Epidemiological Evaluation of Meniscal Ramp Lesions in 3214 ACL-Injured Knees from the (X) Database: A Risk Factor Analysis and Study of Secondary Meniscectomy Rates Following 769 Ramp Repairs.

Abstract

Background: Ramp lesions are characterized by disruption of the peripheral meniscocapsular attachments of the posterior horn of the medial meniscus. Ramp repair performed at the time of ACL reconstruction has been shown to improve knee biomechanics.

Hypothesis/Purpose: Primary objectives of this study were to evaluate the incidence and risk factors for ramp lesions in a large series of patients undergoing ACL reconstruction, Secondary objectives were to determine the re-operation rate for failure of ramp repair, defined by subsequent re-operations for partial medial meniscectomy

Study Design: Case series

Methods: All patients underwent trans-notch posteromedial compartment evaluation of the knee during ACL reconstruction. Ramp repair was performed if a lesion was detected. Potentially important risk factors were analyzed for their association with ramp lesions. A secondary analysis of all patients who underwent ramp repair and had a minimum follow-up of two years was undertaken in order to determine the secondary partial meniscectomy rate for failed ramp repair.

Results: The overall incidence of ramp lesions in the study population was 23.9% (769 ramp lesions in 3214 patients). Multivariate analysis demonstrated that the presence of ramp lesions was significantly associated with the following risk factors: male gender, patients aged under 30 years, revision ACLR, chronic injuries, pre-operative side-to-side laxity >6 mm and the presence of concomitant lateral meniscus tears. The secondary meniscectomy rate was 10.8% at a mean follow up of 45.6 months (24.2-66.2). Patients who underwent ACLR + ALLR had a greater than 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)

Conclusion: There is a high incidence of ramp lesions in patients undergoing ACLR. The identification of important risk factors for ramp lesions in this study in an individual patient should help raise an appropriate index of suspicion and prompt posteromedial compartment evaluation. The overall secondary partial meniscectomy rate after ramp repair is 10.8%. Anterolateral ligament reconstruction appears to confer a protective effect on the ramp repair performed at the time of ACLR and results in a significant reduction in secondary meniscectomy rates.

Key Terms: Ramp lesions. ACL, ACLR, ALL, ALLR, Meniscus. Meniscus repair

What is known about the subject:

Ramp lesions are important because they have adverse effects on the stability and biomechanics of the ACL injured knee. It is known that isolated ACLR fails to restore this fully in the presence of a ramp lesion, but that when ramp repair is performed concurrently, normal stability can be restored.

Although previous studies have reported the incidence of ramp lesions in the ACL injured knee, the majority have had very small sample sizes and therefore it is difficult to hold great confidence that they reliably estimate the true incidence. The same comment can be made regarding previously reported risk factors for ramp lesions.

There is very little published in the literature regarding failure rates of ramp repair.

What this study adds to existing knowledge:

To the knowledge of the authors this study is considerably larger than any other epidemiological and risk factor evaluation of ramp lesions in ACL injured knees. It is our opinion that the size of this series helps to give confidence that the incidence of ramp lesions seen in this study is a reliable estimate of the true incidence. Furthermore, this study has been able to confirm that many previously reported potential risk factors are significantly associated with ramp lesions but refute others which have been proposed on the basis of studies that were likely hindered by small sample sizes.

This study also adds to existing knowledge by reporting secondary meniscectomy rates after ramp repair and also demonstrating that anterolateral ligament reconstruction confers a protective effect on ramp repairs, as evidence by a significant reduction in secondary meniscectomy rates.

Introduction

Meniscal ramp lesions are typically associated with anterior cruciate ligament (ACL) deficiency. They are characterized by a disruption or tear of the peripheral meniscocapsular attachments of the posterior horn of the medial meniscus.[7] The term "ramp lesion" was first attributed to this injury pattern by Strobel in the 1980's,[44] and is useful for differentiating this particular tear morphology from other types of longitudinal posterior horn tear. Despite the long history of recognition of ramp lesions, it is evident that the risk factors for developing this type of injury, the incidence, and the outcomes of treatment remain incompletely defined. This is partly due to the small populations evaluated in previous reports. As a result, the study of ramp lesions continues to be a subject of great interest.[33,35]

The biomechanical importance of these lesions has been demonstrated by cadaveric studies that have performed posterior meniscocapsular sectioning in the ACL-deficient knee. These studies have demonstrated that ramp lesions are associated with increases in both anterior tibial translation and external rotation.[1,29,43] More importantly, from the perspective of clinical applicability, these studies have also demonstrated restoration of knee biomechanics after meniscocapsular lesion repair.[1,43] It is therefore considered important to identify these lesions in order to repair them when necessary. However, it should be noted that historically these injuries were probably under-appreciated because pre-operative examination[50] and imaging modalities[3,6,15,20,37] have a low sensitivity for ramp lesions. Furthermore, a substantial number of these lesions may also be missed at the time of arthroscopic evaluation, particularly if this is performed using standard anterior portal viewing only.[40] In order to minimize the risk of missed diagnoses of ramp lesions, it is imperative to undertake a systematic arthroscopic examination, including that of the posteromedial compartment.

The primary objectives of this study were to evaluate the incidence of ramp lesions in a large series of patients undergoing posteromedial compartment evaluation at the time of ACL reconstruction, and also to determine the risk factors associated with ramp lesions. The secondary objectives of this study were to determine the re-operation rate for failure of ramp repair, defined by subsequent re-operations for partial medial meniscectomy of the repaired posterior horn, at a minimum follow-up of 2 years.

Methods

Institutional review board approval (IRB COS-RGDS-2018-03-003) was granted for this study and all patients gave valid consent to participate. A retrospective analysis of prospectively collected data from the XXXX (anonymized for review) study group database was conducted. All patients who underwent arthroscopic primary or revision anterior cruciate ligament reconstruction (ACLR) between September 2012 and March 2018 were considered for study eligibility. Patients were only excluded if they underwent major concomitant surgery (for example multiligament reconstruction and/or high tibial osteotomy) or had other types of medial meniscal lesions (including root tears, horizontal tears, radial tears or vertical tears more centrally located than the red-white zone).

Preoperatively, all patients had sustained an ACL tear, diagnosed on the basis of clinical examination and magnetic resonance imaging (MRI). The patients had been unable to resume their previous levels of activity because of instability symptoms and therefore underwent ACL reconstruction. The decision to use a particular graft type for ACLR was based on patient factors/choice and the evolving indications for performing a concomitant anterolateral ligament reconstruction (ALLR) during the study period. This decision was taken preoperatively and was independent of the status of the MM. ~~Indications for ALLR included one or more of the following criteria: grade 3 pivot shift, high level of sporting activity, participation in pivoting sports, deep lateral femoral notch sign on radiographs, associated Segond fracture, chronic ACL rupture (>3months after injury), and patients < 25 years old.~~

Surgical Technique

All surgical procedures were performed by a single surgeon (Y) with the patient positioned in the standard arthroscopy position, a lateral support at the level of a padded tourniquet, and a

foot post to allow the knee to be maintained at 90 degrees of flexion when required. Meniscal and chondral lesions were addressed prior to ACLR.

