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PII: S2059-7754(24)00088-9
DOI: https://doi.org/10.1016/j.jisako.2024.05.001
Reference: JISAKO 266

To appear in: Journal of ISAKOS

Received Date: 27 March 2023
Revised Date: 7 March 2024
Accepted Date: 4 May 2024

Please cite this article as: Saithna A, Helito CP, Bin Abd Razak HR, Cristiani R, Secondary Restraints in ACL Reconstruction: State of the Art, Journal of ISAKOS, https://doi.org/10.1016/j.jisako.2024.05.001.

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Secondary Restraints in ACL Reconstruction: State of the Art

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Keywords: Anterolateral Ligament, Anterior Cruciate Ligament Reconstruction, Secondary Restraints, Medial Collateral Ligament, Ramp Lesion, Meniscus Tear
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Abstract:

At-risk patients continue to experience a high likelihood of graft rupture after anterior cruciate ligament (ACL) reconstruction (ACLR). This narrative review seeks to provide the reader with an evidence-based synopsis of state-of-the-art concepts related to secondary restraint lesions, and how addressing them surgically might result in improved outcomes of ACLR.

Introduction

Despite numerous advances in anterior cruciate ligament (ACL) surgery over the last few decades Liukkonen et al recently demonstrated in a meta-regression analysis of 52,878 patients that graft failure rates following ACL reconstruction (ACLR) are not significantly lower in contemporary practice than they were fifty years prior\(^1\). Liukkonen et al also reported that overall graft rupture rates are generally low, but remain high in at-risk populations\(^1\). For example, the overall second ACL injury rate in elite female athletes is reported in a recent meta-analysis at 26% (95% CI 19-33%)\(^2\). Such high rates of re-injury in at-risk populations are clearly a concern and it is the opinion of the authors that comprehensively addressing secondary restraint lesions can significantly reduce graft failure rates. Table 1 presents a summary of essential diagnostic tests, imaging and measurement devices in evaluation of secondary restraints in the ACL injured knee.

<table>
<thead>
<tr>
<th>Table 1. Essential of the diagnostic tests, imaging and measurement devices to assess secondary restraints in the ACL-injured knee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perform a careful clinical knee examination. High-grade Lachman and Pivot-shift tests should raise suspicion for injuries to the secondary restraints (ALL structures, medial meniscus, ramp lesions, lateral meniscus, lateral meniscus posterior root tears)</td>
</tr>
<tr>
<td>Perform a careful examination of the MCL (valgus stress at 0 and 30 degrees of knee flexion, dial test) and grade the degree of laxity</td>
</tr>
</tbody>
</table>
Perform a systematic assessment on MRI of all secondary restraints to reduce the risk of overlooking them.

Consider the use of measurement devices (KT-1000/2000 arthrometer, Kira, stress radiographs) for a more precise assessment of knee laxity and for research purposes.

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27 Lateral Extra-Articular Procedures

One of the most controversial areas in ACL surgery over the last decade has been the role of lateral extra-articular procedures (LEAPs) and in particular the anterolateral ligament. Although the very existence of this ligament was questioned by some authors as recently as 2015 there is now broad consensus that not only does the anterolateral ligament (ALL) exist as a discrete anatomical structure, but that its reconstruction confers significant clinical advantages. Some controversy also exists regarding which structures on the anterolateral compartment of the knee would be more important to control anterolateral rotatory laxity, including the ALL, the ITB and its Kaplan fibers. Even though biomechanical studies do show some variability, in the clinical scenario a number of surgical procedures may work properly with some advantages and disadvantages.

