State of the Art Review

Combined anterolateral complex and anterior cruciate ligament injury: Anatomy, biomechanics, and management—State-of-the-art

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ABSTRACT

Anterior cruciate ligament (ACL) rupture typically occurs because of sudden axial loading of the knee in conjunction with a coupled valgus and rotational moment about the tibia. However, the ACL is not the only structure damaged during this mechanism of injury, and studies have shown that the anterolateral complex (ALC) of the knee is also commonly involved. Biomechanical studies have established that the ALC plays an important role as a secondary stabiliser to control anterolateral rotatory laxity (ALRL). Indeed, it has been suggested that failure to address injury to the ALC at the time of ACL reconstruction (ACLR) may increase the risk of graft failure owing to persistent ALRL. The concept of combining a lateral extra-articular procedure to augment ACLR for the treatment of ACL injury emerged with a view to decrease the failure rate of either procedure in isolation. This state-of-the-art review discusses the history of the anatomy of the ALC, the biomechanics of a variety of lateral extra-articular augmentation procedures, and provides clinical guidelines for their use in primary ACLR.

Introduction

Injury to the anterolateral complex (ALC) of the knee has been established as a significant contributing factor in the aetiology of anterolateral rotatory laxity (ALRL) \cite{1}. The ALC is comprised of superficial and deep aspects of the iliotibial band (ITB) with its Kaplan fibre (KF) attachments on the distal femur, along with the anterolateral ligament (ALL) which has been defined as a structure within the anterolateral capsule \cite{1}. Much of our understanding of the ALC and the contribution of each of the individual structures has emanated from anatomical dissection and biomechanical sectioning studies \cite{2,3}. However, since 2013 it has become increasingly evident with biomechanical and clinical studies that ACL reconstruction (ACLR) alone in the setting of ACL injury may not always eliminate residual ALRL and symptoms of instability \cite{7,9}. Moreover, the addition of a lateral extra-articular procedure to augment the ACLR has the potential to restore native knee kinematics in the setting of a combined ACL and ALC injury and decrease the rates of re-injury \cite{10,18}. A number of different lateral extra-articular procedures have been described to augment ACLR \cite{19}; for the purpose of this review the collective term for these procedures is hereinafter referred to as ‘lateral extra-articular augmentation procedure’ (LEAP). However, it is important to recognise that a LEAP is not always an innocuous procedure and carries the risk of certain complications \cite{14}. Also, a LEAP should not be used ubiquitously in every primary ACLR. The aims of this state-of-the-art review are as follows:

- To provide an overview of the evolution of our understanding of the anatomy of the anterolateral side of the knee
- To analyse the biomechanics of a number of different LEAP of the knee
- To discuss the indications for a LEAP in the setting of primary ACL injury and suggest a guide for clinical decision-making

Anatomy of the anterolateral side of the knee: an evolution in understanding

Numerous historical studies have been published exploring the anatomy of the anterolateral side of the knee \cite{2,3}. However, since 2013 and the publication of a seminal study by Claes et al. entitled, ‘Anatomy of the anterolateral ligament of the knee’, this topic has gained renewed attention \cite{20}. Notwithstanding the importance of the ALL, which itself has been the source of much controversy, what has emerged is that this structure is not a newly identified structure but is part of the ALC of the knee \cite{1,4}.

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The original description was made by a French surgeon, Paul Segond in 1879, in his study entitled, ‘Les épanchements sanguins du genou par entorse,’ which was a treatise on the origin of a traumatic haemarthrosis of the knee following a so-called sprain [5]. Segond’s treatise is based on an anatomical and biomechanical study of 90 cadaveric knees. Murgier et al., in their commentary of the translation of Segond’s original work, made some key comments which are highly relevant in the understanding of the role of the structures of the ALC of the knee:

