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Injury to the Meniscofemoral Portion of the Deep MCL Is Associated with Medial Femoral Condyle Bone Marrow Edema in ACL Ruptures

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Background: The primary goal of the present study was to investigate injury to the deep medial collateral ligament (MCL), specifically the meniscofemoral ligament (MFL) portion, and its association with medial femoral condyle (MFC) bone marrow edema in acute anterior cruciate ligament (ACL) ruptures. The secondary goal was to examine the association between MFL injury and medial meniscal tears (MMTs) in these same patients.

Methods: Preoperative magnetic resonance imaging (MRI) scans of 55 patients who underwent ACL reconstruction surgery were retrospectively reviewed by 2 board-certified musculoskeletal radiologists. MRI scans were examined for MFC edema at the insertion site of the MFL. This site on the MFC was referred to as the central-femoral-medial-medial (C-FMM) zone based on the coronal and sagittal locations on MRI. The presence or absence of bone marrow edema within this zone was noted. The prevalence, grade, and location of superficial MCL and MFL injuries were also recorded on MRI. The correlations between MFL injuries and the presence of MFC bone marrow edema were examined. Lastly, the presence and location of MMTs were also recorded on MRI and were confirmed on arthroscopy, according to the operative notes.

Results: On MRI, 40 (73%) of the 55 patients had MFL injuries. MFL injuries were significantly more common than superficial MCL injuries ($p = 0.0001$). Of the 27 patients with C-FMM bruising, 93% (25 patients) had MFL tears ($p < 0.00001$). In addition, of the 40 patients with an MFL injury, 63% (25 patients) had C-FMM bruising ($p = 0.0251$). Chi-square testing showed that MMTs and MFL injuries were significantly associated, with 12 (100%) of 12 patients with MMTs also having a concomitant MFL injury ($p = 0.0164$).

Conclusions: The prevalence of MFL injury in ACL ruptures is high and MFC bone marrow edema at the MFL insertion site should raise suspicion of injury. MFL injuries can present with clinically normal medial ligamentous laxity in ACL ruptures. Additionally, MFL injuries were significantly associated with posterior horn MMTs, which have been shown in the literature to be a potential risk factor for ACL graft failure.

Clinical Relevance: As deep MCL injuries are difficult to detect on physical examination, our findings suggest that the reported MFC edema in ACL ruptures can act as an indirect sign of MFL injury and may aid in the clinical detection. Additionally, due to the anatomical connection of the deep MCL and the meniscocapsular junction of the posterior horn of the medial meniscus, if an MFL injury is suspected through indirect MFC edema at the insertion site, the posterior horn of the medial meniscus should also be assessed for injury, as there is an association between the 2 injuries in ACL ruptures.

The medial collateral ligament (MCL) is the primary valgus stabilizer of the knee joint, and concomitant MCL and anterior cruciate ligament (ACL) injuries occur in 8% to 42% of total ACL ruptures[1-4]. Magnetic resonance imaging (MRI) studies of bone marrow edema patterns that are observed in isolated MCL injuries are limited, and there is controversy with regard to the location of these lesions. However, the contribution of concomitant MCL injury to the edema patterns seen in ACL ruptures is unknown[5,6].

The MCL is categorized into 2 separate divisions: the deep MCL and superficial MCL[7]. The deep MCL consists of 2 distinct regions, the proximal half (meniscofemoral ligament [MFL]) and

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the distal half (meniscotibial ligament [MTL]). The MFL of the deep MCL inserts on the medial femoral condyle (MFC), posterior and inferior to the medial femoral epicondyle and deep to the insertion point of the superficial MCL (Fig. 1)[7-9]. At the joint line, the center of the deep MCL attaches to the medial meniscus, which provides additional support to resist rotational forces[7]. Compared with the number of anatomical, functional, and biomechanical studies conducted on the superficial MCL, there is a paucity of literature that has reported on the deep MCL[7-9].

