospectively followed and interviewed in a sports activity survey during a 2-year follow-up.

Results Despite all patients returning to sports after revision ACLR surgery, 52.6% resumed playing at their preinjury level. Furthermore, patient-reported functional outcomes improved significantly following revision surgery, as evidenced by improvements in IKDC [64.4 (± 12) to 87.8 (± 6)], Lysholm [71.27 (± 12) to 84.2 (± 9.7)], and SF-12 scales [Physical: 53.3 (± 3) 57 (± 1.2); Mental: 50.2 (± 3.3) to 52.7 (± 2.4)]. One case (5.3%) experienced persistent pain and underwent reoperation for a partial meniscectomy.

Conclusion After revision ACLR using autologous BPTB and LET, all active individuals are expected to RTS, similar to primary ACLR. The difference comes down to returning to the preinjury level, where the levels are lower depending on the sport and initial level of play. Good mid-term functional outcomes with a low complication rate can be expected in most cases.

Study design Case series; Level of evidence IV.

Ethical Committee Approval Number PR(ATR)79/2021 and HCB/2023/0173.

Keywords Anterior cruciate ligament · Autografts · Tenodesis · Revision · Knee

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Introduction

Reconstruction of the anterior cruciate ligament (ACLR) is one of the most common surgical procedures, with a reported failure rate of 3–14% [1]. Patient outcomes are less favourable when failures occur, and they undergo revision procedures. These procedures have higher failure rates, complications, and poor functional outcomes [2, 3]. Most athletes who undergo revision ACLR aim to return to their preinjury sport at a similar level of performance while minimizing the risk of reinjury. However, for many, these goals are not always attained. Return-to-sport (RTS) rates after revision ACLR have a relatively high rate of RTS at any level (56–100%) but a relatively low rate of RTS at the preinjury level of play (13–69%) [4, 5].

Several factors, including recurrent instability, stiffness, and pain, may lead to less-than-expected results and prevent athletes from RTS [5]. Although the cause of rotational instability after revision ACLR is multifactorial, adding an extra-articular procedure is based on its ability to restrict rotational laxity [6]. Patient satisfaction, overall knee function, RTS, and functional scores appear to correlate more with the restoration of rotational stability than with translational stability, making it a critical short-term to mid-term goal [7, 8]. The limited body of evidence has shown that adding soft tissue procedures may lower the risk of graft re-rupture rates and improve overall outcomes [9]. Furthermore, compared to allografts, autografts have improved sports function, patient-reported outcome measures, and decreased graft re-rupture rate at a 2-year follow-up [3, 10].

In recent years, several studies [8, 11–22] have emphasized the crucial role of simultaneous revision ACLR using an autologous graft and LET in improving rotational stability and graft protection. Despite these findings, the scientific evidence remains highly heterogenous, with variations in patient selection, graft type, and surgical technique. To date, no study has specifically examined the RTS of athletes following revision ACL using concomitant autologous bone-patellar tendon-bone (BPTB) and LET (modified Lemaire), with a minimum follow-up of 2 years. Therefore, it is imperative to conduct a thorough analysis that primarily examines the assessment of RTS while also taking into account the clinical outcomes and potential complications that may arise in athletes who undergo this procedure. Our hypothesis suggests that by adopting this approach, we can anticipate positive outcomes in the short to mid-term, with good rates of RTS and minimal complications.

Material and methods

Patients recruitment and follow-up assessment

This study was approved by Hospital Universitari Vall d'Hebron and Hospital Clínic de Barcelona Ethics Committee, and patients signed informed consent before being included. All patients who underwent revision ACLR using autologous BPTB and modified Lemaire LET between January 2019 and January 2020 were screened for eligibility for this prospective study. Inclusion criteria were (1) age above 16 years and capable of giving consent for study participation; (2) patients with ACLR graft rupture diagnosed by clinical symptoms and physical exam, confirmed by magnetic resonance images (MRI); (3) Tegner Activity Scale Level ≥ 6 before primary ACL rupture and before primary ACLR. Exclusion criteria included (1) concomitant ligament injuries or coronal plane deformity; (2) incomplete follow-up and clinical data.

Patients' demographic, clinical and radiological data were collected preoperatively, postoperatively, and during the follow-up period until 24 months postoperatively. Patients were asked to complete a sports activity survey. The assessment included Tegner Activity Scale (TAS), International Knee Documentation Committee (IKDC) score, Lysholm Knee Score, and Short-Form Health Survey (SF-12) Physical and Mental. Concomitant lesions were recorded in radiological (radiographs, CT and MRI) and arthroscopic evaluation during the primary and revision surgery.