Posteromedial compartment evaluation

All patients underwent a systematic arthroscopic exploration of the knee as previously described.[40] In order to assess the posteromedial compartment, trans-notch visualization was performed with the arthroscope placed in the anterolateral portal. Visualization of the posterior horn medial meniscocapsular attachment was optimized by the application of tibial internal rotation (Fig 1).[47]

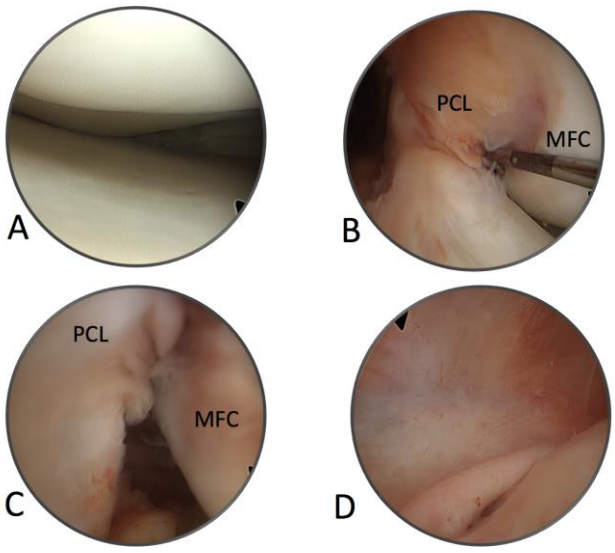

Figure 1. Intra-operative images from a Right knee. All images taken with 30 degree arthroscope placed through the anterolateral portal: A) Standard view of the medial compartment, the ramp lesion is not visualised B) The probe is placed in order to demonstrate the location in the notch between the medial femoral condyle (MFC) and the posterior cruciate ligament (PCL) through which the arthroscope will subsequently be advanced into the posteromedial compartment, C) Placing the knee in approximately 30 degrees flexion and valgus allows opening of this space and facilitates passage of the arthroscope into the posteromedial compartment, D) View of posteromedial compartment

shows the ramp lesion; Visualization was optimized by the application of tibial internal rotation

Using the same methodology as Liu et al, the menisco-capsular attachments and meniscus were evaluated by probing using either a needle or an arthroscopy hook inserted through a posteromedial portal.[47] For the purposes of differentiating from other types of meniscal lesion, a ramp lesion was defined as a medial meniscocapsular tear of the posterior horn of the medial meniscus. The rationale for including only ramp repairs performed through a posteromedial portal was based on reports from several authors that different tear types are associated with different failure rates.[18,25,32,34]

Ramp Repair

If a ramp lesion was identified, a shaver was inserted through the posteromedial portal and both surfaces of the tear were prepared (Fig 2).

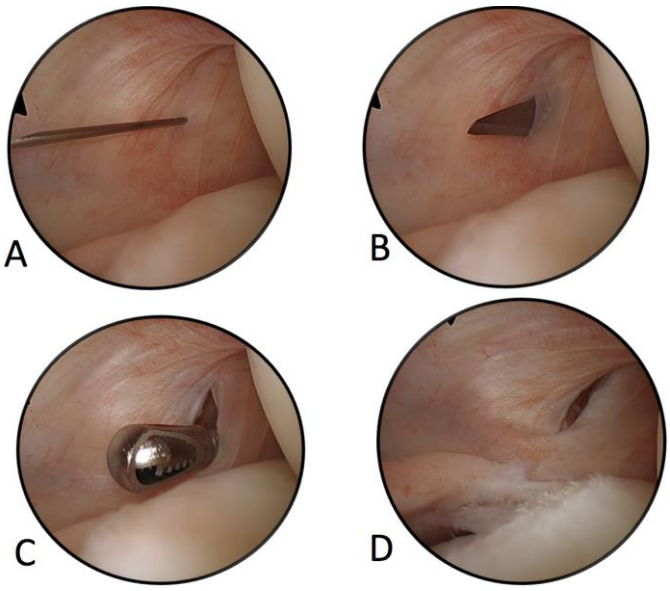

Figure 2. Posteromedial compartment evaluation in a Right knee. Trans-notch view obtained with arthroscope placed through anterolateral portal: A) Needle localisation of portal is performed, B) 11-blade scalpel is used to create the portal under direct vision, C) A shaver is inserted and both surfaces of the tear are debrided to encourage healing, D) Appearance of the tear after preparation is completed

A 25° suture hook (SutureLasso; Arthrex) loaded with a No. 0 absorbable monofilament suture (PDS; Ethicon) was then inserted, and between one and three separate sutures were used to perform a repair. After passage, the sutures were tied using a sliding knot and half hitches. A satisfactory repair was confirmed by evaluation with an arthroscopic probe placed through the anteromedial portal (Fig 3).

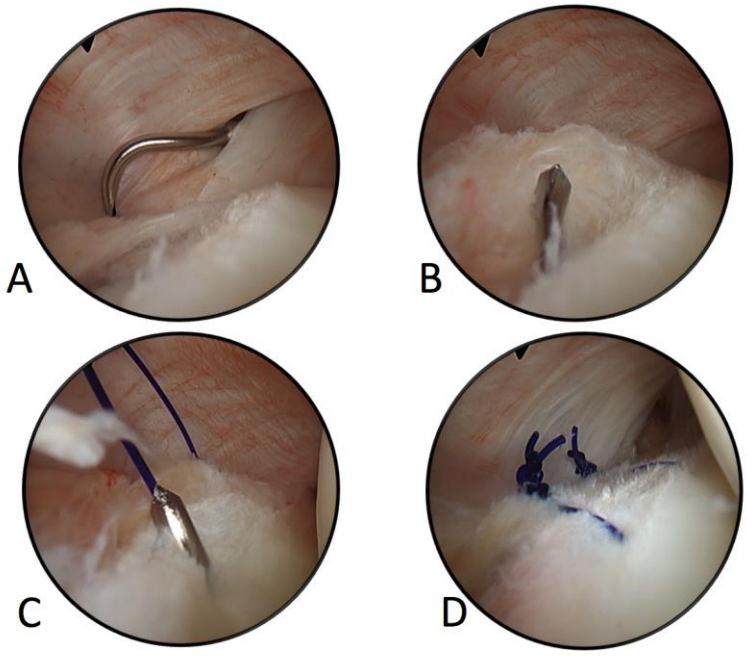

Figure 3. Ramp repair performed in a Right knee. Trans-notch view of posteromedial compartment obtained with arthroscope placed through anterolateral portal: A) 20 degree left suture hook (Arthrex, Naples, USA) is inserted via the posteromedial portal, B) Suture

hook passed through meniscocapsular junction into the tear. This allows the hook to be repositioned and then passed into the meniscus body, C) The suture hook is passed into the meniscus body. The 0-PDS suture is then advanced and retrieved through the posteromedial portal after which it is tied, D) The ramp lesion has been repaired, two 0-PDS sutures have been placed using the steps demonstrated. They have been tied with a sliding knot and half hitches via the posteromedial portal under direct vision

ACLR with or without concomitant ALLR.

ACLR was performed either as an isolated procedure or in conjunction with ALLR. The ACL grafts used included quadrupled semitendinosus tendons;[41] bone-patellar tendon-bone[13] quadruped hamstring tendons (4HT) or in the case of combined ACL+ALL grafts (HT) a tripled semitendinosus with a single strand of gracilis. [22] In those cases where an ALLR was performed independently of the ACL graft, the ALL reconstruction was performed with gracilis autograft. Our current indications for ALLR include a grade III pivot shift, associated Segond fracture, chronic ACL rupture, high levels of sporting activity, participation in pivoting sports (eg, soccer, rugby, handball, basketball), patients ≤25 years old, preoperative side-to-side laxity >6 mm, lateral femoral notch sign on plain radiographs, and patients undergoing revision ACL reconstruction.

