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. 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.

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

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

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**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.)
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\(^1\). 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 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.

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The locations of the medial ligamentous injuries (superficial MCL, deep MCL) were described as proximal, mid-substance, or distal. The medial ligamentous injuries were graded on MRI according to Rasenberg et al.\(^1\). 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).


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 0.9.

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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\(^5\)\. Typically, injuries at osseous ligament attachment sites lead to minimal or no marrow edema on MRI\(^2\)\. Two types of ligamentous attachments (direct and indirect) have been reported in the radiographic literature based on the attachment site's anatomical characteristics\(^3\)\. The ligamentous fibers in a direct attachment extend into the bone at a right angle and tend to show bone marrow edema on MRI\(^3\)\. The MFL portion of the deep MCL has a direct-type attachment to the MFC, posterior and inferior to the medial femoral epicondyle\(^24\)\. 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\(^25\)\. 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) |
|------------------|------------------|
| MFL Tear | CF-MFC Edema |
| Yes     | 25              | 15               |
| No      | 2               | 15               |

*Z-test for the overall distribution of events.

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.
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.

TABLE VI MFL Tear Compared with MMT Status

| MFL Tear | MMT |
|----------|-----|
| Yes      | 12  |
| No       | 28  |

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