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Historically, LEAPs were widely abandoned in the 1980s, except in some European centers, but more recent surveys show a resurgence in popularity. A survey of ACL study group members published in 2021 reported that 83% of respondents considered that there was a selected role for LEAPs at the time of primary ACLR. Similarly, a survey of members of the Pediatric Research in Sports Medicine Society revealed that 56% and 79% of surgeons sometimes perform a lateral extra-articular procedure in primary and revision ACLR, respectively. The findings of these surveys are a reflection of the publication of numerous comparative clinical studies demonstrating the clinical efficacy of LEAPs on global practice trends.
Although there has historically been difficulty in adequately imaging the anterolateral ligament, partly due to confusion stemming from the debate regarding whether the ALL even exists or not (and therefore its precise anatomy\textsuperscript{11}), this is no longer the case.\textsuperscript{12} The anatomy, biomechanics and MRI characteristics are well-defined and numerous studies demonstrate that the normal and injured ALL can be reliably visualized using MRI\textsuperscript{12}. Confidence in the utility of MRI is high because Monaco et al demonstrated good percentage agreement (88\%) between MRI and lateral surgical exploration with respect to the overall rate of injury to the anterolateral structures (96.5\% of patients with an acute ACL-injured knee had injury to the anterolateral structures identified at lateral exploration).\textsuperscript{13} Furthermore, recent MRI studies reporting the rate of anterolateral ligament injuries are broadly consistent in the message that the rate is typically high in acute-ACL-injured knees (57\%-96.5\%).\textsuperscript{13-18} However, unlike the medial collateral ligament (MCL), ALL injuries have low intrinsic healing potential. In a prospective MRI study, Saithna et al demonstrated that only 30\% of partial ALL tears, and none of the complete tears, went on to exhibit complete healing (based on normal MRI appearances) by two years following ACLR.\textsuperscript{19} Similarly, Lee et al also reported poor healing of the injured ALL in 70\% of patients following ACLR.\textsuperscript{20} The importance of these findings is that biomechanical studies have shown that when an isolated ACL reconstruction is performed (in the setting of a combined ACL+ALL injury) normal kinematics cannot be restored.\textsuperscript{21} This results in increased persistent laxity (with increased tibial translation, internal rotation and combined internal rotation and anterior translation)\textsuperscript{21}, excessive and abnormal forces on the graft\textsuperscript{21-23}. This leads to a higher risk of graft failure as suggested by Sobrado et al who reported that in a series of patients undergoing isolated ACLR, those who had combined ACL+ALL injuries had a significantly worse graft failure rate (10.2\% vs 1.4\%, p=0.029).\textsuperscript{24} The concept of the ALL conferring a protective effect on the ACL graft (through load sharing and more reliable restoration of knee kinematics, including anterior translation\textsuperscript{21,22}) can logically also be
extrapolated to the medial meniscus due to its role as a secondary restraint to anterior tibial translation. This is supported by clinical studies demonstrating that patients who undergo an ALLR at the time of ACLR with concomitant medial meniscus repair have a significantly lower secondary medial meniscectomy rate than those who do not undergo ALLR. Biomechanical studies have also provided considerable additional insight into our understanding of the role of the ALL. Important studies performed by Nitri et al., Rasmussen et al., and Geeslin et al. tried to quantify the role of the anterolateral structures in its reconstruction procedures in restraining anterolateral knee laxity. Monaco et al demonstrated in sectioning studies that high grade pivot shift did not occur with isolated ACL injuries but only when the ALL was also sectioned. Again, this is supported by clinical studies. In a comprehensive analyses of potential risk factors (patient, surgical, osseous and soft-tissue criteria) the only significant risk factor identified for the occurrence of a grade 3 pivot shift was injury to the anterolateral structures. This was further supported by Helito et al who also reported injury to the ALL to be the only significant risk factor for high grade pivot shift. The association between pre-operative high-grade pivot shift and inferior post-operative outcomes is well-recognized. Significant advantages of combined ACLR+LEAP have been demonstrated in numerous studies of primary ACLR in high-risk populations including young patients participating in pivoting sports, those with hyperlaxity, chronic injuries, and elite athletes. It has also been proven effective in randomized controlled studies (RCT) and further RCTs are currently in progress. In the meantime, recent large and long-term studies have added supporting evidence. Pioger et al reported the largest matched pair series to date and demonstrated that the isolated ACLR with the “gold standard” BTB graft conferred a three-fold increase in
the risk of graft rupture compared to hamstring tendons + ALL reconstructions (hazard ratio, $3.554 \ [95\% \ CI, \ 1.744-7.243]; \ P = .0005$, at a mean follow up of 101 months).\textsuperscript{44}

Even though several recent studies have focused on anatomical ALL reconstruction, results from systematic reviews, showed that non-anatomical anterolateral procedures using the iliotibial band also can produce good clinical results\textsuperscript{47}. A recent study by Getgood et al. showed that the addition of an anterolateral ITB tenodesis (modified Lemaire) improved clinical results and decreased the failure rate when hamstrings grafts were used for the ACLR\textsuperscript{48}. Other procedures as the Ellison technique also can provide good results and restore knee laxity as reported by Devitt et al\textsuperscript{49}.

The evidence for LEAP in the revision ACLR setting is less robust. In part this is due to much less available evidence (smaller studies reflecting the infrequency of revision compared to primary ACLR). Recently, the ESSKA consensus statement recommended that consideration be given to the systematic use of LEAP in the revision setting.\textsuperscript{50} These recommendations were supported by a subsequent systematic review of comparative clinical studies from Saithna et al.\textsuperscript{51} The authors reported that the majority of published studies favored combined reconstructions for revision ACLR with respect to reduced graft rupture rates and better knee laxity. In the revision scenario, both ALL reconstruction and ITB tenodesis can be used with good functional results. Helito et al. demonstrated no differences between ALL reconstruction and the modified Lemaire technique in the revision scenario, but both were better than isolated intra-articular ACL revision surgery.\textsuperscript{52} Similarly, Boksh et al. in a systematic review concluded that revision ACL reconstruction with a LET or an ALLR can improve subjective IKDC scores, restore rotational laxity, and reduce failure rates compared with isolated ACLR.\textsuperscript{53}
Table 2 presents indications and key issues of patient selection for a concomitant LEAP.

