Diagnosis and treatment strategies of the multiligament injured knee: a scoping review

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► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/bjsports-2022-106425).

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Accepted 9 February 2023

ABSTRACT

Objective To map the current literature evaluating the diagnosis and treatment of multiligament knee injuries (MLKIs).

Design Scoping review.

Data sources Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews and Arksey and O'Malley frameworks were followed. A three-step search strategy identified relevant published literature comprising studies reporting on at least one aspect in the diagnosis or treatment of MLKI in adults. Data were synthesised to form a descriptive analysis and thematic summary.

Results Overall, 417 studies were included. There was a substantial chronological increase in the number of studies published per year, with 70% published in the last 12 years. Of included studies, 128 (31%) were narrative reviews, editorials or technical notes with no original data. The majority of studies (n=239, 57%) originated from the USA; only 4 studies (1%) were of level I evidence. Consistent themes of contention included clinical assessment, imaging, operative strategy, timing of surgery and rehabilitation. There was a lack of gender and ethnic diversity reported within patient groups.

Conclusions There remains insufficient high-level evidence to support definitive management strategies for MLKI. There is considerable heterogeneity in outcome reporting in current MLKI literature, precluding robust comparison, interpretation and pooling of data. Further research priorities include the development of expert consensus relating to the investigation, surgical management and rehabilitation of MLKI. There is a need for minimum reporting standards for clinical studies evaluating MLKI.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Multiligament knee injuries (MLKIs) represent a heterogeneous spectrum of pathology.
⇒ Clinical evaluation, diagnosis and management of these injuries remains controversial

WHAT THIS STUDY ADDS

⇒ This scoping review has mapped the current literature evaluating the diagnosis and management of multiligament knee injury(MLKI).
⇒ The majority of MLKI literature is composed of small retrospective studies, and a significant proportion (30%) is composed of narrative reviews presenting no original data.
⇒ The lack of diversity within patient groups that comprise MLKI research has been highlighted. Further research priorities include the development of expert consensus relating to strategies for the investigation, management and rehabilitation of patients with MLKI, and the development of minimum reporting standards for clinical studies evaluating MLKI.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This scoping review provides a map of the current landscape of literature evaluating diagnosis, management and rehabilitation of multiligament knee injuries.
⇒ We have highlighted consistently contentious themes including MLKI nomenclature, choice of imaging, early versus delayed surgery, operative versus non-operative management and strategies for rehabilitation.
⇒ We have also highlighted the significant heterogeneity in reporting of important outcome variables, diagnostic and treatment strategies in the current literature evaluating MLKI
⇒ This study has highlighted specific aspects of the diagnosis and management of MLKI which remain contentious, and should provide a useful foundation upon which future studies can be designed to gain consensus.

INTRODUCTION

Multiligament knee injuries (MLKIs) are defined as a tear of two or more of the major knee ligaments comprising the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), posteromedial corner (PMC) (which includes the medial collateral ligament (MCL)) and posterolateral corner (PLC) (which includes the lateral collateral ligament, LCL).[1] Such injuries can have life-changing consequences, such as accelerated progression of post-traumatic osteoarthritis,[2 3] an inability to return to work or sport[4] and associated neurovascular injuries.[5] Left untreated or inappropriately treated, the prognosis is poor, with persistent pain and instability, and patients undergoing repeated surgical interventions.[6] A recent registry-based study identified that 28% of patients with an MLKI underwent at least one further surgical procedure subsequent to their index procedure, and 22% underwent multiple subsequent surgical procedures.[7] Furthermore, MLKI in the context of knee dislocation is associated with a concomitant vascular injury in up to 38% of cases,[8] which can lead to significant comorbidity and may even necessitate amputation.

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To cite: Makaram NS, Murray IR, Geeslin AG, *et al*. *Br J Sports Med* Epub ahead of print: [*please include* Day Month Year]. doi:10.1136/bjsports-2022-106425

Despite these potentially devastating consequences, there is currently no comprehensive consensus approach to the investigation and treatment of MLKI. These injuries represent a heterogeneous spectrum of pathology and occur markedly less frequently than single ligament injuries. A recent large population database study estimated the incidence of MLKI at 0.072 events per 100 person-years.[9] A separate study estimated that single-ligament ACL reconstruction is 60 times more common than MLKI reconstruction.[7] This makes the design of appropriately powered prospective studies challenging.[10] Despite recent attempts at pooling existing literature, there remains considerable variation in the strategies employed for investigation, treatment, rehabilitation and outcome assessment following MLKI. Examples of variations in approach to management include repair versus reconstruction of injured ligaments, early versus delayed surgery, single-stage versus staged surgery and a variety of rehabilitation strategies ranging from early casting to early mobilisation.[1 11–15] No study has yet provided a comprehensive overview evaluating the extent, range and overall summary of literature relating to MLKI injuries. The aim of this study was to perform a methodologically rigorous scoping review, mapping the literature evaluating the diagnosis and management of MLKI. The findings of this study would aid shared decision-making, while identifying gaps in the literature to establish future research priorities.

METHODS

This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews.[16] The methodology is described in detail in our published protocol.[17] The following summarises our approach to each stage:

Stage 1: identify the research question

A broad research question was formulated: What is currently known about the diagnosis and treatment of MLKIs in the literature?

Stage 2: identify relevant studies

Relevant inclusion and exclusion criteria were developed through researcher and expert consultation, as displayed in table 1. Experts were defined as physicians treating high numbers of patients with MLKI (>30 per year) and who have presented internationally on MLKI (RFL, IRM AGG, JC and GM).

