Knee Surgery, Sports Traumatology, Arthroscopy (2019) 27:590–595
https://doi.org/10.1007/s00167-018-5171-4

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Abnormal tibial alignment is a risk factor for lateral meniscus posterior root tears in patients with anterior cruciate ligament ruptures

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Received: 6 April 2018 / Accepted: 21 September 2018 / Published online: 4 October 2018

Abstract

Purpose The purpose of this study was to identify if abnormal tibial alignment was a risk factor for lateral meniscus posterior root tears (LMPRT) in patients with acute anterior cruciate ligament (ACL) ruptures.

Methods The medical charts of 200 patients treated for ACL ruptures between 2013 and 2016 were retrospectively reviewed and evaluated. MRI images and reports were assessed for concurrent meniscal tears. Radiographs were reviewed for tibia vara and tibial slope angles and MRI reports identifying lateral root tears were compared to intraoperative reports to determine accuracy. Multiple logistic regression models were constructed to identify potential risk factors for LMPRTs.

Results Of the 200 patients reviewed, a total of 97 individuals with concurrent meniscal injuries were identified. In patients sustaining a concurrent meniscal injury, there was a 4% incidence of medial meniscus posterior root tears and a 10.3% incidence of LMPRTs. Patients sustaining an ACL injury with an LMPRT were found to have greater tibia vara angles (4.2 ± 1.0 vs. 2.9 ± 1.7; $p = 0.024$), increased tibial slopes (12.6 ± 1.5 vs. 10.7 ± 2.9; $p = 0.034$), and higher BMIs (27.3 ± 2.9 vs. 25.3 ± 5.9; $p = 0.034$) when compared to patients without meniscus tears. There was low agreement between MRI and arthroscopic findings (kappa rate = 0.54). Multiple logistic regression analysis demonstrated that a tibia vara angle > 3 was associated with a 5.2-fold increase (95% CI 0.99–27.01; $p = 0.050$), and a tibial slope > 12 with a 5.4-fold increase (95% CI 1.03–28.19; $p = 0.046$) in LMPRTs.

Conclusions Patients with greater tibia varus angles, increased tibial slopes, and higher BMIs were found to have an increased risk of LMPRTs when sustaining an ACL rupture. There was a low rate of agreement between MRI and arthroscopy in identifying LMPRTs. In patients with ACL ruptures who have abnormal tibial alignment or increased BMI, physicians should be watchful for lateral meniscus posterior root tears.

Level of evidence 3.

Keywords Meniscus · Root tear · Knee · ACL · Ligament · Risk factors

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Abbreviations

LMPRT	Lateral meniscus posterior root tear
MMPRT	Medial meniscus posterior root tear
ACL	Anterior cruciate ligament
BMI	Body mass index
ASA	American Society of Anesthesiologists
KLG	Kellgren–Lawrence Grade
TPAA	Tibial proximal anatomic axis
ATC	Anterior tibial cortex
PTC	Posterior tibial cortex

Introduction

Injuries to the anterior cruciate ligament (ACL) are one of the most studied injuries in orthopedics, due in part to the more than 120,000 ACL injuries occurring annually in the United States [11]. Quite often, ACL injuries are associated with other pathology, namely, meniscal tears. Early investigations found the incidence of lateral and medial meniscus tears to be 56% and 37%, respectively [20, 25]. The consequences of a meniscus injury include loss of joint congruence as well as the inability to transmit axial load into hoop stresses.

The meniscal root provides a firm anchor for the meniscus to the tibial plateau. A compromised meniscal root has been likened to complete menisectomy with significant consequences to long-term osteoarthritic changes and knee stability [2, 5, 12, 17, 21]. It is important to note that not all posterior meniscal root tears are identical, as sub-types can present as incomplete tears which maintain meniscal root stability [22]. Due to the lasting implications of ignoring meniscal root tears, early anterior cruciate ligament reconstruction (ACLR) (within 6 months) with concurrent meniscal repair or debridement is advocated to preserve meniscus integrity, maximize pain relief, and prevent early osteoarthritis [8, 15, 17].

Diagnosis of concurrent meniscal injury during ACLR is paramount in restoring knee mechanics and preventing future arthritic changes. In the setting of ACL tear, diagnosis of meniscal tear is often confirmed by MRI [4]. More complex meniscal injuries, such as posterior root tears, can often be missed by MRI alone and require a more thorough investigation [6, 27]. While the risk factors for medial meniscus posterior root tears (MMPRT) have been reported, the risk factors for a lateral meniscus posterior root tear (LMPRT) are not as clearly elucidated in the literature. Knowing the risk factors for LMPRTs may increase physician awareness of when additional evaluation of the meniscal root is warranted.