Rehabilitation

All patients underwent the same post-operative rehabilitation. This comprised immediate brace-free mobilization, weight bearing as tolerated, and a restricted range of motion from 0-90° for the first 4 weeks postoperatively.[30] Full extension and quadriceps activation were key

elements of the early physiotherapy. Return to sports was allowed gradually with non-pivoting sports at 4 months, pivoting non-contact sports at 6 months and pivoting contact sports at 8-9 months.

Follow-up

Postoperative evaluation was conducted by a sports physician, independent of the primary surgeons at 3 and 6 weeks, and 3, 6 and 12 and 24 months. Only those patients who had a minimum follow up of two-years and underwent ramp repair were included in the analyses of secondary meniscectomy rates. In this subgroup, all patients were contacted at final follow-up by an investigator (Z), independent of the primary surgeon to determine if they had undergone ipsilateral re-operation for secondary meniscectomy. If further surgery had been undertaken, the operative records were obtained and reviewed. For the purposes of this study the term "secondary meniscectomy" was used to describe failure of ramp repair defined by a re-operation for partial medial meniscectomy involving the previously repaired posterior horn. A flowchart of included patient is presented in Fig 4.

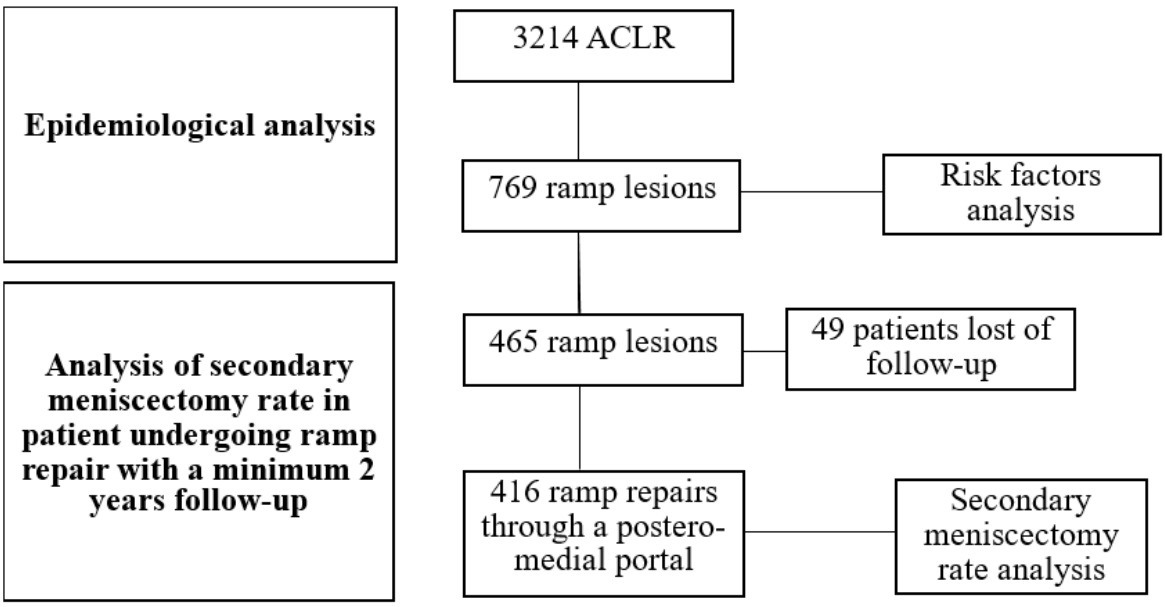

Figure 4. Flowchart of included patients

Epidemiological and Risk Factor Analysis of Ramp Lesions

The epidemiology of ramp lesions was characterized by their incidence stratified by key demographic parameters. Potentially important risk factors were evaluated for association with ramp lesions and this included gender, body mass index, primary or revision ACLR, age, time between injury and surgery, type of sport (contact vs non-contact); associated lateral meniscus tears and; pre-operative side-to-side laxity difference (<6 mm vs >6mm).

Statistical Analysis

All calculations were made with SAS for Windows (v 9.4; SAS Institute Inc), with the level of statistical significance set at $p < 0.05$. Descriptive data analysis was conducted depending on the nature of the considered criteria. For quantitative data this included number of observed (and missing, if any) values, mean, standard-deviation, median, first and third quartiles, and minimum and maximum. For qualitative data this included the number of observed (and missing, if any) values, and the number and percentage of patients per class. A multivariate logistic regression was performed in order to identify predictive factors of ramp lesions. The factors considered in the multivariate analysis were selected by the way of an univariate approach, including statistically significant effects at the 20% threshold. Moreover, the incidence of such lesions, stratified by time interval from injury to surgery, was described and graphically displayed. The characteristics of patients with ramp lesions were compared between the two groups, defined according to the type of surgery (isolated ACL or ACL + extra articular reconstruction), using the Chi-Square or Fisher exact tests and the Student's t-

247 test for the qualitative and quantitative data, respectively. The time to secondary
248 meniscectomy was analyzed considering Kaplan-Meier approach and adjusted Cox model.
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250 RESULTS

251 3214 patients undergoing ACL reconstruction were included in the study. A ramp lesion was
252 identified and repaired in 769 patients (23.9%). Patient characteristics associated with both
253 the presence and absence of associated ramp lesions are presented in Table 1.

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255 *Table 1 Individual characteristics of patients with or without an associated ramp lesion*

		RAMP lesion	No RAMP lesion
Gender	n	769	2445
	Male	610 (26.2%)	1721 (73.8%)
	Female	159 (18%)	724 (82%)
Age at injury (years)	n (d.m.)	758 (11)	2412 (33)
	<= 20	255 (27.2%)	683 (72.8%)
	20 - 30	321 (26.2%)	900 (73.8%)
	30 - 40	128 (21.3%)	472 (78.7%)
	> 40	54 (13.1%)	357 (86.9%)
BMI (kg/m²)	n	769	2445
	Mean (SD)	23.96 (3.00)	23.89 (3.34)
	Median (Q1; Q3)	23.6 (21.8 ; 25.7)	23.5 (21.6 ; 25.6)
	Min ; Max	17.3 ; 38.6	14.6 ; 41.3
Time from injury (months)	n (d.m.)	758 (11)	2412 (33)
	<= 3	326 (21.6%)	1183 (78.4%)
	3 - 6	175 (24.6%)	535 (75.4%)
	6 - 12	100 (24.6%)	306 (75.4%)
	12 - 24	49 (25.1%)	146 (74.9%)
	> 24	108 (30.8%)	242 (69.2%)
ACLR revision	n	769	2445

		RAMP lesion	No RAMP lesion
	Yes	120 (37.4%)	201 (62.6%)
	No	649 (22.4%)	2244 (77.6%)
Cause of rupture	n	769	2445
	Contact sport	528 (25.7%)	1526 (74.3%)
	Non-contact sport	241 (20.8%)	919 (79.2%)
Laxity (mm)	n	769	2445
	<= 6	346 (21%)	1300 (79%)
	> 6	423 (26.9%)	1145 (73.1%)
Lateral meniscus lesion	n	769	2445
	Yes	297 (33.8%)	582 (66.2%)
	No	472 (20.2%)	1863 (79.8%)

Risk Factors for Ramp Lesions

Multivariate analyses were performed in order to investigate the association of potential risk factors with the occurrence of ramp lesions (Table 2). These analyses demonstrate that male gender, age < 30 years, revision ACLR, side-to-side laxity difference greater than 6mm, and the presence of a lateral meniscal tear are all significant risk factors for ramp lesions. Although the incidence of ramp lesions in contact sports (25.7%) was higher than non-contact sports (20.8%) this was not significant in a multivariate analysis (P = .247).