Segond recognised the importance of an anterolateral rotatory force as a pathomechanism of ACL and ALC injury: ‘Clinical observation and experimentation show that forced rotational movements of the leg on the thigh are responsible for most knee sprains. It is, therefore, the lesions caused by this type of movement that especially cause us to wonder about the reason for the blood.’ Indeed, the methodology employed to induce the knee injury confirms this understanding: ‘We employed, as an immobilization method, 1 or 2 assistants who firmly grasped the thigh while, from our side, we applied forced movements to the knee using the only traumatic force that we were capable of producing ourselves.’ Segond is best known for identifying the fracture, which bears his name (Segond Fracture), on the anterolateral aspect of the tibia, which occurred as a result of the forced anterolateral rotation and subluxation of the tibia which was required to induce an ACL rupture. It should be noted that Segond fractures represent only a small proportion of ALC injuries (between 3 and 10%) and soft tissue damage is often present in the absence of plain radiograph evidence of injury [21,22].

The next point is very simple, often overlooked, but perhaps the most crucial of all. It relates to the method of dissection. The quotation from Segond’s treatise that has been ubiquitously used to draw parallels with the findings of Claes et al. describes, ‘a pearly, resistant, fibrous band that is placed under extreme tension when the knee is forcibly rotated internally.’ What has failed to have been disclosed in manuscripts that use this phrase is the preceding sentence which provides the context and states: ‘This can easily be seen when we examine a knee without its skin envelope.’ It doesn’t describe removing the ITB entirely as is the case in the study by Claes et al. and many others [20,23–25]. What it is actually describing is the ITB itself and not the ALL in isolation. It is very obvious that Segond recognised the importance of the ITB, a fact that is supported by Kaplan and others that followed [2].

Kaplan, an anatomist and hand surgeon, made a significant contribution to understanding the anatomy of this region by describing the layers of the ITB attachment to the distal femur in his publication in 1958 [2,26]. Following this, the lateral side of the knee was largely ignored in the literature for an extended period of time. It was considered by many a region akin to the ‘dark side of the moon’, as described in John Feagin’s seminal book ‘Crucial Ligaments’, such was its mystery, obscurity, and complexity [6]. Terry et al. finally shone some light on the area in their study published in 1986, which meticulously detailed the two main component parts of the lateral fascia lata; the iliopatellar band and the iliobibial tract (ITT) [3]. The authors used the term ‘anterolateral ligament’ in this manuscript to refer to the deep, capsulo-osseous, and superficial layers of the ITT [3]. Around the same period, Lobenhoffer et al. further defined the contribution of the ITT by documenting the existence of ‘the retrograde tract’ which provides a connection from the postanterolateral aspect of the femur to Gerdy’s tubercle (GT) on the anterolateral aspect of the tibia [27]; the authors describe this connection as “an arc arching the knee joint” and make reference to a similar finding by Müller et al. called the “lig. femoro-tibiale laterale anterius.” [28]

‘Chinese whispers’ reference to a children’s game in which a sequence of repetitions of a story are told, each one differing slightly from the previous, so that the final telling bears only a scant resemblance to the original. This is a particularly apt description of how the confusion surrounding the nomenclature used to describe the complex anatomy of the anterolateral side of the knee was created [1]. Vieira et al. are often credited with coining the phrase ‘Anterolateral ligament’, although they clearly make reference to the term originating from the study by Terry et al. [29]. But, the term actually goes back further and was indeed mentioned by Kaplan in his original work on the surgical approach to the lateral side of the knee which even preceded his anatomical treatise on the ITT [30]; he makes the following statement: “In extensive lateral approaches to the knee joint, it was noted that the iliobibial tract acted as an accessory anterolateral ligament of the knee preserving stability in which the lateral collateral ligament was lost.” The structure which Vieira et al. later described is a capsulo-osseous extension of the ITT which “starts from the lateral supracondylar region, bordering the lateral edge of the lateral epicondy and inserting laterally to the Gerdy’s tubercle” [29].

There have been a myriad of anatomical studies focussing on the ALL, including dissection at the time of total knee replacement in live patients as well as a number of cadaveric dissections [3,24,29]; each report slight variations in attachment sites and relationship to adjacent structures. The theory also emerged that the ALL and the mid-third lateral capsular ligament were one and the same thing [31]. Caterine et al., in addition to others, performed histological analysis of the ALL structure and further substantiated the belief that it has ligamentous properties as a result of its well-organised collagen bundles [24,31,32]. Indeed, it has been demonstrated that the ALL has significantly different biomechanical properties to the adjacent capsule; this is analogous to the shoulder and the inferior glenohumeral ligament [33].

