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MRI injury patterns in surgically confirmed and reconstructed posterolateral corner knee injuries

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Abstract

Purpose The posterolateral corner (PLC) of the knee is anatomically complex with similarly complex MR imaging findings in acutely injured knees. The purpose of this study was to define the MRI pattern of injury in cases of PLC disruption requiring surgery because of clinical instability.

Methods The knee MRIs of 22 patients who underwent surgical repair and/or reconstruction of PLC injury were retrospectively reviewed. The fibular collateral ligament (FCL), popliteus tendon (PT), biceps femoris (BF), popliteofibular ligament (PFL), arcuate ligament (AL), and fabellofibular ligament (FFL) were evaluated and graded as follows: complete tear, high-grade partial tear, low-grade partial tear, and normal.

Results In the 22 cases of PLC injury that necessitated surgery, a constellation of findings involving the larger structures of the PLC was identified. Of the FCL, PT, and BF (considered larger structures), at least two were abnormal in all 22 injury cases. Of the PFL, AL, and FFL (considered smaller structures), the PFL appeared abnormal in 19 cases, yet neither the AL nor FFL were confidently characterized in the injury group.

Conclusion The larger structures of the PLC are easily evaluated using standard MRI techniques. This study identified a predictable pattern of imaging findings involving these more easily assessed structures in those patients who were felt to be clinically unstable and underwent surgical reconstruction, as at least two were abnormal in all 22 cases. The smaller structures of the PLC are difficult to assess with MRI; however, direct visualization of their involvement on MRI is not necessary to report a clinically unstable PLC injury. Emphasis of this simplified but critical analysis of the FCL, BF and PT on MRI scans reviewed by radiologists and orthopaedic surgeons may help to prevent delayed diagnosis of unstable PLC injuries.

Level of evidence III.

Keywords Posterolateral corner injury · MRI · Instability

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Introduction

Injury of the posterolateral corner (PLC) of the knee can be associated with profound morbidity, especially in cases of missed or delayed diagnosis [3, 8, 10]. In the acute setting, patients can present with knee pain, swelling, and possibly sequelae of peroneal nerve injury, including foot numbness or weakness, though the injury may also result in no immediate disability [4, 9]. In subacute or chronic presentations, patients report instability of the knee with inadvertent hyperextension or a varus thrust, while weight bearing as well as difficulty maintaining full extension of the knee, with particular problems while ascending or descending stairs or inclines [9]. The natural history of PLC injuries

supports nonoperative management of low-grade injury [18]; however, more significant PLC injury and multiple ligament injuries require operative intervention to avoid poor outcomes [11, 12]. For example, one study on the natural history of PLC injuries treated nonoperatively determined that those with significant, grade III disruptions of the lateral ligament complex suffered from a multitude of complications at 8-year follow-up, including persistent posterolateral rotatory instability, muscle weakness, and secondary osteoarthritis [10]. Additionally, the instability related to an unrecognized and untreated PLC injury alters the knee's biomechanics, resulting in higher force transmission to ACL and PCL grafts and increasing the risk of failure [7, 17, 19].

The PLC is anatomically complex; thus, thorough assessment via MRI can be difficult, especially for radiologists not subspecialty trained in musculoskeletal imaging. The larger structures that comprise the PLC, namely the fibular collateral ligament (FCL), the popliteus tendon (PT), and the biceps femoris (BF), are easily assessed using standard MRI techniques and reading patterns. The remaining smaller structures of the PLC, including the popliteofibular ligament (PFL), arcuate ligament (AL), and fabellofibular ligament (FFL), are more inconsistently visualized on standard knee MRIs and may be at least partially obscured in the acutely injured knee by more diffuse post-traumatic soft tissue oedema that is commonly present within the posterior soft tissues of PLC-injured knees.

The study hypothesis is that cases of clinically unstable PLC injury that require operative intervention, and thus those cases most at risk for increased morbidity from missed or delayed diagnosis, can be confidently identified via assessment of only the larger, more easily assessed structures of the PLC. This pattern of MRI assessment has not been previously emphasized in the orthopaedic or imaging literature. The purpose of this study is therefore to examine the key MRI findings in cases of clinically unstable, surgically treated PLC injuries to identify more simplified imaging patterns that would facilitate recognition of this uncommon yet potentially debilitating injury.

