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REVIEW ARTICLE

A Systematic Review of all Published Systematic Reviews (SRs) on Multiligament Knee Injuries (MLKIs)

Nagashree Vasudeva[1] · Ajay Gowtham Amutham Elangovan[2] · Rajagopalakrishnan Ramakanth[3] · Prahalad Kumar Singhi[4] · Riccardo D'Ambrosi[5] · Srinivas B. S. Kambhampati[6]

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Abstract

Introduction Multiligament knee injuries are an uncommon and heterogeneous group of injuries and standardizing reporting on these injuries is a challenge. Given the complexity of multiligament knee injuries (MLKIs) and the ongoing debate regarding optimal management strategies, a comprehensive understanding of the current evidence is essential to guide evidence-based decision-making and improve patient care.

Aim In this systematic review, we aimed to assess the systematic reviews and meta-analyses on MLKIs and synthesize their findings. This will enable us to identify areas where the current evidence is strong and where further research is needed.

Methods Adhering to PRISMA guidelines, a comprehensive search in PubMed, Embase, and Cochrane Library identified 36 eligible systematic reviews. AMSTAR 2 criteria were used to assess the methodological quality. For agreement between the raters, the inter-rater reliability Cohen's kappa was used.

Results Most of the systematic reviews assessed with AMSTAR 2 criteria had a critically low level of evidence ($n = 26$), with the rest being low ($n = 8$), moderate ($n = 3$), and one high, indicating caution in interpreting findings.

Discussion This study highlights the scarcity of high-quality systematic reviews (SRs) on multiligament knee injuries (MLKIs), largely due to the diversity in injury patterns, management protocols, and reporting standards.

Conclusion Most research on these injuries are of low quality, and recommendations have been made to improve reporting. Many areas of these injuries require further studies to improve the outcomes.

Keywords Multiligament knee injuries (MLKIs) · ACL tear · PCL tear · MCL/PMC tear · LCL/PLC tear

Introduction

Multiligament knee injuries (MLKIs) are complex and severe orthopaedic traumas that disrupt two or more of the knee's major ligaments. Typically resulting from high-energy trauma such as motor vehicle accidents or significant falls, MLKIs not only compromise joint stability and kinematics, but also profoundly impact long-term functional outcomes, potentially leading to accelerated osteoarthritis and considerable difficulty in returning to daily activities or sports [1,

✉ Srinivas B. S. Kambhampati
kbssrinivas@gmail.com

Nagashree Vasudeva
drnagashreev@gmail.com

Ajay Gowtham Amutham Elangovan
ajaygowthamae3@gmail.com

Rajagopalakrishnan Ramakanth
ramjesh64@yahoo.co.in

Prahalad Kumar Singhi
docpsin2001@yahoo.co.in

Riccardo D'Ambrosi
riccardo.dambrosi@hotmail.it

1 Mahaveer Medical Centre, Mangalore, India

2 Gowtham Multispecialty Hospital Pvt Ltd, Coimbatore, India

3 Ganga Medical Centre & Hospital, Coimbatore, India

4 Preethi Hospital, Madurai, India

5 IRCCS Istituto Ortopedico Galeazzi, Milan, Italy

6 Sri Dhaatri Orthopedic, Maternity & Gynaecology Centre, Vijayawada, Andhra Pradesh 520008, India

2]. These injuries are further complicated by the frequent association with neurovascular damage, which poses additional risks of severe long-term consequences, including limb loss, if not promptly and appropriately managed [3].

The management of MLKIs presents a significant challenge, encapsulating a spectrum of clinical concerns from the timing of surgical intervention to decisions between ligament repair and reconstruction and the intricacies of postoperative rehabilitation. Early surgical interventions aim to restore joint stability and optimize long-term outcomes, but they also carry the risk of stiffness and arthrofibrosis [4]. Conversely, delays in surgical treatment can exacerbate joint instability and the degradation of soft tissues, potentially culminating in poorer functional recovery and an elevated risk of developing osteoarthritis [5].

Despite advancements in diagnostic techniques and surgical treatments, a consensus on the optimal management strategy for MLKIs remains elusive. The field continues to debate critical aspects such as the ideal timing for surgery, the most effective surgical techniques and approaches to managing neurovascular injuries, and the design of rehabilitation protocols that best support recovery and functional restoration [6].

Given the complexity of MLKIs and the ongoing debates surrounding their management, this systematic review aims to synthesize high-quality evidence from existing systematic reviews and meta-analyses meticulously [7]. By doing so, we intend to delineate areas of consensus and identify persistent controversies in managing MLKIs. As this is a systematic review of systematic reviews, quantitative data compilation and analysis is not feasible. Specifically, this review will focus on assessing the methodological quality and potential biases within the existing literature, examining the efficacy of different surgical interventions, examining findings from published reports, and evaluating the role of rehabilitation in improving long-term patient outcomes.