An attempt to develop consensus on the relative importance of the ALL and the other anterolateral structures of the knee was made with the formation of the Anterolateral Complex Consensus Group which consisted of 36 international researchers and clinicians in the field [1]. The group met in London, United Kingdom, in October 2017. The aims of the group were three:

1. Develop a consensus in terms of the anatomical terminology utilised for structures within the anterolateral capsule.
2. Produce position statements as to the kinematic role of key structures in the knee, pertaining specifically to ALRL and ACL deficiency.
3. Provide clinical guidance on when to utilise an anterolateral procedure in the ACL-deficient knee.

The group made specific reference to the layers of the lateral side of the knee and ACL. In particular, the anatomical work of Seebacher et al. was heavily referenced, in which the lateral structure of the knee can be divided into three distinct layers [34] (Fig. 1). The authors described Layer 3 of the anterolateral capsule as splitting into a superficial and deep lamina anterior to the LCL, and enveloping it postero-laterally. Accordingly, the consensus group concluded that the ALL is a structure within Layer 3 of the anterolateral capsule and that the superficial lamina is the ALL with the deep lamina being the true capsule of the knee at this level.

The group made the following statement regarding the anatomy of the anterolateral complex of the knee:

1. The ALL is a structure within the anterolateral complex
2. The structures of the anterolateral complex, from superficial to deep, are
   a. Superficial IT band and iliopatellar band
   b. Deep IT band incorporating
      i. Kaplan fibre system
      1. Supracondylar attachments
         a. Proximal
         b. Distal
      ii. Retrograde (Condylar) attachment continuous with capsule-osseous layer of the IT band
   c. ALL and capsule
3. The ALL is a capsular structure within Seebacher Layer 3 of the anterolateral capsule of the knee [34].
4. The ALL has variable gross morphology between individuals in terms of size and thickness.
5. The ALL predominantly attaches posterior and proximal to the lateral femoral epicondyle and the origin of the LCL, runs superficial to the
LCL, and attaches on the tibia midway between the anterior border of the fibular head and the posterior border of GT.

6. There is an attachment of the ALL to the lateral meniscus.

Based on this consensus, it is reasonable to conclude that the ALC of the knee is complex by name and complex by nature.

The concept of 'anterolateral rotatory instability' of the knee was introduced by Hughston et al., in 1976 [35]. In their study, the authors described an injury pattern 'caused by a tear of the middle one-third of the lateral capsular ligament but it may be accentuated by other tears, principally a tear of the anterior cruciate.' As this theory began to evolve, the pedants pointed out that 'instability' is a subjective feeling experienced by the patient and what we, as physicians, can assess clinically is actually joint laxity. Therefore, the terminology has changed to reflect the correct scientific jargon: Anterolateral rotatory laxity (ALRL).

**Biomechanics of LEAP**

The ALC of the knee also plays a critical role in normal knee kinematics. The assessment of knee kinematics is typically performed in the clinic by clinical examination; this involves the examination of all six-degrees of freedom of the knee, through the assessment of range of motion and a variety of specialty tests designed to measure sagittal, coronal, and rotatory laxity. With respect to ACL injury and assessment, the examination of the knee involves the assessment of both anterior tibial translation with the Lachman or anterior drawer tests, and also anterolateral tibial translation with tests such as the pivot shift test.

In order to simplify the understanding of the biomechanics of LEAPs, they have been broadly classified in two groups (Fig. 2):

- Anatomical reconstructions: Anterolateral ligament reconstruction
- Non-anatomical reconstructions: LEAPs using the ITB

The majority of LEAPs are based on a proximally fixed construct, typically with a strip of ITB, which remains attached to its insertion at or near to the GT [19]. The free proximal end passes either deep or superficial to the lateral collateral ligament (LCL) and is typically fixed to the femur posterior and proximal to the lateral epicondyle; the main varieties of this technique discussed in this review are the MacIntosh and the modified Lemaire procedures [36,37]. A distally fixed ITB transfer, originally described by Ellison, has also been used [38]. This technique uses a strip of ITB, which is elevated from the GT with or without a sliver of bone and reflected proximally and then passed deep to the LCL and reattached to the region of the GT. Finally, the ALLR typically involves using a free graft of gracilis tendon, which is fixed to a point posterior and proximal to the origin of the LCL on the lateral femoral epicondyle and passed to a point of the tibia mid-way between the fibular head and GT [39,40]. The graft is passed deep to the ITB.