Bone marrow edema patterns seen on MRI can provide data for determining the underlying mechanism of injury in ACL ruptures[1,10-13]. However, the relationship between these edema patterns and concomitant soft-tissue injuries has not been well studied. In this current study, it was hypothesized that patients who had MFC edema near the MFL femoral insertion site would show higher rates of MFL tears than those without this edema pattern. Our other hypothesis predicted that there would be an association between the MFL and medial meniscal tears (MMTs), as both structures work together to resist rotational forces experienced in ACL ruptures[1,10,14,15]. A distinct bone marrow contusion pattern that may be used to infer deep MCL injury may be a useful diagnostic tool for clinicians to alert them to not only this injury, but other concomitant medial-sided soft-tissue injuries.

Materials and Methods

A total of 116 patients were identified using the Current Procedural Terminology (CPT) code 29888; all of these patients underwent ACL reconstructive surgery from 2018 to 2020 performed by a single surgeon (M.J.M.). Of these patients, 55 met the following inclusion criteria for this study: <30 days between the date of the reported injury and the date of the MRI, documented mechanism of injury, no previous ipsilateral knee injury, and MRI scan sequences available in both the coronal and sagittal planes. The mechanism of injury was recorded as contact or non-contact based on the patient's account of the injury. The dates of the injury and the MRI, previous ACL injuries, and graft failure were also recorded. A 30-day cutoff was used between the dates of the injury and the MRI to minimize the potential for the resolution of bone edema[16,17]. Institutional review board approval was granted for this study.

All 55 patients underwent MRI on a 3-T scanner using an established institutional standard knee protocol. All of the

