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Techniques for treating Anterior Cruciate Ligament tears - Current status of extra-articular techniques

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Techniques for treating Anterior Cruciate Ligament tears - Current status of extra-articular techniques

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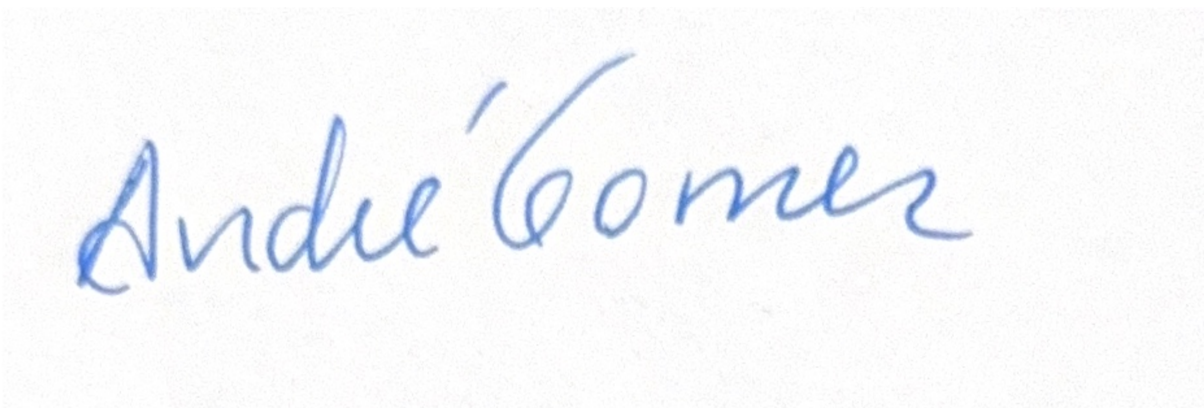

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A todos vocês, obrigado.

Resumo

Introdução: A lesão do ligamento cruzado anterior (LCA) representa uma das lesões de joelho mais prevalentes nos jovens atletas, com uma incidência de aproximadamente 74,6 lesões por 100 000 indivíduos, nos Estados Unidos da América. Embora as técnicas de reparação do ligamento cruzado anterior (ACLR) tenham evoluído consideravelmente ao longo do tempo, muitos pacientes continuam a apresentar instabilidade rotacional anterolateral residual (ALRI) após a cirurgia, o que pode resultar em resultados insatisfatórios relatados pelos pacientes e um aumento na taxa de falha do enxerto. A reintrodução de procedimentos extra-articulares laterais (LEAPs), incluindo tenodese extra-articular lateral (LET) e a mais recente reconstrução do ligamento anterolateral (ALLR), como adições à ACLR, transformou significativamente a prática clínica. Esta revisão bibliográfica examina as evidências atuais sobre a ACLR combinada com LEAPs para avaliar o seu papel no tratamento da instabilidade residual e na melhoria dos resultados dos pacientes.

Objetivos: O objetivo principal desta tese de mestrado é fornecer uma revisão bibliográfica da literatura que examina as abordagens atuais e emergentes para a reconstrução do LCA com aumento extra-articular lateral. Especificamente, esta revisão visa avaliar a segurança e a eficácia dessas técnicas e comparar os resultados entre diferentes métodos cirúrgicos para o tratamento de lesões do LCA.

Metodologia: Foi realizada uma pesquisa bibliográfica abrangente utilizando as bases de dados PubMed e Scopus, com foco em estudos que descreviam a anatomia, o desenvolvimento histórico, as propriedades biomecânicas e os resultados clínicos da ACLR e LEAPs. Os termos de pesquisa incluíram «Reconstrução do ligamento cruzado anterior», «Procedimentos extra-articulares laterais», «Tenodese extra-articular lateral» e «Reconstrução do ligamento anterolateral». Estudos publicados até março de 2026 foram incluídos se atendessem aos seguintes critérios: artigos escritos em inglês com níveis adequados de evidência científica e relevância clínica, qualidade metodológica aceitável e resultados clínicos relatados relacionados às opções terapêuticas para ACLR. Apesar de ter sido dada prioridade às publicações dos últimos 10 anos, artigos mais antigos considerados particularmente importantes para o tema também foram tidos em consideração. A avaliação dos artigos iniciou com uma análise dos títulos e resumos para avaliar a sua conformidade com os objetivos da revisão, seguida de uma revisão do texto completo para verificar a sua relevância. Os estudos mais relevantes identificados serviram como «artigos semente» na aplicação Litmaps para localizar as pesquisas mais pertinentes relacionadas com o tema. A aplicação Zotero® foi utilizada para gerir a literatura.

Resultados: A análise da literatura selecionada confirma que o ligamento anterolateral (ALL) atua como uma restrição secundária significativa à rotação tibial interna. A adição de LEAPs à ACLR está associada a uma redução estatisticamente significativa nas taxas de falha do enxerto. Na reconstrução do ACLR combinada com a LET reduz a taxa de falha de 11,1% para 3,9%, enquanto a reconstrução do ACLR combinada com a ALLR a reduz de 7,9% para 0,8% e a uma redução no fenómeno persistente de *pivot-shift*. A análise comparativa não sugere diferenças significativas nas taxas de falha entre LET e ALLR, embora o LET esteja associado a taxas mais elevadas de irritação do *hardware* e o ALLR a riscos técnicos, como a convergência do túnel. Além disso, os procedimentos combinados demonstram taxas mais elevadas de retorno ao desporto em comparação com a reconstrução isolada. As evidências apoiam a expansão das indicações para além dos atletas jovens, incluindo pacientes com mais de 30 anos e aqueles com cenários de revisão ou hiperlaxidez.

Conclusão: As evidências atuais apoiam o uso de LEAPs como uma adição segura e eficaz para ACLR, particularmente para pacientes de alto risco. Esses procedimentos combinados reduzem significativamente o risco de rutura do enxerto e restauram a estabilidade rotacional sem aumentar o risco de osteoartrite do compartimento lateral a médio prazo. Embora a complexidade técnica seja maior, os benefícios clínicos na prevenção de novas lesões justificam seu uso em populações específicas. Pesquisas futuras devem-se concentrar em dados de segurança a longo prazo e na padronização das indicações cirúrgicas.

Palavras-chave: Reconstrução do ligamento cruzado anterior; Procedimentos extra-articulares laterais; Ligamento anterolateral; Instabilidade rotacional; Falha do enxerto.

Abstract

Introduction: Anterior cruciate ligament (ACL) injury represents one of the most prevalent knee injuries among young athletes, with an incidence of approximately 74,6 injuries per 100 000 individuals, in the United States of America. While techniques for anterior cruciate ligament reconstruction (ACLR) have evolved considerably over time, many patients continue to experience residual anterolateral rotatory instability (ALRI) following surgery, which can result in poor patient-reported outcomes and an increased rate of graft failure. The re-emergence of lateral extra-articular procedures (LEAPs), including lateral extra-articular tenodesis (LET) and the newer anterolateral ligament reconstruction (ALLR), as additions to ACLR has significantly transformed clinical practice. This bibliographic review examines the current evidence regarding ACLR combined with LEAPs to evaluate their role in addressing residual instability and improving patient outcomes.

Objectives: The primary objective of this master's thesis is to provide a bibliographic review of the literature examining current and emerging approaches to ACL reconstruction with lateral extra-articular augmentation. Specifically, this review aims to evaluate the safety and effectiveness of these techniques and compare outcomes between different surgical methods for treating ACL injuries.

Methodology: A comprehensive literature search was conducted using PubMed and Scopus databases, focusing on studies that described the anatomy, historical development, biomechanical properties, and clinical outcomes of ACLR and LEAPs. Search terms included "Anterior cruciate ligament reconstruction," "Lateral extra-articular procedures," "Lateral extra-articular tenodesis," and "Anterolateral ligament reconstruction”. Studies published up to March 2026 were included if they met the following criteria: articles written in English with appropriate levels of scientific evidence and clinical relevance, acceptable methodological quality, and reported clinical outcomes related to therapeutic options for ACLR. Priority was given to publications from the last 10 years, but older articles considered particularly important to the topic will also be considered. The evaluation of articles began with an analysis of titles and abstracts to assess their conformity with the objectives of the review, followed by a review of the full text to verify their relevance. The most relevant studies identified served as "seed articles" in the Litmaps application to locate the most pertinent connected research on the topic. The Zotero® application was used to manage the literature.

Results: An analysis of the selected literature confirms that the ALL acts as a significant secondary restraint to internal tibial rotation. These procedures demonstrate significantly lower graft failure rates compared to isolated ACLR.In ACLR combined with LET reduces failure from 11.1% to 3.9%, while ACLR combined with ALLR reduces it from 7.9% to 0.8%, alongside improved control of the pivot-shift phenomenon. Comparative analysis suggests no significant difference in failure rates between LET and ALLR, though LET is associated with higher rates of hardware irritation and ALLR with technical risks such as tunnel convergence. Furthermore, combined procedures demonstrate higher return-to-sport rates compared to isolated reconstruction. Evidence supports expanding indications beyond young athletes to include patients older than 30 years and those with revision scenarios or hyperlaxity.

Conclusion: Current evidence supports the use of LEAPs as a safe and effective augmentation to ACLR, particularly for high-risk patients. These combined procedures significantly reduce the risk of graft rupture and restore rotational stability without increasing the risk of lateral compartment osteoarthritis in the mid-term. While technical complexity is higher, the clinical benefits in preventing reinjury justify their use in specific populations. Future research should focus on long-term safety data and the standardization of surgical indications.

Keywords: Anterior Cruciate Ligament Reconstruction; Lateral Extra-articular Procedures; Anterolateral Ligament; Rotational Instability; Graft Failure.