A total of 23 consecutive patients were initially screened; three were excluded for failing to meet the inclusion criteria; one case had an incomplete follow-up. At 24 months follow-up, 19 patients (men, n = 9; women, n = 10; mean age 27.7 years; SD 7.2) were available for follow-up. Two patients underwent a 2-stage revision and were also included.

Twenty-four-month outcome data for the cohort are available in the Appendix.

Surgical technique

Combined spinal anaesthesia with regional nerve blockade was used. All patients were assessed under anaesthesia for ROM, Lachman, Pivot Shift, LCL, MCL, and pulse exams. A preliminary arthroscopic inspection was performed to help diagnose and treat associated meniscal and chondral injuries. Furthermore, the size of the intercondylar fossa is evaluated, and notchplasty is done if needed to avoid impingement. Progressive drilling of the tibial and femoral tunnels with cannulated drills of different sizes

until completing the debridement of the previous graft site was done. BPTB autografts were prepared, usually 10 × 25 mm bone plugs; suspension systems were used for femoral fixation (TightRope® RT; Arthrex, Naples, FL), interferential screw (Biocomposite®; Arthrex, Naples, FL) and ligament staple were used for a hybrid fixation on the tibia (see Fig. 1). Lastly, a modified Lemaire LET was performed [23].

Patients were offered a two-stage surgery (1) if tunnel widening was so significant on both the tibia and femur that one-stage bone grafting is not feasible, usually enlarged over 14–16 mm; (2) malpositioned, which could result in tunnel overlapping; (3) arthrofibrosis or (4) local infection. The two-stage procedure involved an initial bone-allografting procedure and LET. Then an incorporation phase of 20–24 weeks, allowing the bone graft to heal before the subsequent second stage; a CT scan at 3–4 months was performed to confirm correct incorporation.

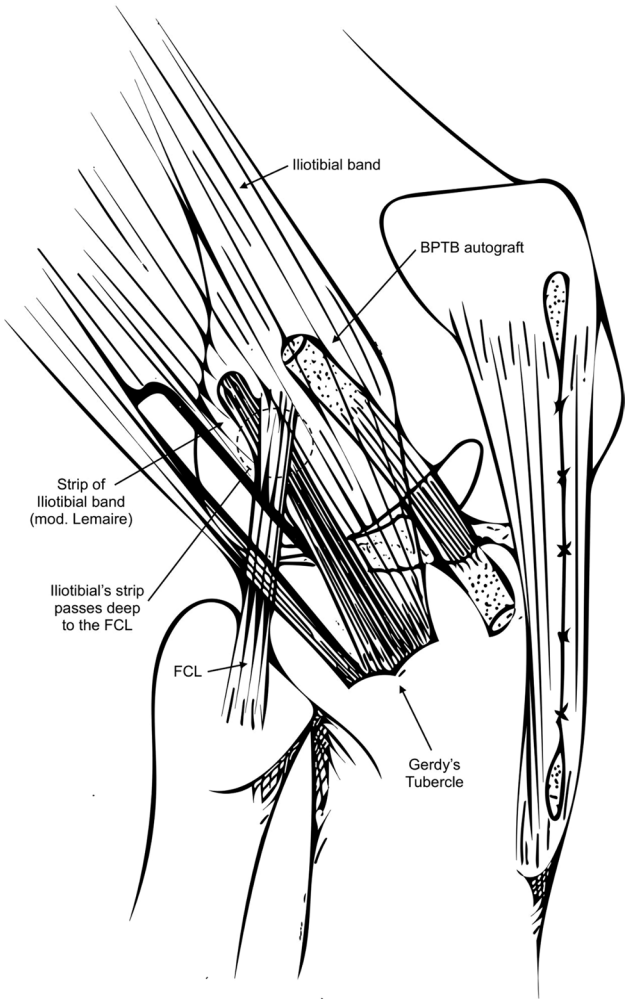

Fig. 1 Schematic drawing of the lateral aspect of a right knee demonstrating a revision anterior cruciate ligament reconstruction (ACLR) using a bone–patellar tendon–bone autograft and a lateral extra-articular tenodesis procedure (modified Lemaire), with the iliotibial band autograft passed deep to the fibular collateral ligament (FCL), oriented with a 30° anterior angle in the axial plane and 30° proximal in the coronal plane

Rehabilitation

For the first 4–6 weeks, walking with partial weight bearing was allowed using two crutches. Patients were encouraged to perform complete knee flexion and extension. Closed kinetic chain exercises and the use of a balance board to regain proprioception were performed for the first three months, and after that, open kinetic chain exercises were started. To authorize RTS, we considered physical and psychological aspects. In general, sports activities are allowed after a period of 9 months, but it is important to prioritize functional criteria when deciding to engage in them.