The following search strategy was then employed:

Step 1: a systematic search

An initial limited search of MEDLINE and EMBASE for relevant articles was conducted.[17]

Step 2: identify key words and index terms

A systematic search of MEDLINE and EMBASE was performed from date of inception to 13 July 2022, using the search terms 'multiligament' OR 'multi-ligament' OR 'multi ligament' OR 'multiple ligament' AND 'knee'. Boolean terms AND and OR were used to extract relevant studies.

Step 3: further searching of references and citations

The reference lists of all studies meeting criteria for inclusion were themselves searched until no further relevant articles were identified. Authors of relevant primary comprehensive, scoping or systematic reviews were contacted for further information.

Stage 3: study selection

Relevant titles and abstracts were evaluated for eligibility by one reviewer (NSM). A second reviewer (IRM) completed the same process with a random sample of 10% of the titles and abstracts, with concordance >97% regarding inclusion/exclusion decision. Where consensus was not reached, the study proceeded to full-text review.

Stage 4: charting the data

Charting tables were used to record and assimilate extracted data. A priori categories were charted as well as emerging themes. Where reported, diversity within populations studied and within the author groups of these studies, was noted, including gender and geographical location. Two reviewers (NSM and IRM) undertook data extraction. NSM extracted data from 50% of included studies and IRM extracted data from 50% of studies. IRM checked 10% of NSM's data extractions for accuracy and vice versa. Any discrepancies were discussed at online meetings by a wider group including clinician scientists and sports orthopaedic surgeons.

Stage 5: collating, summarising and reporting the results

The methods employed in this scoping review enabled us to collate and consolidate existing knowledge on this broad subject and summarise the report as:

1. A descriptive analysis, mapping the data, showing distribution of studies by time period of publication, country of origin, study method and theme/focus.
2. A thematic summary, describing how identified research relates to the research question and aims, and the main findings from these organised by theme.

RESULTS

Descriptive analysis

The results of the search and study selection process are outlined in figure 1. Overall, 417 eligible studies relevant to the aims and research question were identified. In keeping with wider bibliometric trends in research of all aspects of MLKI, there was substantial chronological increase in the number of studies relating to diagnosis and treatment of MLKI (figure 2).

Research studies were identified from 37 countries, with 57% (239 studies) originating from the USA. A heatmap illustrating

Table 1 Selection criteria for included studies

Inclusion criteria	Exclusion criteria
▶ Individual case reports, technical notes, opinion pieces and narrative reviews regarding multiligament knee injuries ▶ Clinical studies related to multiligament knee injuries ▶ Preclinical studies related to multiligament knee injuries ▶ Studies reporting outcomes of management of chronic multiligament knee injuries	▶ Studies including paediatric patients (aged <16, skeletally immature) ▶ Studies evaluating only single ligament knee injuries ▶ Studies combining outcomes for management of single ligament knee injuries and multiligament knee injuries ▶ Studies not relevant to multiligament knee injuries ▶ Conference abstracts ▶ Studies not in the English language ▶ Studies reporting on patellar tendon rupture, medial patellofemoral ligament rupture in combination with one or more ligaments of the knee joint ▶ Studies including open fractures ▶ Book chapters

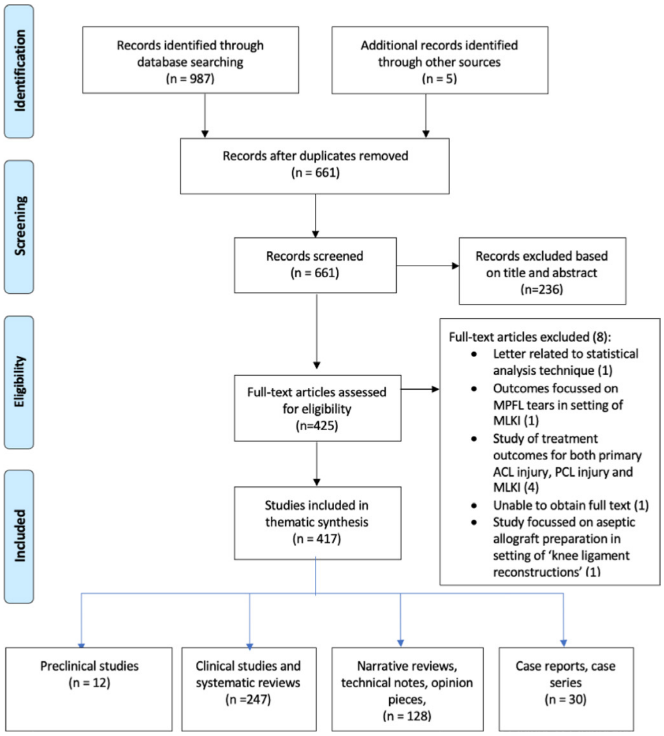

Figure 1 The Preferred Reporting Items for Systematic Reviews and Meta-Analyses, extension for Scoping Reviews flow chart for study inclusion. MLKI, multiligament knee injury; MPFL, medial patellofemoral ligament; PCL, posterior cruciate ligament.

the countries with the greatest number of publications is shown in figure 3 (further details in online supplemental table 1).

Study design and level of evidence

The studies varied considerably in their design and methodology (figure 4). As scoping reviews are intended to provide a map of what evidence has been produced as opposed to seeking only the best available evidence, no formal quality assessment was performed. Most studies were of lower order evidence, with over 90% being levels III–V. There were four randomised controlled trials (RCTs)—three assessed different aspects of rehabilitation following surgical treatment of MLKI[18–20] and one assessed non-operative versus operative treatment of MLKI.[21] Of the remaining studies, 31 were prospective, 189 were retrospective, 23 were systematic reviews, 30 were case reports/series and 128 comprised narrative reviews, technical notes and editorials. There were 12 preclinical studies.