Abbreviations list

ACL - Anterior cruciate ligament

ACLR - Anterior cruciate ligament reconstruction

ALL - Anterolateral ligament

ALLR - Anterolateral ligament reconstruction

ALRI- Anterolateral rotatory instability

AM - Anteromedial

AMB - Anteromedial bundle

BPTB- Bone-Patellar Tendon-Bone

DB-Double-Bundle

FCL- Fibular collateral ligament

HT-Hamstring Tendon

ITB-Iliotibial Band

IKDC- International Knee Documentation Committee

LCL - Lateral collateral ligament

LEAPs - Lateral extra-articular procedures

LET - Lateral extra-articular tenodesis

NC-ACLI-Non contact ACL injury

PL – Posterolateral

PLB - Posterolateral Bundle

SB-Single-Bundle

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1. Introduction

Anterior cruciate ligament (ACL) is one of the most frequent and clinically relevant knee injuries, especially in young athletes who participate in pivoting and contact sports (ski, basketball, rugby and football). (1) It is characterized by disruption of the ligamentous structure that provides primary restraint to anterior tibial translation and secondary restraint to rotational stability(1,2). ACL tears represent a substantial clinical and public health burden, with an incidence of approximately 74,6 injuries per 100 000 individuals in the United States annually. (3) Even with the improvement of surgical methods, the rates of graft failure after isolated ACLR are high, and they range between 5% and 11% in the general population, and even higher in the young and active population. (4,5)

A significant proportion of patients continue to experience residual anterolateral rotatory instability (ALRI) following isolated ACLR, which contributes to poor outcomes and increased graft failure rates. (6,7) Combined procedures utilizing lateral extra-articular procedures (LEAPs) such as lateral extra-articular tenodesis (LET) and anterolateral ligament reconstruction (ALLR) have been defined by the implementation of an extra-articular component, which aims at controlling tibial rotation and minimizing graft strain. These procedures demonstrate significantly lower graft failure rates compared to isolated ACLR, ACLR combined with LET reduces failure from 11.1% to 3.9%, while ACLR combined with ALLR reduces it from 7.9% to 0.8%, alongside improved control of the pivot-shift phenomenon (5,8)

The 2016 Anterolateral Ligament Expert Group Meeting established international consensus regarding the role of the anterolateral ligament (ALL) as a significant anatomical structure and secondary restraint to internal tibial rotation. (6) This consensus has led to the re-introduction of lateral extra-articular augmentation methods as possible complements to ACLR, especially in the high-risk groups. Patients with combined ACL and anterolateral complex injuries who undergo combined procedures demonstrate superior rotational stability outcomes and lower graft failure rates. (9,10)

However, important questions remain regarding optimal surgical indications, technique selection, and long-term safety. (11,12) Currently, the primary goal is to identify patients who will benefit most from combined procedures and to prevent primary graft failure through appropriate surgical strategies. Residual rotational instability and graft overload have become targets for innovative surgical strategies, particularly the incorporation of lateral extra-articular augmentation in high-risk populations. In this context, the re-emergence and refinement of LEAPs are essential, both in the prevention of primary graft failure and in revision scenarios, in order to restore comprehensive knee stability and improve long-term clinical outcomes. (13-15)

2. Anatomy and Function of the ACL and ALL and Mechanisms of ACL Injury

The anterior cruciate ligament (ACL) is one of the primary stabilizing structures of the knee joint. It originates from the medial surface of the lateral femoral condyle and inserts into the anterior intercondylar area of the tibia, just anterior and lateral to the medial tibial spine. The ligament measures on average 22-41 mm in length and 7-12 mm in width, with a cross-sectional area that is notably irregular, and demonstrates progressive enlargement from the femoral to tibial attachment sites, ranging from 34 mm^2 proximally to 42 mm^2 distally. (1)

2.1 Anatomy

2.1.1 Femoral and Tibial Attachment

The femoral attachment of the ACL is located on the posterior aspect of the inner surface of the lateral femoral condyle. (1)

The tibial insertion occurs within a fossa positioned anterior and lateral to the medial tibial spine. (1) This attachment area is broader and mechanically stronger than its femoral counterpart. (1) As the ACL fibers approach their tibial insertion, they demonstrate a characteristic fan-out pattern, with some fibers extending beneath the transverse intermeniscal ligament and occasionally blending with the meniscal attachments. (1)

2.1.2 Functional Anatomy: Two Bundle Model

Current anatomical models of the ACL emphasise a functionally significant two-bundle configuration: the anteromedial bundle (AMB) and the posterolateral bundle (PLB). (1) This two-bundle model is widely accepted as the most accurate framework for understanding ACL biomechanics. The AMB originates from the most anterior and proximal aspect of the femoral attachment and inserts at the anteromedial portion of the tibial attachment site. (1) In contrast, the PLB arises from the posterodistal region of the femoral attachment and inserts posterolaterally on the tibia. (1) The two bundles are non-isometric, as the AMB goes taut in flexion, whereas the PLB goes taut in the vicinity of extension, especially in rotatory strains. Moreover, the PLB has more fascicles than the AMB. (2)

2.2 Biomechanical Function

2.2.1 Restraint Functions

The ACL is the major restraint of anterior tibial translation with 82-89% of all the restraint force at 30 degrees of knee flexion and 74-85% at 90 degrees flexion.(1) Anterior forces above 50 N will start creating measurable ACL strain, and the strain will reach a maximum of 6% in higher loads. (1) The contribution of the bundles to the range of motion is different and ensures good restraint: PLB is dominant in the extension, and AMB is dominant in flexion. This additional role justifies the use of anatomic double-bundle(DB) reconstruction methods. (1)

Beyond its primary role in controlling anterior translation, the ACL functions as a major secondary restraint to internal tibial rotation, particularly near full extension. (1) The ligament also provides minor secondary restraint to external rotation and varus-valgus angulation, especially under weight-bearing conditions. (1,3)

2.3 Association with Other Knee Stabilizers

The ACL acts synergistically with other structures: the posterior cruciate ligament (PCL) forms a central pivot for anteroposterior control; the medial and lateral collateral ligaments (MCL, LCL) resist valgus-varus stresses; and secondary stabilizers, such as the menisci and anterolateral capsule, contribute to rotational stability. The ACL is interdependent with the lateral meniscus, especially, as the latter has direct fiber linkages with it. (1)

2.4 Non-Contact ACL Injury Mechanism

The most common ACL ruptures (70% of all ruptures) in athletes are non-contact anterior cruciate ligament injuries (NC-ACLI), which result in significant short and long-term morbidity (surgery, lengthy rehabilitation, and increased osteoarthritis risk). This injury most commonly happens during a single-leg landing or sudden deceleration in team sports. (16)

2.4.1 Mechanism of injury

Boden & Sheehan synthesize video, MRI, in-vivo and cadaveric data to propose that an axial compressive (impulsive ground-reaction) force acting on the knee in a specific whole-body posture is the principal driver of most NC-ACLIs. (16)

2.4.1.a Primary Mechanism: Axial Compressive Forces

This study presents compelling evidence that axial compressive forces are the principal factor in NC-ACLI, marking a significant departure from previous theories. The critical factor is the failure of protective mechanisms during landing, particularly the inability of the calf muscles to absorb ground reaction forces when athletes land in the "provocative position". (16)

Athletes with NC-ACLI usually strike the ground with the flat-footed or hindfoot strike in the sagittal plane compared to the forefoot strike in the controls. They also demonstrate significantly reduced ankle plantarflexion at initial contact (11° compared with 23° in controls, $p = 0.0059$), a trend toward less knee flexion (18° versus 22°), and significantly greater hip flexion (50° versus 26°, $p = 0.0003$). The trunk is also, positioned posteriorly relative to the base of support. (16)

At first contact in the coronal plane, there is no significant difference in knee valgus between the injured and control groups (5.5° versus 5.6°). However, valgus differences emerge later, approximately 67 milliseconds after initial contact, a time point that occurs well beyond the estimated window of injury occurrence, which is between 17 and 50 milliseconds. (16)

2.4.1.b Biomechanical Explanation

During the safe landing posture, the initial point of contact is the forefoot, which enables the calf muscles to absorb the impulsive ground reaction forces like an airbag in a car. The gastrocnemius contraction initiates knee flexion, and the leg acts as an accordion, flexing at the ankle and knee to allow leg muscles to absorb ground reaction forces. (16)

In contrast, the provocative position makes the calf muscles useless in attenuating the ground reaction forces wherein the impulsive forces bypass the calf muscles and pass directly to the knee. In the case of a 70 kg athlete, ground reaction forces can range from 2 to 18 times body weight during one-leg landing maneuvers, easily exceeding the ACL injury threshold of 2160 N when protective mechanisms fail. (16)

2.4.1.c Tibiofemoral Kinematics

Magnetic resonance imaging studies have revealed critical anatomical factors contributing to non-contact ACL injury (NC-ACLI). The tibial slope is significantly more vertical in the provocative position, with a 13° difference relative to the femur and 30° when measured relative to gravity. In this position, joint contact occurs on the flat anterior portion of the lateral femoral condyle rather than the round, posterior aspect observed in safer positions. This anatomical configuration promotes sliding or pivot shift rather than rolling when axial compressive forces are applied. (16)

2.4.1.d Contributing Factors

Although the main mechanism is the axial compression, there are two factors that can reduce the injury threshold.