This approach will help clarify the current evidence landscape and highlight knowledge gaps that warrant further investigation. By providing a comprehensive overview of the state of research, this systematic review seeks to inform evidence-based clinical decision-making and guide future research directions in managing MLKI.

Materials and methods

Study Protocol and Registration

This systematic review adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [8] and checklist and the protocol was registered with INPLASY (International Platform of Registered Systematic Review and Meta-analysis Protocols) bearing number INPLASY202470017.

Search Strategy

A comprehensive literature search was performed on February 2, 2024, utilizing PubMed, Embase, and the Cochrane Library. The search was conducted using the keywords "multi ligament knee injuries," "knee dislocation," "anterior cruciate ligament," "posterior cruciate ligament," "medial collateral ligament," "lateral collateral ligament," "meniscus," "posterolateral corner," and "systematic reviews." Only English-language studies were included. This search resulted in 76 articles from PubMed, 95 from Embase and 4 from Cochrane reviews. After merging the results and removing duplicates, two authors (NV and AG) independently reviewed the titles and abstracts for eligibility. The full texts of the selected studies were then examined to verify they met the inclusion criteria. References in these studies were also checked for any potentially relevant research that might have been overlooked. Any disagreements were resolved through discussion or consultation with the senior author (KBS). In total, 36 articles met the inclusion criteria and were included in the final analysis (Table 1).

Eligibility Criteria

Systematic reviews and meta-analyses on MLKI published in English were included. A "multiligament" injury is defined as the disruption of at least two of the four major knee ligaments. Studies not published in English, as well as literature or open reviews, were excluded.

Data Extraction and Collection

Data extraction was conducted using a checklist, to collect information on authors, article title, publication year, level of evidence, study design, number of cases, primary aim, complications, and limitations. The AMSTAR 2 criteria, consisting of 16 questions, were used to assess the methodological quality of the studies [9]. Each question had three responses: yes, partial yes, and no. Two authors (NV and AG) independently evaluated each study, and the kappa coefficient was employed to determine interobserver reliability. Disagreements were resolved through discussion between the reviewing authors or by consulting the same third author (KBS).

We understand that the inconsistencies in the application of AMSTAR 2 criteria and variations in how these criteria are interpreted and applied by different reviewers can introduce bias into the evaluation of systematic reviews. Hence, the authors reviewing and evaluating the studies according to the AMSTAR 2 criteria thoroughly familiarized themselves with the guidelines prior to the commencement of

Table 1 Systematic reviews and meta-analyses on multiligamentous knee injuries (MLKIs) published in English

Sl. no	First author	Journal/book	Year of publication	Country	Number of patients	No. of studies	Highest evidence	Lowest evidence	Meta-analysis	No. of ligaments
1	Christopher J. Barnes [54]	Journal of Trauma and Acute Care Surgery	2002	USA	284	7	NA	4	Yes	2
2	Bruce A. Levy [19]	Arthroscopy: The Journal of Arthroscopic and Related Surgery	2009	USA	464	12	3	4	No	2+
3	William R.Mook [12]	The Journal of Bone and Joint Surgery- American volume	2009	USA	396	24	4	4	No	3+
4	Rudy Kovachevich [46]	Knee Surgery, Sports Traumatology, Arthroscopy	2009	USA	86	8	4	4	No	2
5	Rocco Papalia [45]	British Medical Bulletin	2010	UK	1705	23	1	4	No	2
6	Grant JA [41]	Arthroscopy	2012	USA	455	17	1	4	No	2
7	Karl-Heinz Frosch [32]	Knee Surgery, Sports Traumatology, Arthroscopy	2013	Germany	195	9	4	4	Yes	2
8	Tommaso Bonanzinga [50]	The American journal of sports medicine	2014	Italy	95	6	2	4	No	2
9	G. Rochecongar [49]	Orthopaedics and Traumatology: Surgery and Research	2014	France	390	13	2	4	No	2
10	Wu Jiang [24]	Knee Surgery, Sports Traumatology, Arthroscopy	2014	China	150	12	4	4	No	3+
11	Omar Medina BS [28]	Clinical Orthopaedics and Related Research	2014	USA	862	23	2	4	No	NA
12	Jarret M. Woodmas [58]	Knee Surgery, Sports Traumatology, Arthroscopy	2015	Canada	214	13	2	4	No	NA
13	Dean C.S [64]	Orthopaedic Journal of Sports Medicine	2016	USA	353	13	4	4	Yes	4
14	Sirisena D [48]	Knee surgery, sports traumatology, arthroscopy	2017	London UK	1078	4	4	4	No	2
15	Hohmann E [26]	Knee	2017	UAE	260	8	3	4	Yes	4+
16	Antonios N. Varelas [47]	Orthopaedic Journal of Sports Medicine	2017	USA	275	10	1	4	No	2+
17	Everhart J.S [65]	Arthroscopy—Journal of Arthroscopic and Related Surgery	2018	USA	524	21	3	4	No	4+
18	Ujash Sheth [21]	Journal of ISAKOS Joint Disorders & Orthopaedic Sports Medicine	2019	Canada	320	11	4	4	No	2+
19	Giovanni Vicenti [23]	Injury	2019	Italy	145	12	1	4	No	2
20	Kim SH [25]	Knee Surgery & Related Research	2021	France	3549	30	1	4	Yes	4+
21	Ryan S. Marder [11]	Orthopaedic Journal of Sports Medicine	2021	USA	2594	31	2	4	No	2
22	Fayed A.M. [35]	Knee surgery, sports traumatology, arthroscopy	2021	USA	384	19	2	4	No	4
23	Kim SH [10]	Orthopaedic Journal of Sports Medicine	2021	France	3391	45	2	4	Yes	4+
24	Robert S Dean [16]	The American journal of sports medicine	2021	USA	641	15	NA	4	Yes	2
25	Keeling L.E [52]	Sports Medicine and Arthroscopy Review	2021	USA	597	21	1	4	No	2+
26	Austin McCadden [37]	Journal of ISAKOS	2021	USA	145	7	3	4	No	
27	Shahbaz S. Malik [34]	Orthopaedics & Traumatology: Surgery & Research	2022	UK	114	60	2	4	No	2
28	Wybren A. van der Wal [36]	Arthroscopy: Journal of Arthroscopic and Related Surgery	2022	USA	432	43	4	4	No	2+
29	Rao R [38]	Journal of Orthopaedics	2022	London UK	3655	52	1	4	No	2
30	Fahlbusch H [60]	Archives of Orthopaedic and Trauma Surgery	2023	Germany	709	25	2	4	No	4+