The purpose of this study was to identify if abnormal tibial alignment was a risk factor for LMPRT in patients with ACL ruptures. The hypothesis was that patients with increased tibia vara and tibial slope angles would be at increased risk for LMPRTs when sustaining an ACL rupture.

Materials and methods

A retrospective review of 200 ACLRs from a single surgeon between 2013 and 2016 was performed. IRB approval was obtained prior to data collection. Patients were excluded if they had a history of multi-ligamentous knee injury, a delayed ACL rupture (> 6 months), or demonstrated grade 4 osteoarthritis. The dates of knee injury, MRI, and surgery were recorded.

Meniscal injury was identified by experienced musculoskeletal radiologist using a 3.0 T MRI and subsequently confirmed during arthroscopic surgery. Demographic variables collected in this study included age, sex, and BMI. Radiologic factors included Tibia vara angle, tibial slope angle, and Kellgren–Lawrence Grade (KLG) for osteoarthritis [13].

Two independent reviewers examined patient radiographs and were blinded to patient identity, pathology, or treatment. Tibial angles were measured using standing AP and lateral plain radiographs. Tibial vara angle was defined as the angle between a line drawn tangential to the tibial plateau (AP view) and the perpendicular line from the center of the plateau to the tibial plafond on an AP-standing radiograph. Tibial slope was defined using the technique described by Utzschneider et al. on lateral standing radiographs of the tibia [26]. Slope was measured as the angle between the posterior inclination of the medial and lateral plateaus and the line perpendicular to the tibia's proximal anatomic axis (TPAA). The TPAA was determined by first establishing the anterior tibial cortex line (ATC) and the posterior tibial cortex line (PTC) at 5 cm distal to the tibial tubercle and 15 cm distal to the joint line, respectively. The mean of the medial and lateral tibial slopes from these measurements was used to determine the overall tibial slope.

To assess the joint cartilage integrity, KLG was reported on standing AP radiographs. KLG was defined as 0 (normal), 1 (doubtful narrowing of joint space and possible osteophyte lipping), 2 (definite osteophytes and definite narrowing of joint space), 3 (moderate multiple osteophytes, definite narrowing or joint space, some sclerosis, and possible deformity of bone contour), and 4 (large osteophytes, marked joint space narrowing, severe sclerosis, and definite deformity of bone contour). In addition, mechanism of injury was reported. Patients were classified as having an injury in a high impact sport if the sport involved player-to-player contact, high speeds, or running. Non-contact sports that were performed at low speed or stationary as well as non-sporting injuries were classified as low impact. No patients with grade 4 osteoarthritis underwent ACLR. During arthroscopy, intraoperative findings of concurrent pathology were recorded. MRI findings of LMPRT were compared to intraoperative findings to determine diagnostic accuracy. The Henry Ford Institutional review board approved this study (IRB no. 11655).

Statistical analysis

All statistical analyses were performed using SAS 9.4 and statistical significance was established at $p < 0.050$. Demographic and clinical variables are summarized as median and range for numeric variables and frequency and percentage for categorical variables. Agreements between MRI and operative reports were calculated using the kappa statistic. Differences between patients with concurrent LMPRT and those with isolated ACL injuries were tested using Wilcoxon rank sum for continuous variables or Fisher's exact test for categorical variables. To identify risk factors for LMPRT, multiple logistic regression models were constructed.

Results

Of the 200 patients with ACL ruptures, 105 patients with MRI reports of concurrent meniscal injuries were identified. Eight patients were confirmed as having no meniscus pathology at time of surgery. This yielded a 6.8% false positive rate of identifying meniscus tears by MRI in the context of ACL rupture. These patients were reclassified as having an ACL rupture without meniscal injury and 97 patients (60 males/37 females) were included in the final subgroup of patients sustaining concurrent meniscal injury (Fig. 1). The median age was 24 (range 14–45) and the median BMI was 26.6 (range 16.4–37.7). In individuals with meniscus injury, the average duration of time from injury to imaging was 26 days (±35.3), the average time from imaging to surgery was 44.1 days (±41.4), and the average time from injury to surgery was 70.1 days (±58.1). Demographic variables and injury characteristics are listed in Table 1.