The 23 systematic reviews that were included in this scoping review were evaluated to gain a representative insight into the estimated age, ethnicity and gender ratio of included participants in studies reporting on aspects of diagnosis and management of MLKI. Of the 23 included systematic reviews, 8 (35%) reported specifically on the gender of patients included. The overall percentage of included participants that were women in these systematic reviews was 22%, and the mean age of included participants was 31.8 years. No systematic reviews reported on the ethnicity of included participants.

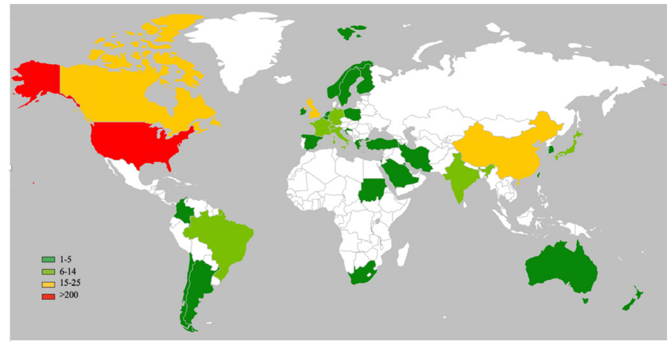

Figure 3 Heatmap of countries by number of MLK-related publications. MLK, multiligament knee.

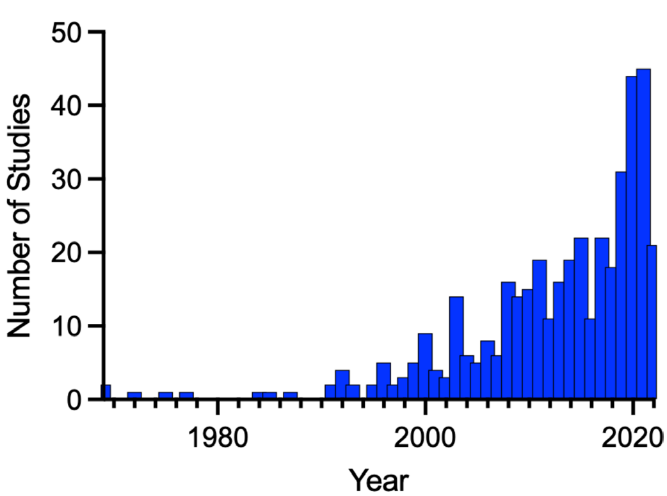

Figure 2 The number of multiligament knee injury studies published per year.

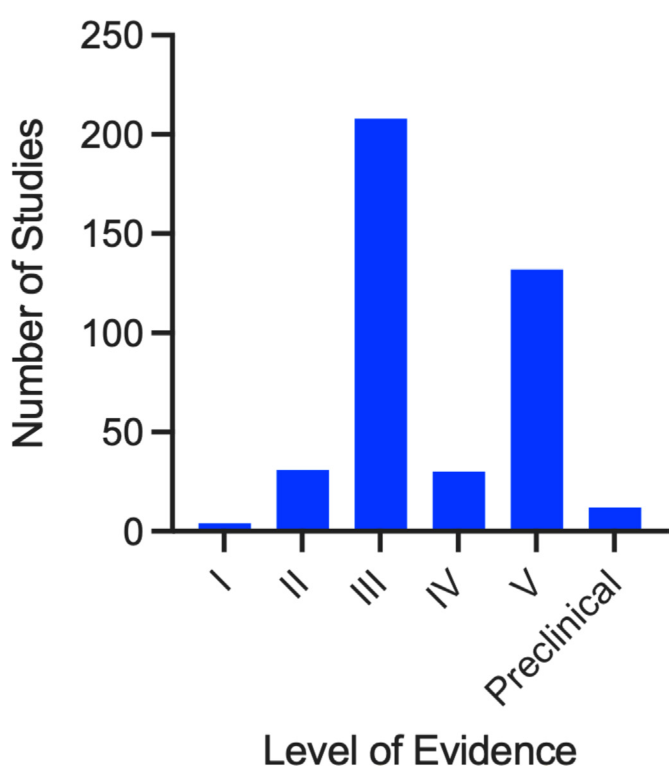

Figure 4 The number of MLKI studies included by level of evidence. MLKI, multiligament knee injury.

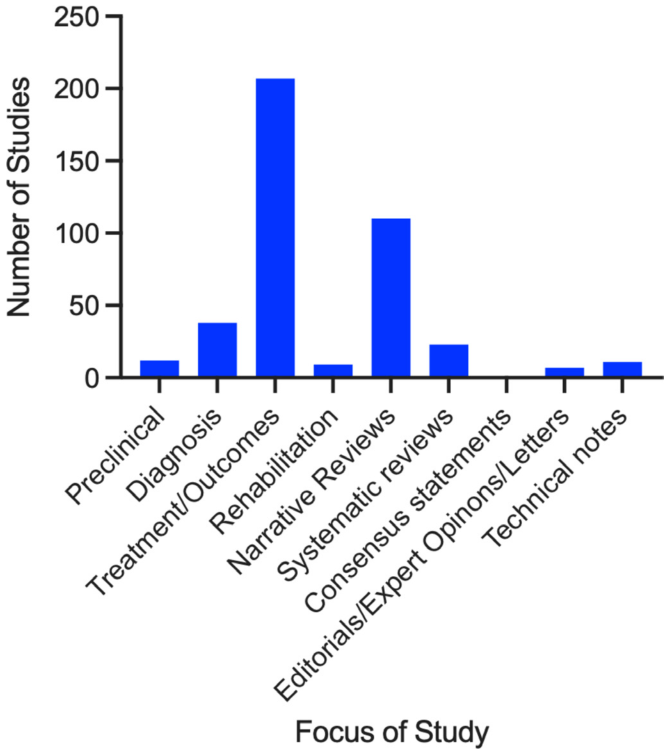

Figure 5 The number of MLKI studies by focus of study. MLKI, multiligament knee injury.