Table 1 (continued)

Sl. no	First author	Journal/book	Year of publication	Country	Number of patients	No. of studies	Highest evidence	Lowest evidence	Meta-analysis	No. of ligaments
31	Margaret L. Wright [39]	Arthroscopy, Sports Medicine, and Rehabilitation	2023	USA	546	19	1	4	No	2
32	Emre Anil Özbek [57]	Knee Surgery, Sports Traumatology, Arthroscopy	2023	USA	4195	36	2	4	Yes	4
33	Shultz CL [40]	The American Journal of Sports Medicine	2023	USA	1543	18	1	4	Yes	2
34	David Constantinescu [53]	Journal of the American Academy of Orthopaedic Surgeons	2023	USA	37087	19	1	4	No	NA
35	Jelle P. van der List [44]	Arthroscopy: the Journal of Arthroscopic & Related Surgery	2024	USA	821	27	1	4	No	2
36	Fortunato Giustra [33]	European Journal of Orthopaedic Surgery & Traumatology	2024	Italy	49	4	3	4	No	3

NA not available

the evaluation. They also discussed their interpretations to reach a common understanding, ensuring uniformity in their assessments.

Statistical Analysis

The collected data were entered in the Microsoft Excel 2016 and analysed with IBM SPSS Statistics for Windows, Version 29.0. (Armonk, NY: IBM Corp). To describe about the data descriptive statistics, frequency analysis and cross tabulation were used. To find the significant agreement between the raters, the interrater reliability cohen's kappa was used. In the above statistical tool, the probability value 0.05 is considered as a significant level.

Results

Literature Search

The search revealed 76 articles from PubMed, 95 from Embase, and 4 from Cochrane reviews. Thus, we had a total of 88 papers after deduplication. Further after title and abstract screening, 42 full text articles were assessed, out of which 6 did not meet the criteria and were excluded. Finally, 36 systematic reviews, including 717 studies and 676,255 patients were considered for the present review. The outcomes of our electronic database search, including the number of studies excluded at each stage, are illustrated in the PRISMA flow diagram (Fig. 1).

Characteristics of the Studies

The baseline characteristics of all included studies are presented in Table 1. Out of the 36 reviews, 11 studies were on knee dislocations, 5 described the impact of early vs delayed surgery, 5 studied the management of combined ACL and MCL tears, and 4 were on complications following MLKI and others. Most of the systematic reviews were from the USA ($n=20$), with the other contributions from the UK ($n=4$), Italy ($n=3$), Canada ($n=2$), Germany ($n=2$), France ($n=2$), China ($n=1$), and UAE ($n=1$) (Table 1). A meta-analysis was done only in nine of the included studies. The highest level of evidence of the included studies was level 1 and the lowest was level 4; no level 5 evidence was included in our analysis.