A significantly higher incidence of ramp lesions was observed in patients with chronic ACL ruptures compared to acute ACL ruptures (26% vs 21.6%; *P* = .0037). Specifically, there was a significant increase in the incidence of ramp lesions in the groups with greater chronicity for all time intervals studied, up to 60 months (Table 3). Regression analysis demonstrates the correlation between time since injury and the increasing incidence of ramp lesions (Fig 5)

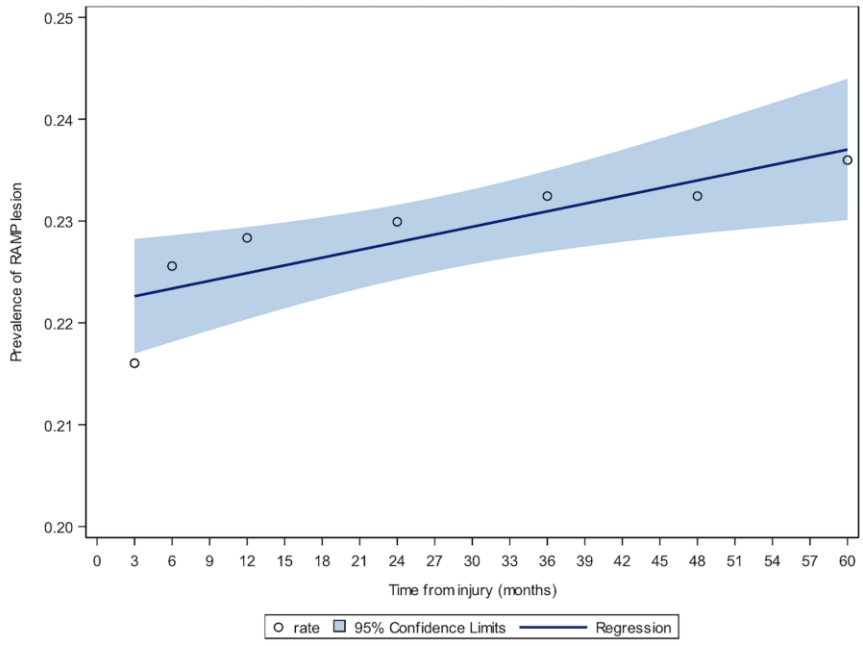

Figure 5. Scatter plot of the incidence of ramp lesions identified in patients undergoing surgery at the following time intervals since injury: ≤ 3 months, ≤ 6 months, ≤ 12 months, ≤ 24 months, ≤ 36 months, ≤ 48 months and ≤ 60 months. The linear regression line and corresponding 95% confidence limits are shown.

278 *Table 2 Multivariate logistic regression analysis of the association of potentially important*
279 *risk factors with ramp lesions* [α]

Risk factor	Comparison	OR (N= 3170)	OR IC95%	*P* value
Gender				**<.001**
	Male vs Female	1.498	[1.228; 1.836]	
Age at injury (years)				**<.001**
	<= 30 years vs > 30 years	1.609	[1.33; 1.952]	
Time from injury (months)				**0.002**
	]12, 24] months vs]6, 12] months	0.965	[0.64; 1.442]	
	]3, 6] months vs]6, 12] months	0.979	[0.733; 1.312]	
	]12, 24] months vs]3, 6] months	0.985	[0.671; 1.43]	
	]12, 24] months vs <= 3 months	1.248	[0.865; 1.774]	
	]3, 6] months vs <= 3 months	1.266	[1.019; 1.569]	
	]6, 12] months vs <= 3 months	1.293	[0.99; 1.681]	
	> 24 months vs]6, 12] months	1.313	[0.944; 1.829]	
	> 24 months vs]3, 6] months	1.342	[0.998; 1.799]	
	> 24 months vs]12, 24] months	1.361	[0.909; 2.058]	
	> 24 months vs <= 3 months	1.698	[1.296; 2.218]	
ACLR revision?				**<.001**
	Yes vs No	1.821	[1.41; 2.344]	
Laxity (mm)				**0.047**
	> 6 mm vs <= 6 mm	1.190	[1.002; 1.413]	
Lateral meniscus lesion?				**<.001**
	Yes vs No	1.905	[1.594; 2.276]	
Cause of rupture	Contact vs Non-contact sport			0.257

280 [α]*Bolded P values indicate statistical significance; ALCR : Anterior cruciate ligament reconstruction*

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Table 3 The incidence of ramp lesions in the study population, stratified by class of time interval between injury and ACLR

Time From Injury	Total number of Patients	Patients with ramp lesions n (%)	*P* Value*
≤3 mo[α]	1509	326 (21.6%)	0.0037
>3 mo	1661	432 (26%)	
≤6 mo	2219	501(22.6%)	0.0072
>6 mo	951	257 (27%)	
≤12 mo	2625	601 (22.9%)	0.0032
>12 mo	545	157 (28.8%)	
≤ 24 mo	2820	650 (23%)	0.0012
>24 mo	350	108 (30.9%)	
≤36 mo	2927	682 (23.3%)	0.0051
>36 mo	243	76 (31.3%)	
≤48 mo	2970	692 (23.3%)	0.0019
>48 mo	200	66 (33%)	
≤60 mo	3006	711 (23.7%)	0.1433
>60 mo	164	47 (28.7%)	

*[α]3 months after injury was defined as a time between acute anterior cruciate ligament rupture and chronic injury; * Chi-square test*

Secondary meniscectomy rate with a minimum of 2-years of follow-up

Of those patients who underwent ramp repair, 465 had a minimum post-operative follow-up of two years and were considered eligible for the secondary meniscectomy analysis. However, 49 (10.5%) were lost to follow-up despite attempts to contact them by telephone, mail and via their primary care physician. The final subgroup population therefore comprised 416 patients with a mean follow up of 45.6 months (range 24.2-66.2 months). At final follow up, 45 patients (10.8%) had undergone reoperation for partial medial meniscectomy at a mean delay of 21.5 months (3.9-66.2).

This subgroup of 416 patients was further divided into 2 groups: isolated ACLR (n=225) and ACLR + ALLR (n=191) (Table 4). Figure 6 shows the cumulative survivorship of MM repairs derived from Kaplan-Meier analysis, with reoperation for medial meniscectomy as an endpoint. At both 24 and 48 months follow-up, rates of failure of ramp repair were significantly lower for patients who underwent combined ACLR + ALLR compared to those who underwent isolated ACLR (*P* = .0178). Patients who underwent ACLR + ALLR had a greater than 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).