Among patients who presented with an ACL injury with a concurrent meniscal injury ($N=97$), there was a 4% incidence of MMPRT ($N=4$) and 10.3% incidence of LMPRT ($N=10$). The incidence of LMPRT in the entire population of ACL ruptures ($N=200$) was 5%. When comparing patients who had an ACL tear and concurrent LMPRT to patients who had an ACL tear with no meniscal injury, patients with LMPRT demonstrated higher tibia vara angles (4.2 ± 1.0 vs. 2.9 ± 1.7; $p=0.024$) and higher tibial slopes (12.6 ± 1.5 vs. 10.7 ± 2.9; $p=0.034$). Patients with LMPRTs on average were also found to have a greater BMI compared to patients without meniscal injury (27.3 vs. 25.2, $p=0.034$). No other patient demographics or injury characteristics were found to contribute to a higher incidence of LMPRTs (Table 2). Multiple logistic regression analysis demonstrated that a tibia vara angle > 3 was associated with a 5.2-fold increase (95% CI 0.99–27.01; $p=0.050$), and a tibial slope > 12 with a 5.4-fold increase (95% CI 1.03–28.19; $p=0.046$) for LMPRT. While patients with a BMI > 25 demonstrated a 4.3-fold increase in LMPRTs, this was not found to be statistically significant (Table 3).

In assessing MRI and intraoperative concordance for LMPRT, we found a kappa rate of 0.54 and a kappa rate of 0.53 for MMPRT. All cases of LMPRTs were found to

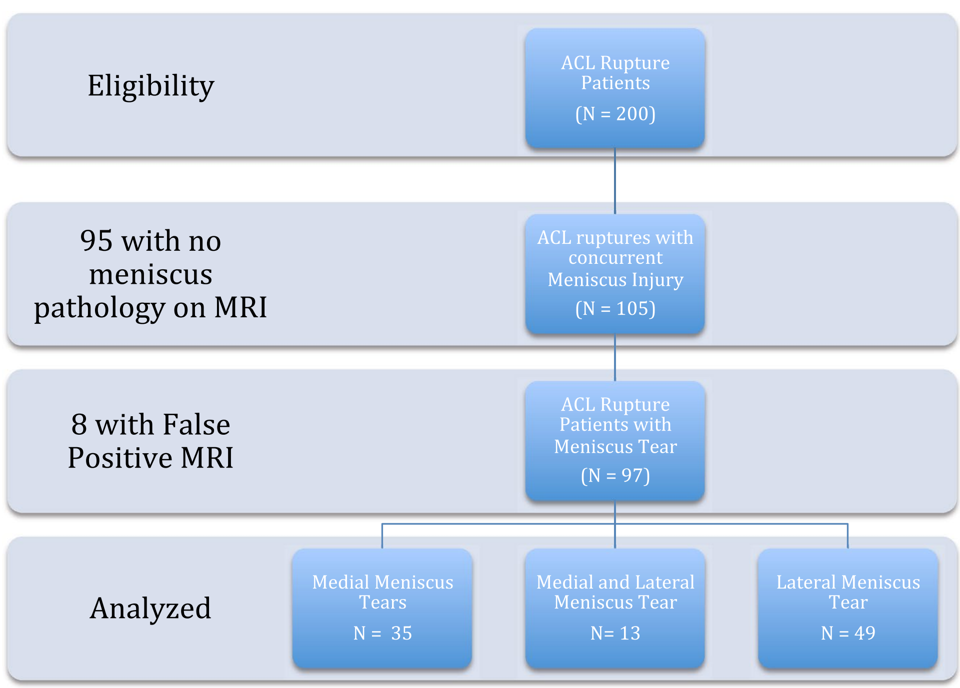

Fig. 1 Patient allocation for analysis. A sample of 200 anterior cruciate ligament reconstructions (ACLR) were selected for this study. After exclusion of patients without meniscus injuries, final 97 subjects with ACLRs were examined for analysis

Table 1 Demographics and injury characteristics of patients with meniscal tears

Variable	
Males (*N*)	60
Females (*N*)	37
BMI [mean (range)]	28 (16.4–37.7)
Age [mean (range)]	27.2 (14–45)
ASA classification	
1	53
2	42
3	2
Tibia vara angle ± SD	3.1 ± 1.5
Tibial slope ± SD	11 ± 2.4
Kellgren–Lawrence Grade [*N* (%)]	
0	60 (62)
1	27 (28)
2	9 (9)
3	1 (1)
Injury type [*N* (%)]	
Contact	8 (8.2)
Non-contact	89 (91.8)
Sport impact level [*N* (%)]	
High impact	71 (73.2)
Low impact	4 (4.1)
Non-sport	22 (22.7)