Statistical analysis

Performed with Statistics STATA/IC 15.1 (StataCorp®). Categorical variables were described with their absolute values and percentages. Quantitative variables were presented by their measures of central tendency (mean and standard deviation). Preoperative and postoperative tests were compared using paired Mann–Whitney U tests. Differences with p values < 0.05 were considered statistically significant.

Results

Table 1 provides a summary of the demographic data for the cohort of athletes who underwent revision ACLR using autologous BPTB and LET. Although all patients were able to return to some level of sports activity, the rate of return to preinjury level of sport was lower after the revision procedure. Out of the nineteen athletes, only ten (52.6%) were able to return to their preinjury level of sport, which is in contrast to the fifteen (79%) who were able to do so after primary reconstruction.

The majority of athletes (79%) participated in contact sports such as basketball and football, with only a few (15.8%) participating in noncontact sports like cycling and athletics, and one athlete (5.3%) involved in collision sports (rugby). Two professional athletes (10.5%) were included in the cohort, one of them did return to her preinjury level after the primary procedure, but not after the revision. The majority of patients (68.4%) were affiliated with a player's federation and engaged in regular sport. Age did not appear to have a significant influence on the return-to-sport (RTS) rate. Interestingly, the RTS rate for women was slightly higher (77.8%) than for men (55.6%). When selecting sports to participate in after revision

Table 1 Demographic data and concomitant lesions of the included patients (n = 19)

Patient data				
Sex, n (%) Female/male	10 (52.6%)		9 (47.4%)	
Side, n (%) Right/left (%)	14 (73.7%)		5 (26.3%)	
Age, y (SD)*	29.8 (± 7.5)			
Number of Stages, n (%) One-/two-stages	17 (89.5%)		2 (10.5%)	
Concomitant lesions	Primary ACLR		Revision ACLR	
	n	%	n	%
Chondral lesion (medial, lateral and femoropatellar)	1	5.3	2	10.5
Meniscus lesion (medial, lateral)	6	31.6	9	47.4
Chondral or meniscal (any lesion)	7	36.9	11	57.9
No chondral nor meniscus lesion	12	63.1	8	42.1

Expressed as the n and (percentage). *Expressed in mean and (± SD)

ACLR anterior cruciate ligament reconstruction

ACLR, most patients opted for noncontact sports like padel (42.1%) and cycling (26.1%), with all of them also attending a gym for general fitness. Additionally, patients were asked to indicate the main reason why they did not return to their previous level of sport from among four categories, with knee-related reasons, such as pain or instability, only corresponding to 26.3% of the cases. Table 2 provides an overview of the RTS results. The mean time to return to sport was 10.3 months (as shown in Fig. 2).

The functional improvement of patients was assessed using various scales. The IKDC score increased from 64.4 (± 12) to 87.8 (± 6), while the Lysholm score increased from 71.27 (± 12) to 84.2 (± 9.7). The SF-12 scale also showed significant improvement in both the Physical (from 53.3 ± 3 to 57 ± 1.2) and Mental (from 50.2 ± 3.3 to 52.7 ± 2.4) domains. However, the Tegner Activity Scale demonstrated a significant decrease in activity level from 7.2 (± 1) to 6.6 (± 1.1). An overview of these results can be found in Table 3.

In addition, 57.9% of patients had concomitant lesions, which is a higher proportion than the 36.8% observed in the same group of patients who underwent primary ACLR. Table 1 provides a summary of the associated lesions. Notchplasty was performed in 6 cases (31.6%) due to intercondylar notch impingement.

Major complications accounted for one case (5.3%) of residual pain, where a partial meniscectomy was later performed. Minor complications accounted for 3 cases (15.8%), which included one case of hemarthrosis and two cases of material discomfort (see Table 1). Despite this, patient satisfaction and functional outcomes remained high, and no savage procedure was necessary. There were no cases of anteroposterior and rotational laxity detected (Lachman and Pivot-Shift tests) or reported by the patients. There was one case of contralateral primary ACL rupture.