Table 2. Indications for adding a LEAP and key issues of patient selection:

<table>
<thead>
<tr>
<th>Broadly speaking, LEAPs are indicated in patients who have risk factors for ACL graft rupture, and it is also indicated to protect a repaired medial meniscus. The following indications have all been reported in the literature:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young patients participating in high-risk sports</td>
</tr>
<tr>
<td>High grade pivot shift</td>
</tr>
<tr>
<td>Chronic ACL Injury</td>
</tr>
<tr>
<td>Hyperlaxity</td>
</tr>
<tr>
<td>Imaging proven injury to the anterolateral structures</td>
</tr>
<tr>
<td>Segond fracture</td>
</tr>
<tr>
<td>Lateral femoral notch sign</td>
</tr>
<tr>
<td>Medial meniscus repair</td>
</tr>
<tr>
<td>Revision ACL setting</td>
</tr>
</tbody>
</table>

Overall, complications of LEAP appear to be low. This contrasts with historically poor results that led to widespread abandonment.\(^5\) It is the opinion of the authors that these historical results should be interpreted carefully bearing in mind that at that time (in the 1970s-80s) many LEAPs were performed independent of ACLR, and patients were splinted in extension post-operatively, often for extended periods of time. Clearly both aspects could be a major explanation for poor outcomes. However, scrutiny of contemporary literature is also needed to
ensure that adding a LEAP does not result in a significantly increased rate of complications. Thaunat et al reported a large series of consecutive ACL+ALLR and demonstrated an overall rate of complications of 0.5% that could specifically be attributed to the ALLR. These were all related to femoral hardware. There was one femoral tunnel blowout and two issues with prominent screws. Screw prominence can be an issue if one does not consider that the more horizontal single femoral tunnel (a single femoral tunnel is used for both the ACL and ALL tunnels) is shorter than a standard anteromedial portal drilled ACL femoral tunnel and this should be accounted for. Furthermore, in an interim analysis of the ongoing SANTI RCT no ALLR specific complications were noted. In contrast, in the Stability Study there were several complications attributable to the ITB tenodesis. These included painful hardware, overconstraint and injury to the LCL. Of course, this leads to the question whether one type of LEAP is better than any other. To our knowledge only two clinical studies have evaluated this topic (both in the revision, but not primary ACLR setting) but neither found any important differences between outcomes following modified Lemaire versus ALLR, but both were likely underpowered and further study is needed. Table 3 summarises validated outcomes for assessing clinical outcomes after ACL injury. Although a definitive statement cannot be made about whether one LEAP is best, it should be emphasized that there are major differences in the anatomy and biomechanics of currently popular techniques, and that these may be shown to be important in the future when further data is available. Even though Schon et al. demonstrated a possible overconstraint in internal rotation at any fixation angle after an ALLR (using supraphysiological tensioning forces of 88N), several biomechanical studies have shown a greater risk of overconstraint with the modified Lemaire procedure. This seems to be logical since the procedure is non-anatomical and behaves isometrically, rather than anisometrically like the native ALL. Regardless, based on currently available literature it appears that clinical overconstraint is rare and that the benefits of LEAP outweigh the
theoretical risks of overconstraint.\textsuperscript{64} This commentary is supported by systematic review showing no evidence of increased rates of OA at long term follow-up, and even evidence of lower rates of OA in some studies.\textsuperscript{65} However, the literature is conflicting and the only RCT evaluating this specific topic shows evidence of increased lateral compartment OA following the modified Lemaire procedure (incidence of OA at mean follow up of > 19 years: isolated ACLR group 22\%, ACLR + modified Lemaire group 59\%, p=0.02).\textsuperscript{66} However, it should be noted that the modified Lemaire technique used at that time was not the same as the one currently used.

In summary of this section, it seems reasonable to conclude that there are many new comparative clinical studies demonstrating that adding a LEAP is effective in improving knee laxity and reducing graft rupture rates in high-risk patients. Although further RCTs are required, and are in process, there is broad agreement that LEAPs are clinically effective. Table 4 provides a list of four key LEAP related articles, published recently, that the authors believe all surgeons performing ACLR should be familiar with.

Table 3 Validated outcomes for assessing clinical outcomes after ACL injury\textsuperscript{a}

<table>
<thead>
<tr>
<th>Category</th>
<th>Name of validated tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee-specific outcome</td>
<td>KOOS\textsuperscript{57}</td>
<td>42 items (of which 5 are related to QoL) with each item being scored 0-4</td>
</tr>
<tr>
<td>Knee-specific outcome</td>
<td>Lysholm score\textsuperscript{58}</td>
<td>Eight factors are rated to produce an overall score on a point scale of 0 to 100. Then an assignment is given as \textquoteleft{}excellent\textquoteright{} for 95 to 100 points; \textquoteleft{}good\textquoteright{} for 84 to 94 points, \textquoteleft{}fair\textquoteright{} for 65 to 83 points, or \textquoteleft{}poor\textquoteright{} for less than 65 points. The factors of limp, support, and locking are worth a potential of 23 points; pain and instability, 25 points each; swelling and stair climbing, 10 points each; and squatting, 5 points.</td>
</tr>
<tr>
<td>Activity rating scale (Knee-specific)</td>
<td>IKDC-SKF\textsuperscript{69}</td>
<td>4: Very strenuous activities like jumping or pivoting as in...</td>
</tr>
</tbody>
</table>
| Activity rating scale | Tegner Activity Scale[^1] | Level 10 competitive sports: soccer, football, rugby (national elite)  
|                       |                           | Level 9 competitive sports: soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball  
|                       |                           | Level 8 competitive sports: racquetball or bandy, squash or badminton, track and field athletics (jumping, etc), downhill skiing  
|                       |                           | Level 7 competitive sports: tennis, running, motorcar speedway, handball; recreational sports: soccer, football, rugby, bandy, ice hockey, basketball, squash, racquetball, running  
|                       |                           | Level 6 recreational sports: tennis and badminton, handball, racquetball, downhill skiing, jogging at least 5 times per week  
|                       |                           | Level 5 work: heavy labor (construction, etc); competitive sports: cycling, cross-country skiing; recreational sports: jogging on uneven ground at least twice weekly  
|                       |                           | Level 4 work: moderately heavy labor (eg, truck driving, etc)  
|                       |                           | Level 3 work: light labor (nursing, etc)  
|                       |                           | Level 2 work: light labor; recreational sports: walking on uneven ground possible but impossible to backpack or hike  
|                       |                           | Level 1 work: sedentary (secretarial, etc)  
|                       |                           | Level 0: sick leave or disability pension because of knee problems  