Materials and methods

Institutional Review Board of Mayo Clinic (Rochester, MN) approval was obtained for this Health Insurance Portability and Accountability Act-compliant retrospective research protocol, and the requirement for informed patient consent was waived. Using this institution's surgical database, knee MRI examinations of 22 patients with unstable PLC injury requiring surgical intervention dating from 2007 to 2011 were identified. Additionally, a control group consisting of 27 patients with knee MRIs interpreted either as normal or as abnormal only along the medial knee was established for comparison.

All MRI examinations were performed with a 1.5 ($n = 13$) or 3 T ($n = 9$) magnet (Signa HDx, GE Healthcare, Waukesha, WI, USA) utilizing a dedicated 8-channel transmit receive phased array knee coil. The standard knee MRI protocol utilized at this institution includes the following imaging positions and parameters: sagittal proton density-weighted images (3 mm, TR/TE 2200/18); sagittal, coronal and axial fat-suppressed intermediate-weighted sequences (3 mm, TR/TE 4000-6000/45); and coronal T1-weighted images (3 mm, TR/TE 700-900/minimum). The field of view was 160 mm, and the matrix/NEX was $384 \times 256/2$ for all studies.

The PLC injury group ($n = 22$) consisted of 16 male and 6 female patients who ranged in age from 16 to 52 years old (mean age 32 years), while the control group ($n = 27$) consisted of 19 male and 8 female patients who ranged in age from 14 to 54 years old (mean age 32 years). The mean time from injury to MRI was 19.5 days (range 0–120 days) and from MRI to surgery was 94.5 days (range 9–447 days). The clinical information of the study group is summarized in Table 1.

Advanced imaging evaluation

Two experienced attending, board-certified, fellowship-trained musculoskeletal radiologists, with 15 and 25 years of experience, both of whom were blinded to the final diagnoses, retrospectively evaluated each MRI exam in

Table 1 Baseline demographic information of the PLC injury group and control group

	PLC injury group	Control group
n	22	27
Gender	16 male 6 female	19 male 8 female
Age	16–52 years old (mean 32 years)	14–54 years old (mean 32 years)
Time from injury to MRI	0–120 days (mean 19.5 days)	NA
Time from MRI to surgery	9–447 days (mean 94.5 days)	NA

consensus. The FCL, PT, BF, PFL, AL, and FFL were individually evaluated on each MRI. For the purposes of this study the FCL, PT, and BF were considered "larger PLC structures" and the PFL, AL, and FFL were considered "smaller PLC structures." The anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) were also evaluated. Abnormalities were graded by severity into one of the following categories: complete tear, high-grade partial tear, low-grade partial tear, and normal. Arbitrarily, complete tears were defined as complete fibre disruption with interposed fluid signal within the fibre gap; high-grade partial tears as extensive fibre distortion without complete disruption, with intermediate to high signal; low-grade partial tears as mild fibre distortion without fibre disruption with intermediate signal and normal as no fibre distortion with uniform dark signal. The fibular styloid process was also evaluated for the presence of either an arcuate fracture or bone oedema with comparisons made to available radiographs.