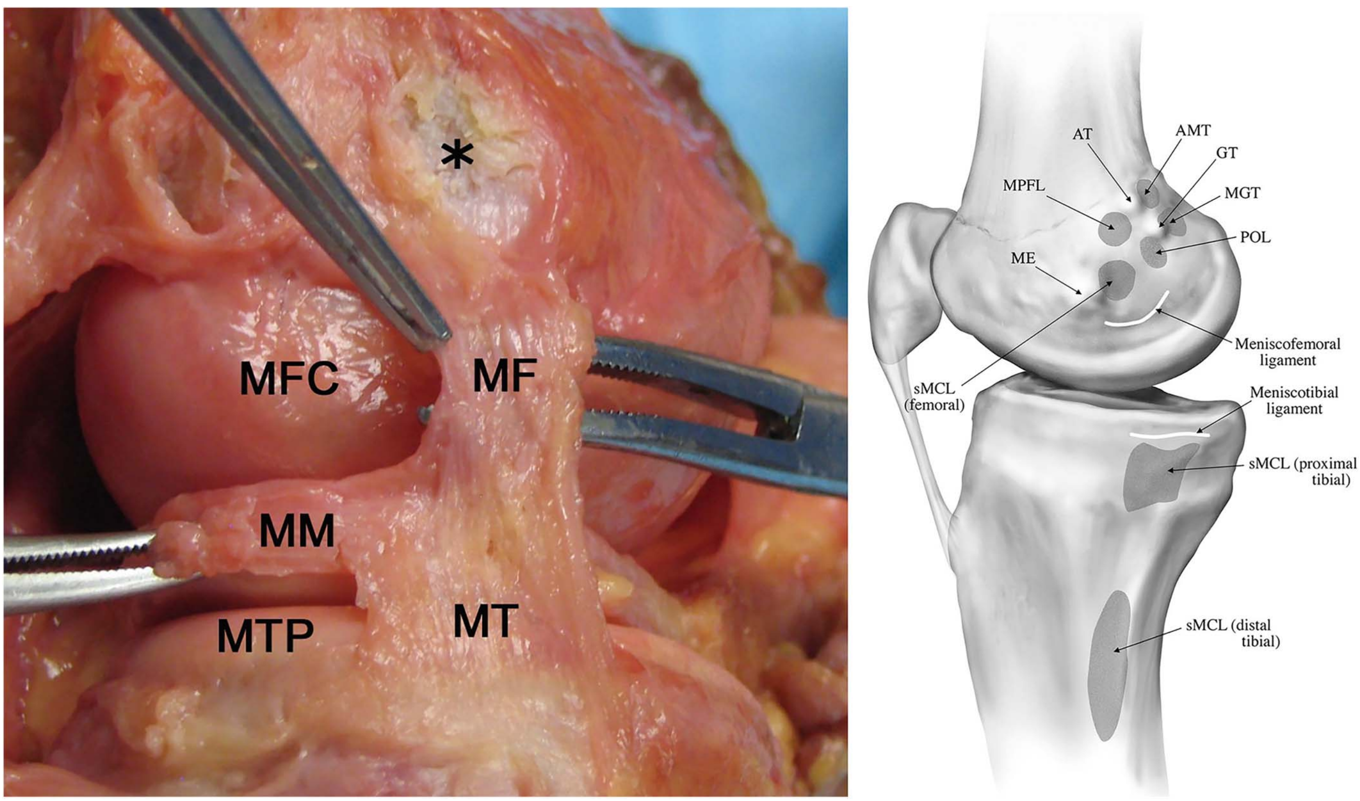

Fig. 1

Left: Cadaveric photograph of the knee showing the anatomy of the deep MCL with the proximal meniscofemoral (MF) attachment site on the MFC, the posterior aspect of the medial meniscus (MM), and the distal meniscotibial (MT) attachment site on the medial tibial plateau (MTP). The asterisk indicates the femoral attachment site of the superficial MCL. *Right:* Illustration showing the femoral osseous landmarks and attachment sites of the main medial knee structures. ME = medial epicondyle, MPFL = medial patellofemoral ligament, AT = adductor tubercle, AMT = adductor magnus tendon, GT = gastrocnemius tubercle, MGT = medial gastrocnemius tendon, POL = posterior oblique ligament, and sMCL = superficial MCL. (Reproduced from: LaPrade RF, Engebretsen AH, Ly TV, Johansen S, Wentorf FA, Engebretsen L. The anatomy of the medial part of the knee. J Bone Joint Surg Am. 2007 Sep;89[9]:2000-10.)

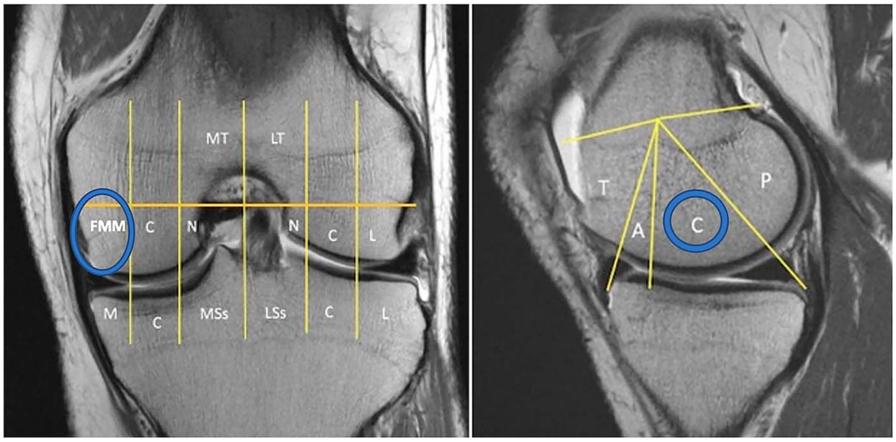

Fig. 2
Proton density, T2-weighted, MRI scans showing the C-FMM zone on the MFC marked by both blue circles. *Left:* The coronal location of the MFL insertion site on the most medial aspect of the femur (FMM). MT = medial trochlea, LT = lateral trochlea, M = medial, C = central, N = notch, MSs = medial sub-spine, LSs = lateral sub-spine, and L = lateral. *Right:* The sagittal location of the MFL insertion site on the central (C) aspect of the medial femoral condyle. T = trochlea, A = anterior, and P = posterior.

imaging studies were reread by 2 senior board-certified musculoskeletal radiologists. Interrater and intrarater reliabilities for MRI readings were assessed using intraclass correlation coefficients (ICCs). Only fat-saturated, T2-weighted, coronal and sagittal images were reviewed to determine the location of bone edema. The radiologists were blinded to all clinical data.