Table 4 Kaplan-Meier Rates of Medial Meniscus Repair Failure by Follow-up Period[α]

	Overall		Isolated ACLR		ACLR + ALLR		
Time point	Rate of second meniscectomy	95%CI	Rate of second meniscectomy	95%CI	Rate of second meniscectomy	95%CI	Log-Rank test: *P* Value
1 years	4.08%	[2.59% ; 6.39%]	5.90%	[3.54% ; 9.76%]	1.96%	[0.74% ; 5.14%]	**0.0178**
2 years	6.67%	[4.68% ; 9.46%]	9.40%	[6.29% ; 13.93%]	3.50%	[1.68% ; 7.20%]	
3 years	8.97%	[6.56% ; 12.20%]	11.88%	[8.29% ; 16.87%]	5.57%	[3.00% ; 10.21%]	
4 years	11.26%	[8.33% ; 15.13%]	14.82%	[10.55% ; 20.62%]	6.66%	[3.64% ; 12.01%]	
5 years	11.26%	[8.33% ; 15.13%]	14.82%	[10.55% ; 20.62%]	6.66%	[3.64% ; 12.01%]	

[α]Values are expressed as mean percentage (95%). Bold indicates statistical significance, P<0.05. ACLR, anterior cruciate ligament reconstruction; ALLR, anterolateral ligament reconstruction.

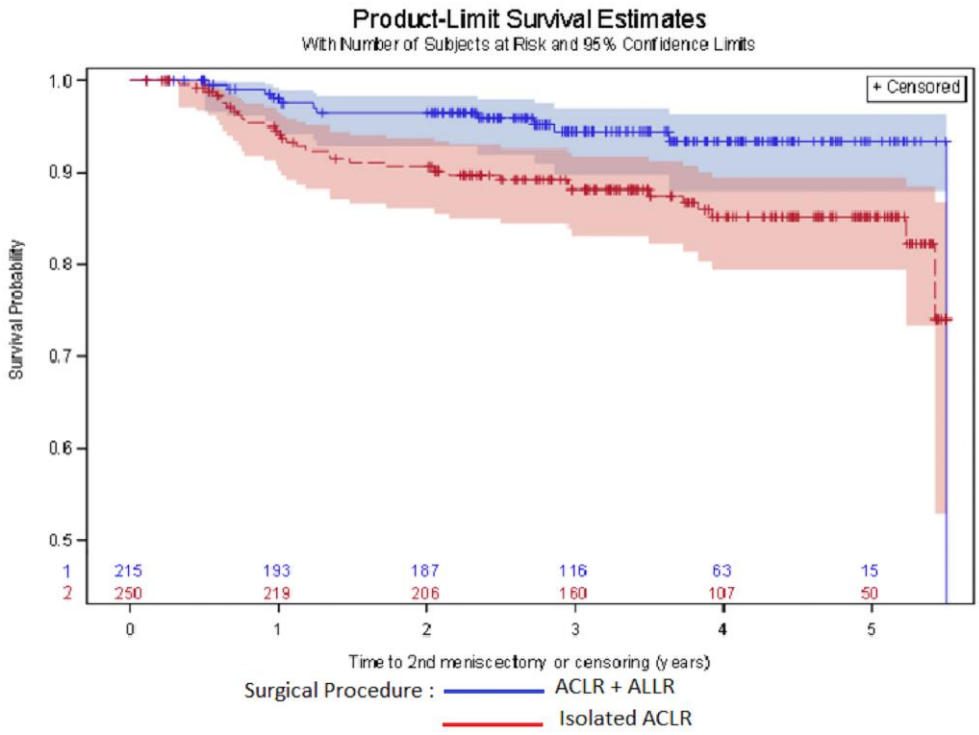

Figure 6. Kaplan-Meier Survivorship with reoperation for secondary partial medial meniscectomy (as previously defined) as an endpoint. Numbers at risk with 95% CI. ACLR, anterior cruciate ligament reconstruction, ALLR, anterolateral ligament reconstruction

DISCUSSION

A key finding of this study was that the incidence of ramp lesions was 23.9% in ACL deficient knees. Previous authors have reported rates of diagnosis between 9% to 30%,[6,10,11,15,20,36] but it has been unclear how reliably this data can be used to estimate the true incidence of ramp lesions due to the majority of studies including only a small number of patients. Bollen et al. reported a rate of 9.3%, following arthroscopic examination, in a prospective series of 183 ACL reconstructions.[6] Di Vico et al. reported a rate of 9.6% in a series of 115 patients who underwent ACL reconstruction.[11] Liu et al. reported a incidence of 16.6% in a series of 868 patients with ACL injury[20] and more recently, Seil et al. reported a rate of 24% in 224 patients.[36] These variations in incidence may also be related to the diagnostic techniques used. Specifically, pre-operative examination of knee laxity under anesthesia has been shown to be ineffective at predicting the presence of ramp lesions.[50] Imaging is also unreliable and a number of studies have reported difficulty identifying these lesions with MRI, which has a high specificity, but a moderate sensitivity, leading to an underestimation the true incidence.[3,6,10,15,20,37] For example, Bollen et al reported that pre-operative MRI failed to detect a single ramp lesion in a group of eleven knees with arthroscopically confirmed lesions.[6]

In the current study, a systematic evaluation of the posteromedial compartment was undertaken in all 3214 knees. This is an important point when considering incidence data because, as reported in a previous series, many (approximately 17%) ramp lesions were only identified after probing the tear through a posteromedial portal in conjunction with a minimal debridement of the superficial soft tissue layer.[40] These hidden lesions are highly likely to be missed if arthroscopic examination is only conducted through standard anterior portals.

The other major findings of this study relate to the evaluation of risk factors associated with ramp lesions. This study has confirmed previous findings from other authors that male gender, younger age (<30 years), a concomitant lateral meniscus lesion and chronicity, are significantly associated with ramp lesions.[20,36] However, the findings of the current study, based on multivariate analysis, disputed previous work by Seil et al,[36] which suggested that contact sports injuries were an important risk factor for ramp lesions. It could be the case that the discrepancy between studies is a result of the difference in sample sizes.

In any case, there are a number of risk factors which should be emphasized because they have now been demonstrated to be of significance by several authors. This increases the confidence in the strength of evidence and highlights the need for posteromedial compartment evaluation in patients with these characteristics. Delay between injury and ACLR is significantly associated with increasing incidence of ramp lesions over time. In 1984, Woods and Chapman reported on arthroscopic assessment of a series of 234 knees with ACL rupture. Although not defined as ramp lesions, they found posterior meniscocapsular disruptions of the medial meniscus occurred in 20 of 112 (17.8%) acute cases (<3 months) versus 31 of 122 (25.4%) at an average time of 37 months.[50] Liu et al. demonstrated that with increased time delay between ACL injury and surgery, the incidence of ramp lesions increased up until 24 months.[20] Church et al. equally found an increased number of all types of meniscal lesions after 12 months, recommending early ACL reconstruction to avoid these injuries.[9] Other series have also found an association between medial meniscal tears and increased time to surgery.[9,17,28,46]

Gender and age are also important risk factors identified by numerous authors. In the current study, the male gender was associated with a significantly higher incidence of ramp lesions (27%) compared to females (19%). Liu et al. similarly observed a significantly increased rate

in males (18.56% versus female patients 11.97%).[20] Seil et al. reported an increased rate of 27% for males versus 17% for females, although this difference did not reach significance due to a small sample size.[36] The current study also demonstrated that there was also a significantly higher incidence of ramp lesions in patients under the age of 30. Similarly, results are found in previously published data. Malatray et al. found that the prevalence of ACL-associated ramp lesions in children and adolescents is similar to adult populations.[23] Liu et al. also found that those younger than 30 years of age had a significantly higher incidence of ramp lesions.[20]