Quadriceps contraction represents the first contributing factor, in which an energetic eccentric contraction of the quadriceps is capable of decreasing compressive axial forces needed to cause ACL rupture by 45 percent. The quadriceps provides the most significant contribution with its compressive (superior) at least twice as much as the anterior at 0 o knee flexion. (16)

The second factor is knee abduction/valgus alignment, where valgus alignment compounds the effect of axial compressive load on the ACL disruption. A 2-degree shift in valgus alignment reduces the compressive force threshold for ACL injury by the equivalent of one body weight. This relationship enables females to experience NC-ACLI at lower ground reaction forces than males. (16)

2.5 Anterolateral Ligament Anatomy and Function: Implications for ACL Reconstruction

2.5.1 Origin and Attachments

The anterolateral ligament (ALL) of the knee is a distinct anatomical structure. Paul Segond first described it in 1879 as a "pearly, resistant, fibrous band" associated with lateral tibial avulsion fractures. This has long been considered to be simply a thickening of the anterolateral capsule of the knee until recent anatomical studies have given it detailed characterization of its morphology and functional role. (17)

2.5.1.a Femoral and tibial insertion:

The ALL originates at the prominence of the lateral femoral epicondyle and is positioned slightly anterior to the origin of the lateral collateral ligament (LCL). The mean width at the femoral origin measures 8.3 ± 2.1 mm, with superficial fibers extending toward the lateral intermuscular septum and posterior fibers blending with the proximal LCL. (17)

The ligament inserts on the anterolateral aspect of the proximal tibia, demonstrating characteristic distal flaring with an insertion width of 11.2 ± 2.5 mm. The insertion site is located approximately 21.6 ± 4.0 mm posterior to Gerdy's tubercle and 23.2 ± 5.7 mm anterior to the fibular head tip, maintaining complete separation from the iliotibial band (ITB). (17)

2.5.2. Microstructure / histology

Histological studies reported in reviews show an organized collagen architecture consistent with ligament tissue (distinct from capsular tissue), supporting the ALL as a true ligament rather than an artifactual capsular thickening. (7)

2.5.3 Biomechanical role

Cadaveric and robotic studies identify the ALL as a secondary restraint to internal tibial rotation and an important contributor to the pivot-shift phenomenon, particularly in the ACL-deficient knee. Sectioning of the ALL in ACL-deficient models increases coupled internal rotation and pivot-shift magnitude. Conversely, ALL reconstruction or lateral extra-articular tenodesis (LET) with ACL reconstruction (ACLR) decreases residual internal rotation and pivot-shift in most laboratory experiments. The size and clinical impact however, differs across reports and is dependent on the ACLR method, the lateral procedure selected, and the tunnel/fixation locations.(6)

2.5.4 Anterolateral capsule and its layers

The anterolateral knee capsule is a multilayered structure, which interrelates with the periarticular tissue, such as ITB, the lateral collateral ligament (LCL), and the anterior lateral ligament (ALL). Conventionally, there are three layers that have been outlined in the anterolateral area as per the descriptions by Hughston and subsequent revisions. The ITB and its expansions form the superficial layer and the superficial ITB inserts itself on Gerdy tubercle but also contributes capsular attachments and expansions to the patella, femur, and tibia. The middle layer has the capsulo-osseous layer of the ITB and thickened capsular structures, such as the ALL (as currently known) and the Kaplan fibers connecting the ITB to the distal femur. The deep layer corresponds to the true lateral capsule of the knee joint and is intimately related to the lateral meniscus, meniscotibial ligaments, and the coronary ligament. (6,17)

3. ACL surgery techniques

3.1 The History of ACL Surgery: From First Successful Surgery to Current Practice

3.1.1 Introduction

One of the greatest developments in orthopedic surgery during the last century is the development of ACL surgery. A depiction of the several stages of the ACL surgery evolution is shown in Figure 1. Since the initial successful repair in 1895 up to the current modernized methods of reconstruction, ACL surgery has been refined over time due to better knowledge of the knee biomechanics, surgical technology and evolving patient demands for return to high-level activities. (4)

3.1.2 The Pioneer Years

The first successful case of ACL repair was performed by Robson in 1895, who sutured the cruciate ligament at its femoral attachment site. At 8-year follow-up, the patient demonstrated good joint function with no signs of instability.(4) This breakthrough surgery led to the establishment of a surgical approach in the treatment of ACL tears, having replaced the conservative approach of extended immobilization with which the cruciate ligaments had been treated since Galenus described the cruciate ligaments in the follies around A.D. 170. (4)

3.1.3 The Arthroscopic Revolution (1980-2000)

The most important development in ACL surgery since the invention of ACL reconstruction procedures was the introduction of arthroscopy in the 1980s. Initially developed by Robert Jackson and David Dandy for meniscal lesions, arthroscopy was first applied to ACL reconstruction by Dandy et al. in 1982 using a synthetic graft. (4)

Initial arthroscopic procedures involved arthrotomy in the preparation of the femoral tunnel, the arthroscope was mostly used in visualization of the tibial tunnels. The emergence of arthroscopic drills and offset guides made arthroscopic surgeries possible in their entirety making it possible to prepare femoral tunnels either by passing through tibial tunnel (transtibial technique) or by passing through an anteromedial portal. (4)

3.1.4 Evolution of Graft Selection and Fixation

The arthroscopic period was accompanied by a revival of interest in hamstring tendon (HT) grafts due to the issue of anterior knee pain and morbidity of the donor sites with bone-patellar tendon bone (BPTB) grafts. The publication of combined semitendinosus and gracilis tendon autografts by Lipscomb in 1982 formed the basis of the modern hamstring methods. The use of four-strand HT grafts was introduced by Friedman in 1988, and it offered better mechanical properties which prompted the use of this procedure in a wide manner. (4)

The development of interference screws represented another crucial advancement, providing secure fixation within the bone tunnels and enabling more aggressive rehabilitation protocols. This innovation significantly reduced the need for external fixation methods and postoperative immobilization. (4)

3.1.5 Contemporary Developments (2000-Present): Anatomical Reconstruction and Double-Bundle Techniques

The first part of the 21st century saw a resurgence of interest in the anatomical reconstruction of ACL functioning. The understanding that ACL is composed of anteromedial and posterolateral bundles with different biomechanical characteristics resulted in technique of the DB reconstruction. The first description of anatomic reconstruction with two distinct bundles of ACL was suggested by Viernstein and Keyl in 1972, and the DB procedure that is still in use today was described by Muneta et al. in 1999. (4)

However, clinical studies have failed to demonstrate the consistent superiority of double-bundle over single-bundle(SB) techniques, while adding technical complexity and surgical time. Meta-analyses have shown no statistically significant difference in clinical outcomes, leading many surgeons to favor SB techniques for primary reconstruction. (4)

3.1.6 Anterolateral Augmentation Renaissance

The 2013 description of the anterolateral ligament (ALL) by Claes et al. sparked renewed interest in addressing rotational instability following ACL reconstruction. (4)This anatomical "rediscovery" led to the revival of lateral extra-articular procedures that had fallen from favor after the 1989 AOSSM consensus conference. (4)

3.1.7 Current Practice Patterns and Patient Selection: Contemporary Surgical Techniques

ACL reconstruction now is mainly done using arthroscopic SB reconstruction where autografts are used. Although many treatment methods have been developed in the last 2 decades, autografting has still been the preferred method of treatment. BPTB or HT autografts remain the most popular procedures, but quadriceps tendon grafts are becoming increasingly popular because of their good biomechanical characteristics and less morbidity of the donor site. (4)

Surgical technique has evolved to emphasize anatomical tunnel placement. Recent cadaveric studies have shown that when anterolateral structures are deficient, isolated ACL reconstruction fails to restore normal knee kinematics, resulting in residual tibial internal rotation and anterior translation compared with the intact state. (18)The addition of anterolateral procedures, whether anatomical ALL reconstruction or lateral extra-articular tenodesis, significantly reduces rotational laxity and restores kinematics closer to normal. (18)

3.2 Single-Bundle Reconstruction Technique

3.2.1 Anatomic Single-Bundle Approach

Anatomic SB reconstruction is a modern method of overcoming the limitations of traditional methods of reconstruction by focusing on anatomic placement of the tunnel in the original ACL footprint. This method was described by Hussein et al., whereby the femur tunnel is done through the accessory medial tunnel and done in the middle of the marked sites of insertion, between the target point of the AM and PL bundles. In chronic cases, the tunnel is placed below the lateral intercondylar ridge at the lateral bifurcate ridge, or in the lower third of the medial wall of the lateral femoral condyle when bony landmarks cannot be identified. (19)

The key technical elements include independent femoral tunnel drilling through accessory medial portals, with the femoral tunnel positioned centrally between the AM and PL bundle insertion sites. The tibial tunnel is placed at the center of the ACL tibial insertion site using a 55° angle, and graft tensioning is performed at full extension with forced posterior drawer. The anatomic approach requires identification of bony landmarks, including the lateral intercondylar ridge ("resident's ridge") and lateral bifurcate ridge when present, which separates the origins of the AM and PL bundle insertion sites and runs perpendicular to the lateral intercondylar ridge. (20)

3.2.1.a Advantages of Single-Bundle Reconstruction

SB reconstruction offers several key advantages, beginning with technical simplicity, as it requires fewer tunnels and less complex surgical planning, thereby lowering the learning curve and operative time. Additionally, this approach is cost-effective because it requires fewer grafts and fixation devices. Furthermore, proven clinical outcomes have been demonstrated, with Hussein et al. showing good clinical results using an anatomic SB technique, achieving 91.8 Lysholm scores and 90.6% subjective IKDC scores. (19) Moreover, the technique has broader applicability, making it suitable for patients with a smaller native footprint, where DB reconstruction may not be technically feasible, including those with tibial insertion sites measuring 14 mm or less. (20)Finally, extensive literature supports the effectiveness of SB reconstruction through established outcomes, with systematic reviews showing outcomes comparable to those of DB techniques. (19)

3.2.1.b Disadvantages of Single-Bundle Reconstruction

The main drawback of SB reconstruction, however, is that the reconstruction does not restore anatomy fully because it is not able to fully recapitulate the complex biomechanics of the two separate bundles. Besides this limitation, there are also rotational control limitations where systematic reviews have always revealed that DB reconstruction exhibits superiority in pivot-shift test in contrast to SB reconstruction. (21)

3.3 Double-Bundle Reconstruction Technique

The principles of anatomic DB ACL reconstruction are as follows: reconstruction of AM and PL bundles, anatomical positioning of tibial and femoral tunnels in the location of native insertions, bundle-specific tensioning based on native patterns, and customization to the individual anatomy and level of activity.(20)

Graft Preparation:

Hussein et al. utilized semitendinosus and gracilis tendons harvested through a longitudinal anteromedial incision, with each graft trimmed to the appropriate diameter and EndoButton CL attachment. (19) Hofbauer et al. described an alternative using the quadriceps tendon with a bone block, where the tendon was split to create AM and PL bundles. (20)

Tunnel Placement:

The technique requires four tunnels: two femoral (AM and PL) and two tibial (AM and PL). Hussein et al. detailed the specific approach: (19) Two major configurations are available. The former is DB of the quadriceps tendon and bone block, which is one femoral tunnel and two tibial tunnels. The second one makes use of DB using soft-tissue grafts (gracilis and semitendinosus), which requires separate femoral AM and PL tunnels, with corresponding tibial tunnels. (20)

Surgical Steps for Quadriceps Tendon DB Reconstruction:

The procedure starts with placing the femoral tunnel halfway between AM and PL sites of insertion and has a depth of at least 20 mm. Then, two tibial tunnels are made using the PL guide of 45° and the AM guide of 55°. The separation at the entrance of the tunnel needs 2 cm on tibial cortex with minimum 12 mm intra-articular pin spreading. Then the bone block is inserted through the medial portal and placed in the femoral tunnel and fixed by means of suspensory fixation. Last, the PL bundle is maintained at 0°, and AM bundle at 45° of knee flexion.(19)

Surgical Steps for Soft-Tissue Grafts DB Reconstruction:

The process commences with creating the PL femoral tunnel, which is placed at the center of the PL femoral insertion site, approximately 6 mm arthroscopically posterior to the anterior articular cartilage border and 3 mm superior to the inferior border. Next, the AM femoral tunnel is positioned approximately 2 mm posterior to the posterior rim of the PL tunnel in a horizontal or slightly superior position. For the tibial tunnels, the PL bundle tunnel is created using a 55° guide angle, whereas the AM bundle tunnel uses a 45° angle, with starting points ensuring an adequate bone bridge.(19)

3.3.1 Advantages of Double-Bundle Reconstruction

The evidence from systematic reviews demonstrates several significant advantages. First, DB reconstruction provides superior objective stability, as multiple systematic reviews have found that DB reconstruction showed improvements in KT-1000 testing, Lachman scores, and IKDC objective scores compared with SB techniques. (21) Additionally, enhanced rotational control is achieved, with seven systematic reviews published between 2013 and 2014 consistently finding improved pivot shift test results with DB reconstruction. (21)

3.3.2 Disadvantages of Double-Bundle Reconstruction

Despite the observed advantages, there are several drawbacks that should be considered. First, it is more complicated technologically and more expensive, because DB reconstruction needs high level skills of surgeon, prolonged length of surgery and more advanced instruments. In addition, the risk of complications increases because of the possibility of tunnel convergence, where at least 12 mm intra-articular distance and 2mm bone bridge between tunnels are required. (20) Also, the requirements of patient selection are higher since the technique cannot be applied to patients with small tibial insertion sites (less than 14 mm), narrow intercondylar notches (less than 14 mm), and other anatomical limitations. (20) Lastly, there is no clinical superiority, even when objective improvements occur as systematic reviews indicate no significant differences in the outcomes of subjective measures, such as Lysholm, Tegner, and IKDC subjective scores, between the DB and SB techniques. (21)

4. Lateral extra-articular procedures (LEAPs) in ACL Reconstruction

4.1 Rationale and the Gap They Address

Anterior cruciate ligament reconstruction (ACLR) is the gold standard for restoring knee stability following ACL rupture. However, a persistent challenge lies in addressing anterolateral rotatory laxity, manifested clinically by the pivot-shift phenomenon, which remains in up to 25% of patients after isolated intra-articular reconstruction. (9,22). Persistent pivot shift correlates with poor functional outcomes, increased graft failure, and higher revision rates in young athletes engaged in pivoting sports. (5)

The rationale for incorporating lateral extra-articular procedures (LEAPs) lies in supplementing the biomechanical restraint of the ACL by addressing the anterolateral complex. This technique has demonstrated in cadaveric and clinical studies that it can provide an additional check-rein against excessive tibial internal rotation. (5) There are several surgical techniques that apply this rationale, the subsequent sections explore the three most common ones and the corresponding summary is presented in Table I .

4.2 Contemporary Modified Lemaire Technique

New improvements in the procedure have resulted in the new modified Lemaire procedure, which includes the improvements in the understanding of the knee biomechanics and eliminates the overconstraint problems of the previous methods. Williams et al. explained a modern method, which overcomes the drawbacks of historical methods while maintaining biomechanical benefits. (18)

4.2.1 Surgical Technique

The modified Lemaire procedure utilizes a standardized approach, as described in the STABILITY study. An oblique skin incision measuring approximately 5 cm is made between the lateral femoral epicondyle and Gerdy's tubercle. “A 1 × 8-cm strip is harvested from the ITB, leaving the attachment at Gerdy's tubercle intact.” (5) The proximal end of the ITB graft is whip-stitched using No. 1 Vicryl suture for handling. (5)

Critical to the technique is the identification of the fibular collateral ligament (FCL), with the ITB graft passing deep to the FCL before fixation to the distal femur. The fixation point is positioned just anterior to the intermuscular septum and proximal to the femoral attachment site of the FCL, typically using a barbed Richards fixation staple. Importantly, fixation is performed with the knee at 0° to 60° of flexion and the tibia at 0° of rotation, with minimal tension applied to the ITB graft. (5,11).

The free end of the ITB graft is looped back onto itself and sutured using the previously placed Vicryl suture. The ITB defect is then partially closed, stopping short of the transverse retinacular ligament to avoid compartment syndrome. A diagram of this procedure can be seen in Figure 2. (5)

4.2.2 Technical Refinements

Modern LET techniques focus on a number of key technical aspects that set them apart over historical methods. One important difference is the use of neutral rotation fixation, whereas earlier techniques often secured grafts in external rotation, contemporary methods employ neutral tibial rotation during fixation to avoid overconstraint of internal rotation. (18) In addition, attention to controlled tension is critical. Laboratory studies have shown that graft tension forces of 20 N do not increase tibiofemoral contact pressures when secured in neutral rotation, whereas higher forces of 88 N lead to a loss of internal tibial rotation. This stands in clear contrast to ACL grafts, which are typically tensioned to approximately 80 N during fixation. (18) Finally, the graft's anatomical position is essential, placement deep to the LCL provides the necessary pulley effect while preserving appropriate isometric behavior throughout the range of motion, thereby ensuring optimal biomechanical function. (18)

4.3 Modified MacIntosh Technique: Cocker-Arnold

The modified MacIntosh technique as outlined by Arnold and Coker, is a polished version of the lateral extra-articular tenodesis technique, which has proved to be effective in the treatment of rotational instability after ACL reconstruction. (23)

The surgery procedure starts with the positioning of the patient and the making of a lateral curved incision of the femur that is 11-12 centimeters long. The method is suitable enough to expose the lateral compartment structures without compromising the cosmetic results. The procedure involves harvesting a strip of the iliotibial tract measuring 10 cm in length and 1 cm in width, with the harvest commencing at Gerdy's tubercle. This anatomical landmark serves as both the origin point for graft harvest and the eventual site of distal fixation. (23)

Following harvest of the iliotibial band strip, the graft is proximally divided and subsequently passed beneath the lateral collateral ligament in an anterior-to-posterior direction. This passage preserves the integrity of the LCL while establishing a desired vector for rotational control. The ITB is then folded upon itself, creating a loop configuration that enhances the biomechanical properties of the reconstruction. (23)

Fixation represents a critical component of the procedure, with the folded ITB secured to Gerdy's tubercle using a No. 0 Vicryl suture. The knee positioning during fixation is standardized at 90 º of flexion with 30 º of external rotation, which optimizes the tension and orientation of the reconstructed lateral structures. Additional stability is achieved through supplementary suturing of the iliotibial tract to the lateral collateral ligament, creating a reinforced construct that addresses multiple vectors of instability. (23) A diagram of the procedure can be seen in Figure 3 along with comparison to other lateral extra-articular plasties.

4.4 Anterolateral Ligament (ALL) Reconstruction Techniques

4.4.1 Double-Bundle ALL Reconstruction

Sonnery-Cottet et al. pioneered anatomical ALL reconstruction techniques and developed a double-bundle approach that replicates the triangular shape of the native ALL. This inverted Y-shaped configuration accurately mimics the native ALL anatomy, with its respective narrow and broad femoral and tibial attachments. (24)

4.4.2 Surgical Setup and Landmarks

Patient positioning required supine placement with a lateral post proximal to the knee and a foot roll to prevent hip external rotation while maintaining knee flexion at 90°. Three critical bony landmarks are marked before draping: the fibular head, Gerdy's tubercle, and the lateral epicondyle. The distal ALL insertion is located approximately halfway between Gerdy's tubercle and the middle of the fibular head. (24)

4.4.3 Graft Preparation and Tunnel Placement

This technique utilizes both semitendinosus and gracilis tendons, with the semitendinosus tibial insertion preserved to improve fixation and vascularization. The semitendinosus graft is tripled over two suture loops to obtain a 12 cm length from its tibial insertion, whereas the gracilis is detached from its tibial insertion and sutured to the tripled semitendinosus graft. A diagram of this process can be seen in Figure 4. (24)

Tibial tunnel preparation involves two stab incisions: one just above the superolateral corner of Gerdy's tubercle and a second above and lateral to this point. A 3.2 mm drill creates the bony tunnel, with the proximal drill hole situated at the site of the Segond fracture (representing the tibial footprint of the ALL) and the distal hole positioned anterior and inferior to ensure an adequate osseous tunnel and replicate ALL isometry. (24)

4.4.4 Femoral Tunnel and Fixation

The femoral tunnel is created using an outside-in ACL femoral guide introduced through the anteromedial portal and inserted at the femoral footprint of the ACL. The guide angulation is adjusted to allow drill sleeve placement at the previously identified isometric point on the lateral femoral condyle, which is positioned slightly proximal and posterior to the lateral epicondyle. (24)

The ACL portion of the graft (tripled semitendinosus with an additional gracilis strand) is fixed with bioabsorbable interference screws with the knee at 0° of flexion. The gracilis portion, forming the ALL reconstruction, is routed deep to the ITB through the intraosseous tunnel and secured with an interference screw in the distal tibial tunnel in extension and neutral rotation (11,24). A diagram of the completed combined ACL and anterolateral ligament reconstruction can be seen in Figure 5.