In this study, we used an iteration of the whole-organ MRI score (WORMS) in order to record the location of the edema on the MFC[18]. The zone for MFC edema was described in relation to the coronal and sagittal locations of the MFL insertion site on the MFC. On the coronal images, the MFL insertion was defined within the most medial aspect of the MFC and was termed the femoral-medial-medial (FMM) zone, and, on the sagittal images, the insertion site was defined both posterior and inferior to the medial femoral epicondyle, which correlates with the central (C) zone on our mapping scheme (Fig. 2). Together, the presence or absence of MFC edema within the central-femoral-medial-medial (C-FMM) zone was recorded. If multiple contusions were present on the MFC, but not located within the C-FMM zone, these contusions were not counted. If there was any edema present in the C-FMM zone, it was counted. The signal intensity and volume of the contusions were not recorded.

The locations of the medial ligamentous injuries (superficial MCL, deep MCL) were described as proximal, midsubstance, or distal. The medial ligamentous injuries were graded on MRI according to Rasenberg et al.[19]. The presence or absence of MMTs was noted from MRI and then was confirmed on arthroscopy, according to the operative notes for each patient. Lateral meniscal tears were not recorded. MMTs were localized to the anterior horn, the mid-body, or the posterior horn. Lastly, ACL graft failure was retrospectively assessed and defined by the presence or absence of a revision surgical procedure. Examples of MRI findings in this study are displayed in Figures 3, 4, and 5.

A Z-test was used to compare proportions of categorical variables between 2 populations. Chi-square tests were used to determine whether 2 categorical variables were associated, and the two-tailed t test was used for continuous variables. All statistics were calculated in Excel (Microsoft).

Fig. 3
Coronal, fat-saturated MRI demonstrating normal anatomy. The solid white arrow shows a normal superficial MCL and the dashed white arrow shows a normal MFL. The thick white arrow depicts a normal ACL.

Fig. 4

Coronal, fat-saturated MRI demonstrating a normal superficial MCL (solid white arrow), a torn MFL (dashed arrow), and a torn ACL (thick solid white arrow).

Source of Funding

No funding was used for this study.

Results

Of the 55 patients who met inclusion criteria, 42 (76%) reported a non-contact injury and 13 (24%) reported a contact injury. The mean age (and standard deviation) was 27.5 ± 14.5 years for the non-contact group and 24.2 ± 9.0 years for the contact group. Female patients comprised 42% of the non-contact group and 46% of the contact group. The mean time between the initial ACL injury and MRI was 11.8 ± 8.3 days for the non-contact group and 9.3 ± 6.2 days for the contact group, with no significant difference between the 2 groups ($p = 0.2744$) (Table I).

Of the 55 patients in the study, 18 patients (33%) had MRI evidence of superficial MCL injury and 40 patients (73%) demonstrated MRI evidence of MFL injury. There was MRI evidence of injury to both the superficial MCL and MFL in 17 patients (31%). MFL injuries were significantly more common than superficial MCL injuries ($p = 0.0001$).

Superficial MCL injuries were most commonly grade 1 (8 [44%] of 18) (Table II), and most frequently occurred proximally (11 [61%] of 18) (Table III). MFL injuries were most commonly complete tears (grade 3) (35 [88%] of 40), and most frequently occurred proximally (32 [80%] of 40). There were no grade-1 MFL injuries (Table II).

Superficial MCL injuries were noted in 2 (15%) of 13 patients who reported a contact injury and in 16 (38%) of 42 patients who reported a non-contact injury ($p = 0.1285$). MFL injuries were noted in 8 (62%) of 13 patients who reported a contact injury and 32 (76%) of 42 patients who reported a non-contact injury ($p = 0.2983$). Combined superficial MCL and MFL injuries were noted in 2 (15%) of 13 patients who reported a contact injury and 15 (36%) of 42 patients who reported a non-contact injury ($p = 0.1645$). There was no significant difference in the number of superficial MCL and MFL injuries between the 2 groups.