Clinical evaluation

All 22 of the patients in the surgically treated PLC injury group were clinically evaluated by one of two experienced orthopaedic surgeons, sports medicine fellowship trained, with specific expertise in knee ligament and PLC reconstruction. The FCL/PLC examination under anaesthesia as well as surgical anatomic confirmation of injury served as the reference gold standard for this study. Physical examination included the varus stress test at 0° and 30°, the dial test at 30° and 90°, the hyperextension/recurvatum test, and the external rotation drawer test to provide a targeted assessment of the PLC's stability. Additionally, bilateral fluoroscopic varus stress views were obtained on each patient to compare lateral joint space opening. The dial test is performed by assessing the degree of tibial external rotation at 30° and 90° with a greater than 15° difference relative to the contralateral, uninjured knee considered a positive exam, indicative of an injury to the popliteus tendon and/or PFL. Increased tibial external rotation at 30° of flexion corresponds to an isolated PLC injury, while a positive exam at both 30° and 90° corresponds to injury to both the PLC and the PCL. The varus stress test at 0° and 30° is performed by assessing for asymmetric opening of the lateral compartment, with grade I, II, and III injuries corresponding to 5, 5–10, and >10 mm, and is indicative of an injury to the FCL. Using fluoroscopy, lateral joint space opening of 2.5 mm or greater compared to the uninjured knee is consistent with isolated FCL deficiency, whereas 4 mm or greater compared to the uninjured knee is consistent with FCL/PLC deficiency [11]. Finally, a concomitant PLC and PCL injury is indicated by a Grade 3 posterior drawer sign, which involves a greater than 10 mm step-off at the medial joint line [15]. Injury to the FCL typically leads to an increase in varus stress. Injury to the popliteus tendon typically leads to an increase in external rotation.

Surgical indications

Indications for surgical repair and/or reconstruction of the FCL/PLC structures included grade III instability to varus stress at 0° or 30° and two or more of the following clinical findings: (1) greater than 4 mm of side-to-side difference on varus stress radiography, (2) Grade III posterior drawer, (3) Grade III external rotation drawer, (4) positive dial test at either 30° or 90°, (5) positive asymmetric hyperextension/recurvatum test. Positive clinical examination findings were then correlated with the injury patterns seen on MRI.

Results

Larger PLC structures

The FCL was abnormal in all 22 MRIs, including a complete tear in 19 cases (86.4 %), a high-grade partial tear in two cases (9.1 %), and a low-grade partial tear in one case (4.5 %).

A complete tear of the popliteus was observed in 15 knees (68.2 %) and a high-grade partial tear in six cases (27.3 %). The popliteus appeared normal in only one knee (4.5 %). The sole patient with PLC injury and an uninjured popliteus suffered an arcuate fracture with involvement of both the FCL and the BF.

The BF was completely torn in 11 of 22 knees (50 %), with two instances (9.1 %) of high-grade partial tearing and four cases (18.2 %) of low-grade partial tearing also identified. The BF was normal in five knees (22.7 %).

Notably, at least two of the three structures, the FCL, popliteus, and BF, were abnormal in all of the study patients (Fig. 1).

Smaller PLC structures

The PFL demonstrated an abnormal appearance in 19 of 22 MRIs (82.6 %) with a complete tear in 16 cases (72.7 %) and a partial tear in three (13.6 %). The AL and FFL were not confidently visualized in any patient, though abundant signal abnormality noted in the region of the posterior capsule in all cases could suggest injury to the AL.

Other findings

A high incidence of associated ACL and PCL injuries was encountered.

Fig. 1 27-Year-old male involved in a moderate speed motorcycle accident. Coronal T2-weighted images (**a**, **b**), demonstrate complete avulsion of the BF (*white arrow*) and FCL (*white arrowhead*) off of the fibula, and high-grade partial tearing of the PT at its femoral insertion (*asterisk*). The conjoint tendon is retracted several millimetres proximally. Sagittal (**c**) and axial (**b**) T2-weighted images demonstrate high-grade partial tearing of the PFL (*white arrow*) and thickening of the peroneal nerve (*black arrow*) with extensive posterolateral soft tissue oedema

The ACL was abnormal in 20 of 22 patients (90.9 %), including 17 complete tears (77.3 %), one high-grade partial tear (4.5 %), and two low-grade partial tears (9.1 %). With respect to the PCL, 19 of 22 demonstrated an abnormality (86.4 %), including 17 complete tears (77.3 %), one high-grade partial tear (4.5 %), and one low-grade partial tear (4.5 %). In only one of 22 cases (4.5 %) were both the ACL and PCL normal in appearance.

Eight of 22 knees (36.4 %) sustained an arcuate fracture, while two (9.1 %) demonstrated localized oedema within the fibular head without evidence of fracture. The remaining 12 fibular heads were normal in appearance (54.5 %). The imaging findings of the study group are summarized in Tables 2 and 3.