4.5 ACLR+ LEAPS

4.5.1 Clinical Benefits

4.5.1.a Enhanced Rotational Stability

The main benefit of ACLR+LEAP is its superior rotational control compared to isolated ACLR. Meta-analyses consistently demonstrate significant improvements in pivot shift test outcomes. Pooled analysis of 14 studies involving 1,141 patients revealed a statistically significant reduction in positive pivot-shift results (odds ratio 0.50, 95% CI 0.32-0.78, p=0.002) when LET was added to ACL. (10). A broader pooled analysis including both LET and ALLR studies similarly demonstrated a significant reduction in high-grade positive pivot-shift rates of 6% in combined procedures versus 14% in isolated ACLR (OR 0.42, 95% CI 0.26-0.65, p<0.001), with zero positive pivot-shift findings at final follow-up in the ALLR-specific cohorts within this analysis. (25) This enhanced rotational stability is particularly pronounced in patients with high-grade preoperative pivot-shift, where combined procedures achieved 84.1% grade 0 pivot-shift results at the final follow-up. (22)

4.5.1.b Significant Reduction in Graft Failure Rates

One of the most compelling benefits of ACLR+LEAP is the substantial reduction in graft failure rate. Multiple systematic reviews demonstrate a decrease in failure rates from 12% in isolated ACLR to 3% in combined procedures, representing a relative risk reduction of 0.26 (95% CI 0.17-0.41, p<0.001) (25) When comparing isolated ACLR versus ACLR+ALLR, failure rates decreased from 7.9% to 0.8%, while ACLR+LET demonstrated reductions from 11.1% to 3.9% . (8) This protective effect extends to the revision setting, where the addition of a lateral extra-articular procedure to revision ACLR was associated with a significant reduction in re-failure, with an odds ratio of 0.44 in favour of the augmented group (p=0.007) (26) At the individual trial level, the SANTI randomised controlled trial with a five-year follow-up of 556 patients reported graft failure rates of 4.2% in the ACLR+ALLR group compared to 10.3% in the isolated ACLR group (OR 2.54, 95% CI 1.27-5.36, p=0.006), with a number needed to treat of 17 overall, falling to 9 in patients under 25 years of age (27). As can be seen in Table II.

The mechanism that is thought to be behind these better results is connected to the load-sharing nature of LEAPs, which offers a protective effect in the process of critical ligamentization of the ACL grafts. Cadaveric biomechanical evidence has shown that the extra LET decreases the stress on the HT graft by about 43%. (9,13) This load-sharing mechanism may promote successful bone-tendon healing and reduce graft micromovement in the tunnel, contributing to the observed reduction in graft failure rates and providing a biomechanical rationale for the superior clinical outcomes demonstrated in the literature.

4.5.1.c Improved Patient-Reported Outcomes

Though it has not been found to be significant in all measures, a number of studies have demonstrated functional outcome improvement. Systematic review data show significant improvements in Lysholm scores (mean difference 2.86, 95% CI 1.37-4.36, $p<0.001$) favoring combined procedures. (25) ACLR+LEAP demonstrates consistent improvements in instrumented laxity measurements, with mean differences of -0.64 mm (95% CI -1.20 to -0.08, $p=0.03$) in side-to-side anterior translation. (25)

4.5.1.d Enhanced Return to Sport Outcomes

Meta-analyses show that return-to-sport rates are higher after ACLR +ALLR than after isolated ACLR with odds ratios of 1.88 (95% CI 1.44-2.46, $p=0.00001$) and 3.10 (95% CI 1.56-6.16, $p=0.001$) respectively. (28) These odds ratios reflect the relative benefit of combined procedures over isolated ACLR; at the absolute level, approximately 72.3% of patients return to their pre-injury sport level at a mean of 6.3 months following ACLR+LEAP. (14)

4.5.2 Clinical Concerns and Limitations

4.5.2.a Risk of Overconstraint

The principal concern with LEAPs is the potential knee overconstraint, particularly affecting the lateral tibiofemoral compartment. Current evidence presents conflicting findings regarding this risk. Declercq et al examined the LET procedure in relation to osteoarthritis development, presenting evidence that suggests the procedure is safe without increasing osteoarthritis risk, with no statistically significant differences observed between various LET techniques. (12) Conversely, robust evidence demonstrates reduced lateral compartment translation when assessed through stress radiography. (13) Additionally, one study found that LET was associated with a significantly elevated risk of lateral tibiofemoral osteoarthritis, although this finding was complicated by a higher incidence of lateral meniscal lesions in the LET group. (29)

Further investigation is required to clarify and understand this area and to determine the long-term effects on patient outcomes.

4.5.2.b Technique-Related Complications

Different LEAPs techniques have varying complication profiles. LET procedures demonstrate higher reoperation rates than ALLR (13.8% vs. 9.6%), primarily due to hardware irritation, stiffness, or infection requiring secondary procedures. (14) ALLR procedures face the challenge of tunnel convergence, with a reported rate of 53.3% when femoral tunnels are placed inappropriately. (8)

4.5.2.c Limited Long-term Safety Data

Although the results in the medium-term are encouraging, there is limited information on long-term safety. Although there is evidence that there is no higher risk of lateral compartment osteoarthritis at medium-term follow-up, most studies use the evaluation period that is too short to identify late degenerative alterations in the knee. Only one underpowered study mentioned long-term radiographic follow-up for lateral tibiofemoral osteoarthritis. (25)

4.5.2.d Technical Complexity and Learning Curve

LEAP procedures increase technical complexity in ACLR, requiring additional surgical time, specialized instrumentation, and surgeon experience with extra-articular anatomy. The variability in techniques for both LET and ALLR reflects the ongoing evolution of surgical approaches and the lack of standardized protocols.

4.5.3 Indications for the Use of Lateral Extra-Articular Procedures in ACL Reconstruction

4.5.3.a High-Risk and Young Active Patients.

Young, active individuals engaged in pivoting or contact sports represent the clearest candidates for LEAP augmentation. These patients demonstrate higher rates of graft failure following isolated ACLR, whereas combined procedures significantly improve graft survival and reduce rerupture rates. (12,15,30).

4.5.3.b High-Grade Rotational Instability

Strong expert consensus supports LEAP addition in patients with grade 3 pivot shift. (12,30) This indication reflects the biomechanical understanding that isolated ACLR may be insufficient to control high-grade rotational instability, particularly when the anterolateral structures are compromised.

4.5.3.c Objective Signs of Laxity.

Patients with marked anterior laxity on Lachman testing or symptomatic knee hyperextension are at particular risk of residual instability when managed with isolated ACLR. Hyperextension represents a risk factor for both primary ACL injury and subsequent graft failure, likely due to increased stress on intra-articular reconstructions during terminal extension. In such cases, adding a LEAP provides an additional restraint against tibial rotation and anterior translation, lowering the risk of graft overload and subsequent failure. (30)

4.5.3.d Revision and Chronic Injuries.

Revision ACLR is a strong indication for LEAPs. Comparative analyses consistently show that combined procedures reduce re-rupture and persistent rotatory laxity compared with isolated revision ACLR. (30) Likewise, in chronic symptomatic ACL deficiency, often associated with longstanding instability and increased anterolateral laxity, combined ACLR and LEAP have demonstrated superior stability and lower failure rates. (30)

4.5.3.e Concomitant Meniscal Pathology and Ramp Lesions.

The presence of meniscal pathology at the time of ACL reconstruction represents an increasingly recognised indication for LEAP augmentation. Data from the SANTI professional athlete cohort demonstrate that the systematic adoption of a combined protocol, incorporating thorough posteromedial arthroscopic evaluation, suture-hook ramp lesion repair, and routine LEAP, was associated with a significant reduction in secondary meniscal surgery, from 10.8% to 3.3% ($p=0.0052$), alongside a reduction in overall graft rupture rates. (31) These findings suggest that untreated or undertreated meniscal pathology, particularly ramp lesions of the posterior horn of the medial meniscus, which are frequently missed on standard anterior arthroscopic assessment, contributes to persistent rotatory instability and graft overload. The addition of a LEAP in the context of concomitant meniscal repair may provide a protective biomechanical environment during the healing phase, reducing rotational stress on both the repaired meniscus and the intra-articular graft. Although the contribution of LEAP cannot be isolated from the broader protocol changes in the Hopper cohort, the consistent reduction in secondary meniscal procedures following systematic augmentation supports its consideration in patients with confirmed or suspected ramp lesions, particularly those undergoing repair rather than resection.

4.5.3.f Morphological and Historical Risk Factors.

Anatomical and historical features also influence decision-making. An increased posterior tibial slope, particularly above 12°, is associated with a higher graft rupture risk, and the addition of LEAPs mitigates this risk. (30) Similarly, patients with a history of contralateral ACL rupture are at elevated risk of reinjury and may benefit from combined reconstruction. Skeletally immature patients also demonstrate high graft failure rates, with combined procedures showing improved outcomes compared with ACLR alone. (30)

4.5.3.g Expanding Indications Beyond Youth.

Although initially reserved for younger athletes, recent large-scale analyses have shown that the benefits extend to older individuals. In patients older than 30 years, ACLR combined with LEAP was associated with more than a three-fold reduction in graft rupture risk and a lower rate of secondary meniscectomy than isolated ACLR. (15) These findings suggest that surgical decision-making should be guided more by activity level and risk profile than by chronological age alone.

4.5.3.h Unresolved Indications.