In terms of comparison, the three main biomechanical functions of these procedures have been considered: control of anterior tibial translation; control of internal rotation (IR) of the tibia; ALRL during a simulated pivot shift (PS) test.

**Anterior tibial translation**

The majority of available studies show that the ALLR has little or no influence on the control of anterior tibial translation [41,42]. In contrast, because of the more horizontal course of the graft, the lateral extra-articular tenodesis (LET) using ITB seems to have a greater effect on this translation parameter [43,44]. This can be explained by a difference in geometry between the anatomical fixation points of the grafts. While there is no difference in the femoral insertion location between the two techniques (they both use a tunnel positioned posterior and proximal to the femoral epicondyle), there is a difference in their tibial fixation locations. The ALL tibial insertion is at a point midway between a line connecting GT and the fibular head [20,39]. The tibial positioning of the
LET is located at the GT, which is more anterior (approximately 18-20 mm) to that of the ALLR [39]. Thus, the force resisting antero-posterior translation and IR of the tibia (particularly its horizontal anteroposterior component), will be greater for the LET than for the ALLR [39,45] (Fig. 2).

IR

The role of the ALLR and LET in controlling tibial IR is widely supported in the literature [41,46]. Injury or sectioning of the ALC structures, including the ALL, KF, and ITB, in ACL-deficient knees has been shown to significantly increase IR of the tibia [41,47,48]. With an increased lever arm, structures on the anterolateral aspect of the knee will have more influence on controlling rotation than an intra-articular structure (Fig. 3) [44]. Its torque will be greater than that of the ACL. These structures have a synergistic function with the ACL in controlling the rotational laxity of the knee [49]. The ALL controls IR of the tibia at the start of knee flexion, between 0 and 30° of flexion [41,49,50]. However, in contrast, the ITB and KFs maintain their control of IR through the whole cycle of knee flexion, with a maximal control around at 90° of knee flexion [51,52]. When comparing different LEAP, Neri et al. demonstrated that only the ALLR and modified Ellison procedure restored overall IR kinematics, through the full range of flexion, compared to the normal intact knee [9]. From 0° to 90° of flexion, the addition of ALLR produced a significant additional control compared with isolated ACLR, which resulted in a near normal overall kinematics pattern. The addition of a modified Ellison procedure caused a significant decrease in IR between 0° and 45° of knee flexion with a lack of rotational control beyond this range. The authors also found that, regardless of the degree of knee flexion, the superficial and deep Lemaire and modified MacIntosh tenodeses tended to overconstrain the knee during IR (see Fig. 4).

Simulated pivot shift

A number of studies have examined the involvement of anterolateral structures in the ALRL found during the PS test [12–15]. Like many aspects of the ALC, controversy also exists as to which components of the

![Fig. 2. A–E: A variety of lateral augmentation procedures divided into 2 groups [9]: anatomic and Non-Anatomic. A. Anatomic: Anterolateral ligament reconstruction, B–E, Non-anatomic: B, Modified Ellison; C, Modified Deep Lemaire; D, Modified Superficial Lemaire; E, MacIntosh technique.](image)

![Fig. 3. A and B: Biomechanical considerations for graft location explaining the biomechanical differences between the ALLR and LET procedures, such as the deep modified Lemaire [9](FALLR: overall action of ALLR, with horizontal (FxALLR) and vertical (FYALLR) components; FLET: overall action of LET, with horizontal (FxLET) and vertical (FYLET) components). ALLR, anterolateral ligament reconstruction, LET, lateral extra-articular tenodesis.](image)
Biomechanical comparison of different techniques