Values are provided as number of subjects or mean value with ranges, percentages, and standard deviations (SD) where appropriate

ASA American Society of Anesthesiologist, *BMI* body mass index

Table 2 Univariate analysis of lateral root tears vs. No meniscus tear

Variable	Level	No meniscus tear	Lateral root tear	*p* value
Gender	Male	40 (51%)	8 (80%)	n.s.
	Female	39 (49%)	2 (20%)	
Age	–	25.8 (14–45)	22.2 (16–35)	n.s.
BMI	–	25.3 (16.4–45.2)	27.3 (23.2–32.3)	**0.034**
Tibia vara	–	2.9 ± 1.7	4.2 ± 1.0	**0.024**
Tibial slope	–	10.7 ± 2.9	12.6 ± 1.5	**0.034**
Injury type	Contact	7 (9%)	0 (0%)	n.s.
	Non-contact	72 (91%)	10 (100%)	
Mechanism	High impact	60 (76%)	9 (90.0%)	n.s.
	Low impact	19 (24%)	1 (10.0%)	

Values are presented as number of subject (percentage of all subjects) mean (minimum–maximum) or mean ± standard deviation

Bold values indicate statistical significance

BMI body mass index

be radially oriented and involving the root. The tears were classified as type 2 (radial with intact meniscofemoral ligaments) based on the Forkel classification [11]. As these tears were avascular, in the white–white zone of the meniscus, and were deemed to be stable with no pathologic excursion, no formal repair or reattachment was required. These tears were debrided to a stable rim. After debridement, these tears were manually probed to confirm a stable rim with intact root attachment.

Table 3 Logistic models of potential risk factors for lateral meniscus posterior root tear

Effect	Odds ratio	95% CI		*p* value
Age (≥ 25 vs. < 25)	0.63	0.15	2.62	n.s.
Gender (female vs. male)	0.26	0.05	1.28	n.s.
BMI (≥ 25 vs. < 25)	4.32	0.86	21.62	n.s.
Tibia vara (> 3 vs. ≤ 3)	5.18	1.00	27.01	**0.050**
Tibial slope (> 12 vs. ≤ 12)	5.40	1.03	28.19	**0.046**
Mechanism of injury (low vs. high)	0.35	0.04	2.95	n.s.

Bold values indicate statistical significance

BMI body mass index, *CI* confidence interval

Discussion

The most important finding of our study was that patients with greater tibia vara angles, increased tibial slopes and higher BMIs had an increased incidence LMPRTs. In addition, the study found a higher incidence of LMPRTs than MMPRTs in patients sustaining an ACL tear. Identifying patient traits that predispose to these injuries can signal more detailed evaluation of the meniscal root and diagnosis of LMPRT.

In the general population, MMPRTs are more common than LMPRTs [21]. The majority of MMPRTs are associated with chronic degenerative changes to the knee and its intraarticular components [5]. Conversely, lateral meniscus tears, specifically LMPRT, are more common in the setting of acute ACL ruptures [5, 9, 14, 20]. In a review of 549 patients, Hagino et al. found the rate of all lateral meniscus tears to be close to 82% in acute ACL injuries. Rates of LMPRT have ranged widely between various studies. Ahn et al. reported an LMPRT rate of 7% in their review of 388 patients with ACL ruptures treated surgically [1]. Forkel et al. found an LMPRT prevalence of 14% in their sample of 228 ACL reconstructions [7]. Our study revealed an overall 5% incidence of LMPRT within all ACL ruptures, and a 10% incidence of LMPRT within individuals with any type meniscus tear. In contrast, MMPRTs exhibited an overall incidence of 2% amongst all ACL ruptures, with a relative incidence of 4% amongst patients with any meniscus tear. This is similar to the previous studies, which demonstrates that LMPRTs are more prevalent than MMPRTs and physicians should by mindful of this possible injury.