Several potential indications for its use remain controversial. These include small-diameter grafts, female athletes, and imaging-based findings of anterolateral complex injury, such as Segond fractures or deep femoral notch signs. Regarding meniscal pathology, ramp lesion repair is emerging as a supported indication, whereas the role of LEAP in the context of isolated meniscectomy remains unresolved. (30)

4.5.4 Comparison of the techniques

When comparing the Modified Lemaire LET and ALLR across the available evidence, several clinically meaningful distinctions emerge, though direct head-to-head trial data remain limited. Other lateral augmentation techniques, including the Arnold-Coker, Modified Ellison, Kocher-Micheli, and Marcacci-Zaffagnini procedures exist but lack sufficient comparative clinical data to support meaningful analysis in this context and are therefore excluded from this comparison. (11) Notably, among an international expert panel of 55 knee surgeons, the Modified Lemaire and ALLR emerged as the two most widely adopted techniques, preferred by 45.2% and 25.8% of respondents respectively, reflecting their dominant position in contemporary practice. (11)

With respect to graft failure, both LEAP techniques substantially reduce failure rates compared to isolated ACLR. When LET is added to ACLR, failure rates fall from approximately 11.1% to 3.9%, while ACLR+ALLR reduces failure from 7.9% to 0.8%.(8) The SANTI RCT, providing the first Level I evidence for ALLR augmentation, demonstrated a failure rate of 4.2% in the ACLR+ALLR group versus 10.3% in the isolated ACLR group (adjusted OR 2.54; 95% CI 1.27-5.36; p=0.008), with the protective effect becoming most evident after three years of follow-up.(27) Across the broader systematic review literature, graft failure rates between LET and ALLR were broadly equivalent (3.2% vs 3.0%, p=0.7), suggesting that both approaches achieve comparable reductions in intra-articular graft stress. (14)

Rotational stability outcomes, as assessed by pivot-shift testing, are improved by both techniques. Pooled analysis demonstrates a significant reduction in positive pivot-shift results with the addition of any LEAP (OR 0.50; 95% CI 0.32-0.78; p=0.002), with the benefit most pronounced in patients with high-grade preoperative pivot shift, in whom combined procedures achieved 84.1% grade 0 results at final follow-up. (10,22) LET-based procedures, however, appear to produce slightly lower residual anterior laxity on Lachman testing, whereas ALLR is associated with a higher Lachman positivity rate (OR 3.1, p<0.01), reflecting a modest degree of greater residual anterior translation. (14)

Regarding patient-reported outcomes and return to sport, LET demonstrates a modestly higher IKDC score (MD 5.6, p=0.04) and a higher return-to-sport rate (80.8% vs 67.6%, OR 0.5, p<0.01) compared with ALLR in the largest available synthesis.(14) However, the IKDC difference did not reach the established MCID of 13.8 points, limiting its clinical significance. The SANTI RCT similarly found that IKDC and Lysholm scores were statistically significantly improved in the ACLR+ALLR group, though again without exceeding MCID thresholds.(27)

The most consistent difference between techniques concerns reoperation rates and surgical morbidity. ALLR is associated with significantly lower reoperation rates than LET (9.6% vs 13.8%, OR 0.7, p=0.01), driven primarily by hardware irritation, staple removal, wound complications, and infection in the LET group. (14) In the Pettinari matched-pair analysis, the overall reoperation rate was substantially higher in the BPTB+LET group of 73 patients compared with 292 receiving HT+ALLR (24.7% vs 10.6%, HR 2.57; p=0.02), alongside a notably higher infection rate (4.1% vs 0.7%, p=0.0075) and higher rate of secondary meniscal surgery (12.3% vs 4.5%, p=0.0006).(32)

Any comparison of ALLR and LET techniques cannot be considered in isolation from intra-articular graft selection, as the two variables are clinically inseparable. When a HT graft is planned, the gracilis strand can be repurposed for the ALLR without requiring an additional incision, meaning the ALLR adds no meaningful incremental morbidity to the reconstruction. (24) In contrast, LET procedures require a separate lateral incision and ITB harvest in addition to the primary graft harvest, creating a dual donor-site burden with distinct morbidity at each site, including risks of wound complication, hardware irritation, and ITB-related symptoms. (5,11)

In the SANTI RCT, operative time for the LEAP component was substantially shorter with HT+ALLR than with BPTB+LET (approximately 33 vs 58 minutes), and infection rates were significantly lower.(27) These differences reflect not only the relative complexity of the two LEAP techniques but the cumulative effect of single versus dual harvesting. When LET is performed alongside a HT graft, as in the STABILITY trial the added morbidity is more modest, though hardware-related reoperation (3.4%) and higher early pain scores remain measurable concerns. (5)

Taken together, the available evidence suggests that HT+ALLR offers a marginally superior overall profile when considering the composite outcome of graft survival, reoperation burden, and surgical morbidity. The absence of a second harvest site and the consistently lower reoperation and infection rates represent a clinically meaningful advantage.(14,27) While LET-based constructs demonstrate comparable rotational control and potentially modestly superior functional scores in some analyses, these benefits do not clearly outweigh the added morbidity when an ALLR can achieve equivalent graft protection through a single surgical field. (8,25)The optimal technique, however, remains patient and surgeon specific, and the current evidence base is predominantly retrospective and confounded by graft type, underscores the need for prospective, graft-matched trials before definitive recommendations can be established.(11,28)

4.5.5. Clinical Decision Algorithm

A systematic approach to patient selection and technique choice for LEAP is essential in contemporary ACL surgery. The clinical decision algorithm presented in Figure 6 integrates the key determinants of LEAP indication, graft selection, surgeon experience, and patient-specific risk stratification, synthesized from the evidence reviewed in this chapter.

5.Conclusion

Anterior cruciate ligament injury is a major clinical problem especially because of the residual rotational instability that is left after the reconstruction thus causing high levels of graft failure and poor patient outcomes. Current knowledge about knee stability biomechanics has enabled advances in ACL injury management, with lateral extra-articular procedures, particularly LET and ALLR, emerging as promising adjuncts that allow for improved rotational stability and implementation of preventive strategies against graft failure.(5,25)

Lateral extra-articular procedures are the only proven surgical approach in reducing the rates of graft failures in high-risk groups. Multiple systematic reviews demonstrate a decrease in failure rates from 12% in isolated ACLR to 3% in combined procedures (OR 0.26, 95% CI 0.17-0.41, p<0.001), with ACLR+LET specifically reducing failure from 11.1% to 3.9% and ACLR+ALLR from 7.9% to 0.8%.(8,25) This protective effect extends to the revision setting, where lateral augmentation was associated with a significant reduction in re-failure (OR 0.44, p=0.007).(26) At the individual trial level, the SANTI randomised controlled trial confirmed these findings with a five-year follow-up, reporting graft failure rates of 4.2% versus 10.3% for isolated ACLR (OR 2.54, 95% CI 1.27-5.36, p=0.006).(27) Emerging indications include patients older than 30 years, revision scenarios, and those with generalised hyperlaxity, although robust clinical trials with long-term follow-up are still needed to validate efficacy across diverse patient populations. (12,15) The addition of LEAPs has demonstrated benefit in reducing pivot-shift phenomena and improving long-term stability, with residual rotational instability representing a validated therapeutic target with established clinical benefits. (7,8,10)

In summary, current evidence supports the selective use of LEAPs in ACLR, with the strongest indications in young, active patients with HT autografts and those exhibiting high-grade rotational instability with recent studies indicating that the benefits of LEAPs may also extend to patients aged 30 or older. International consensus statements offer a valuable framework for clinical decision-making, the fact that areas of consensus were absent highlights the necessity of additional studies, especially in terms of technical aspects to reduce complications like overconstraint and hardware irritation, with a perspective of enhancing the quality of life and imaging findings in patients and population-specific issues.

In conclusion, the vast dynamic potential of lateral extra-articular augmentation in ACL reconstruction, despite remaining uncertainties regarding optimal patient selection and long-term safety, is clear and undeniable. The purpose of the narrative review is to add to the existing body of knowledge by offering a recent synthesis of the existing evidence regarding the application of lateral extra-articular procedures in the context of ACL reconstruction, which highlights the necessity to continue research and clinical studies that can help to enhance the outcomes of surgery and patients returning to sport and quality of life.

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Appendix A

Table I- Comparison of Lateral Extra-Articular Procedure Techniques

Adapted from: (4,19,24,25)

Technique	Graft Choice & Harvest	Fixation Method	Key Biomechanical Goal	Advantages	Disadvantages
Modified Lemaire	1 × 8-cm strip harvested from ITB, leaving attachment at Gerdy's tubercle intact; proximal end whip-stitched with No. 1 Vicryl	Barbed Richards fixation staple to distal femur; fixation at 0°-60° flexion with tibia at 0° rotation and minimal tension	Provide additional check-rein against excessive tibial internal rotation while avoiding over-constraint	Neutral rotation fixation prevents over-constraint Anatomical positioning deep to LCL provides optimal isometric behavior	• Requires precise tension control • Risk of compartment syndrome if ITB defect closure is excessive • Learning curve for optimal graft positioning
Modified MacIntosh (Cocker-Arnold)	10 cm × 1 cm strip of ITB harvested starting at Gerdy's tubercle; graft proximally divided and folded upon itself creating loop configuration	Number 0 Vicryl suture to secure folded ITB to Gerdy's tubercle; knee positioned at 90° flexion with 30° external rotation during fixation	Address rotational instability through reinforced lateral construct with multiple vectors of control	Loop configuration enhances biomechanical properties Supplementary suturing to LCL creates reinforced construct Addresses multiple vectors of instability Uses established anatomical landmarks	• Requires larger incision (11-12 cm) • Fixed positioning during fixation may not account for individual anatomical variations • More complex graft preparation with folding technique
Double-Bundle ALL Reconstruction	Semitendinosus (tripled over two suture loops, tibial insertion preserved) + gracilis (detached from tibial insertion); creates inverted Y-shaped configuration	Bioabsorbable interference screws; ACL portion fixed at 0° flexion, ALL portion (gracilis) fixed in extension and neutral rotation	Replicate native ALL anatomy with triangular shape and respective narrow/ broad femoral/ tibial attachments	Anatomically accurate replication of native ALL Preserves semitendinosus tibial insertion for improved fixation/vascularization Combined ACL + ALL reconstruction in single procedure Uses established ACL tunnel placement techniques	• More complex surgical technique requiring multiple tunnels • Requires harvesting of two tendons • Technically demanding with steep learning curve • Longer operative time • Potential for tunnel convergence or malposition