Inderhaug et al., in their seminal paper, demonstrated that there are significant kinematic differences between different LEAP techniques [63]. They reported that only the modified MacIntosh and deep Lemaire procedures restored native knee kinematics, while the ALLR did not [14]. The method of fixation of the ALLR has been questioned in this study, as this was fixed with suture anchors and not interference screws, which were employed for the other techniques. Geesling et al., in a robotic study, reported that both the ALLR and LET procedures resulted in significant reductions in tibial IR compared to the intact state, regardless of graft tension or fixation angle [20]. However, this study only analysed the deep Lemaire and ALLR on isolated knees. It should be noted that the ITB was not loaded in either of these studies, a point which is perhaps highly relevant considering the reported importance of this structure [64]. The vast majority of cadaveric studies performed used knees that were transected at the level of the mid-femur and mid-tibia—as such, the ITB band had no proximal attachment and its only distal attachment to the femur was through the KF, which were sectioned along with the anterolateral capsule and the ALL to create a ‘worst-case scenario injury’. This effectively removed any load through the ITB and effectively rendered it defunct as a secondary stabiliser to the knee [65].

Devitt et al., in a novel robotic testing model, loaded the ITB to test a distally-based LET, the modified Ellison procedure, and demonstrated that it closely restored native knee kinematics and only resulted in slight over-constraint with isolated IR at 30° of knee flexion [21]. Neri et al. subsequently carried out an in vitro biomechanical study, maintaining the entire lower limb intact thereby preserving the effect of the ITB and biceps femoris, and demonstrated that the addition of ALLR or the modified Ellison procedure to an ACLR in an ACL and ALC deficient knee closely restored native knee kinematics [18]. The superficial and deep Lemaire LET, as well as modified MacIntosh procedure, achieved an excellent rotational control but tended to over-constrained IR, resulting in a change in intact knee kinematics. So, what is the reason for these differences?

It has been proposed that the mechanical properties of the graft might be a factor. The ALLR reconstruction is typically performed with a free strip of gracilis tendon while the LET procedure uses the ITB. Wytrykowski et al. analysed the mechanical characteristics of the different grafts and found that the gracilis had a maximum load to failure of 200 N, a stiffness of 131.7 N mm⁻¹, and an elongation at failure of 19 mm, whereas the ITB had a maximum load to failure of 160 N, a stiffness of 39.9 N mm⁻¹, and an elongation at the failure of 20.8 mm [28]. However, it unlikely these small differences are not enough to explain the change in kinematics.

A more likely explanation stems from the difference in the geometry of the fixation points of the two grafts [3]. The tibial positioning of the LET is uniform with most techniques as the distal attachment of the ITB is left intact at GT; this is the same for the modified Ellison technique [66]. The distal ALL insertion on the tibia is more posteriorly located, thereby potentially explaining why the forces resisting IR and anteroposterior translation of the tibia are different (Fig. 2). It has also been suggested that the force applied to tension the graft may also play a factor in possibly over-constraining the lateral compartment. Indeed, Inderhaug et al., in their biomechanical study exploring a variety of LEAP techniques, reported a tendency towards over-constraint of anterior translation in deep flexion occurred only with 40 N of tension [63]. They stated that “during pilot testing before the study, 80 N was found to approximate a clinical maximum manual pull, but because of unfavourable kinematic responses to the lesser 60 N, these tensions were not included in the study.” The authors advised that, “surgeons performing combined procedures should be aware of the risk of overconstraining the knee when tensioning and fixing the graft.”

Another important consideration is the effect of passing the graft beneath the LCL. Neri et al. showed that passing the ITB above the LCL (superficial Lemaire) resulted in greater constraint in full flexion than
when the graft was passed beneath the LCL (deep Lemaire or modified MacIntosh) [18]. Biomechanically, there is no clear explanation. One hypothesis could be that in flexion, the superficial graft must pass over the epicondyle, which represents a longer distance in flexion than the path beneath the LCL, which closer to the bone. An alternate explanation is that passage of the graft beneath the LCL may create a pulley effect, mainly in extension. Thus, it can be expected that the deep graft is likely to be tighter in extension and the superficial graft tighter in flexion. With the modified Ellison technique, the lack of a femoral attachment increases the range of variation in graft length, potential making this procedure less rigid.