Focus of studies

Of the included studies that presented original clinical data (n=254), 38 focused on aspects surrounding the diagnosis of MLKI (14.9%) (figure 5), including associated soft-tissue knee injuries, neurovascular injuries and the value of specific diagnostic modalities. Thirty-six studies were of level II or III evidence, consisting of 10 prospective and 26 retrospective studies; the remaining 2 were case reports.

The majority of included studies presenting original data reported on aspects of treatment of MLKI (n=207). These varied from assessing outcomes of surgical repair or reconstruction of MLKI, comparing timing of surgical intervention, non-operative management and predictors of poor outcome following surgical treatment of MLKI. Twenty-one studies (10.1%) were prospective, including one RCT. Seven studies (2.8%) representing original data focused on methods of rehabilitation following treatment of MLKI, and notably 42.9% of these were RCTs (n=3).

A small number of studies assessed MLKI in the context of high-level sport (n=15) or in a military setting (n=2); however, most studies did not specify such context.

We additionally reviewed the top authors by number of publications within the MLKI field, as first or senior author (online supplemental table 2). Most of these authors were from the USA, reflecting the geographical distribution of studies published. All were male, and all but one was white (n=22/23, 96%).

Thematic summary

Nomenclature and definitions

MLKI has been traditionally defined as disruption to at least two of the four major knee ligaments comprising the ACL, PCL, MCL and LCL.[14] More recently, there has been greater understanding of the significance of associated soft-tissue knee structures and their relative significance in conferring knee stability, leading to studies expanding this definition to include the posterolateral corner (PLC) and posteromedial corner (PMC) of the knee.[22] Several recent systematic reviews assessing MLKI define the term specifically as 'disruption of at least two of the four major knee ligaments, comprising the ACL, PCL, MCL (and PMC) and LCL (and PLC)'.[1 4 15 23] Numerous original research studies and systematic reviews do not explicitly define their interpretation of MLKI, or do not define their interpretation of the 'four primary knee ligaments'.[24–30] One recent systematic review defined MLKI as 'three or more ligaments injured and/or knee dislocation' .[31] Future studies should specifically state their definition of MLKI. We suggest a definition of the traumatic disruption of at least two of the major ligaments of the knee, comprising the ACL, PCL, PMC (superficial and deep MCL, posterior oblique ligament) or PLC (fibular collateral ligament, popliteus tendon, popliteofibular ligament (PFL)). Furthermore, 'knee dislocation' has often been used interchangeably with MLKI. This may be because historically, reported multiligament injuries were only observed in the context of knee dislocations (defined as total disruption of the tibiofemoral joint verified clinically or radiographically). In a landmark observational study by Wascher *et al*,[32] the authors reported that 50% of knee dislocations were reduced at time of presentation. Therefore, the definition of knee dislocation was expanded to include bicruciate knee ligament injuries with or without involvement of the collateral ligaments. Schenck developed a classification system for knee dislocations that was later modified by Wascher to include fracture dislocations.[32 33] This classification did not cater for other MLKI that were not caused by knee dislocations. A greater understanding of knee anatomy, biomechanics and modern imaging have improved our understanding of both knee dislocations and MLKI. Importantly, it has become clear that although knee dislocations result in MLKI, not all MLKI are knee dislocations. This has created a lack of nomenclature for MLKI that are not classified as knee dislocations. Recent reports have demonstrated that MLKI not caused by knee dislocations are more common than those caused by knee dislocations.[34 35] We suggest the term knee dislocation should be used with caution because it does not specify injured structures and might lead to misdiagnosis of relocated knee dislocations.

According to the Schenck classification, Schenck's Knee Dislocation I (KD I) represents knee dislocations verified clinically or radiologically with one of the cruciate ligaments intact, which is a rare phenomenon.[33] Some published studies have used the KD I classification to include MLKI involving a cruciate ligament and collateral ligament without verified dislocation[36 37]

Although the definitions may be equivocal or implied, there is a need for clarity to enable robust pooling and comparison of outcome data, and clear systematic searches to be performed. A universal consensus definition of MLKI and a requirement to state the author's definition of such in any future study assessing MLKI may be warranted.

Clinical diagnosis

The value of clinical examination in the context of MLKI is unequivocal; however, the principles differ based on acute or chronically presenting injury. In acute injuries, MLKIs are often associated with high-energy trauma, and thus assessment using Advanced Trauma Life Support principles is advocated.[38] Fifty per cent of knee dislocations reduce spontaneously prior to first assessment by a physician, and given the high correlation between knee dislocations and MLKIs, each MLKI should be treated as a true knee dislocation until proven otherwise.[39] In subacute and chronic settings, the literature notes that physical examination of the knee is the initial method of choice for the diagnosis of MLKI, but appropriate examination in these settings relies on the patient's ability to relax and the clinician's ability to detect endpoints.[40]

In the subacute or chronic setting, patients with MLKIs may present with ligament injuries that initially go unrecognised, due to the extent of simultaneous injuries to other structures. Patients with chronic MLKIs may present with persistent pain, feelings of instability, especially during twisting and impact activities, and a mild knee effusion.[41] Specific attention should be given to examining the integrity of the ACL, PCL, PLC, MCL and LCL.