Discussion

The main finding of this cohort was that the addition of a LET to an autologous BTPB revision ACLR provides improved rates of RTS, patient-reported functional outcomes and minimal complications. Although all athletes did return to some level of play, only ten out of nineteen athletes (52.6%) could return to their preinjury level after a 2-year follow-up. Significant improvements were seen on Lysholm, IKDC and SF-12 Physical and Mental scales. When comparing the revision to the primary reconstruction, there was a notable increase in the prevalence of meniscus and osteochondral injuries, with the percentage rising from 36.9 to 57.9%. The rate of complications remained low, with only one case (5.3%) experiencing residual pain and reoperation for a partial menisectomy. To date, few studies have analysed the results of revision ACLR and LET [12–22], with differences in graft type and surgical technique. Furthermore, selecting a uniform group of patients presents a challenge. In an effort to achieve homogeneity, we carefully established our inclusion criteria.

This study presents some limitations. First, it is noncomparative, with the inherent biases of this type of study. Second, our cohort is small despite no consistent losses, and it has limited statistical power and, therefore, generalizability of the results. Third, the outcomes are not evaluated with objective radiological measurements, but with subjective tests and scales, with 24-month follow-up. However, our study provides information on using a single type of

Table 2 Return to sport (RTS) outcomes summary and comparison (n = 19)

Tegner Activity Score (TAS)*				
Before ACLR		7.4 (± 1)		(6–10)
After ACLR		7.1 (± 1)		(6–10)
Revision ACLR		6.4 (± 1)		(5–10)
List of sports	After primary ACLR		After revision ACLR	
Basketball	10	(52.6%)	6	(31.6%)
Football	6	(31.6%)	2	(10.5%)
Tenis/Padel	1	(5.3%)	7	(36.8%)
Athletics	1	(5.3%)	1	(5.3%)
Rugby	1	(5.3%)	1	(5.3%)
Cycling	–	–	2	(10.5%)

Level of return to sport			
	Same sport, same level	Same sport, lower level	Another sport, lower level
Total	10 (52.6%)	6 (31.6%)	3 (15.8%)
< 25 y	4 (57.1%)	2 (28.6%)	1 (14.3%)
≥ 25 y	6 (50%)	4 (33.3%)	2 (16.7%)

Reasons for changing or stopping the preinjury sport played			
Job-related[a]	Personal reasons[b]	Knee-related[c]	Medical reasons[d]
5 (26.3%)	6 (31.6%)	5 (26.3%)	2 (10.5%)

Values for outcomes are expressed expressed as n and (%). *Expressed in mean and (± SD)

ACLR anterior cruciate ligament reconstruction

[a]Job-related included work-related constraints

[b]Personal reasons included personal preferences or interests that might have changed

[c]Knee-related included those directly related to the limitations after the surgery, such as pain or instability

[d]Medical reasons included other conditions or indications that could prohibit the return

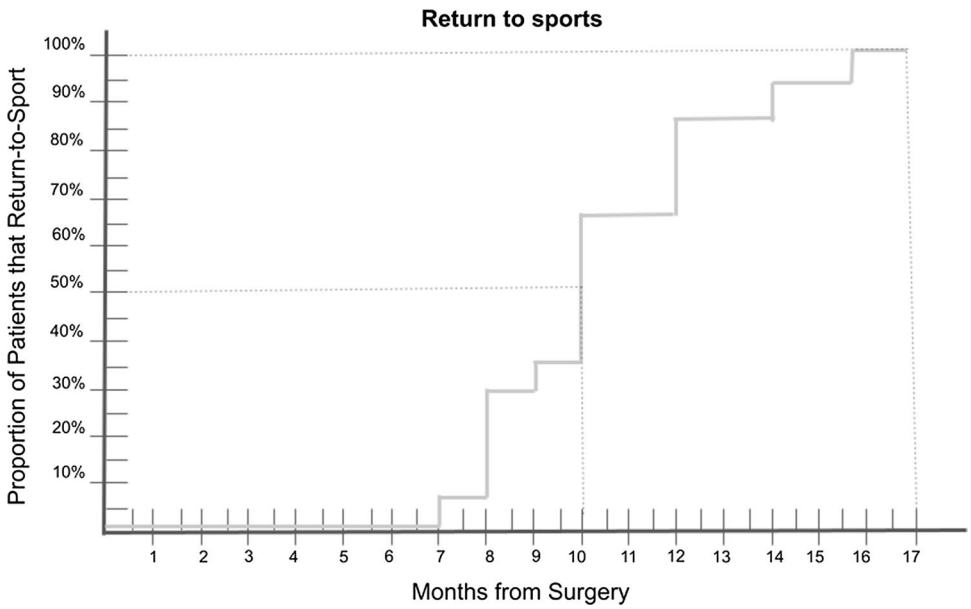

Fig. 2 The proportion of patients that return-to-sport (RTS), measured in time in months