**Lateral augmentation procedures in primary ACLR: A guide for clinical decision-making**

The goal of surgical management of an ACL rupture is to achieve a knee that feels as normal as possible, functions as normal as possible, and that has the lowest possibility of being reinjured. Isolated ACLR does not achieve these objectives in all patients. In high risk populations, re-rupture rates range from 10–28% [67,68]. Reoperation rates for reasons other than graft rupture are as high as 26–30% [69]. Residual rotatory laxity, as defined by pivot shift, can be as high as 51.7% in some cohorts [70] and return to the same level sport can be less than 50%, even in expert centres [71]. It is clear that there is room for improvement and the addition of a lateral augmentation procedure may provide some benefit in achieving this. However, a number of lingering questions remain:

1. Should we use a lateral augmentation procedure in primary ACLR?
2. What are the indications for its use?
3. And, which one should we use?

**Should we use a lateral augmentation procedure in primary ACLR?**

Multiple studies have demonstrated the effectiveness of different LEAPs in reducing graft re-rupture risk in primary ACLR. Getgood et al. observed almost a 3-fold reduction in re-rupture rate for ACLR and LET compared to ACLR alone (4% versus 11%, respectively) [14]. Sonnery-Cottet et al. reported that ACLR with hamstring tendon (HT) autograft and ALLR had a 3.1 times lower re-rupture rate than 4-strand HT alone, and 2.5 times lower than bone patellar tendon bone (BPTB) autograft (4.13% versus 16.77% versus 10.77%, respectively) [18]. More recently, the SANTI study group reported 100-month follow-up data comparing isolated ACLR to ACLR, and ALLR and showed that patients undergoing isolated ACLR were at >5-fold greater risk of graft rupture and had double the re-operation rate (30% versus 15%) [72]. In another long-term study with mean follow-up of 15.7 years, Viggletta et al. demonstrated a significant difference in ACL graft rupture rates between ACLR and LET (1.3%) and ACLR (10.5%) alone [73].

The benefit of combined procedures seems to be even more pronounced in patients diagnosed with joint hyperlaxity as reported by Helito et al., in 2019, where the ACLR group alone had a 21.7% re-rupture rate versus 3.3% for those with combined ACLR and ALLR using gracilis tendon [70]. A systematic review and meta-analysis in 2021 by Beckers et al. supports this weight of evidence for combining a LEAP with other graft types, such as patellar tendon and quadriceps tendon autografts, in reducing the risk of graft rupture.

The effect of LEAPs on functional outcomes with the exclusion of re-rupture risk is a little more mixed [74]. Importantly, there are few studies demonstrating that isolated ACLR patients have improved outcomes in comparison to combined ACLR and LEAPs. Beckers et al., in a systematic review of 11 studies that reported on a combined total of 1892 patients, showed a strong trend towards improved IKDC, Lyshom, and Tegner scores with combined procedures, with the pooled data for Lyshom reaching statistical significance compared to isolated ACLR [74].

Getgood et al. demonstrated no significant differences in return to sport (RTS) between isolated ACLR and combined ACLR and LET (85% versus 82%, respectively) [14]. Sonnery-Cottet et al. reported that ACLR and ALLR had higher RTS than ACLR alone with HT (odds ratio of 1.94) but no difference when compared to isolated BPTB ACLR [18]. Rosenthal et al. reported a high RTS for professional athletes for combined ACLR and ALLR (85.7% return to play at same level at 8 months), but there was no control group [75]. While Feller et al. in a pilot study of the modified Ellison in a high-risk population showed RTS of 74% at the pre-injury level or higher [66].