The current study also identified several new significant risk factors, including revision ACLR. This finding may be explained by either a failure to repair a ramp lesion at the first surgery or by chronic residual laxity following ACLR leading to a new lesion. Similarly, a pre-operative anteroposterior side-to-side laxity difference greater than 6mm, was also found to be an important newly recognized association. However, it is unclear whether this excessive laxity may predispose to ramp lesions or whether it is simply a reflection of the role of the medial meniscus as a secondary restraint to anterior laxity of the knee,[1] with the abnormality being a consequence of a ramp lesion rather than the cause. Another explanation may be that a high-energy mechanism or injury is often involved in ramp lesions.[5] Other risks factors previously reported in the literature, but not evaluated in the present study, were a complete rupture versus partial [36] and a higher medial tibial slope.[39]

The importance of clearly defining risk factors is in aiding surgeons to hold an appropriate index of suspicion for ramp lesions, prompt them to perform a posteromedial compartment evaluation, and identify and repair injuries in order to restore knee stability. When ramp lesions are overlooked in an ACL reconstruction, anterior and rotatory instability

persists[1,24,43] but meniscocapsular repair has been demonstrated to restore normal knee biomechanics.[1,43]

If ramp repair is to be advocated in a large proportion of patients undergoing ACLR it is important to understand the secondary meniscectomy rate. In this study, it was found to be 10.8% at a mean follow up of 45.6 months. These results are in keeping with previous reports.[16,48] However, a new finding is that the secondary meniscectomy rate after ramp repair was significantly lower after combined ACLR + ALLR reconstruction compared to isolated ACLR (P = .0178). The combined procedure was associated with a greater than two-fold reduction in the failure rate of RR (P= .021). This supports the results of a previous study, which demonstrated the protective effect of ALLR on medial meniscal repairs.[42]

Meniscal healing after repair remains a topical issue.[27] In 1983, Hamberg et al. reported high healing rates (84%) with suture repair of a series of 43 peripheral medial meniscal tears using an open posteromedial approach.[14] More recent studies of arthroscopic repair using all-inside techniques with suture hook [2] or fast-fix anchors [19] have reported good functional results, with complete healing of 84.3% of tears. A comparison of all-inside repair with outside-in repair showed similar meniscal healing rates (71.4% vs.70.6%) at a mean follow-up of 36 months.[8] Some authors have suggested that not all ramp meniscal lesions need repair.[12,38,50] Liu et al. reported that stable ramp lesions can be treated with abrasion and trephination alone with equivalent results to repair.[21] Unfortunately, these studies are limited by relatively small samples size, and do not present conclusions about the optimal treatment. Pujol et al, in systematic review, evaluated ten studies in which meniscal tears were left in-situ during ACLR.[31] Tears were generally left if they were deemed stable on arthroscopic probing or were less than 10mm in size. Using the endpoint of significant pain or meniscectomy at

follow-up, medial meniscal tears left in-situ failed in 10-66% of the cases (mean 14.8%). They concluded that repair of stable peripheral tears should always be performed to decrease the risk of postoperative pain or subsequent meniscectomy. In our practice, we therefore aim to repair all ramp lesions. If the surgeon is already creating a posteromedial portal to perform abrasion and trephination, a meniscal repair through the same portal is relatively easily performed with minimal additional risk.

Limitations

The limitations of a retrospective study design are well recognized. Despite that, this methodology has advantages, particularly allowing a large sample size, which has been a limitation of previous studies. This study did not include an assessment of functional outcomes or a comparison with a control group, for example patients undergoing non-operative treatment of ramp lesions, or tear debridement without repair. In addition, the study methodology did not include routine second-look arthroscopy, MRI or clinical functional evaluation of all patients at final follow-up. This may have resulted in missed diagnoses of both ramp lesions and of failed ramp repair. However, routine second look arthroscopy is now rarely reported in the literature due to the unnecessary risk to the patient and evidence that arthroscopic findings often do not correlate with patient symptoms.[4,45] Furthermore, performing routine follow-up MRI for the entire series of patients in order to evaluate the healing of the meniscus was not economically or technically feasible in such a large population. However, all patients were contacted by telephone at final follow up and those who had symptoms were recalled for these investigations and assessment. Failure of a ramp lesion repair was instead based on the hard end-point of patients who underwent subsequent re-operation of the posterior horn of the medial meniscus. Previous studies have defined failure of meniscal repair by the presence of osteoarthritis, abnormal MRI, clinical symptoms

or subsequent meniscal surgery.[26,27,49] Another limitation is that we have not reported upon the possible etiology or size of ramp lesions that underwent repair and then secondary partial meniscectomy. Although it would have been interesting to study this the relevant data was not recorded or available due to the retrospective study design. A further study limitation is that the results of this study cannot be extrapolated to patients with ACL injury who undergo non-operative treatment as they were not evaluated arthroscopically in this study.

CONCLUSION

The high incidence of ramp lesions identified in this study, along with description of important risk factors, allows an appropriate index of suspicion to be held for these injuries at the time of ACLR and prompt posteromedial compartment evaluation in order to reduce the rate of missed diagnoses.

The overall secondary meniscectomy rate after ramp repair was 10.8% in this series but this was significantly lower in those patients who underwent ACLR and anterolateral ligament reconstruction, the latter appearing to confer a protective effect.

References

1. Ahn JH, Bae TS, Kang K-S, Kang SY, Lee SH. Longitudinal tear of the medial meniscus posterior horn in the anterior cruciate ligament-deficient knee significantly influences anterior stability. *Am J Sports Med*. 2011;39(10):2187-2193. doi:10.1177/0363546511416597.

2. Ahn JH, Lee YS, Yoo JC, Chang MJ, Koh KH, Kim MH. Clinical and second-look arthroscopic evaluation of repaired medial meniscus in anterior cruciate ligament-reconstructed knees. *Am J Sports Med*. 2010;38(3):472-477. doi:10.1177/0363546509348102.

3. Arner JW, Herbst E, Burnham JM, et al. MRI can accurately detect meniscal ramp lesions of the knee. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(12):3955-3960. doi:10.1007/s00167-017-4523-9.

4. Asahina S, Muneta T, Yamamoto H. Arthroscopic meniscal repair in conjunction with anterior cruciate ligament reconstruction: factors affecting the healing rate. *Arthroscopy*. 1996;12(5):541-545.

5. Bisson LJ, Kluczynski MA, Hagstrom LS, Marzo JM. A prospective study of the association between bone contusion and intra-articular injuries associated with acute anterior cruciate ligament tear. *Am J Sports Med*. 2013;41(8):1801-1807. doi:10.1177/0363546513490649.

6. Bollen SR. Posteromedial meniscocapsular injury associated with rupture of the anterior cruciate ligament: a previously unrecognised association. *J Bone Joint Surg Br*. 2010;92(2):222-223. doi:10.1302/0301-620X.92B2.22974.

7. Chahla J, Dean CS, Moatshe G, et al. Meniscal Ramp Lesions: Anatomy, Incidence, Diagnosis, and Treatment. *Orthop J Sports Med*. 2016;4(7):2325967116657815. doi:10.1177/2325967116657815.