Table 3 Patient-reported outcomes summary and comparison (n = 19)

Patient-reported outcome scales	Preoperative	24 month follow-up	*p* value
Lysholm[a]	64.4 (± 12)	87.8 (± 6)	0.0001
IKDC[b]	71.27 (± 12)	84.2 (± 9.7)	0.0005
SF-12 Physical[c]	53.3 (± 3)	57 (± 1.2)	0.0002
SF-12 Mental[c]	50.2 (± 3.3)	52.7 (± 2.4)	0.0025
TAS	7.2 (± 1)	6.6 (± 1.1)	0.0005

Expressed in mean and (± SD)

TAS Tegner Activity Scale

[a]Lysholm Knee Scoring System

[b]International Knee Documentation Committee subjective knee form

[c]Short Form (12) Health Survey

autograft combined with LET for revision ACLR in a very homogenous cohort.

There is a discrepancy between the rate of RTS at any level and the rate of return to sport to the preinjury level, which is more pronounced following revision ACLR [4, 5, 11]. Lefevre et al. (BTB/HS + extra-articular tenodesis with tensor fasciae latae tendon) compared RTS rates between patients who underwent primary ACLR and revision ACLR and found no significant difference in the rates of return to sport at any level between the two groups. However, the authors also found that athletes returned to their preinjury sport at a significantly higher rate after primary ACLR (64%) than after revision (49%) [12]. Similarly, in two recent systematic reviews, Grassi et al. reported that 53.4% (CI 37.8–68.7), and Glogovac et al. a range from 13 to 69%, of patients following revision ACLR had returned to the same sport at a preinjury level [4, 11]. Likewise, the rate of RTS at a preinjury level we saw in our cohort remained within that range at 52.3%. Table 4 summarises the results from the most important published studies on the subject to date.

There is undoubtedly significant heterogeneity in the results found in different studies [4, 11–22]. The reason for this is multifactorial but we believe it has a lot to do with the athletes' age, type of sport and initial level of play (elite, professional, or semi-professional). Our series was composed of professional and semi-professional athletes, and at a young age (median age 27.7 years). Younger age was associated with a higher rate of return to sport following revision ACLR in multiple studies [13–15]. When asked for reasons why they did not RTS at preinjury level only 26,3% attributed it "to the knee" and that it did not behave as well as before. Other reasons included personal reasons (31.6%), since the sport played did not represent the same importance in these patients' lives, professional reasons (26.3%) where work–life balance prohibited returning to the same training routines and 10.5% attributed to other medical conditions.

Many authors [6, 8, 9, 11–22] already advocate the critical role of adding an extra-articular procedure due to its ability to restrict rotational laxity [6]. Getgood et al. have recently found that adding LET to primary ACLR in young patients at high risk of failure results in a statistically significant reduction in graft rupture and persistent rotatory laxity two years after surgery. Some studies have looked into RTS after revision ACLR and LET [8, 11–22, 24], finding good functional outcomes, low rates of residual rotatory laxity, re-ruptures or complications. Louis et al. stated that combining ALL stabilization with revision ACLR improves functional outcomes by improving rotational stability without increasing the risk of early or late complications [24]. Alessio-Mazzola et al. [13] reported a RTS rate at preinjury level of 91.7% in professional soccer players and a mean time of return of 9.2 months. Similarly, we reported a 10.2 months mean time of return.

There are concerns about overtightening the lateral compartment during different LET techniques, which subsequently may lead to osteoarthritis [6, 9]. However, according to Declercq et al.'s comparison of modified Lemaire and Cocker-Arnold procedures, the choice of LET technique appears to have minimal impact on both clinical and radiographic outcomes [25]. In our series, we did not see any signs of overtightening or osteoarthritis.