Twenty-seven (49%) of 55 patients demonstrated bone marrow edema within the C-FMM zone at the MFC. Chi-square testing demonstrated that the distribution of these injuries was significantly different between groups, as, of the 27 patients with C-FMM bruising, 25 patients (93%) had an MFL injury ($p < 0.00001$) (Table IV). In addition, of the 40 patients with an MFL injury, 25 (63%) had C-FMM bruising ($p = 0.0251$).

For the assessment of the MFL tears, the intrarater ICC was 0.93 and the interrater ICC was 0.92. For the location of MFL tears, the intrarater ICC was 0.93 and the interrater ICC was 0.9. Similarly, for the assessment of the superficial MCL tears, the intrarater ICC was 0.9 and the interrater ICC was

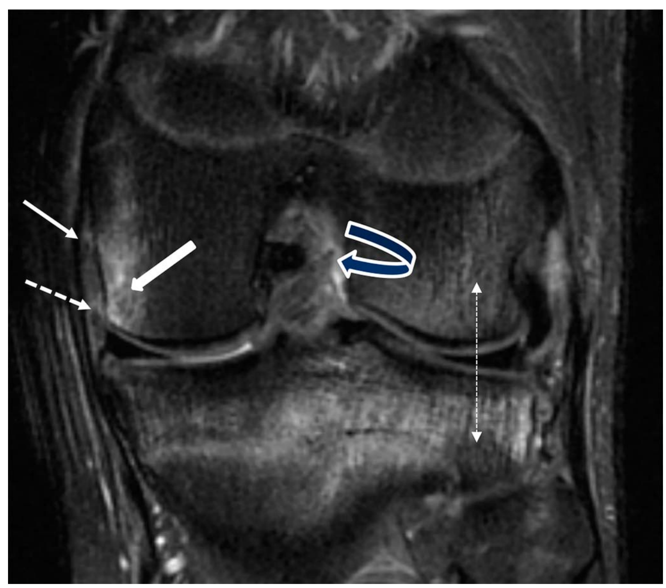

Fig. 5

Coronal, T2-weighted MRI with fat saturation. The white arrow indicates a normal MCL, the dashed arrow indicates a torn MFL, the thick white arrow indicates MFC edema secondary to an MFL tear, and the curved blue arrow indicates a torn ACL. The double-headed dashed arrow points to edema in the lateral femoral condyle and lateral tibial plateau secondary to a pivot shift injury.

TABLE I Patient Demographic Characteristics (N = 55)

Mechanism of Injury	Contact Group (N = 13)	Non-Contact Group (N = 42)
Age* *(yr)*	24.2 ± 9.0	27.5 ± 14.5
Female sex	46%	42%
Time between injury and MRI* *(days)*	9.3 ± 6.2	11.8 ± 8.3

*The values are given as the mean and the standard deviation.

TABLE II Superficial MCL and MFL Injury Grade

Injury Grade	Superficial MCL*	MFL*
Grade 1	44% (8)	0% (0)
Grade 2	22% (4)	13% (5)
Grade 3	33% (6)	88% (35)

*The values are given as the percentage, with the number of patients in parentheses.

0.88. For the location of superficial MCL tears, the intrarater ICC was 0.9 and the interrater ICC was 0.74. Lastly, for the assessment of the presence of C-FMM edema, the intrarater ICC was 0.9 and the interrater ICC was 0.85.

In our cohort, 12 (22%) of 55 patients experienced MMTs. The majority (10 [83%] of 12) of these MMTs were localized to the posterior horn ($p < 0.0001$) (Table V). Chi-square testing showed that MMTs and MFL injuries were significantly associated, with 12 (100%) of 12 patients with MMTs also having a concomitant MFL injury and 12 (30%) of 40 of patients with MFL tears also having MMTs ($p = 0.0164$) (Table VI).

Preoperatively, the majority of patients (38 [95%] of 40) with MFL tears showed no increase in the medial compartment joint space opening at 0° or 30° of flexion. Lastly, 1 patient experienced ACL graft failure at 12 months after the index surgical procedure, and, although the patient did have a deep MCL injury without evidence of a superficial MCL injury, the low number of events means that no conclusions can be drawn.