Table II-Comparison of ACL Reconstruction Studies: Graft Failure, Patient Numbers & Techniques

Study	Patients per arm	Total N	Technique(s) compared	Graft failure rate	Effect size
Systematic reviews & meta-analyses - primary ACLR					
Beckers et al., 2021 *SR + MA* 11 studies	**Isolated ACLR:** 1,057 **ACLR + LA:** 835 **5 RCTs:** 465 vs 460 **6 cohorts:** 592 vs 375	1,892	Isolated ACLR vs ACLR + any lateral augmentation: **ALLR:** 405 pts (49%) **ITB-LET:** 375 pts (45%) **MITBT:** 28 pts (3%) **Cocker-Arnold:** 27 pts (3%)	**Isolated:** 12% **+ LA:** 3%	OR 0.26 (95% CI 0.17-0.41) $p < 0.001$
D'Ambrosi et al., 2025 *SR + MA* 17 RCTs	**ALLR subgroup:** Isolated: 283 + ALLR: 281 **LET subgroup:** Isolated: 777 + LET: 659 **Grand total:** 2,000	**ALLR:** 564 **LET:** 1,436	Isolated ACLR vs ACLR+ALLR (5 RCTs) and ACLR+LET (12 RCTs)	**ALLR:** 7.9% → 0.8% **LET:** 11.1% → 3.9%	**ALLR:** M-H OR 6.78 ($p = 0.002$) **LET:** M-H OR 3.14 ($p < 0.00001$)
Systematic review - revision ACLR					
Boksh et al., 2024 *SR + MA* 10 studies	**Isolated revision:** 390 **+ LET/ALLR:** 403	793	Isolated revision ACLR vs revision ACLR + LET or ALLR	Significantly lower in augmented group	OR 0.44 ($p = 0.007$)

Study	Patients per arm	Total N	Technique(s) compared	Graft failure rate	Effect size
	Total: 793				
Randomised controlled trial					
Sonnery-Cottet et al., 2026 *RCT* 5-year follow-up (SANTI)	**ACLR+ALLR:** 283 **Isolated ACLR:** 310 **Total:** 593	593(37 lost to follow-up)	ACLR+ALLR (hamstring autograft) vs isolated ACLR (BPTB autograft)	**ACLR+ALLR:** 4.2% **Isolated ACLR:** 10.3%	OR 2.54 (95% CI 1.27–5.36) p = 0.006 NNT = 17 overall NNT = 9 (age < 25 yrs)

Notes: SR = Systematic Review; MA = Meta-Analysis; RCT = Randomised Controlled Trial; ACLR = Anterior Cruciate Ligament Reconstruction; ALLR = Anterolateral Ligament Reconstruction; LET = Lateral Extra-articular Tenodesis; LA = Lateral Augmentation; ITB = Iliotibial Band; MITBT = Modified Iliotibial Band Tenodesis; BPTB = Bone-Patellar Tendon-Bone; HT = Hamstring Tendon; OR = Odds Ratio; M-H = Mantel-Haenszel; NNT = Number Needed to Treat.

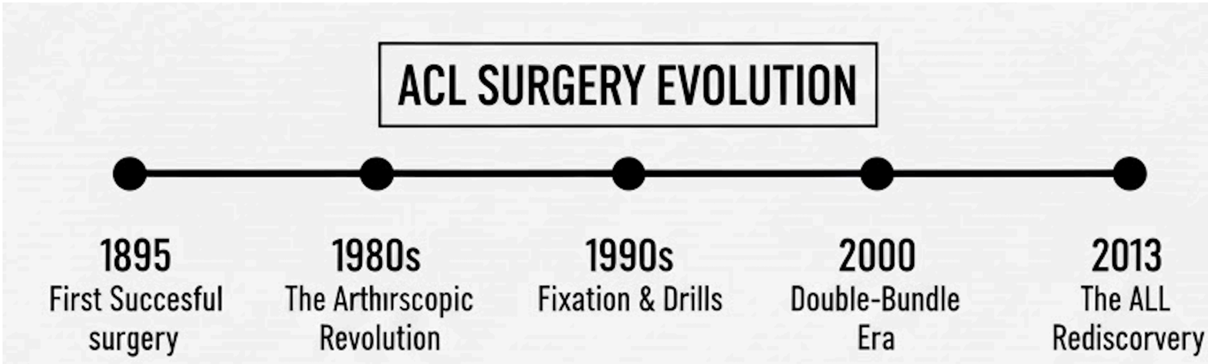

Figure 1-Timeline of ACL Surgery evolution

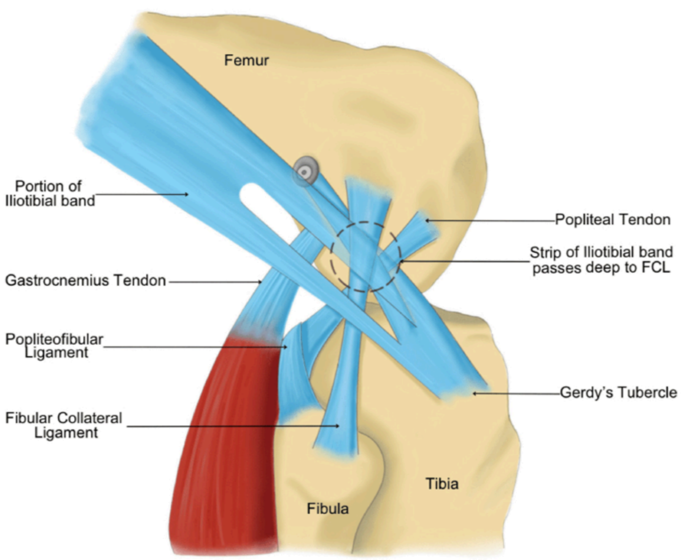

Figure 2- Diagrammatic picture of modified Lemaire's technique of lateral extra-articular tenodesis

The black dotted circle highlights the iliotibial band, which passes deep to the lateral collateral ligament. Reproduced from Jeevo et al under the terms of the Creative Commons Attribution 4.0 International License.*(33)*

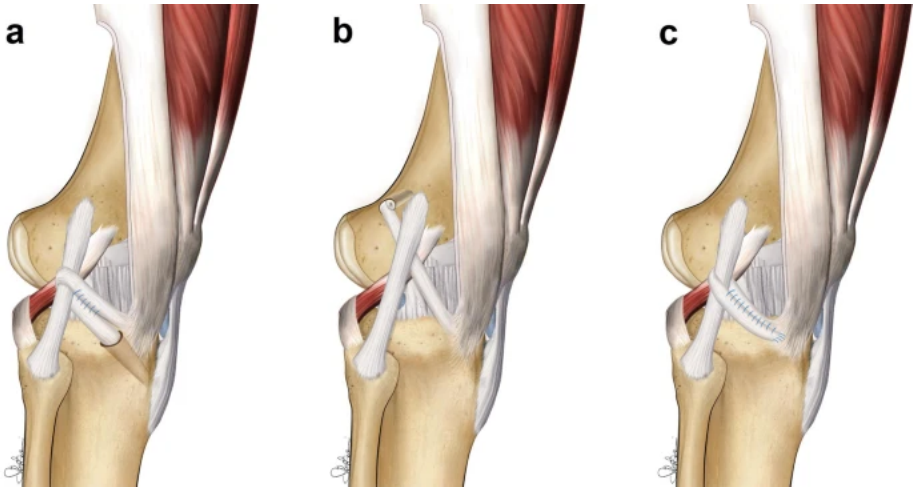

Figure 3-Lateral extra-articular plasties.

a) Ilio-tibial band (ITB) tenodesis technique (modified Lemaire). The graft is passed around the lateral collateral ligament (LCL), stitched to itself and fixed intra-osseous with an interference screw b) The graft is passed below the LCL and fixed posterior an proximal to the epicondyle (Lemaire technique) c) Cocker-Arnold modification of the MacIntosh procedure. A portion of the ITB is detached proximally, reflected and passed under the LCL, and sutured with periosteal stitches to Gerdy's tubercule. Produced with permission from Springer Nature and Alberto Grassi Vincenzo Condello et al,2019. License number 6230990273420 provided by RightsLink.(34)