Quality of Evidence

The quality of the included systematic reviews was assessed with AMSTAR 2 criteria. The interobserver reliability was calculated by using the kappa coefficient and found to be 0.81, which depicted a strong agreement between the

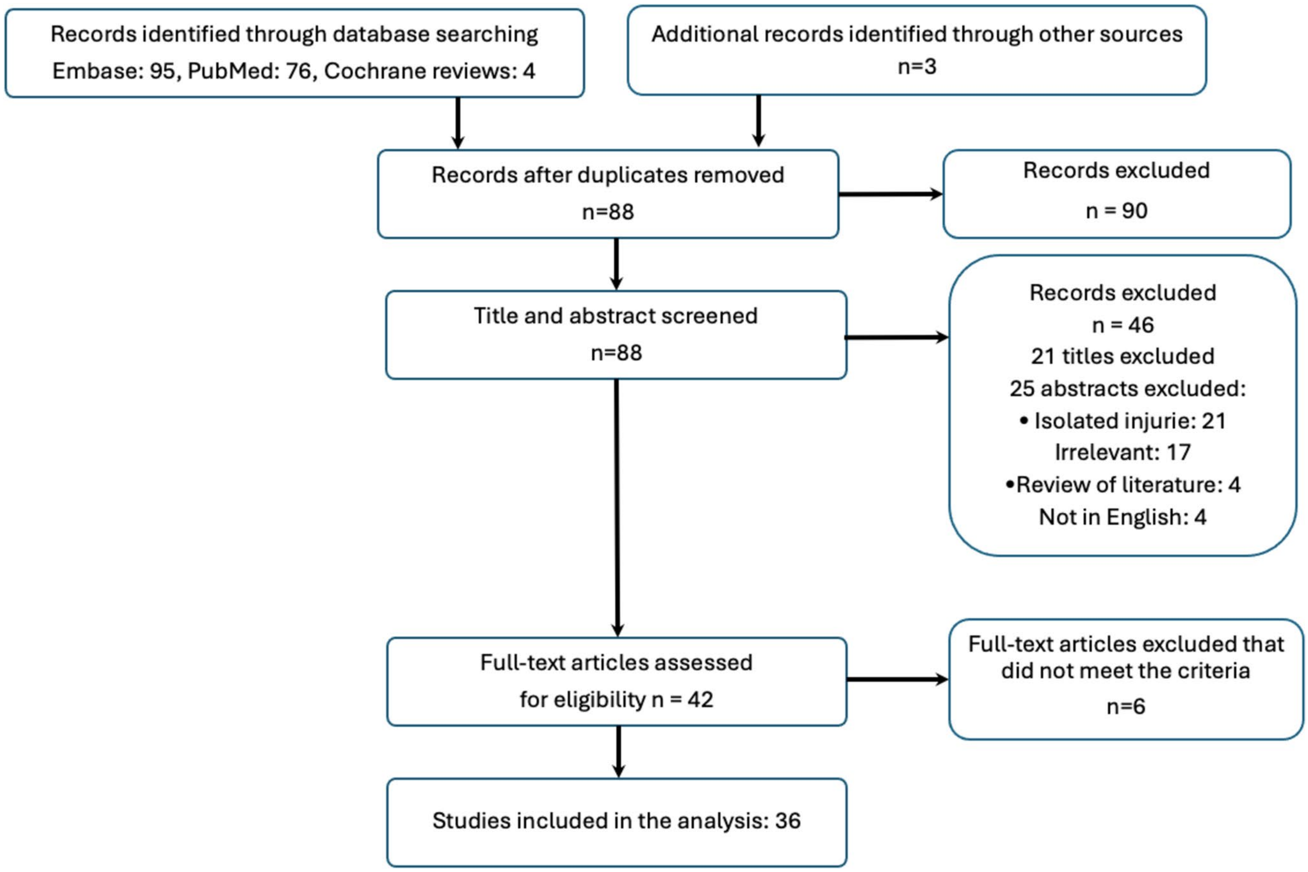

Fig. 1 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart illustrating the process of literature search, screening, and selection of eligible articles

reviewers. The majority were rated as having a critically low level of evidence ($n=25$), with the rest being categorized as low ($n=7$), moderate ($n=3$), and only one as high-level evidence (Table 2).

The low quality of systematic reviews significantly diminishes the overall strength of the evidence. Common methodological flaws, such as the lack of protocol registration, arbitrary study selection, unexplained heterogeneity, and inadequate risk of bias assessment, contributed to this lowered quality. Therefore, while these reviews provide valuable insights, their conclusions should be interpreted with caution.