The ACL is examined using the anterior drawer test, the Lachman test, and the Pivot Shift test. However, in the setting of chronic MLKI, isolating a positive ACL tear using anterior drawer is increasingly challenging. First, under normal circumstances, at 90° of knee flexion, the anteromedial tibia lies approximately 1 cm anterior to the distal femoral condyles. After disruption of both cruciate ligaments, this relationship may be altered, making it difficult to appreciate a true ACL injury via the anterior drawer test due to posterior subluxation of the tibia.[41] Furthermore, although the pivot shift test is a useful clinical test to detect anterior knee instability, in the context of MLKI it may be limited if an associated tear or avulsion of the iliotibial band is present, which may not allow the shift to occur as the knee is progressively flexed during testing.[41]

The MCL and LCL are tested with a valgus and varus stress, respectively, with the knee held at 30° of flexion to isolate the collateral ligaments. Each test is repeated with the knee in full extension. Excessive lateral joint opening with varus stress in full knee extension suggests injury to other structures, which may include the ACL, PCL and PLC, in addition to an LCL injury.[42] Similarly, laxity in valgus stress in full extension suggests an associated posteromedial capsular injury, ACL and/or PCL injury, in addition to an MCL injury.[40 42] Thus, although sensitive to detect the presence of associated injuries, these tests are unspecific.

The dial test is used to evaluate the structures that contribute to PLC stability, including the LCL, popliteus tendon and PFL.[42] The test is performed with the knee held at both 30° and 90° of flexion. Increased external rotation at 30° but not at 90° is consistent with an isolated PLC injury, while increased external tibial rotation at both 30° and 90° suggests injury to both the PCL and PLC.[41 43] An increase solely at 90° of flexion suggests a partial or complete tear of the PCL.[41] The clinician must be aware that an increase in external rotation at both 30° and 90° during the dial test may also signify anteromedial rotatory instability instead of a PLC injury.[44] Although useful, in the context of MLKI the dial test is again relatively unspecific in characterising individual injuries.[45]

Studies that have evaluated the sensitivity and specificity of individual clinical tests to detect ligamentous injury, such as those described here, are confined universally to single or two-structure injuries in MLKI,[46–52] thus their sensitivity and specificity is largely unknown in the context of chronic MLKI. However, the sensitivity and specificity of these clinical tests is often reduced compared with their quoted accuracy in single or dual structure injuries due to the extent and severity of injury present in MLKI, and the number of structures affected.[29 40 53–55] Therefore, although useful, it is essential that clinical examination is accompanied by sensitive and specific imaging.

Vascular injury and investigation

Nineteen studies were identified that specifically assessed vascular injury in the context of MLKI associated with knee dislocations (online supplemental table 3). Two systematic reviews[5 8] have attempted to quantify the incidence of vascular injuries associated with knee dislocations; one reported an incidence of associated vascular injury ranging between 6% and 38%,[8] and the other reporting an estimated overall incidence of 18% (171 of 862 patients from studies included).[5] However, these studies included all classifications of knee dislocations and did not exclusively look at vascular injuries associated with MLKIs not caused by knee dislocations. Therefore, the prevalence and risk of vascular injuries in MLKIs not caused by knee dislocations is unknown, although there is low quality evidence suggesting that the risk of vascular injury is higher in cases of MLKI associated with knee dislocations, than in MLKIs involving two ligaments and not caused by knee dislocations.[35]

There is a significant body of low order evidence suggesting that clinical examination of pedal pulses alone is insufficient for the accurate diagnosis of vascular injury associated with MLKI,[56–58] and there is general agreement that further investigation is required, most commonly in the form of Ankle Brachial Pressure Index (ABPI) measurement . However, controversy remains regarding the selective use of angiography based on combined pedal pulse and ABPI assessment, or routine angiography, in the context of knee dislocation.[56 59–61] The majority of evidence assessing the relative value of investigative techniques for vascular injury in MLKI is composed of retrospective studies of relatively small case series.[56 59 62–64] Currently, there is a tendency towards selective angiography due to associated risks and costs of routine invasive investigation, and CT angiography has been advocated due to its superior sensitivity and specificity in general orthopaedic trauma.[65] Although attempts have been made to devise decision algorithms to aid selective angiography using risk profiles based on mechanism, physical examination and ABPI findings (ABPI <0.9),[56] these are based on low order evidence or expert opinion and have not been independently validated for sensitivity and specificity. Nicandri *et al*[56] showed in a retrospective study the significant benefit of using an evidence-based standardised protocol for evaluation of suspected vascular injury in patients with MLKI; the use of an evidence-based protocol significantly reduced incidence of delay in diagnosis of vascular injury >8 hours, which translated to better clinical outcomes. However, such selective algorithms and evidence-based protocols have not been compared with routine CT angiography in high-quality randomised trials or prospective studies in the context of acute MLKI.