Despite LMPRT being found more commonly in ACL ruptures, little is known about the inherent risk factors for sustaining this secondary injury. Previous studies have identified risk factors for MMPRT [3]. Hwang et al. identified greater varus mechanical axis as risk factor along with age, female gender, BMI, increased KLG, and lower sports activity level; however, this study did not stratify patients into those with ACL injuries [10]. Similarly, Markl et al. reviewed 71 patients and found a increased likelihood (odds ratio 3.44) of lateral meniscal tears in ACL rupture patients with a high tibial slope (defined by > 10°); however, their findings did not reach statistical significance [19]. Our study found that individuals with LMPRT had greater tibia vara angles, higher tibial slopes, and increased BMIs. These findings suggest that tibial plateau alignment with greater varus and posterior tibial slope and increased patient weight may put greater stress on the posterior root of the lateral meniscus, especially with a deficient ACL. Identification of anatomical risk factors for a posterior root tear may prompt physicians to perform a more detailed investigation of the root. A study by Sonnery-Cottet demonstrated that only 60% of meniscal root lesions are identified during routine diagnostic arthroscopy [24]. By analyzing the posterior horn of the medial meniscus through the notch or probing of the meniscus through an additional posterior medial portal, they were able to identify the remaining 40% of posterior root medial meniscus tears.

The diagnosis of meniscus pathology at the time of acute ACL rupture is often difficult. Our study demonstrated a kappa rate of only 0.54 when compared to the gold standard of arthroscopy. Our review demonstrated eight patients diagnosed with a meniscus tear that was absent at time of arthroscopy, yielding a false positive rate of 6.8%. In addition, ten patients were identified as not having meniscus tears by MRI, but were found to have either a medial or lateral meniscus tear at time of surgery, a rate of 10.3%. The previous studies examining the diagnostic accuracy of MRI have demonstrated similar deficiencies [16]. In a study of 356 patients, Dufka et al. found only moderate sensitivity and specificity using MRI for both medial and lateral meniscus injuries. They did not demonstrate any significant associations between injury to MR time or imaging to surgery time and the need for surgical intervention [6]. Similarly, LaPrade et al. discovered low positive predictive value and moderate sensitivity for posterior root tears in his examination of 287 patients who had MRI followed by arthroscopy. Furthermore, their study found the MRI sensitivity to be higher for MMPRT vs. LMPRT [18]. It is known that as time increases from injury to imaging, meniscal injuries may heal which can affect identification of lesions on imaging. Whereas after patients obtain imaging, any subsequent mechanical event affecting the knee may lead to further injury not found on initial imaging. Song et al. examined ACL rupture patients with high-grade pivot shift and found a greater incidence of complete LMPRT in individuals who had ACL reconstruction delayed after 12 weeks [23]. These studies combined with our results suggest that the difficulty in identifying meniscal root tears with the use of MRI alone and the clinician should be prepared for undiagnosed posterior root tears during diagnostic arthroscopy. The findings of this study provide surgeons with potential risk factors for lateral meniscus posterior root tears. In patients with these identified factors, a more careful evaluation of the meniscal root during arthroscopy may be warranted.

This study does have potential limitations. Importantly, this is a retrospective study and carries with it the inherent shortcomings of a retrospective study including potential confounding bias. The results from our single-center, single surgeon study may introduce an inherent selection and population bias; however, our rates of LMPRT are consistent with the prevailing literature and the large region encompassed by our health system minimizes the effect of this bias. In addition, the single-center nature of the study could be viewed as a strength by minimizing the variability in MRI findings or interpretation. The variable time period from MRI and ACL reconstruction may explain why some meniscus tears found on MRI may not have been present at time of surgery. Whether those tears were false positives on MRI or healed by time of surgery is difficult to ascertain. Furthermore, it is a possibility that in the time between imaging and surgical intervention patients sustained subsequent knee injuries causing additional meniscal lesions. These factors are unable to be controlled for in this retrospective study. Unfortunately, while the majority of ACL injuries are non-contact injuries, the lack of contact injuries prevents us from examining mechanism of injury as a risk of LMPRT. Finally, a sample size calculation could not be performed, as the study was limited to all of a single surgeons patients. Due to the relatively low incidence of these injuries as a whole, a larger patient volume may be needed to fully elucidate risk factors for posterior root tear sub-types.

Conclusion

Our study found a higher rate of LMPRT than MMPRT in patients with acute ACL injuries. Patients with higher tibia vara angles, higher tibia slope angles, and increased BMIs were found to have an increased incidence of concurrent LMPRT. The agreement rate between MRI and intraoperative findings was low in patients with LMPRT. These findings report the incidence of LMPRTs and intrinsic risk factors that may predispose patients to LMPRT when sustaining an ACL rupture.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval The local institutional review board approved this study (IRB: Henry Ford Hospital, Detroit, MI).

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