Discussion

The most important finding in this study is that there are few SRs related to the MLKI. Many studies on this topic suffer from low-quality evidence due to heterogeneity. Heterogeneity in systematic reviews arises from variability in study designs, populations, interventions, reporting, and outcomes measured across the included studies. In the case of MLKIs, this variability is further complicated by the diverse injury patterns and treatment approaches as discussed in Table 3

Synthesis of Findings from SRs

The incidence of MLKIs is reported to be 0.2% of all orthopaedic injuries and 11–20% of knee ligament sprains. Kim et al. [10] reviewed 45 studies, with 3,391 patients finding high rates of associated injuries: 30.4% for medial meniscal tears, 27.5% for lateral meniscal tears, and 27.5% for cartilage injuries. The rates of peroneal nerve injury, vascular injury, and arthrofibrosis ranged from 11 to 19%. These results highlight the importance of careful assessment and management of MLKIs in clinical practice.

Knee dislocations, which are even rarer injuries, occur in 0.02% of all orthopaedic injuries and are often associated with MLKIs. They are reported separately in the literature due to their common association with vascular and neurologic injuries [11]. The rate of amputation in knee dislocations is 12%, while rates of nerve and vascular injury are 18% and 25%, respectively [11]. Using the Schenk classification, KDIIIM is the most common knee dislocation,

Table 2 AMSTAR 2 criteria for methodological quality of all the studies depicted in this table (Y—yes, N—no, PY—partial Yes, NMA—no meta-analysis conducted)

Sl. no	First author	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Quality of evidence
1	Christopher J. Barnes [54]	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N	NMA	N	CRITICALLY LOW
2	Bruce A. Levy [19]	Y	Y	N	PY	Y	N	N	Y	N	N	NMA	NMA	N	N	NMA	Y	CRITICALLY LOW
3	William R.Mook [12]	Y	N	N	PY	N	Y	Y	N	N	N	NMA	NMA	N	N	NMA	Y	CRITICALLY LOW
4	Rudy Kovachevich [46]	Y	N	N	PY	Y	N	N	PY	N	N	NMA	NMA	N	N	N	N	CRITICALLY LOW
5	Rocco Papalia [45]	Y	N	N	N	Y	Y	N	PY	N	N	NMA	NMA	N	Y	N	N	CRITICALLY LOW
6	Grant JA [41]	Y	N	N	Y	Y	Y	PY	Y	N	N	NMA	NMA	N	N	NMA	N	CRITICALLY LOW
7	Karl-Heinz Frosch [32]	Y	N	N	PY	N	N	Y	Y	N	N	N	N	N	N	NMA	Y	CRITICALLY LOW
8	Tommaso Bonanzinga [50]	Y	N	N	PY	Y	Y	Y	PY	N	N	NMA	NMA	N	N	NMA	Y	CRITICALLY LOW
9	G. Rochecongar [49]	Y	N	N	PY	Y	N	N	PY	N	N	NMA	NMA	N	N	NMA	Y	CRITICALLY LOW
10	Wu Jiang [24]	Y	N	N	PY	N	N	Y	Y	N	N	NMA	NMA	N	N	NMA	Y	CRITICALLY LOW
11	Omar Medina BS [28]	N	N	N	N	Y	Y	N	N	N	N	NMA	NMA	N	Y	NMA	Y	CRITICALLY LOW
12	Jarret M. Woodmas [58]	Y	Y	N	PY	Y	Y	PY	Y	N	N	NMA	NMA	N	N	NMA	Y	CRITICALLY LOW
13	Dean C.S [64]	Y	N	N	PY	Y	Y	Y	Y	N	N	N	N	N	Y	N	Y	CRITICALLY LOW
14	Sirisena D [48]	Y	PY	N	PY	Y	Y	Y	PY	PY	N	NMA	NMA	Y	Y	NMA	Y	MODERATE
15	Hohmann E [26]	Y	PY	N	Y	Y	Y	Y	Y	PY	N	Y	Y	Y	Y	Y	N	MODERATE
16	Antonios N. Varelas [47]	Y	PY	N	PY	N	N	Y	Y	N	N	NMA	NMA	N	N	N	Y	CRITICALLY LOW
17	Everhart J.S [65]	N	PY	N	PY	Y	Y	PY	Y	Y	N	NMA	NMA	N	N	NMA	Y	LOW
18	Ujash Sheth [21]	Y	N	N	PY	Y	Y	Y	Y	PY	N	NMA	NMA	N	N	NMA	Y	LOW
19	Giovanni Vicenti [23]	Y	N	N	N	N	N	N	PY	N	N	NMA	NMA	N	N	N	N	CRITICALLY LOW
20	Kim SH [25]	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	HIGH
21	Ryan S. Marder [11]	Y	N	N	PY	N	N	Y	PY	N	N	NMA	NMA	N	N	NMA	Y	CRITICALLY LOW
22	Fayed A.M. [35]	Y	N	N	PY	Y	N	Y	Y	N	N	NMA	NMA	Y	Y	NMA	Y	LOW
23	Kim SH [10]	Y	Y	N	PY	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N	Y	LOW
24	Robert S Dean [16]	Y	Y	N	PY	Y	N	Y	PY	N	N	N	N	N	N	N	Y	CRITICALLY LOW
25	Keeling L.E [52]	Y	N	N	PY	Y	Y	PY	Y	N	N	NMA	NMA	N	N	NMA	Y	CRITICALLY LOW
26	Austin McCadden [37]	Y	N	N	PY	N	N	Y	PY	N	N	NMA	NMA	N	N	N	Y	CRITICALLY LOW
27	Shahbaz S. Malik [34]	N	Y	N	PY	Y	Y	Y	N	Y	N	NMA	NMA	N	N	NMA	Y	LOW
28	Wybren A. van der Wal [36]	Y	N	N	PY	Y	Y	Y	PY	N	N	NMA	NMA	N	N	N	Y	CRITICALLY LOW
29	Rao R [38]	Y	PY	N	Y	Y	Y	PY	Y	N	N	NMA	NMA	N	Y	NMA	Y	CRITICALLY LOW
30	Fahlbusch H [60]	Y	PY	N	PY	Y	Y	Y	Y	PY	N	NMA	NMA	Y	Y	NMA	Y	MODERATE
31	Margaret L. Wright [39]	Y	N	N	PY	Y	Y	PY	PY	N	N	NMA	NMA	N	Y	NMA	Y	CRITICALLY LOW
32	Emre Anil Özbek [57]	Y	Y	N	PY	Y	N	PY	PY	N	N	N	N	N	Y	N	Y	CRITICALLY LOW
33	Shultz CL [40]	Y	N	N	PY	Y	Y	Y	Y	N	N	N	N	N	N	N	Y	CRITICALLY LOW
34	David Constantinescu [53]	N	N	N	N	N	Y	PY	Y	N	N	NMA	NMA	N	N	NMA	Y	CRITICALLY LOW
35	Jelle P. van der List [44]	Y	N	N	Y	Y	Y	Y	Y	Y	N	NMA	NMA	Y	Y	NMA	Y	LOW
36	Fortunato Giustra [33]	N	N	N	PY	N	Y	Y	Y	PY	N	NMA	NMA	Y	N	NMA	Y	LOW