Imaging

Nineteen studies specifically assessed imaging modalities in MLKI (online supplemental table 4). Timely and appropriate imaging is essential in managing MLKI, particularly given that spontaneous reduction of knee dislocations occurs in up to 50% of acute dislocations. This can often lead to diagnosis of MLKI being missed acutely and presenting in the chronic setting.[66] Although the use of MRI is widely advocated, literature assessing the sensitivity and specificity of MRI in patients with MLKI is limited.[67–73] Original data regarding the value of MRI are of levels II-III evidence.[56 67 70 73 74] However, studies report a wide range of sensitivity and specificity. Generally, the literature reports high sensitivity (97%–100%) but lower specificity (50%–67%) for MRI in the diagnosis of cruciate and collateral ligament tears.[71] Few studies have assessed the diagnostic ability of MRI to identify injuries to the posteromedial and posterolateral structures, but two have noted reduced sensitivity of MRI in identifying injuries to these structures.[67 71] Conversely, LaPrade *et al*[75] noted high sensitivity and specificity of MRI in identifying injuries to the posterolateral structures, ranging from 68% to 100%. Thus, modern MRI techniques may enable sensitive and specific identification of injuries to some soft-tissue knee structures; however, MRI has limitations particularly for PLC and PMC injuries, and there is no consensus describing the accepted sensitivity and specificity of MRI for diagnosing individual structural injuries in MLKI.

Although MRI is useful in diagnosing and characterising MLKI, it cannot demonstrate the functional consequences of ligament injuries as it is a static study.[76] Furthermore, operative decision-making based on degree of instability cannot be made on MRI findings alone.[77] Clinical examination risks subjective variation and error, as appropriate examination in these settings relies on the patient's ability to relax and the clinician's ability to detect endpoints during application of valgus and varus load at 30° of knee flexion and anteroposterior load.[40] The presence of concurrent injuries, often associated with MLKI, can obscure subtle findings in clinical examination, such as injuries to the PMC or PLC. Stress radiographs have been advocated as a useful imaging modality to demonstrate the magnitude of knee instability in an objective and quantifiable way, which can aid preoperative decision making. They have also been advocated for postoperative follow-up of MLKI.[78–80] However, there remains controversy regarding the technique of choice for such radiographs, with a variety being described.[81–84] Although literature advocates the value of stress radiographs in isolated ligamentous injuries,[40 82 85] the yield of such techniques in the setting of MLKI is not well studied, and most studies combine patients with both single ligament injuries and MLKIs in their case cohort. The literature assessing stress radiography in homogeneous cohorts of patients with MLKI is limited almost exclusively to small case series or technical notes,[40 86–88] and incorporate a variety of techniques.[89] There is a need for higher-quality evidence, perhaps through pooling of comparable data to more robustly inform on the value of stress radiography in MLKI . Furthermore, consensus is required regarding standardisation of stress radiography techniques to allow for pooling of comparable data.

Operative versus non-operative management

Of 11 studies included, 3 were systematic reviews of published evidence and two were narrative reviews (online supplemental table 5). Of remaining studies, one was an RCT published over 15 years ago, and five were retrospective. Over half of published studies were from the USA (n=6). Halinen *et al*[73] reported, in a prospective randomised study that compared non-operative and operative management of MLKI involving ACL and MCL rupture, equivalent functional results. However, all three systematic reviews favoured operative management of MLKI compared with non-operative management, reporting significantly higher rates of return to work, return to sport and functional outcome.[1 12] All studies included in these systematic reviews were of low quality or were not formally assessed for quality. Furthermore, several critical aspects of management such as timing of intervention, technique and rehabilitation varied markedly, making objective comparisons of 'operative' and 'non-operative' management challenging. Operative techniques and rehabilitation protocols have also greatly evolved in recent years, and several of the studies included in these systematic reviews were over 20 years old. There is a distinct lack of high-quality pooled quantitative analyses of outcomes following operative versus non-operative management of MLKI, reflecting the heterogeneous nature of these injuries and treatment protocols.

Early versus delayed surgery

Fourteen studies reported on timing of surgery for MLKI (online supplemental table 6), although most focused on bicruciate ligament injuries. Of these, eight (60%) were from the USA. All studies were of levels III–V evidence, and 10 were appraisals of published evidence—8 were systematic reviews and 2 were narrative reviews. Therefore, only 5/15 studies (33%) comprised original research assessing early versus delayed surgery. There is consensus for the demarcation in time point between 'early' and 'late' surgery for MLKI[1 23 25 90–94]; early being <3 weeks and late being >3 weeks; however, the evidence for this demarcation is unclear. Levy *et al*[1] noted that 3 weeks had been considered a critical time period following injury, when tissue planes can be identified and are of sufficient integrity to allow reapproximation and suture placement. Such an arbitrary cut-off may oversimplify the concept of optimal time for surgical intervention in MLKI.

The number of appraisals of published evidence compared with original data regarding timing leads to multiple pooled analyses of similar datasets. Eight systematic reviews have drawn varying conclusions regarding relative advantages of early versus delayed intervention in MLKI. Marder *et al*,[25] Barfield *et al*[95] and Jiang *et al*[28] found there was insufficient evidence to advocate one approach over the other, but Marder *et al*[25] did note better functional outcomes in the delayed intervention cohort. This contrasts with pooled analyses by Levy *et al*,[1] Vicenti *et al*,[23] Hohmann *et al*[30] and Mook *et al*[14] who reported higher functional outcome scores with early intervention, although some have identified greater rates of stiffness.[1 14] Ultimately, these studies all suffer from the same flaws: the overwhelming majority comprise retrospective case series or small cohorts, there is inconsistent reporting of a variety of differing outcomes, functional outcome scores used are not validated for MLKI, and separate reviews assess heterogeneous patient populations.