In the control group, none of 27 patients had an abnormal appearance to any structure of the PLC. Of note, the reviewers did not perceive a distinct advantage in assessing the PLC structures within the study or control group at 3 versus 1.5 T.

Clinical findings

The most common mechanism of injury was high-energy trauma. Fourteen patients sustained their knee injury in a motor vehicle or motorcycle accident. Low-energy trauma occurred in nine patients. Four patients were injured after falling from a height of at least four feet, three patients sustained a varus force to their medial knee while playing

Table 2 Comparison of radiologic findings for PLC injured group and control group. Control group demonstrated no injury to PLC structures

	Complete tear		High-grade partial tear		Low-grade partial tear		Normal	
	PLC group	Control group	PLC group	Control group	PLC group	Control group	PLC group	Control group
FCL	19/22 (86.4 %)	0/27 (0 %)	2/22 (9.1 %)	0/27 (0 %)	1/22 (4.5 %)	0/27 (0 %)	0/22 (0 %)	27/27 (100 %)
PT	15/22 (68.2 %)	0/27 (0 %)	6/22 (27.3 %)	0/27 (0 %)	0/22 (0 %)	0/27 (0 %)	1/22 (4.5 %)	27/27 (100 %)
BF	11/22 (50 %)	0/27 (0 %)	2/22 (9.1 %)	0/27 (0 %)	4/22 (18.2 %)	0/27 (0 %)	5/22 (22.7 %)	27/27 (100 %)
PFL	16/22 (72.7 %)	0/27 (0 %)	3/22 (13.6 %)	0/27 (0 %)	NA	NA	3/22 (13.6 %)	27/27 (100 %)
ACL	17/22 (77.3 %)	0/27 (0 %)	1/22 (4.5 %)	0/27 (0 %)	2/22 (9.1 %)	0/27 (0 %)	2/22 (9.1 %)	27/27 (100 %)
PCL	17/22 (77.3 %)	0/27 (0 %)	1/22 (4.5 %)	0/27 (0 %)	1/22 (4.5 %)	0/27 (0 %)	3/22 (13.6 %)	27/27 (100 %)

Table 3 Comparison of fibular head injury between PLC injured group and control group, control group demonstrated no injury to the fibular head

	Avulsion fracture		Oedema		Normal	
	PLC group	Control group	PLC group	Control group	PLC group	Control group
Fibular head	8/22 (36.4 %)	0/27 (0 %)	2/22 (9.1 %)	0/27 (0 %)	12/22 (54.5 %)	27/27 (100 %)

football (2) or fighting (1), one patient suffered a twisting deceleration injury while playing beach volleyball, and one patient dislocated his knee when a tree fell on his leg.

In all, 10 of the 22 patients with PLC injury experienced a peroneal neuropathy (45.5 %) manifested by numbness and paresthesias along the anterolateral distal lower extremity and/or a footdrop. Two of the 22 patients also suffered injury to the popliteal artery (9.1 %) requiring a bypass graft; one of these two patients subsequently underwent a below knee amputation.

All of the 22 patients surgically treated with FCL/PLC repair and/or reconstruction met surgical indication criteria as noted above. The specific tear patterns noted on MRI correlated with clinical examination findings in all patients with regard to physical examination findings and PLC structures noted to be abnormal (Table 2).

Discussion

The PLC of the knee is a complex functional unit with similarly complex imaging findings. The PLC can be injured by a variety of mechanisms. The most frequent scenario involves a high-energy, varus force applied to the proximal anteromedial tibia of an extended knee [20]. A noncontact injury causing hyperextension and external rotation or severe tibial external rotation in a partially flexed knee can also result in PCL injury [1, 16]. A fall can result in a PLC injury if a posterolateral force is applied to the knee in near full extension [5]. Isolated PLC injuries are exceedingly rare. The PLC is most commonly injured along with other ligamentous structures, in particular PCL and ACL [13]. In

fact, the association between concomitant PLC injury in a patient with a torn PCL has been reported to be as high as 62 % [6]. In the setting of such internally deranged knees, the diagnosis of PLC injury can be challenging and relies upon both extensive clinical and imaging assessments [15].