Table 3 Heterogeneity and biases identified and its effect on the results

Heterogeneity and bias identified	Impact on the results and conclusions
• Some reviews have included injuries involving different combinations of ligaments, while others have focused on specific ligament combinations • Variability in surgical techniques and rehabilitation approaches including surgical techniques (repair vs. reconstruction), timing of surgery (acute vs. delayed), and rehabilitation protocols	• The failure to address heterogeneity adequately and the absence of a protocol to guide the review process can lead to an underestimation of the variability among studies. This results in conclusions that might not be applicable across different patient populations, injury types, or treatment modalities
• Lack of standardization in outcome measures across studies	• It is difficult to aggregate results and draw uniform conclusions
• A significant number of reviews did not assess publication bias. This is crucial because studies yielding positive results are more likely to be published than those with negative outcomes, potentially skewing the evidence in favour of interventions that might not be as effective as the published data suggests	• Not assessing the risk of bias in individual studies and not considering publication bias can result in an overestimation of treatment effects. Conclusions drawn from such biased data may recommend practices that are not truly effective
• The systematic reviews included studies of varying designs (randomized controlled trials, observational studies) and quality. Most studies have critically low to low levels of evidence, indicating prevalent methodological flaws	• The critical flaws identified by AMSTAR 2 in the systematic reviews suggest that the overall strength of the evidence is weak. This compromises the ability to make strong recommendations for clinical practice, particularly in areas where evidence is deemed critically low

followed by KD IIIL. Avulsion fractures are common in paediatric cases and knee dislocations [12]. Capogna et al. proposed the need to modify Schenck's classification [13] for knee dislocations(KD) and include another sub-component, consisting of an MLKI in conjunction with an extensor tendon injury [14]. He emphasized the need for a reproducible classification system with acceptable interobserver reliability to aid in treatment strategy formulation [14, 15].

Energy of Injury

Dean et al. [16] conducted a meta-analysis of 15 studies with 641 patients with MLKIs, categorized by energy of injury (275 high energy and 366 low energy). They found no significant differences in subjective clinical outcomes or failure rates between the groups after a minimum follow-up of 2 years. However, they excluded cases of vascular and nerve injuries, more common in the high-energy group, which could lead to worse outcomes. High-energy injuries were mainly from motor vehicle accidents, while low-energy injuries were sports related [16]. Additionally, low-energy MLKIs can occur in obese individuals after domestic/trivial falls, and these patients also report vascular injuries.