There is a need for consistent outcome reporting in future studies to allow for pooling of data, robust comparisons of interventions and further analyses of more specific time intervals for intervention. Specifically, we require robust evidence that assesses whether bicruciate ligament injuries act similarly, and therefore, should be managed similarly, to MLKI involving one cruciate and one corner. Given that most existing evidence assessing early versus delayed surgery in MLKI assesses bicruciate MLKI, it is still unclear whether this data can be extrapolated to other patterns of injury. Multicentre prospective trials and a registry dataset with common reporting variables may enable high-quality and sufficiently powered studies to be performed to achieve consensus in this regard.

Staged versus single stage surgery

Of those studies that assessed single versus staged approaches to surgery for MLKI, three were systematic reviews (online supplemental table 7)[14 25 95]; two found that neither approach was superior, and both concluded that the evidence was currently insufficient in both number and quality to draw clear conclusions. Mook *et al* noted better functional outcomes and less stiffness with staged procedures.[14] There appears to be crossover in nomenclature regarding 'early versus late' intervention and 'single versus staged' intervention, with some studies using these terms interchangeably, incorporating both repair and reconstruction in both strategies.[25 95] Furthermore, it remains unclear whether all patterns of MLKI act similarly, and therefore, should be managed singularly. For example, concomitant fracture or extensor injury in MLKI is not an uncommon occurrence, particularly in the context of knee dislocation, and can influence management choice of single versus staged surgery. There is a need for specific evidence and consensus regarding the choice of single versus staged intervention depending on pattern of injury and associated injuries.

Reconstruction versus repair

Seventeen studies explicitly evaluated surgical reconstruction versus repair in MLKI (online supplemental table 8). Fifteen were of level III evidence: two were systematic reviews and the remainder were retrospective. The main controversies lie in whether both extra-articular and intra-articular ligament injuries should be entirely reconstructed or repaired, or whether a combination of these strategies is most appropriate and should be tailored to the pattern of MLKI.

Several studies have approached the subject of repair and reconstruction by assessing individual ligaments separately, and the authors recommend this approach. Vicenti *et al*[23] evaluated reconstruction versus repair for cruciate ligament rupture, PLC and PMC in the context of MLKI in a systematic review. They described higher-quality studies by Stannard *et al*[96] and Levy *et al*[97] which identified significantly lower rates of failure when the PLC was reconstructed, with higher rates of stability. Although retrospective case series have been described advocating repair of the PLC and lateral structures,[98 99] no high-quality prospective evidence has yet been identified showing significant advantages over reconstruction.

Recently, Ishibashi *et al*[100] advocated the acute repair of extra-articular ligaments and a delayed reconstruction of cruciate ligaments, noting that there was no difference in functional outcome between those who had primary extra-articular ligament repair and intra-articular ligament reconstruction, or extraarticular ligament repair only. A more recent retrospective study by Gan *et al* has also supported this protocol of repair of extra-articular ligaments and reconstruction of cruciate ligaments for Schenck's KD III (KD III) and IV (KD IV) MLKI.[101]

Debate continues regarding the treatment of individual ligament injuries with repair or reconstruction in the context of MLKI. The highest quality evidence currently supports reconstruction. The authors advocate a tailored approach with surgical strategy planned separately for individual ligaments. This should be based on the available evidence for outcomes of reconstruction and repair specific to the single ligament in question, the operating surgeon's preference based on their own skill-set and experience, and patient factors including comorbidity profile, functional level and their own priorities relating to timing of recovery for the purposes of return to work or sport. There is a need for high-quality prospective evidence to assess these operative strategies and achieve consensus.

Early versus delayed range of movement for rehabilitation

Fifteen studies assessed aspects of rehabilitation following MLKI (online supplemental table 9). The two areas of investigation within MLKI rehabilitation that were subject to the highest quality evidence were (1) Early versus delayed mobilisation following surgical intervention for MLKI and (2) the method of bracing postoperatively. Interestingly, postoperative rehabilitation following MLKI has been subject to the highest quality of research within all fields of MLKI research, with three of the four RCTs identified i focused on rehabilitation.[18–20]

RCTs investigating the benefit of bracing have largely compared two approaches, hinged external fixation or hinged knee bracing.[18 19] Angelini *et al*[18] compared a hinged external fixator to rigid casting in extension (for 3 weeks), followed by gradual progressive passive range of movement exercises, with weightbearing only permitted after 6 weeks. Functional outcomes were significantly higher in the external fixator group. They concluded that the use of an external fixator following MLKI reconstruction is beneficial; however, the fact that this was compared with an alternative strategy of casting in extension for a period of 3 weeks was not emphasised. Stannard *et al*[19] compared hinged external fixation with hinged knee brace following MLKI reconstruction in an RCT. The trial was not sufficiently powered; however, no significant difference was observed in rate of failures between brace or external fixator, although 28% of MLKI reconstructions failed in brace compared with 15% in fixator. Functional outcome, pain, return to work and overall ROM were comparable.

Hoit *et al*[20] compared early (day 1) versus late (following 3 weeks of full-time extension splint immobilisation) physiotherapy in an RCT. No statistical difference was found between the need for postoperative MUA between groups in the first 6 months post-procedure, however, the study was underpowered. No differences were found in ROM, stability or patient-reported quality of life at 1 year.