Given this complexity, precise visualization and characterization of the smaller PLC structures may be very challenging using standard MRI acquisition techniques and review patterns, especially in the setting of acutely injured knees. The PLC was arbitrarily divided into large and small structures and emphasized assessment of the larger PLC structures when evaluating acute injuries. The study hypothesis stated that the smaller PLC structures, namely the PFL, the AFL, and the FFL, do not need to be characterized in order to identify clinically unstable knees that require surgical intervention. Such a distinction has not been previously reported in the imaging or orthopaedic surgical literature. This simplified MRI assessment may be particularly beneficial to radiologists and orthopaedic surgeons with less subspecialty expertise.

In the 22 cases of PLC injury requiring surgical repair, neither the AL nor the FFL was confidently identified in a single knee. This was mainly due to the presence of diffuse generalized posterior soft tissue oedema, which is common in ACL and PCL injured knees. Cases of unstable PLC injury that necessitated surgical intervention, however, demonstrated a pattern of injury involving the larger, more readily characterizable structures. In all 22 knees of the surgical cohort, at least two of the larger PLC structures (FCL, BF, and popliteus) demonstrated an abnormal imaging appearance. Additionally, the FCL was abnormal in all 22 cases, and in only a single case was the degree of injury

to the popliteus more severe than that to the FCL. The FCL was also the most frequent structure to suffer a complete tear. The ligament attachments make the FCL more vulnerable to distraction forces as compared to the myotendinous BF and popliteus [2]. The smaller PFL was completely disrupted in 16 cases and partially disrupted in an additional three cases. Although visualization of a torn PFL is supportive of significant PLC injury, identification is not necessary to diagnosis of an unstable PLC injury requiring surgery.

This series demonstrates the high incidence of concurrent injury to the PLC and the cruciate ligaments. The ACL and PCL appeared normal in only one knee with associated FCL, BF, and PT injuries. This remains consistent with the previously documented rarity of isolated PLC injury, which have been encountered in as few as 1.6 % of knees clinically managed for acute ligamentous injuries [3, 5]. Injuries to one or both of the cruciate ligaments should provoke increased scrutiny of the posterolateral knee complex.

Arcuate fractures involving the fibular styloid process were also relatively common in this series, occurring in just over a third of the knees. This emphasizes the importance of careful review of the initial radiographs to identify the presence of subtle fractures as initial evidence for an underlying PLC injury. Prior studies have demonstrated that different morphologies of this avulsed fragment are predictive of the site of involvement. Smaller fracture fragments (0.1–0.8 cm) that are only mildly displaced superiorly and medially suggest involvement of the PFL and AL, whereas larger fracture fragments (1.5–2.5 cm) with longer, more central displacement suggest involvement of the FCL and BF [14].

Weaknesses of this study include the retrospective design and small number of cases due to the rarity of this injury. Additionally, this study was performed with consensus reading by the radiologists; however, the purpose of the study was to establish anatomic injury patterns, not test accuracy and perceptive ability of the radiologist. The surgical cohort reflects the clinical bias of this tertiary care orthopaedic practice.

Conclusion

The MRI assessment of the PLC is challenging because of its anatomic complexity, but the larger structures (FCL, BF, PT) are easily evaluated using standard MRI techniques. The study hypothesis was confirmed by identifying a predictable pattern of imaging findings involving these larger, more easily assessed structures of the PLC in those patients who required surgical reconstruction of their injury, as at least two of the three larger structures were abnormal in all 22 cases in this surgical cohort. In particular, the FCL was always abnormal. The remaining smaller structures of the PLC, including the PFL, AL, and FFL, are more difficult to assess with MRI due to diffuse post-traumatic soft tissue oedema and their small size; importantly, however, direct visualization of their involvement on MRI is not necessary to report a clinically unstable PLC injury. These abnormal MRI findings correlated with clinically significant FCL/PLC deficiency requiring surgical intervention.

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