Timing of Surgery

Barfield et al. [17] and Marder et al. [11] found no difference in outcomes between acute and delayed surgery for MLKIs due to knee dislocations, while other studies reported better outcomes after acute reconstructions [12, 18–22]. They suggest that other studies may have included patients under 18 years of age, whom Marder et al. excluded, and considered the severity of injury.

Most studies agree on defining acute surgery as occurring within 3 weeks and chronic surgery as occurring after 3 weeks. This is considered the optimal duration, as tissue dissection and differentiation become challenging beyond this period. Patients treated acutely exhibited more flexion deficits compared to those managed chronically.

Vicenti et al. [23] reported that surgeries within 3 weeks showed better functional outcomes than nonoperative approaches, with higher Lysholm scores and improved stability and motion, underscoring the benefits of timely surgical intervention. However, their study had methodological limitations due to poor-quality literature. Mook found that staged treatment had the highest proportion of excellent and good outcomes (79%), with acute and staged treatments requiring additional procedures for stiffness compared to chronic treatment [12]. However, chronic or delayed reconstructions produced similar results to acute surgeries, but with significantly fewer excellent/good outcomes [12]. Reconstruction of the medial collateral ligament (MCL) may be preferable in severely unstable knees compared to injuries involving two ligaments [12].

Staging should be a prominent consideration in the presence of collateral or neurovascular injuries along with cruciate injuries [12]. Schenk proposed a classification system for MLKI in 2003 [13], and standardization of reporting these injuries began after the classification was universally accepted a few years later. Systematic reviews conducted in the first decade of the twenty-first century would not have considered studies classified according to Schenk. Due to this lack of standardization, consensus among experts regarding the management of these injuries was lacking. Dean et al. [16] report that early surgery leads to favourable outcomes and early ROM after surgery can prevent arthrofibrosis (AF).

Any avulsion fractures are recommended to be treated acutely, as delayed treatment causes contracture of the structures. Fixation of avulsion injuries is also a risk factor for postoperative knee stiffness [12].

Jiang et al. [24] found excellent to good results in 79.1% of KDIIIM and KDIIIL cases managed by staged treatment, compared to 58.4% treated acutely and 45.5% treated chronically. Even with acute treatment, a 1–2 week delay is recommended for severe injuries to allow for arthroscopic management, as the risk of compartment syndrome due to fluid extravasation is high. This waiting period also reduces inflammation and soft tissue swelling before surgery [24].

Acute surgery in MLKIs is beneficial compared to chronic, but not recommended for knee dislocations due to the aforementioned reasons and increased chances of arthrofibrosis [24]. Factors influencing the timing of surgery include neurovascular status, polytrauma, presence of other injuries, open versus closed injury, and skin condition [24].

Kim et al. [25] conducted a meta-analysis comparing MLKI with ACL injuries and found that delayed surgery increases the risk of meniscus tears, cartilage injury, and worse outcomes. They recommended early surgery for ACL injuries and noted worse outcomes and unclear risks to the meniscus and cartilage in delayed MLKI cases. They defined early surgery as up to 5 months and delayed surgery from 10 weeks to 24 months after injury. Other authors defined early surgery as less than 3 weeks [26]. Sheth et al. found early surgery with early mobilization improved the outcomes in MLKI [21].

Hohmann et al. [26] cite the studies of Levy et al. [19] and McKee et al. [27] to support early surgery (< 3 weeks), concluding that early surgery leads to significantly superior outcomes. Levy et al. [19] found better outcomes with early surgery in MLKI compared to nonoperative or delayed surgery, with higher return to work and sports rates 72% vs 52% and 29% vs 10%, respectively. Addressing all three damaged structures in KD3 injuries at once provided favourable outcomes, minimizing morbidity of two procedures and shortening rehabilitation. Surgical management within the first 6 weeks provided better outcomes in these complex MLKIs [10].

Definitive indications for immediate surgery include open and irreducible dislocations and popliteal artery injury. Poor results have been reported after conservative treatment of knee dislocations.

Repair vs. Reconstruction

Levy et al. [19] found that repair of posterolateral corner (PLC) injuries has higher failure rates compared to reconstruction. Similarly, repair of cruciates resulted in worse outcomes than their reconstruction [19]. Vincenti et al. showed that reconstruction of damaged ligamentous structures yields better long-term results than repair, especially for the posterolateral corner, where repair had significantly higher failure rates [23].