Discussion

After an ACL injury, bone-bruising patterns can be rather revealing with respect to understanding concomitant knee pathologies on MRI[13,20,21]. However, the presence of medial-sided bruising patterns associated with ACL injuries has not been well-documented in the literature. Moreover, there is a paucity of literature that describes injuries to the deep MCL in ACL ruptures, despite this structure's important function. The primary purpose of this study was to analyze the bone marrow edema localized to the MFL insertion site on the MFC in ACL ruptures. A secondary purpose was to examine the association between the MFL and the medial meniscus, as they are both structurally and functionally connected.

Although edema patterns in MCL injuries have not been commonly reported in the literature, in some previous studies, authors have hinted that isolated MCL injuries may be associated with MFC edema[5,6]. Typically, injuries at osseous ligament attachment sites lead to minimal or no marrow edema on MRI[22]. Two types of ligamentous attachments (direct and indirect) have been reported in the radiographic literature based on the attachment site's anatomical characteristics[23]. The ligamentous fibers in a direct attachment extend into the bone at a right angle and tend to show bone marrow edema on MRI[23]. The MFL portion of the deep MCL has a direct-type attachment to the MFC, posterior and inferior to the medial femoral epicondyle[23,24]. In the present cohort, the majority (93%) of patients who showed distinct edema within the C-FMM zone on the MFC had torn the MFL. Therefore, if bone marrow edema is noted within this region in an ACL rupture, there should be a high suspicion of an MFL injury. The presence of this edema pattern may help surgeons to recognize this injury, as MFL injuries are difficult to diagnose on the physical examination.

In a recent biomechanical study, LaPrade et al. showed that the weakest component of the MFL was at its femoral insertion on the MFC and, as a consequence, the most common mechanism of failure induced in cadaveric knees was avulsion off the MFC[25]. Within our cohort, the present study supports these findings by showing that 80% of MFL tears occurred proximally on the MFC. The aforementioned study also showed that the superficial MCL could resist tensile forces up to 557 N, and the deep MCL could only resist forces up to 101 N[25,26]. Biomechanically, the difference in tensile strengths between the superficial MCL and deep MCL

TABLE III Location of MFL and Superficial MCL Injuries for the Entire Cohort

Location of Injury	MFL*	Superficial MCL*
Proximal	80% (32)	61% (11)
Midsubstance	5% (2)	28% (5)
Distal	15% (6)	11% (2)

*The values are given as the percentage, with the number of patients in parentheses.

TABLE IV MFL Tear Compared with C-FMM Bone Marrow Edema (N = 55)

	C-FMM Edema	
MFL Tear	Yes	No
Yes	25	15
No	2	15
P value*	<0.00001	

*Z-test for the overall distribution of events.

TABLE V Location of the MMT in Those with Combined MMT and MFL Injuries

Location of MMT	MMT and MFL Injury* (N = 12)
Anterior horn	0 (0%)
Mid-body	2 (17%)
Posterior horn	10 (83%)

*The values are given as the number of patients, with the percentage in parentheses.

may explain the significantly higher rate of MFL injuries (73%) compared with superficial MCL injuries (33%) in our cohort. The prevalence of superficial MCL injury was slightly higher, but in agreement with Yoon et al.[1], who reported that 22% of the patients with ACL injury in their study had superficial MCL injuries. However, the prevalence of deep MCL injuries went unreported[1]. As there has been a paucity of ACL injury studies that have reported on the status of the deep MCL, we encourage future studies to report these injuries, as they could further support the biomechanical understanding of this understudied ligament.