A recent meta-analysis[14] of early immobilisation versus early mobilisation for patients who had acute surgical intervention for MLKI concluded that a strategy of early mobilisation was significantly better tfor stability, ROM and functional outcome. This has since been supported by a more recent systematic review.[15] However, the authors acknowledged the widely varying protocols for weightbearing, bracing, timing of initiation and types of physical therapy in these studies. Despite the variation in rehabilitation strategies discussed, Keeling *et al* identified that specific rehabilitation protocols were consistently referenced, described by Edson and Fanelli.[91 102]

Consensus has not been reached for a specific rehabilitation strategy following surgery for MLKI; the consistent themes for debate are postoperative weightbearing status, optimal type of bracing required, duration of bracing, rehabilitation protocols and early versus delayed physiotherapy. Evidence suggests early physiotherapy achieves better outcomes in stability, ROM and functional outcome,[14 15 103] however, significant variation in the rehabilitation protocol employed limits the applicability of this conclusion. Although attempts have been made to conduct high-quality RCTs, most have not been sufficiently powered to provide definitive answers to these questions.

Diversity in research

Although gender was reported, ethnicity was not reported for patients in the systematic reviews and we are therefore unable to comment on potential influence of ethnicity on outcomes following MLKI. Gender has been reported to have an influence on risk of ACL injury and may also be associated with risk for MLKI.[104] There was noted to be a lack of gender diversity within author groups, with the 20 most published lead or senior authors being men (online supplemental table 2). A lack of gender and ethnic diversity has been highlighted by multiple sources including the American Orthopaedic Association and British Orthopaedic Association as a critical issue.[105] Diversity in healthcare has been shown to be beneficial multilaterally, including in achieving improved patient communication, education and outcomes.[106]

Strengths and limitations

This methodologically rigorousr scoping review mapsthe existing literature regarding MLKI, highlights current controversies, and identifies important research gaps. Scoping reviews are comprehensive, but not exhaustive, in identifying literature,[107] recognising the balance between breadth and depth of analysis.[108] Our search was subject to older but relevant sources being less available via databases, search platforms and search engines. Scoping reviews are broad in nature and provide an overview of existing literature regardless of quality, providing a broader and more contextual overview than systematic reviews.[108–110] Rigorous and reproducible methods have been applied. A limitation of this study was the inability to discuss in depth the controversies regarding specific aspects of operative techniques in MLKI such as tunnel placement and order of reconstruction/repair, which was beyond the scope of this review.

Future research priorities

The literature relating to outcomes following treatment of MLKI is heterogeneous with a variety of diagnostic and treatment protocols being advocated, mostly based on small retrospective studies or pooled analyses of these studies. A significant proportion of MLKI literature comprises narrative reviews providing no original data. Given the relative rarity of MLKI and the difficulties associated with performing sufficiently powered prospective randomised studies evaluating these injuries, there is a need for effective comparison and pooling of outcome data from MLKI literature. Currently, significant heterogeneity in variable reporting, diagnostic and treatment strategies employed precludes such comparisons being performed. This may be because no consensus guidelines yet exist describing standard of care for such injuries. Further research priorities include the development of expert consensus relating to strategies for the investigation, management and rehabilitation of patients with MLKI. There is a need for minimum reporting standards for clinical studies evaluating MLKI. As reported by Devana *et al*,[104] gender and race may be associated with disparities in injury, treatment course and outcomes in patients with ACL tears although there is limited information available on this topic and we support improved demographic data collection for patients with MLKI. This scoping review has also highlighted lack of diversity among leaders of MLKI research.

CONCLUSION

This scoping review identified 417 studies evaluating the diagnosis and management of MLKI. At present, there is insufficient high-level evidence to support one management strategy over another in multiple fields relating to the investigation, diagnosis and management strategies ifor MLKI, with no expert consensus yet achieved. There is a lack of clear and consistent use of terminology for MLKI, ranging from a specific definition of MLKI to interchangeability of disparate terms. While a number of studies have addressed aspects of investigation, treatment and rehabilitation for MLKI, this is the first scoping review to map the current evidence across this topic.

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Contributors NM: Conceptualisation, methodology, formal analysis, data curation, writing—original draft, writing—review and editing, IRM: Conceptualisation, methodology, formal analysis, data curation, writing—original draft, writing—review and editing, AG: writing—review and editing, JC: writing—review and editing, GM: writing—review and editing, RFL: Conceptualisation, writing—review and editing, supervision and guarantor. All authors contributed to the planning, conduct and reporting of the work described in this article.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests IRM reports the following disclosures:Arthrex: Paid consultant, Bone and Joint Research: Editorial or governing board, Journal of Bone and Joint Surgery—British: Editorial or governing board, Stryker: Paid consultant. AG reports the following disclosures: American Orthopaedic Society for Sports Medicine: Board or committee member, Arthroscopy: Editorial or governing board, Infographics Editor, Ossur: Paid presenter or speaker, Smith and Nephew: Paid consultant; Paid presenter or speaker. JC reports the following disclosures: American Orthopaedic Society for Sports Medicine: Board or committee member, Arthrex: Paid consultant, Arthroscopy Association of North America: Board or committee member, CONMED Linvatec: Paid consultant, International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine: Board or committee member, Ossur: Paid consultant, Smith & Nephew: Paid consultant. GM reports the following disclosures: Smith & Nephew: Paid consultant. RFL reports the following disclosures: American Journal of Sports Medicine: Editorial or governing board, American Orthopaedic Society for Sports Medicine: Board or committee member, Arthrex: IP royalties; Research support, International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine: Board or committee member, Journal of Experimental Orthopaedics: Editorial or governing board, Knee Surgery, Sports Traumatology, Arthroscopy: Editorial or governing board, Linvatec: Research support, Ossur: IP royalties; Paid consultant; Research support, Smith & Nephew: IP royalties; Paid consultant; Research support.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as online supplemental information.

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