[^1]: Patient is asked how often the activities running, cutting, deceleration, and pivoting have been performed during the last year in his/her healthiest and most active state. Each activity is scored on a 0-4 scale as follows:
<table>
<thead>
<tr>
<th>Activity rating scale</th>
<th>Cincinnati sport activity scale(^1)</th>
<th>Divided into 4 major levels with subcategories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Level I: participates 4-7 d/wk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level II: participates 1-3 d/wk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level III: participates 1-3 times/mo</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level IV: no sports</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Subcategories for level I-III (5-point decline for every step downward, starting from 100 points):</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jumping, hard pivoting, cutting (basketball, volleyball, football, gymnastics, soccer)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Running, twisting, turning (tennis, racquetball, handball, ice hockey, field hockey, skiing, wrestling)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No running, twisting, jumping (cycling, swimming)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level IV with the following subcategories and points for each:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40: Activities of daily living without problems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20: Moderate problems with activities of daily living</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0: Severe problems with activities of daily living, on crutches, full disability</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity rating scale (Knee-specific)</th>
<th>IKDC Knee Ligament Standard Evaluation Form(^2)</th>
<th>Level I: jumping, pivoting, hard cutting, football, soccer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Level II: heavy manual work, skiing, tennis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level III: light manual work, jogging, running</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level IV: activities of daily living, sedentary work</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HRQoL (Knee-specific)</th>
<th>ACL-QoL(^3)</th>
<th>A 100mm visual analog scale for 32 items</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRQoL</td>
<td>SF-36(^4)</td>
<td>Item specific questionnaire for 36 items</td>
</tr>
</tbody>
</table>

\(^1\)The Panther Symposium ACL Injury Clinical Outcomes Consensus Group recommends patient-reported outcomes (PRO) should optimally include at least 1 knee-specific outcome tool, 1 activity rating scale, and 1 measure of health-related quality of life (HRQoL)\(^5\)

\(^2\)International Knee Documentation Committee Subjective Knee Form

\(^3\)ACL-QoL

\(^4\)SF-36
Table 4. Four recently published key LEAP related articles, that all surgeons performing ACLR should be familiar with. The reason for notability for each study is presented within the table.

<table>
<thead>
<tr>
<th>KEY ARTICLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firth AD, et al. Predictors of Graft Failure in Young Active Patients Undergoing Hamstring Autograft Anterior Cruciate Ligament Reconstruction With or Without a Lateral Extra-articular Tenodesis: The Stability Experience.(^{46})</td>
</tr>
<tr>
<td>Notable because data is from a high quality randomized controlled trial</td>
</tr>
<tr>
<td>Pioger C, et al. Clinical Outcomes After Combined ACL and Anterolateral Ligament Reconstruction Versus Isolated ACL Reconstruction With Bone-Patellar Tendon-Bone Grafts: A Matched-Pair Analysis of 2018 Patients From the SANTI Study Group.(^{44})</td>
</tr>
<tr>
<td>Notable due to being a very large, matched study population, and also because it strongly challenges the concept of isolated BTB grafts being a gold standard for ACL reconstruction</td>
</tr>
<tr>
<td>Saithna A, et al. ACL Revision Plus Lateral Extra-articular Procedure Results in Superior Stability and Lower Failure Rates Than Does Isolated ACL Revision But Shows No Difference in Patient-Reported Outcomes or Return to Sports.(^{51})</td>
</tr>
<tr>
<td>Notable because to the authors knowledge it is the first systematic review evaluating the efficacy of LEAPs in the setting of revision ACLR, and also because it provides evidence to support recent ESSKA consensus guidelines on this topic</td>
</tr>
</tbody>
</table>

Notable because to the authors knowledge it is the first study reporting long-term clinical outcomes of a contemporary LEAP technique