Assessment of the grade of PS is important as it has been shown to correlate with patient outcomes following ACLR, unlike measurements of anterior knee laxity, which do not [76]. Objective assessment of laxity also favours the combined procedure, particularly for ALRL (pivot shift). Kunze et al., in a recent systematic review and meta-analysis, concluded that ALLR decreases the grade of PS post ACLR [17]. In addition, in the setting of primary ACLR, Devitt et al., in another systematic review, found that the addition of a LET to ACLR reduced the grade of PS; however, this occurred more commonly in the chronic setting (ACLR more than 12-months post injury) rather than in acute ACLR [77]. These same findings have been found in two other systematic reviews [74,78]. Studies by Helito et al., focusing on ALLR, would also corroborate this; the authors found a residual PS in 9.1% of patients who had ACLR and ALLR versus 35.5% in those who had ACLR alone for chronic ACL rupture [79]. In patients with generalised hyperlaxity, a residual PS was present in 26.7% of patients with ACLR and ALLR versus 51.7% for ACLR alone [70]. However, it is important to note that investigations have also shown that the PS phenomenon is multifactorial and that high-grade PS is generally associated with a secondary injury to a variety of structures in addition to the ACL [80]. Two studies have demonstrated increased lateral compartment anterior translation and IR in the setting of lateral meniscus posterior root tears [81,82]. These factors clearly need to be considered in the analysis and interpretation of what significance can be given to the PS grade clinically.

The benefits of a combined procedure should be balanced against its downsides, namely complication rates, surgical time, and expense. Complications after combined ACLR and LEAP in the recent literature are relatively low overall; although as expected, they are slightly higher than in ACLR alone [14,66]. Getgood et al. reported a higher rate of complications with the addition of a modified Lemaire procedure; the complications related almost exclusively to hardware (14/298 in the combined cases versus 4/291 in isolated ACLR - 10 required removal of the staple for the LET) [14]. Sonnery-Cottet et al. and Helitos et al. showed no difference in complications rates using the ALLR [18,70,79].

An ongoing concern is that LEAP may increase or expedite the development of osteoarthritis (OA) as a result of over-constraint or an increase in contact forces to the lateral compartment. In a 19-year follow-up study of ACLR comparing BPTB with or without LET, Castoldi et al. showed that the LET group had half the graft failure rate of isolated BPTB but significantly more lateral compartment OA (59% versus 22%, respectively). However, nearly half of the patients who developed the OA had received a lateral meniscectomy and there was a correlation between the meniscectomy and the development of OA [83]. A recent systematic review, Devitt et al., looking at the risk of OA more than 5 years after the index procedure the conclusion was that there was insufficient evidence to say that adding a LET increased the risk of OA at the medium term [84]. Finally, Viggletta et al. reported a significantly higher risk of long-term OA was found with isolated ACLR than with ACLR combined with a LET procedure [73].

So, as interest in LEAP has risen in the past decade, the weight of clinical evidence has accumulated that in the right context; these procedures will improve clinical outcomes and reduce rates of reinjury, with
a low rate of complications. The first answer to our triumvirate of questions seems to suggest ‘yes’. It’s the answer to next two questions that are more challenging!

**What are the indications for using a lateral augmentation procedure?**

One approach to this conundrum, is to simply add the procedure to every ACLR; the logic being that we don’t just ask bad drivers to wear seat belts! Whilst anecdotally the rate of use of LEAP seems to be rapidly increasing, few surgeons currently use it universally [85]. A more nuanced approach is to stratify each patient based on their risk-profile for graft re-rupture and to add the LEAP to an ACLR when both the surgeon and patient feel the added surgical time, more difficult early rehabilitation and potential complication rate warrants it.

Marmura et al. have demonstrated that the MOON risk calculator is a valid predictor of ACLR graft rupture and is appropriate for clinical practice [86]; the model predictors for the risk calculator include age, gender, body mass index, sport played at the time of injury, Marx Activity Score, preoperative knee laxity, and graft type. Using data from the Stability study, performed by Getgood et al. [14], the authors showed acceptable discriminative ability to detect patients that were high-grade preoperative knee laxity, and graft type were significant predictors of graft rupture in young active patients in this study [86]. They concluded that BPTB and the addition of LET to HT were protective against graft rupture versus HT autograft alone. The risk-weighting for each individual is not exclusive to these factors, and a number of authors have included additional indications for LEAP, including generalised hyperlaxity, knee hyperextension, positive family history of ACL injury, history of re-injury to a contralateral ACLR, increased tibial slop, elite athletes, and chronic ACL injury [1,14,18,66,70,79]. Box 3 provides a summary of commonly recognised risk factors for ACL graft rupture and proposed indications for a LEAP (Box 1, 2).