8. Choi N-H, Kim T-H, Victoroff BN. Comparison of arthroscopic medial meniscal suture repair techniques: inside-out versus all-inside repair. *Am J Sports Med*. 2009;37(11):2144-2150. doi:10.1177/0363546509339010.

9. Church S, Keating JF. Reconstruction of the anterior cruciate ligament: timing of surgery and the incidence of meniscal tears and degenerative change. *J Bone Joint Surg Br*. 2005;87(12):1639-1642. doi:10.1302/0301-620X.87B12.16916.

10. DePhillipo NN, Cinque ME, Chahla J, Geeslin AG, Engebretsen L, LaPrade RF. Incidence and Detection of Meniscal Ramp Lesions on Magnetic Resonance Imaging in Patients With Anterior Cruciate Ligament Reconstruction. *Am J Sports Med*. 2017;45(10):2233-2237. doi:10.1177/0363546517704426.

11. Di Vico G, Di Donato SL, Balato G, et al. Correlation between time from injury to surgery and the prevalence of ramp and hidden lesions during anterior cruciate ligament reconstruction. A new diagnostic algorithm. *Muscles Ligaments Tendons J*. 2018;7(3):491-497. doi:10.11138/mltj/2017.7.3.491.

12. Duchman KR, Westermann RW, Spindler KP, et al. The Fate of Meniscus Tears Left In Situ at the Time of Anterior Cruciate Ligament Reconstruction: A 6-Year Follow-up Study From the MOON Cohort. *Am J Sports Med*. 2015;43(11):2688-2695. doi:10.1177/0363546515604622.

514 13. Garofalo R, Mouhsine E, Chambat P, Siegrist O. Anatomic anterior cruciate ligament
515 reconstruction: the two-incision technique. *Knee Surg Sports Traumatol Arthrosc*.
516 2006;14(6):510-516. doi:10.1007/s00167-005-0029-y.

517 14. Hamberg P, Gillquist J, Lysholm J. Suture of new and old peripheral meniscus tears. *J*
518 *Bone Joint Surg Am*. 1983;65(2):193-197.

519 15. Hatayama K, Terauchi M, Saito K, Aoki J, Nonaka S, Higuchi H. Magnetic Resonance
520 Imaging Diagnosis of Medial Meniscal Ramp Lesions in Patients With Anterior
521 Cruciate Ligament Injuries. *Arthroscopy*. February 2018.
522 doi:10.1016/j.arthro.2017.12.022.

523 16. Jan N, Sonnery-Cottet B, Fayard J-M, Kajetanek C, Thaunat M. Complications in
524 posteromedial arthroscopic suture of the medial meniscus. *Orthop Traumatol Surg Res*.
525 2016;102(8, Supplement):S287-S293. doi:10.1016/j.otsr.2016.08.008.

526 17. Kennedy J, Jackson MP, O'Kelly P, Moran R. Timing of reconstruction of the anterior
527 cruciate ligament in athletes and the incidence of secondary pathology within the knee.
528 *J Bone Joint Surg Br*. 2010;92(3):362-366. doi:10.1302/0301-620X.92B3.22424.

529 18. Laurendon L, Neri T, Farizon F, Philippot R. Prognostic factors for all-inside meniscal
530 repair. A 87-case series. *Orthop Traumatol Surg Res*. 2017;103(7):1017-1020.
531 doi:10.1016/j.otsr.2017.05.025.

532 19. Li W-P, Chen Z, Song B, Yang R, Tan W. The FasT-Fix Repair Technique for Ramp
533 Lesion of the Medial Meniscus. *Knee Surg Relat Res*. 2015;27(1):56-60.
534 doi:10.5792/ksrr.2015.27.1.56.

20. Liu X, Feng H, Zhang H, Hong L, Wang XS, Zhang J. Arthroscopic prevalence of ramp lesion in 868 patients with anterior cruciate ligament injury. *Am J Sports Med*. 2011;39(4):832-837. doi:10.1177/0363546510388933.

21. Liu X, Zhang H, Feng H, Hong L, Wang X-S, Song G-Y. Is It Necessary to Repair Stable Ramp Lesions of the Medial Meniscus During Anterior Cruciate Ligament Reconstruction? A Prospective Randomized Controlled Trial. *Am J Sports Med*. 2017;45(5):1004-1011. doi:10.1177/0363546516682493.

22. Löcherbach C, Zayni R, Chambat P, Sonnery-Cottet B. Biologically enhanced ACL reconstruction. *Orthop Traumatol Surg Res*. 2010;96(7):810-815. doi:10.1016/j.otsr.2010.06.007.

23. Malatray M, Raux S, Peltier A, Pfirrmann C, Seil R, Chotel F. Ramp lesions in ACL deficient knees in children and adolescent population: a high prevalence confirmed in intercondylar and posteromedial exploration. *Knee Surg Sports Traumatol Arthrosc*. March 2017. doi:10.1007/s00167-017-4471-4.

24. Mariani PP. Posterior horn instability of the medial meniscus a sign of posterior meniscotibial ligament insufficiency. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(7):1148-1153. doi:10.1007/s00167-011-1424-1.

25. Morgan CD, Wojtys EM, Casscells CD, Casscells SW. Arthroscopic meniscal repair evaluated by second-look arthroscopy. *Am J Sports Med*. 1991;19(6):632-637; discussion 637-638. doi:10.1177/036354659101900614.

26. Nepple JJ, Dunn WR, Wright RW. Meniscal repair outcomes at greater than five years: a systematic literature review and meta-analysis. *J Bone Joint Surg Am*. 2012;94(24):2222-2227. doi:10.2106/JBJS.K.01584.

27. Noyes FR, Chen RC, Barber-Westin SD, Potter HG. Greater than 10-year results of red-white longitudinal meniscal repairs in patients 20 years of age or younger. *Am J Sports Med*. 2011;39(5):1008-1017. doi:10.1177/0363546510392014.

28. Papastergiou SG, Koukoulias NE, Mikalef P, Ziogas E, Voulgaropoulos H. Meniscal tears in the ACL-deficient knee: correlation between meniscal tears and the timing of ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2007;15(12):1438-1444. doi:10.1007/s00167-007-0414-9.

29. Peltier A, Lording T, Maubisson L, Ballis R, Neyret P, Lustig S. The role of the meniscotibial ligament in posteromedial rotational knee stability. *Knee Surg Sports Traumatol Arthrosc*. 2015;23(10):2967-2973. doi:10.1007/s00167-015-3751-0.

30. Perkins B, Gronbeck KR, Yue RA, Tompkins MA. Similar failure rate in immediate post-operative weight bearing versus protected weight bearing following meniscal repair on peripheral, vertical meniscal tears. *Knee Surg Sports Traumatol Arthrosc*. August 2017. doi:10.1007/s00167-017-4665-9.

31. Pujol N, Beaufils P. Healing results of meniscal tears left in situ during anterior cruciate ligament reconstruction: a review of clinical studies. *Knee Surg Sports Traumatol Arthrosc*. 2009;17(4):396-401. doi:10.1007/s00167-008-0711-y.

32. Pujol N, Panarella L, Selmi TAS, Neyret P, Fithian D, Beaufils P. Meniscal healing after meniscal repair: a CT arthrography assessment. *Am J Sports Med*. 2008;36(8):1489-1495. doi:10.1177/0363546508316771.