Medial Meniscus Lesions

As mentioned above, the medial meniscus is an important secondary restraint to anterior tibial translation. In a study based on 4,497 patients who underwent primary ACLR, Cristiani et al. showed that medial meniscus resection increases, and medial meniscus repair preserves knee laxity. The authors divided the patients into six groups depending on the condition of the menisci: a reference group (isolated ACLR) and five groups with different combinations of meniscus surgery (medial meniscus resection, lateral meniscus resection, medial and lateral meniscus resection, medial meniscus repair, and lateral meniscus repair). A significantly greater mean anterior knee laxity was found for the ACLR + medial meniscus resection and ACLR + medial and lateral meniscus resection compared with the control group (isolated ACLR). Moreover, significantly more surgical failures (defined as a side-to-side AP laxity difference > 5 mm) were found in these groups (9.1% and 8.8% respectively) compared with the control group (3.6%). No significant differences were found between the other groups and the control group. The group ACLR + MM repair had laxity values comparable with those of the isolated ACLR group. Similar results were found in another recent study based on 5,462 patients who underwent ACLR. Medial meniscus resection was found to be a factor associated with abnormal (side-to-side AP laxity difference > 5 mm) knee laxity 6 months after surgery (OR 2.22; 95% CI 1.61 – 3.07; P < 0.001). Conversely, medial meniscus repair was not associated with the presence of abnormal knee laxity. These results highlight that meniscal preservation should be attempted in appropriately indicated patients, in order to restore normal
knee kinematics, and minimize the risk of residual laxity that might lead to a greater risk of ACL graft failure. This concern is further supported by several authors. Papageorgiou et al.\textsuperscript{78} reported that in-situ ACL graft forces increase by 33% to 55% after medial meniscectomy, and Robb et al.\textsuperscript{79} reported lower ACL graft survival in patients with deficient medial or lateral vs intact menisci (94.5% vs 69% respectively) Patients were 4.9 times more likely to have a graft failure (defined as persistent instability, positive pivot shift, MRI or arthroscopy-confirmed ACL graft rupture) in the case of medial or lateral meniscus deficiency but meniscus repair was not significantly associated with graft failure.

\textit{Ramp Lesions}

Another secondary restraint that has generated significant discussion in the last decade has been the ramp lesion. Although, the term “ramp” lesion was first introduced several decades previously, by Strobel\textsuperscript{80}, to describe a longitudinal tear, 2.5 cm in length, located at the meniscocapsular junction, it is only really in the last few years that there has been increasing recognition of their potential importance. The main reasons that ramp lesions have been somewhat neglected have been high rates of missed diagnoses (due to low sensitivity of MRI and a failure to perform posteromedial compartment evaluation at arthroscopy), and therefore an underestimation of their prevalence, and a lack of recognition of their biomechanical and clinical impact in the ACL injured knee.

Ramp lesions are common. In the largest epidemiological evaluation to date (over 3000 consecutive patients undergoing a systematic posteromedial compartment evaluation at the time of ACLR), Sonnery-Cottet et al reported a prevalence of 24\%.\textsuperscript{26} Numerous other studies have reported broadly variable rates (9-41.7\%)\textsuperscript{81} but mostly of these have not performed a
standardized posteromedial compartment evaluation or have had small study populations which make estimations of true prevalence unreliable. Regardless, it is clear that ramp lesions are very common but the reason they are underrecognized is that they cannot reliably be visualized by using classic arthroscopic anterior viewing due to the interposition of the medial femoral condyle between the viewing portal and the meniscocapsular junction. Therefore, unless a systematic posteromedial compartment evaluation is performed, a high rate of missed diagnoses is inevitable. Sonnery-Cottet et al demonstrated that an additional 40% of medial meniscus ramp lesions are identified when a transnotch view of the posteromedial compartment is obtained and the meniscocapsular junction is probed with a needle, compared to standard anterior portal viewing alone.\textsuperscript{82} Although arthroscopic evaluation is the gold standard for diagnosis, and systematic posteromedial evaluation is recommended, it is also important to understand risk factors for ramp lesions because that allows us to hold an appropriate index of suspicion. Previously reported risk factors include a contact (versus non-contact) mechanism of ACL injury, male gender, age <30 years, revision ACLR, chronic injuries, posteromedial tibial edema, pre-operative side-to-side antero-posterior laxity difference of 6 mm or more and the presence of concomitant lateral meniscal tears.\textsuperscript{26,81,83} Pre-operative MRI can also be used to diagnose ramp lesions (by hyperintense signal that can be observed between the meniscus and the capsule) but to exclude ramp lesions posterior compartment evaluation remains important.\textsuperscript{84} However, additional MRI features that may be suggestive (but not diagnostic) of the presence of a ramp lesion include bone bruising in the postero-medial tibial plateau.\textsuperscript{85} In a recent meta-analysis, Green et al reported that in ACL-injured patients with this pattern of bone bruising there is a 2.05 times (95% CI 1.29 to 3.25) greater odds of a ramp lesion.\textsuperscript{86} Cristiani et al suggested that the correlation between this pattern of bone bruising and ramp lesions might be stronger in acute versus chronic injuries, and reported that it occurred in 61% of patients with a ramp lesion who underwent MRI at a mean on 19.6 days from acute ACL injury.\textsuperscript{87}
Having understood how to avoid missed diagnoses, it is important to understand that the presence of a ramp lesion leads to posteromedial laxity.\textsuperscript{88-90} In cadaveric biomechanical studies of ACL-deficient knees the creation of a ramp lesion resulted in an increase in anteroposterior laxity and significant increases in both internal and external rotation laxity.\textsuperscript{88,91} Furthermore, in the presence of a ramp lesion, isolated ACLR fails to restore normal joint kinematics and results in residual laxity and increased forces in the ACL graft. From a biomechanical perspective it has also been demonstrated that repair of these lesions abolishes the pathological increase in laxity and therefore provides a rationale for identifying and repairing these lesions.\textsuperscript{88}