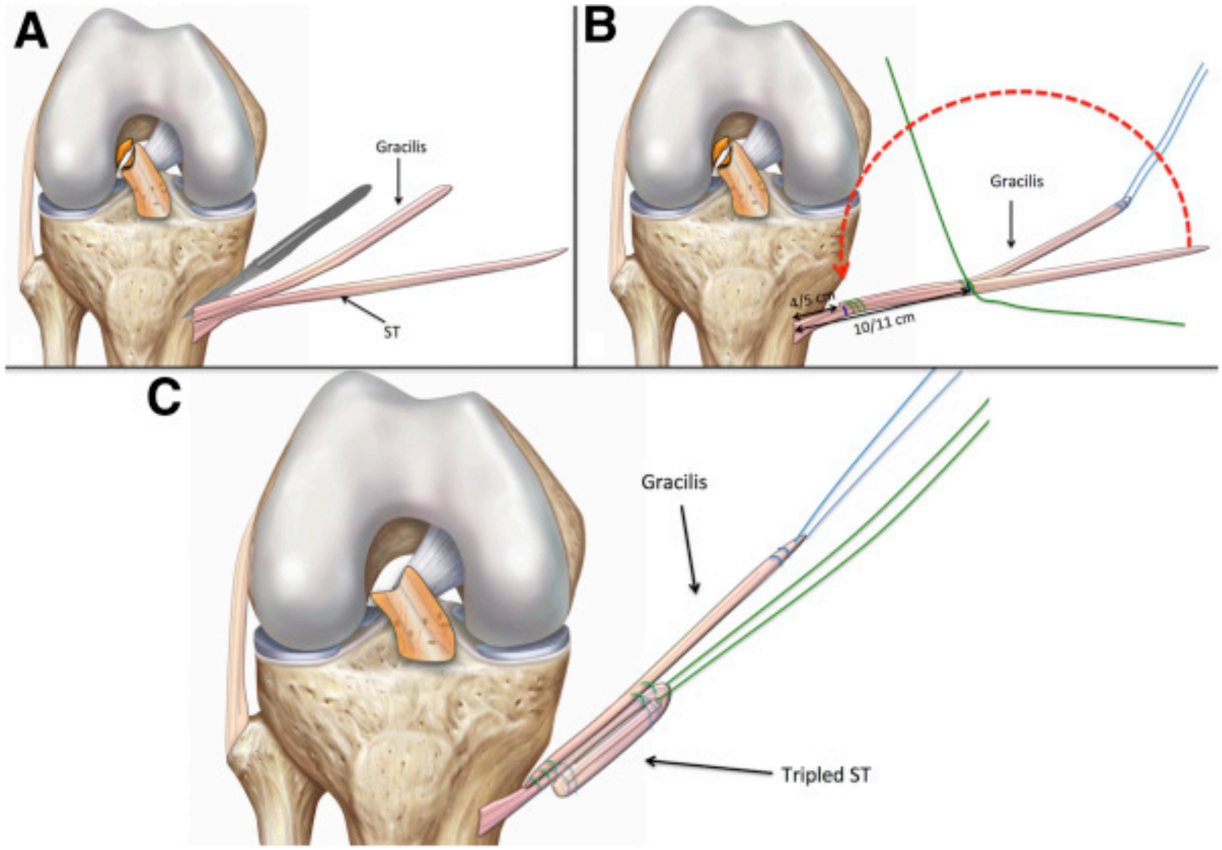

Figure 4- Graft preparation for combined anterior cruciate ligament-anterolateral ligament reconstruction in a right knee

The harvested graft is composed of a tripled-over semitendinosus (ST) and a single strand of gracilis by first incising the gracilis (A), incorporating a doubled-over ST and gracilis (B), and then completing the graft preparation with the insertion of the ST still intact (C). Reproduced from Sonnery-Cottet et al. (2016) under the terms of the Creative Commons Attribution 4.0 International License.(35)

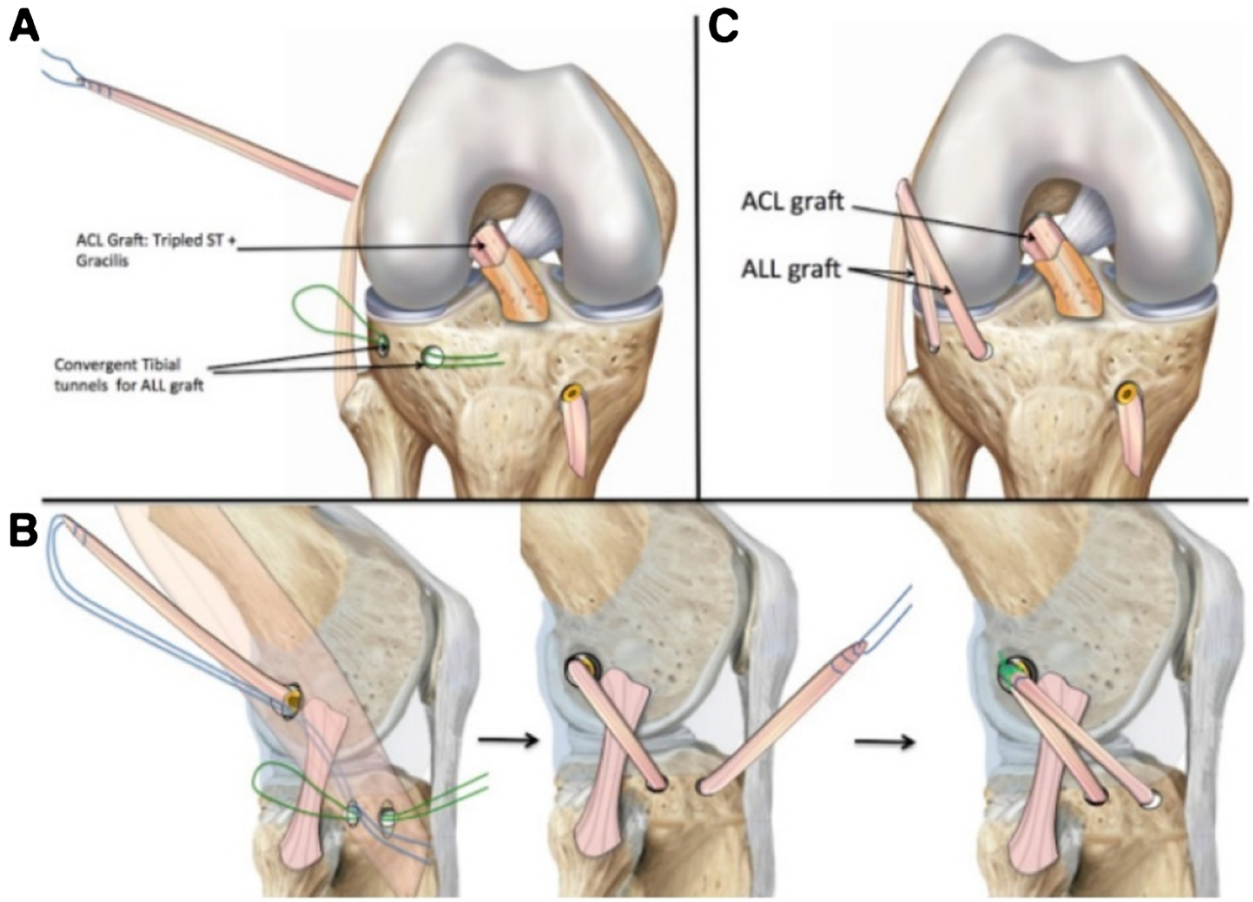

Figure 5-Combined Anterior Cruciate Ligament and Anterolateral Ligament Reconstruction Sonnery-Cottet technique

A) Passage of the anterolateral ligament (ALL) graft for combined anterior cruciate ligament (ACL)-ALL reconstruction in a right knee. After fixation of the ACL graft on the femur, the sutured gracilis graft goes beneath the iliotibial band to the posterior tibial hole; then the sutured graft is passed through the tibial bone tunnels and back proximally under the iliotibial band and out the lateral femoral tunnel incision, as shown in a lateral view (B) and frontal view (C) of a right knee in the supine position. (ST, semitendinosus.). Reproduced from Sonnery-Cottet et al. (2016) under the terms of the Creative Commons Attribution 4.0 International License.(35)

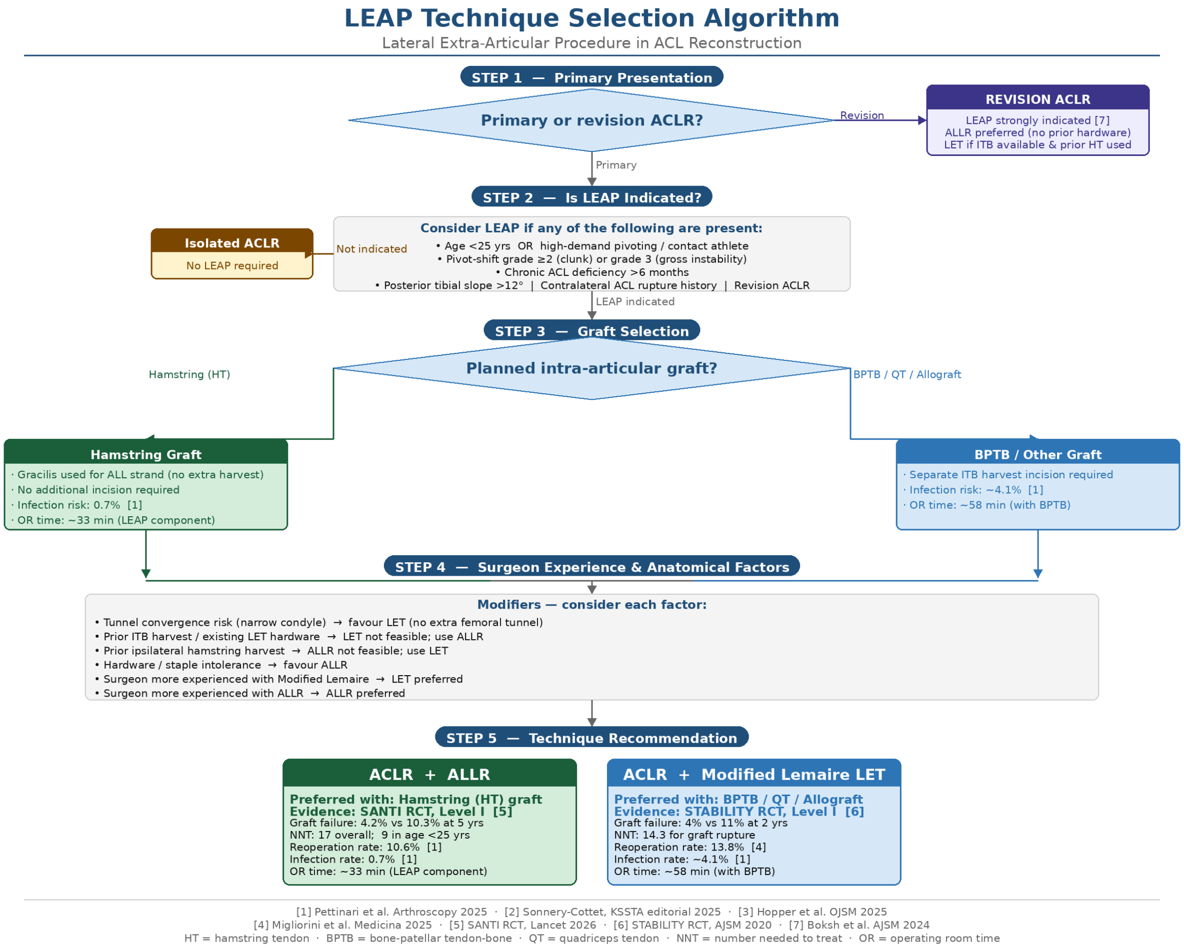

Figure 6-Clinical decision algorithm for the selection of lateral extra-articular procedure in ACL reconstruction

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