There are inconsistent results in the literature regarding the impact of graft type on RTS outcomes [4, 11]. However, some reasons for favoring autografts are their improved patient-reported outcomes, RTS, and decreased graft re-rupture rate compared to allografts [3, 10]. Keizer et al. [26] retrospectively compared outcomes between patients with patellar tendon autografts and allografts, and after a follow-up of 2 years, the rate of RTS was 75% versus 43%, respectively. Shorter RTS times have also been reported [4, 11]. Moreover, Glogovac et al. [4] found that the studies that reported strictly patellar or hamstring tendon autografts demonstrated some of the highest rates of return to sport at preinjury levels (67–69%). In our case, unharvested BPTB has been our first choice for young and active patients, reserving contralateral grafts or allografts only in case of repeated revision, combined ligament reconstruction, or other particular extraordinary circumstances.

Revision ACLR procedures are known to be significantly more challenging and to present meniscal and cartilage injury in nearly 90% of patients [2]. In our case, 57.9% had some concomitant lesions. Minguell et al. has reported that a higher rate of concomitant lesions detected in revision ACLR was associated with reduced RTS at follow-up [27]. In addition, The rate of ACL re-rupture after a revision surgery is higher than the re-rupture rate after primary reconstruction [5]. Shelbourne et al. found a reinjury rate in the first 5 years after revision surgery that ranged from 2 to

Table 4 Summary from published studies on revisions ACLR using autologous grafts and LET: return to sport (RTS) and patient-reported functional outcomes

Authors	Year	Number of Patients	Autologous Graft, (%)	LET Technique	RTS Any Level, %	RTS Same Level, %	Time to Return, m	TAS	IKDC	Lysholm
Lefervre et al. [12]	2017	47 (n = 55)	HT (32.7%)/BPTB (52.7%)/ CFL (14.6%)	Lemaire	87.3	49.1	7.4 (±4.9)	–	–	–
								–	78.4 (16.6)	87.5 (12.9)
Alessio et al. [13]	2018	24	BPTB (79.9%)/HT (20.1%)	Coker–Arnold	100	91.7	9.2 (±2.2)	9.5 (±0.5)	69.5 (±11.1)	58.1 (±11.7)
								9.2 (±1)	88.4 (±8.9)	97.4 (±3.2)
Redler et al. [14]	2018	118	HT	Coker–Arnold	100	41.5	–	3.6 (±1.8)	70.3 (±8.4)	67 (±19.8)
								5.7 (±1.9)	85.7 (±12.3)	90 (±7.2)
Legnani et al. [15]	2019	9	HT	Coker–Arnold	–	78	–	6 (±2.8)	40.2 (±4.2)	62.2 (±3.4)
								6 (±3.2)	85.6 (±4.8)	87.9 (±7)
Legnani et al. [16]	2019	12	HT	Coker–Arnold	–	58		6	35.7 (±2.4)	60.8 (±4.7)
								6	84.8 (±6)	88.7 (±6.1)
Alm et al. [17]	2020	59	HT/BPTB/QT	Lemaire	–	–	–	–	60 ± 23	–
								7 ± 1.3	95 ± 10.8	90 ± 10.7
Ventura et al. [18]	2021	12	HT	Coker–Arnold	–	–	–	6	35.7 (SD: 2.4)	60.8 (SD: 4.7)
								6	84.8 (SD: 6.0)	88.7 (SD: 6.1)
Eggeling et al. [19]	2021	23	HT (39.2%)/BPTB (30.4%)/ QT (30.4%)	Lemaire	47.8	–	–	–	–	49.2 ± 28.1
								5.7 ± 1.3	77.5 ± 16.2	81.9 ± 14.2
Zanna et al. [20]	2022	17	BPTB	Coker–Arnold	94.1	58.8	–	–	71.4 (±9.03)	58.3 (±19.3)
								–	92 (±6.9)	66.8 (±27.7)
Rayes et al. [21]	2022	36	BPTB	Lemaire	86.1	61.1	–	–	54.4 (±17.5)	64.8 (±12.3)
								7.3	86.7 (±10.6)	92.8 (±10.5)
Keizer et al. [22]	2022	42	BPTB	Lemaire	52.3	30.9	–	–	–	–
								6	81.7 (±13.4)	–
Case series (for comparison)	2023	19	BPTB	Lemaire	100	52.6	10.3	7.1 (±1)	71.3 (±12)	64.4 (±12)
								6.4 (±1)	84.2 (±9.7)	87.8 (±6)

Values for outcomes are expressed as mean and (SD). Studies that didn't report on the use of autologous grafts and extra-articular augmentation (individually or by groups) were not included for comparison

TAS Tegner's Activity Scale, *IKDC* International Knee Documentation Committee, *Lysholm* Lysholm Knee Score, *LET* lateral extra-articular tenodesis, *HT* hamstrings tendon, *BPTB* bone–patellar tendon–bone, *CFL* combined fasciae latae

5% [28]. Our case series did not have any re-ruptures at the 2-year follow-up.