The MFL primarily provides stabilization against external rotation at all knee flexion angles[7,25,27]. Similarly, the posterior horn of the medial meniscus acts as a secondary stabilizer for external rotation[7,27,28]. As seen in Figure 1, the MFL joins the medial meniscus at the joint line and plays an essential role in anchoring its peripheral parts. As a result, disruption of any portion of the deep MCL may impair the function of the medial meniscus[7,27]. Mechanistically, external femoral rotation has been reported to play a role in high-energy ACL ruptures[12-14,29], as Quatman et al. showed that anterior tibial translation, coupled with external femoral rotation and internal tibial rotation, conferred a 3.7-fold to 3.9-fold increase in the ACL strain compared with normal landing conditions[14]. In ACL injuries, external rotation may strain the MFL and the posterior horn of the medial meniscus[17-20,22]. The purported rotational movements likely contribute to the high levels of concomitant MFL injuries and MMTs seen in the present study. This association between MMTs and MFL injuries may have important clinical implications.

Injury to any portion of the MCL, including isolated deep MCL injuries, can lead to an imbalance in loading patterns and subsequently increase the risk of a further ligamentous knee injury[7,8,26,27]. In our cohort, all of the patients with MMTs also experienced MFL tears. Although it is hard to make conclusions from this observation, we believe that deep MCL injury may predispose a patient to a meniscal injury, as it forces the posterior horn to disperse more rotational force than normal[8,30]. Our results are in agreement with those by Willinger et al., who reported that deep MCL tears were significantly associated with medial meniscal ramp lesions[30]. Furthermore, untreated posterior horn tears or ramp lesions have been shown to cause instability within the knee, even after an isolated ACL reconstruction[2,28,30,31]. The gold standard to detect these lesions is arthroscopy, as MRI scans have been reported to have varying sensitivities[28,32]. If an MFL injury is suspected on MRI, either through direct recognition or through indirect MFC edema, the posterior horn of the medial meniscus should be assessed for injury, as there is a clear association between the MFL and the medial meniscus in the present study.

The majority of MCL injuries heal with conservative treatment, and few require surgical interventions[7,9]. Narvani et al. published a case series of 17 athletes with isolated injuries to the MFL, all of whom did not respond to conservative treatment and presented, on average, 23.6 weeks after the initial injury. In order to treat these patients, the MFL was surgically reattached to its insertion site on the MFC. At the 1-year postoperative follow-up, all patients remained asymptomatic and returned to their respective sports[24]. This further supports the notion that deep MCL injuries should be considered clinically relevant. In our cohort, patients with a documented MFL injury showed normal MCL laxity and medial joint space opening. However, Narvani et al. showed that their patients with isolated MFL injury expressed pain when external rotation, not valgus stress, was applied to the knee on the physical examination[24]. Additionally, Willinger et al. reported that patients with deep MCL injuries could present with anteromedial rotational instability on physical examination, even in the setting of normal valgus laxity[30]. Although these physical examination techniques were not tested in the current study, future studies should consider testing for anteromedial rotational instability and external rotation, as they may provide more evidence toward diagnosis during the physical examination[30,32]. Nevertheless, our study provides information with regard to the diagnosis of MFL injury through bone marrow edema recognition on MRI, which should be used in conjunction with a precise physical examination.

There were some inherent limitations within this retrospective study. Although our cohort was relatively small with 55 patients, this study represented a single-surgeon series. Additionally, although the deep MCL can be difficult to delineate on MRI, strict imaging requirements, such as the short time between the initial injury and the MRI (mean, 11 days) and high-resolution 3-T imaging, likely led to the excellent interrater agreement on MRI analysis. It is important to note that, although the MFC edema pattern was significantly associated with an MFL injury, MFL injury can still occur without any indication of edema. Although our study aimed to report on the detection of this injury through MRI findings and edema patterns, physical

TABLE VI MFL Tear Compared with MMT Status

	MMT	
MFL Tear	Yes	No
Yes	12	28
No	0	15
P value*	0.0164	

*Chi-square test for the overall distribution of events.

examination findings, such as MCL laxity and medial-sided joint opening, were unable to detect deep MCL injury. Patient-reported outcomes were not sought out, as the main objective of this study was to report on the MRI findings. Although there was 1 patient with graft rerupture who did have an untreated MFL injury, we were unable to draw any conclusions, as more events are needed. Future studies should examine the relationship between untreated deep MCL injuries and ACL graft failure. ■

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