From a clinical perspective Hatayama et al provided evidence to support repair.\textsuperscript{92} First, the authors demonstrated that although small stable tears have some healing potential, the healing rates overall were significantly higher in patients who underwent a repair (60\% vs 100\%, p=0.001). The authors also reported that a healed ramp lesion conferred a significant advantage with respect to post-operative AP side to side laxity differences when compared to those with an unhealed ramp lesion (1.9 ± 1.6 mm vs 3.2 ± 1.1 mm, p = .02).\textsuperscript{92} Despite these promising findings, there remains a lack of high-quality comparative clinical studies and it is not confirmed that repair offers significant advantages with respect to key outcome measures such as ACL graft rupture rates, secondary meniscectomy rates or improved return to sport and other PROMS. However, a recent survey of orthopedic sports medicine fellowship directors in the United States reported that the majority of respondents (86\%) indicated that they routinely identify and repair ramp lesions.\textsuperscript{93} Clearly further study is needed to validate this practice pattern, but some recent publications provide supporting evidence. Tuphe et al reported on a series of 716 consecutive ACLR.\textsuperscript{94} Thirty-nine patients in this series were identified to have stable ramp lesions that were not repaired. At long term follow up (mean 262 months) of the 28 patients available for review, 8 (28.6\%) had a medial meniscus failure of which 6 (21.4\%)
were bucket handle tears. The authors concluded that with nearly one-third of patients
developing meniscal complications, it may not be wise to leave even stable ramp lesions
untreated. Of particular interest was that the mean time before meniscal complications was 86
months, reflecting that short term studies are likely to fail to capture important clinical
outcomes. However, an important limitation of the study was that there was no comparison
group, and secondary meniscectomy rates were not evaluated in the overall study population.
Regardless, overall failure rates of ramp repair appear to be low. Sonnery-Cottet et al reported
a secondary meniscectomy rate of 10.8% at a mean follow-up of 45.6 months (range, 24.2-66.2
months). A notable finding was that patients who underwent concomitant anterolateral
ligament reconstruction had a >2-fold reduction in the risk of reoperation for failure of ramp
repair as compared with patients who underwent isolated ACLR (hazard ratio, 0.457; 95% CI,
0.226-0.864; P = .021). Thaunat et al reported a secondary meniscectomy rate of 7.3%. Notably
this rate was significantly lower with a posteromedial suture hook device vs an all-inside device
(4.3% vs 21.1%, p=.003). This difference can likely be attributed to the fact that the trajectory
of an all-inside device is likely to result in failure to capture the meniscotibial ligament, which
can be more reliably captured with a posteromedial suture hook, therefore improving the
biomechanics and stiffness of the repair. Similarly, in a series of 237 matched pairs with a
mean follow up of almost 100 months, Gousopoulos et al reported that patients with a
longitudinal posterior horn medial meniscus tear who underwent an all inside repair had a >2-
fold higher failure rate compared with patients who underwent suture hook repair through a
posteromedial portal (31.2% vs 15.6%; P = .0003). Again, patients in the suture hook repair
group undergoing additional ALLR demonstrated a >3-fold higher meniscal repair survival
rate compared with all other subgroups (P = .0014). This association was not seen in the all-
inside repair group. The only significant risk factor for meniscal repair failure was the suture
repair technique (hazard ratio, 2.133 [95% CI, 1.383-3.292]; P = .0008). A further important
concept regarding failure of ramp repair is that observed tear patterns at secondary
meniscectomy suggest that the new lesion typically involves a more central part of the
meniscus, anterior to the repair, potentially resulting in a smaller secondary resection than had
partial meniscectomy been performed initially.96

In summary, it is obvious that there is a need for future study to determine comparative clinical
outcomes of ramp repair versus non-operative treatment. However, in the meantime it is clear
that practice patterns, at least in the US, favor systematic posteromedial evaluation and repair
of ramp lesions and this is likely based on biomechanical studies showing deleterious effects
of ramp lesions, but restoration of normal knee kinematics, and load reduction in the ACL with
ramp repair. The limited available literature suggests that repair ramp lesions significantly
increases the likelihood that they will heal, but an unhealed lesion is associated with persistent
anterior laxity. Furthermore, secondary meniscectomy rates after ramp repair are low
(particularly when a posteromedial suture hook repair is performed, and further reduced if a
concomitant ALLR is performed), and that when secondary meniscectomy is needed the
resection is typically smaller than if a meniscectomy had initially been performed.