Conclusions

In conclusion, the rates of RTS at the preinjury level following revision ACLR using autologous BPTB and modified Lemaire LET are lower than those observed after primary ACLR. Nevertheless, it is important to note that the majority, if not all, of the patients can still expect to RTS at some level. Furthermore, patients can expect significant improvements in their patient-reported functional scales, including the IKDC, Lysholm, and SF-12; with a low complications rate.

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Author contributions JMM, MRV, JPB, and JVAP were responsible for surgical operations and for the revision of the final manuscript for publication. FMB was responsible for maintaining the database, compiling information, and writing and revising the manuscript. MRV and JPB were also responsible for the statistical analysis. All authors read and approved the final manuscript.

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Declarations

Conflict of interest The authors declare no conflicts of interest.

Informed consent Every patient has signed an informed consent to participate in this study.

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5. OVERALL SUMMARY OF RESULTS

I. Functional Outcomes:

Significant improvements were statistically observed in the Lysholm, IKDC, and SF-12, indicating enhanced functional outcomes resulting from the procedure. It is important to note, however, that a decrease in activity level was evident according to the TAS. This suggests that patients may be limited to less demanding physical activities following the combined procedure compared to both the index procedure and their pre-lesion state.

II. **Stability**:

Significant improvements in stability were observed in both studies through the administration of stability examination tests, including the Lachman test and pivot shift test. These findings strongly indicate that the combined procedure effectively enhances the rotational and anteroposterior stability of the knee.

III. **Return-to-sport rates**:

In the group of young athletes, the 24-month follow-up revealed that 52.6% were able to return to their preinjury level of sport. This return-to-sport rate stands in contrast to the lower rates seen in a normal population using allografts, where only 10.9% managed to resume the same sport at the same level. Additionally, it is worth noting that all young athletes successfully returned to sport, albeit at least at a lower level. In the first study, the majority of patients (84.8%) were able to participate in sports activities at a recreational level. Furthermore, knee-related limitations accounted for only 26.3% of the cases in which patients in the second study were unable to resume their sport at the same level. Other factors contributing to the inability to return to the same level of sport included job-related constraints, personal reasons, and medical factors.

IV. **Concomitant Lesions**:

Concomitant lesions were observed in a substantial proportion of cases in both studies, with rates ranging from 76.1% in the first study to 57.9% in the second study. These findings highlight the prevalence of these coexisting injuries, which undoubtedly have an impact on the complexity of revision procedures and in the final functional outcomes.

6. OVERALL SUMMARY OF THE DISCUSSION

The primary findings from both studies are that patients undergoing revision ACLR procedures using either allografts or autologous BPTB grafts and LET (Modified Lemaire) experienced significant improvements in Lysholm, IKDC, and SF-12 scales after a one and two year follow-up period. This resulted in low re-rupture rates, minimal postoperative complications, and improved patient-reported outcomes. However, certain factors such as graft type, presence of additional knee structures, patient age, type of sport, and level of play were identified to influence these outcomes.

Despite reports of better sports function, patient-reported outcomes, and decreased graft re-rupture rates with autografts, allografts are still selected in 20-51% of revision cases. The choice of allografts primarily addresses the issue of limited donor tissue availability, decreased operative times, and lower morbidity[56]. Despite potential disadvantages, including risk of disease transmission, immune rejection, delayed remodelling, and prolonged integration process, other studies[60,61] have reported similar outcomes with allografts when compared to autografts, especially non-irradiated ones[60].

Persistent rotatory knee laxity, a common finding after ACLR, has been linked to graft failure[38,42,52]. Lateral augmentation has been recognized as a beneficial technique to manage this issue[42], showing low residual rotatory laxity, low complication rate, and a reduction in graft re-rupture rates. A modified Lemaire LET is being adopted due to its effectiveness in reducing anterolateral rotatory laxity[42,70]. Notably, the use of LET might be particularly beneficial for allografts due to their prolonged integration process and delayed remodelling, offering extra stability during these phases[60,63].