Recent radiological studies have suggested that MRI might potentially offer a tool to determine those patients with ACL injury that could predict those who could benefit from a LEAP in addition to ACLR [87,88]. However, given the lack of consensus on diagnostic parameters for ACL injury and the lack of correlation with clinical examination of ALR, caution should be taken on using radiology evidence of ALC as an indication for a LEAP at this time [89-91]. While the current literature does not yet answer this question of what are the specific indications for a LEAP conclusively, it would stand to reason that the more risk factors for ACL re-injury, the more benefit should be gained from performing it [92]. For now, a risk-benefit analysis on a case-to-case basis is certainly a good practice.

**Which lateral augmentation procedure should we use?**

The final decision is around which procedure we should use from a myriad of choices. There is much debate between the pros and cons of the LET versus ALLR, and between the different types of LET (deep Lemaire, superficial Lemaire, MacIntosh, and Ellison). While there is good clinical and biomechanical evidence to support the use of any of LEAP, there is no clinical evidence to support the use of one over the other. Many surgeons tend to have their ‘favourite’ procedure based upon experience and their interpretation of the literature. There is often a difference in the choice of LEAP based on geography, which likely pertains to the influence of training in certain regions. Slette et al., in a fantastically illustrated systematic review, outlined 12 varieties of LEAP, which incidentally did not include the ALLR [19]. These procedures were conceived by surgeons in North American and Europe, predominantly Italy and France have been adopted internationally. However, putting aside personal preference and regional bias should we be choosing the specific LEAP based on the patient’s unique surgical considerations?

An individual with chronic laxity or grade 3 PS may benefit from a greater degree of constraint than perhaps a young patient with an acute injured and treated ACL. A more distally based tenodesis may be more favourable in a skeletally immature patient to avoid the risk of growth

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**Box 1**

**Key Articles**


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**Box 2**

**Potential pitfalls of biomechanical studies**

- Biomechanical studies are more likely to simulate knee examination in the clinic through manual tests rather than the on-field loads that the knee withstands during sporting activity.
- Results of biomechanical studies are representative of only a ‘time zero’ state and do not take into account subsequent healing, cyclic loading, and rehabilitation.
- The clinical pivot shift is a dynamic examination through a range of motion–biomechanical studies do not replicate in vivo kinematics of the pivot shift but only the coupled laxities.
- Most biomechanical cadaveric studies are performed using knees that were transected at the level of the mid-femur and mid-tibia—as such, the ITB had no proximal attachment and its only distal attachment to the femur was through the KF, which were sectioned along with the anterolateral capsule and the ALL to create a ‘worst-case scenario injury’—this effectively removes any load through the ITB and effectively renders it defunct as a secondary stabiliser to the knee.

ITB, Iliobibial band; KF, Kaplan Fibre; ALL, Anterolateral Ligament.
Box 3: Key issues of patient selection for lateral extra-articular augmentation procedure

<table>
<thead>
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<th>Constraint to IR</th>
<th>Neril et al.</th>
<th>Inderhaug et al.</th>
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<tbody>
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<td>Under-constraint</td>
<td>ALLR</td>
<td>MacIntosh</td>
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<tr>
<td></td>
<td>Deep Lemaire</td>
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IR – Internal Rotation, ALLR – Anterolateral ligament reconstruction.

The ALC of the knee is integral to knee kinematics, especially in the setting of ACL injury. A loss of integrity of the ALC coupled with ACL deficiency can give rise to persistent ALRL of the knee even despite ACLR. The addition of a LEAP to an ACLR has been shown to reduce ALRL and decrease the rates of ACL graft failure. The decision of which LEAP to choose and the indications for its use are not clear and should be made on a case-to-case basis depending on patient risk.

Author contribution

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

Ethical statement

This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

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The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

References