Lateral meniscus

In contrast to the medial meniscus, the lateral meniscus does not provide a “wedge effect” to
resist anterior tibial translation. This is because it is loosely attached to the lateral tibial plateau,
has no attachments to the lateral collateral ligament and because the posterior horn of the lateral
meniscus is not as wide as the posterior horn of the medial meniscus. Cristiani et al. reported
that neither lateral meniscus resection nor lateral meniscus repair in conjunction with ACLR
have a significant effect on postoperative anterior knee laxity.76,77 There is, however, evidence
that the lateral meniscus is of greater importance for rotatory laxity. In a cadaveric
biomechanical study, Musahl et al. have shown that the lateral meniscus is an important restraint to anterior tibial translation during combined valgus and rotatory loads applied during a pivoting maneuver. In a study based on 57 ACL-injured patients, Hoshino et al. quantitively evaluated tibial acceleration during a pivot shift test using an electromagnetic system. The authors reported increased tibial acceleration in patients with concomitant lateral meniscus tears compared with patients with intact menisci. In a later study, Hoshino et al. also demonstrated that ACLR patients with unrepaired lateral meniscus tears exhibit larger pivot shift acceleration compared with patients with intact menisci, but that rotatory laxity was similar between patients with meniscal repair and patients with intact menisci. Similar results were found by Katakura et al. in a study based on 41 patients who underwent ACLR. The authors evaluated tibial acceleration during a pivot shift test using a triaxial accelerometer preoperatively and intraoperatively before and after medial and lateral meniscus repair. Patients with a lateral meniscus tear exhibited greater rotatory laxity in comparison with patients with intact menisci. In addition, lateral meniscus repair (and to a lesser degree also medial meniscus repair) reduced rotatory laxity. This is further supported by Robb et al. who demonstrated that the risk of ACL graft failure increased by 3.5 times in the presence of lateral meniscus deficiency but that lateral meniscus repair was not associated with an increased risk of graft failure.

Posterior lateral meniscus root tears

Meniscal root tears are defined as avulsions of the insertion (root) of the meniscus or radial tears within 10 millimeters from the root. Epidemiological studies reported an incidence of 6.6-12% of these tears in patients with ACL injuries. The recognition and repair of posterior lateral meniscus root tears is of critical importance. Their effect on knee laxity on the ACL-injured knee has been better appreciated over the last years. In a biomechanical study,
Frank et al. reported increased anterior and rotational laxity after lateral meniscus root tear in the ACL-deficient knee. In another cadaveric biomechanical study, Tang et al. showed that a posterior lateral meniscus root tear significantly increased knee laxity in the ACL-reconstructed knee during anterior tibial loading. However, trans-osseus suture root repair reduced knee laxity during anterior tibial loading and a simulated pivot shift test. In addition, root repair reduced ACL graft forces closer to those of the native ACL during anterior tibial loading. Similarly, in another biomechanical study, Shybut et al. reported that the creation of a posterior lateral meniscus root tear in the ACL-deficient knee further increases the translation of the lateral tibial plateau during the pivot-shift maneuver. The literature, therefore, suggests the repair of posterior lateral meniscus root tears whenever possible to reduce knee laxity to a level as close as possible to that of the native ACL-intact knee reducing the ACL graft forces and the risk of graft failure.

Medial-Sided Ligament Injuries

In 2018, in a study of 19,457 patients from the Swedish National Knee Ligament Registry, Svantesson et al reported an increased risk of ACL revision with non-surgical treatment of a concomitant medial collateral ligament injury. The authors found that isolated ACLR implied a lower risk of ACL revision when compared with the presence of a non-surgically treated MCL injury (HR = 0.61 [95% CI 0.41–0.89], p = 0.0097), but that there was no difference in risk of revision when MCL repair or reconstruction was performed. Patients with a concomitant MCL injury also demonstrated inferior 2-year KOOS scores compared with those who underwent isolated ACLR. These findings were somewhat surprising because in general terms most MCL injuries, particularly low-grade injuries seem to heal well with non-operative treatment and high rates of return to sport are expected.
In 2020, Lemme et al reported upon what the authors described as the largest pediatric cohort to date. Specifically, they reported upon a population of 2055 patients aged 20 years or younger, from the PearlDiver database, who had previously undergone ACLR. The authors reported an 18% ACL revision rate at 5 years post-operatively and determined that a concomitant MCL injury conferred a significantly increased risk of graft rupture (OR 1.70; 95% CI 1.31-2.19).

Both of these large (compared to other studies on this topic) registry-based studies raise concern that MCL injuries in the ACL-injured knee may not be benign as previously believed. While this is supported to some extent by biomechanical evidence that demonstrates increased force in the ACL/ACL graft with MCL deficiency, both of the aforementioned registry studies have similar key limitations. Firstly, they did not comprehensively evaluate previously reported risk factors for graft failure and therefore there was a risk of confounding. Secondly, both studies reported simply on the presence or absence of MCL injury but did not stratify by grade of injury. It is therefore not clear whether this increased risk of revision was conferred by high grade lesions or whether patients with low grade MCL lesions were also at risk.

Additional insight into this topic is provided by Lucidi et al who reported a prospective comparative study of patients with combined ACL and grade 2 MCL tears versus isolated ACL tears, both treated with isolated ACLR. At final follow up there was no significant difference between the groups with respect to failure rates [9.7% (3/31) in the ACL group and 5.5% (1/18) in the ACL+MCL group]. These findings are seemingly in contrast to those of the aforementioned large registry studies. Important limitations of this work which should be considered when interpreting the findings are the small study population which likely rendered most analyses underpowered, and the lack of randomization or propensity matching, resulting
in the potential for important baseline differences between groups. It therefore seems reasonable to infer that although there is increasing concern that MCL injuries may not be as benign as previously believed, the recent literature is conflicting and has major limitations. Despite that, these findings should serve to increase the index of suspicion for MCL injuries, which according to Willinger et al are frequently overlooked and occur with a high incidence (incidence of superficial MCL injuries 62%, and deep MCL injuries 31%, in so-called ‘isolated’ ACL rupture). In a recent study, Cristiani et al. also reported a high prevalence of MCL complex injury in patients with ACL tears.