Increased prevalence of meniscal and osteochondral injuries has been reported with revision ACLR[14,15], necessitating careful patient awareness about potential complications. Despite this, in both articles the rate of complications remained relatively low, and functional outcomes remained favorable.

Interestingly, RTS rates after revision ACLR were generally high (84.6% and 100%), but returning to pre-injury level of play was less common (10.9% and 52.6%). The discrepancy between these rates was specially due to different demographics. Furthermore, it may be attributed to personal reasons, changing professional demands, or other medical conditions. The role of extra-articular procedures in enhancing RTS outcomes has been highlighted in several studies[71-73], demonstrating its potential in improving rotational stability, functional outcomes, and reducing graft rupture rates.

Finally, both studies acknowledge some limitations including small cohorts, lack of objective radiological measurements, and the inherent biases of non-comparative studies. Regardless, these studies provide significant insights into the benefits of utilizing LET with either allografts or autografts for revision ACLR, a topic that has gained attention in the last few years. Future studies need to consider these factors to further our understanding of the best practices for revision ACLR.

7. CONCLUSIONS

I. LET has shown effectiveness as an adjunct procedure in both allograft and autograft revision ACLR, contributing to improved outcomes and knee stability, with minimal complications.

II. Revision ACLR using allografts augmented with LET (modified Lemaire) can lead to favorable mid-term functional outcomes and improved knee joint stability, making them a viable option for patients with lower physical activity demands or when autografts are not suitable.

III. Revision ACLR using BPTB autografts and LET (modified Lemaire) can result in favorable mid-term functional outcomes with an acceptable complication rate, making it a reliable option for patients requiring revision surgery.

IV. In young athletes, using autografts augmented with LET (modified Lemaire), a RTS rate of 100% is achievable. However, the ability to return to the pre-injury level of sport may vary based on the specific sport and initial level of play, and it is found to be around 50%. In the same group after a primary RLCA, the RTS is approximately 75%. Understanding the factors influencing successful return to sport rates, such as graft type, specific sport, and initial level of play, can assist in setting realistic expectations and facilitating informed discussions between healthcare providers and patients.

8. FUTURE RESEARCH LINES

I. **Comparative Studies**: Further comparative studies are necessary to compare the outcomes of revision ACLR using different graft options, including allografts with and without LET augmentation, to alternative surgical techniques and graft choices. These studies can provide valuable insights into the relative effectiveness and suitability of various approaches, aiding in the development of evidence-based recommendations for different patient populations.

II. **Long-term Follow-up**: The mid-term functional outcomes reported in this thesis (at one and two years, respectively) underscore the importance of long-term follow-up studies to evaluate the durability and longevity of the outcomes achieved with revision ACLR and LET. Conducting long-term assessments will provide crucial information on the maintenance of functional gains and knee joint stability over an extended period, enabling a more comprehensive evaluation of the procedure's long-term success.

III. **Patient-Specific Factors**: Given the differentiation between athletic and non-athletic populations in this study, further investigation into the influence of patient-specific factors and sport-specific requirements, can help tailor the surgical approach to individual patients. Recognizing that there is no one-size-fits-all solution for revision ACLR, understanding how these factors impact outcomes can facilitate personalized treatment planning and optimize patient satisfaction and functional recovery.

IV. **Rehabilitation Protocols**: Additional research is warranted to develop and evaluate optimized rehabilitation protocols specifically designed for patients undergoing revision ACLR and LET, depending on graft type. Exploring the timing, progression, and specific exercises or interventions that contribute to successful functional outcomes and RTS rates can refine rehabilitation strategies, enhance postoperative

recovery, and optimize patient outcomes.

V. **Complication Management**: Future investigations should prioritize identifying strategies to effectively address and manage the complications associated with revision ACLR and LET, especially using allografts. Given the high complication rate and the presence of chronic instability, innovative approaches are required to minimize the occurrence of complications and optimize patient safety and surgical outcomes.

Addressing these lines of future investigation will contribute to the refinement of surgical techniques, rehabilitation protocols, and patient selection criteria for revision ACLR and LET. This iterative process will ultimately improve patient outcomes and advance the management of ACL injuries, providing clinicians with evidence-based guidance to optimize surgical decision-making and rehabilitation strategies.

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10. ANNEXES

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Barcelona, 18 de maig de 2022

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