33. Reider B. Ramped Up. *Am J Sports Med*. 2017;45(5):1001-1003. doi:10.1177/0363546517700092.

34. Rubman MH, Noyes FR, Barber-Westin SD. Arthroscopic repair of meniscal tears that extend into the avascular zone. A review of 198 single and complex tears. *Am J Sports Med*. 1998;26(1):87-95. doi:10.1177/03635465980260013301.

35. Seil R. Editorial Commentary: Medial Meniscal Ramp Lesions: Lessons Learned From the Past in the Pursuit of Evidence. *Arthroscopy*. 2018;34(5):1638-1640. doi:10.1016/j.arthro.2018.02.032.

36. Seil R, Mouton C, Coquay J, et al. Ramp lesions associated with ACL injuries are more likely to be present in contact injuries and complete ACL tears. *Knee Surg Sports Traumatol Arthrosc*. June 2017. doi:10.1007/s00167-017-4598-3.

37. Seil R, VanGiffen N, Pape D. Thirty years of arthroscopic meniscal suture: What's left to be done? *Orthop Traumatol Surg Res*. 2009;95(8 Suppl 1):S85-96. doi:10.1016/j.otsr.2009.09.004.

38. Shelbourne KD, Rask BP. The sequelae of salvaged nondegenerative peripheral vertical medial meniscus tears with anterior cruciate ligament reconstruction. *Arthroscopy*. 2001;17(3):270-274. doi:10.1053/jars.2001.19978.

39. Song G-Y, Liu X, Zhang H, et al. Increased Medial Meniscal Slope Is Associated With Greater Risk of Ramp Lesion in Noncontact Anterior Cruciate Ligament Injury. *Am J Sports Med*. 2016;44(8):2039-2046. doi:10.1177/0363546516640516.

40. Sonnery-Cottet B, Conteduca J, Thaunat M, Gunepin FX, Seil R. Hidden lesions of the posterior horn of the medial meniscus: a systematic arthroscopic exploration of the concealed portion of the knee. *Am J Sports Med*. 2014;42(4):921-926. doi:10.1177/0363546514522394.

41. Sonnery-Cottet B, Freychet B, Murphy CG, Pupim BHB, Thaunat M. Anterior Cruciate Ligament Reconstruction and Preservation: The Single-Anteromedial Bundle Biological Augmentation (SAMBBA) Technique. *Arthrosc Tech*. 2014;3(6):e689-693. doi:10.1016/j.eats.2014.08.007.

42. Sonnery-Cottet B, Saithna A, Blakeney WG, et al. Anterolateral Ligament Reconstruction Protects the Repaired Medial Meniscus : A Comparative Study of 383 Anterior Cruciate Ligament Reconstruction From the SANTI Study Group With a Minimum Follow-up of 2 Years. *Am J Sports Med*. 2018. doi:10.1177/0363546518767659.

43. Stephen JM, Halewood C, Kittl C, Bollen SR, Williams A, Amis AA. Posteromedial Meniscocapsular Lesions Increase Tibiofemoral Joint Laxity With Anterior Cruciate Ligament Deficiency, and Their Repair Reduces Laxity. *Am J Sports Med*. 2016;44(2):400-408. doi:10.1177/0363546515617454.

44. Strobel M. Menisci. *In: Fett HM, Flechtner P, eds Manual of Arthroscopic Surgery New York: Springer*. 1988:171-178.

45. Tachibana Y, Sakaguchi K, Goto T, Oda H, Yamazaki K, Iida S. Repair integrity evaluated by second-look arthroscopy after arthroscopic meniscal repair with the FasT-Fix during anterior cruciate ligament reconstruction. *Am J Sports Med*. 2010;38(5):965-971. doi:10.1177/0363546509356977.

46. Tandogan RN, Taşer O, Kayaalp A, et al. Analysis of meniscal and chondral lesions accompanying anterior cruciate ligament tears: relationship with age, time from injury, and level of sport. *Knee Surg Sports Traumatol Arthrosc*. 2004;12(4):262-270. doi:10.1007/s00167-003-0398-z.

47. Thaunat M, Fayard JM, Guimaraes TM, Jan N, Murphy CG, Sonnery-Cottet B. Classification and Surgical Repair of Ramp Lesions of the Medial Meniscus. *Arthrosc Tech*. 2016;5(4):e871-e875. doi:10.1016/j.eats.2016.04.009.

48. Thaunat M, Jan N, Fayard JM, et al. Repair of Meniscal Ramp Lesions Through a Posteromedial Portal During Anterior Cruciate Ligament Reconstruction: Outcome Study With a Minimum 2-Year Follow-up. *Arthroscopy*. 2016;32(11):2269-2277. doi:10.1016/j.arthro.2016.02.026.

49. Westermann RW, Duchman KR, Amendola A, Glass N, Wolf BR. All-Inside Versus Inside-Out Meniscal Repair With Concurrent Anterior Cruciate Ligament Reconstruction: A Meta-regression Analysis. *Am J Sports Med*. 2017;45(3):719-724. doi:10.1177/0363546516642220.

50. Woods GW, Chapman DR. Repairable posterior menisco-capsular disruption in anterior cruciate ligament injuries. *Am J Sports Med*. 1984;12(5):381-385. doi:10.1177/036354658401200509.

Figure Legends:

Figure 1. Intra-operative images from a Right knee. All images taken with 30 degree arthroscope placed through the anterolateral portal: A) Standard view of the medial compartment, the ramp lesion is not visualised B) The probe is placed in order to demonstrate the location in the notch between the medial femoral condyle (MFC) and the posterior cruciate ligament (PCL) through which the arthroscope will subsequently be advanced into the posteromedial compartment, C) Placing the knee in approximately 30 degrees flexion and valgus allows opening of this space and facilitates passage of the arthroscope into the posteromedial compartment, D) View of posteromedial compartment shows the ramp lesion; Visualization was optimized by the application of tibial internal rotation

Figure 2. Posteromedial compartment evaluation in a Right knee. Trans-notch view obtained with arthroscope placed through anterolateral portal: A) Needle localisation of portal is performed, B) 11-blade scalpel is used to create the portal under direct vision, C) A shaver is inserted and both surfaces of the tear are debrided to encourage healing, D) Appearance of the tear after preparation is completed

Figure 3. Ramp repair performed in a Right knee. Trans-notch view of posteromedial compartment obtained with arthroscope placed through anterolateral portal: A) 20 degree left suture hook (Arthrex, Naples, USA) is inserted via the posteromedial portal, B) Suture hook passed through meniscocapsular junction into the tear. This allows the hook to be repositioned and then passed into the meniscus body, C) The suture hook is passed into meniscus body. The 0-PDS suture is then advanced and retrieved through the posteromedial portal after which it is tied, D) The ramp lesion has been repaired, two 0-PDS sutures have

been placed using the steps demonstrated. They have been tied with a sliding knot and half hitches via the posteromedial portal under direct vision

Figure 4. Flowchart of included patients

Figure 5. Increasing incidence of ramp lesions with increasing time from initial ACL injury to surgery. Two models of curve estimation of the regression analysis between the incidence of ramp lesion and time interval from anterior cruciate ligament (ACL) injury to surgery.

Figure 6. Kaplan-Meier Survivorship with reoperation for secondary partial medial meniscectomy (as previously defined) as an endpoint. Numbers at risk with 95% CI. ACLR, anterior cruciate ligament reconstruction, ALLR, anterolateral ligament reconstruction.