Further study is needed to determine the optimum management of combined ACL+MCL injuries. However, a recent consensus statement on this topic from the German Knee Society provides guidelines for standardized care. Although it is beyond the scope of this article to review the guidelines in detail some key points are that while there was low scientific evidence for almost all areas considered there was >80% agreement for all statements. This provides some reassurance that these guidelines reflect current practice patterns and are an appropriate benchmark for standard of care. Despite the concerns raised by the aforementioned registry studies regarding higher risk of ACL revision with an untreated MCL injury, there was 91% agreement of the German Knee Society consensus group that partial MCL tears (grade I and II), in a combined ACL/MCL injury should initially be treated non-operatively. A summary of key take home messages regarding the management of these injuries, and tips and tricks to minimize the risk of ACL graft rupture are provided in Tables 5 and 6 respectively. Table 7 provides an overview of major pitfalls in managing secondary restraint lesions in the ACL injured knee. Table 8 provides a summary of future perspectives.
There is emerging evidence from registry studies that MCL injuries in the ACL-injured knee may not be as benign as previously thought.

The German Knee Society has demonstrated broad consensus that combined ACL and grade I and II MCL injuries should be treated with reconstruction of the ACL and non-operative management of the MCL.

Controversy exists about the optimal method of managing a combined ACL and grade III MCL injury.

Overall, treatment should be guided by recent consensus statements and be tailored to the patient based on acuity and grade of the MCL injury.

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**Table 5. Key “Take Home Messages” Regarding the Management of Combined ACL and MCL Injuries**

<table>
<thead>
<tr>
<th><strong>Take Home Messages</strong></th>
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<tbody>
<tr>
<td>Assessment of injuries to the anterolateral structures and eventually perform ALL reconstruction/LET in patients with risk factors for ACL graft failure.</td>
</tr>
<tr>
<td>Assess the presence of associated MCL injuries and treat them accordingly.</td>
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<tr>
<td>Evaluate the presence of associated meniscal tears (including ramp lesions and lateral meniscus root tears) and perform a repair whenever possible.</td>
</tr>
</tbody>
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**Table 6. Tips and Tricks to Minimize the Risk of Graft Failure Depending on Secondary Restraints after ACL Reconstruction**

<table>
<thead>
<tr>
<th><strong>Tips and Tricks</strong></th>
</tr>
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**Table 7. Major Pitfalls of Addressing Secondary Restraints in ACL Reconstruction**

<table>
<thead>
<tr>
<th><strong>Major Pitfalls</strong></th>
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<tr>
<td>The indication for extra-articular reconstruction should not be based solely on physical examination or imaging data, any patient with an increased risk of failure should have an associated anterolateral procedure.</td>
</tr>
</tbody>
</table>
Fixation of an ALL reconstruction in any position that is not in full extension may lead to unfavorable biomechanics of the reconstruction. The modified Lemaire tenodesis can be fixed from 0 to 60 degrees. Both techniques should have the femoral attachment posterior and proximal to the lateral epicondyle.

Not repairing the medial and lateral meniscus tends to increase the ACL failure rate and also the degenerative changes in medial and lateral compartments.

Do not rely only in anterior evaluation to detect a ramp lesion as it common to miss it. Be careful with all inside devices as they tend to have a higher chance of failure.

MRI might not detect a lateral posterior meniscus root tear. Be prepared to repair it in every ACL reconstruction.

It is common to not address combined ACL and MCL injuries. This lesion combination seems to be more common than previously thought. Residual medial laxity might cause an ACL failure.

### Table 8: Future perspectives on secondary restraint lesions in the ACL-injured knee

Numerous comparative studies, including large series with long-term follow up, there is substantial evidence demonstrate significantly reduced ACL graft rupture rates when a LEAP is performed at the time of primary and revision ACLR. However, an exciting future perspective is that there are several large prospective randomized controlled studies in progress that will provide a higher quality of evidence.

Meniscal preservation is well-recognized to be important and biomechanical studies show advantages of ramp repair. However, high quality comparative studies evaluating clinical benefits of ramp repair are lacking and are an important area for future study.

There is an emerging concern that MCL injuries may not be as benign as previously thought. Well-designed prospective comparative studies are needed to precisely define the impact of these injuries. In the meantime, consensus statements help to guide clinical practice.

The authors of this review conclude that there is substantial evidence demonstrating significantly reduced ACL graft rupture rates when a LEAP is performed at the time of primary
and revision ACLR from numerous comparative studies, including large series with long-term
follow up. However, an exciting future perspective is that there are several large prospective
randomized controlled studies in progress that will provide a higher quality of evidence. This
review also highlights the importance of meniscal preservation in the ACL-injured knee but
highlights that despite practice patterns favoring posteromedial compartment evaluation and
ramp repair, there is a need to validate this approach with future high-quality comparative
clinical studies. Finally, with respect to MCL injuries, surgeons should be aware of the
emerging concern that combined ACL+MCL injuries may not be as benign as previously
considered but that consensus exists regarding their management in contemporary practice.

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Conflict of interest

Secondary Restraints in ACL Reconstruction: State of the Art

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None of the authors report any conflicts of interest with respect to this article