Knee Dislocations (KD)

Medina et al. [28] found that 18% of knee dislocations involve vascular injuries and 25% involve nerve injuries, with significant amputation rates. There is no consensus on the best diagnostic method for vascular injuries, although selective angiography is commonly used but not universally accepted. Vascular injury in KD ranges from 3.3 to 18%, with 83.6% involving the popliteal artery and 7.5% the tibial artery. External fixation is useful initially, especially in cases of open knee dislocations, vascular injuries, polytrauma, and in morbidly obese patients, later converting to ligament reconstruction.

Peskun and Whelan [29] and Dedmond and Almekinders [30] reported similar IKDC and Lysholm scores, but found higher rates of return to work and sports in recent studies, indicating improved management and rehabilitation. Operative management shows better outcomes than nonoperative management for KDs, with higher return rates to employment and sports [29].

Smith et al. [31] reported better outcomes with surgery within 6 weeks of injury rather than surgery after 6 weeks. Factors such as transient versus frank KD, isolated versus polytrauma, sex, age, and BMI also influenced outcomes (Table 4). Frosch et al.'s meta-analysis [32] compared primary ligament sutures to ligament reconstruction, finding similar outcomes between the groups. They suggested that suture repair is a viable alternative to reconstruction, particularly for Schenck type III and IV dislocations.

Table 4 Factors related to outcomes in knee dislocation (KD)—Smith et al. [28]

Better outcomes	Worse outcomes
Surgery < 6 weeks after injury	Surgery > 6 weeks after injury
Transient KD	Frank KD
Isolated KD	Polytrauma
Male sex	Female sex
< 30 years age	> 30 years age
BMI < 35	BMI > 35
	Associated articular cartilage injuries
	Combined medial and lateral meniscal injuries
	Nerve injury in the short term

Irreducible Knee Dislocations (IKDs)

IKDs present with a pathognomonic dimple sign. Once diagnosed, closed reduction attempts are not recommended due to the risk of medial necrosis [33]. The most common mechanism leading to IKD was falls [34], with KDIIIM being the most common type, followed by KDIIIL. MCL is the most commonly injured ligament, especially at the femoral attachment or the mid-substance [33].

Surgical management is necessary in all cases as closed manoeuvres cannot extricate medial structures interposed in an IKD. Management of IKDs includes open, arthroscopic, and combined approaches [33]. An initial arthroscopic attempt followed by open surgery if needed is recommended [33, 34]. ROM after surgery often exceeds 100 degrees [33]. Malik et al. [34] reviewed 60 studies with 114 IKD cases, finding a 14.4% complication rate, with 9% involving neurovascular injuries. Medial skin necrosis is a significant complication post-reduction, along with arthrofibrosis, graft failure, hardware irritation, and infection [34]. The rate of neurovascular injury is lower for IKD than for knee dislocations [33].

ACL + PCL Injury

Fayed et al. [35] investigated outcomes based on fixation sequence and knee flexion angle during fixation and found insufficient evidence to make specific recommendations due to variability in the studies. Common practice involves fixing the posterior cruciate ligament (PCL) before the anterior cruciate ligament (ACL), with PCL fixation at 70–90 degrees of flexion and near extension for the ACL. Single-stage reconstruction of both ligaments is more convenient and cost-effective than a two-stage procedure. Issues included various combinations for graft fixation, variability in testing platforms, and inconsistent documentation. None of the studies could restore joint laxity to normal levels. Further complicating the evaluation is the prevalence of non-anatomic reconstructions of the ACL during the times these studies were conducted.

Surgeons treating ACL injuries must identify and address associated injuries like posterolateral corner (PLC) and posteromedial corner (PMC) injuries, as they can stress the reconstructed ACL and lead to failure if untreated [36]. For PCL reconstruction in the context of MLKI, quadriceps tendon bone (QT-B) is a good choice, though BPTB, hamstring autografts, or allografts are commonly used [37].

Cruciate + Collateral

Anterior cruciate ligament (ACL) injuries are the most common, with the combination of ACL and medial collateral ligament (MCL) injuries being the most frequent. This is followed by ACL and lateral collateral ligament (LCL) injuries [38].

ACL + MCL Injury

Among MLKIs, the combination of ACL and MCL injuries has the most systematic reviews. Reconstruction is the gold standard for ACL injuries [39], but MCL injuries can be managed conservatively, with repair, or reconstruction. Management of combined ACL and MCL injuries varies based on the MCL injury grade and surgery timing or staging. Treatment may also differ based on whether the MCL injury is proximal, mid-substance, or distal, as well as the involvement of the posteromedial corner.

For Grade 1 MCL injuries, conservative management is recommended. Shultz et al. [40] reviewed 16 studies with 1,534 cases and found no differences in patient-reported outcomes, quadriceps strength, or range of motion between conservatively treated, repaired, or reconstructed MCL injuries combined with ACL injuries. Delaying ACL management allows time for the MCL to heal, which can then be evaluated and managed during ACL reconstruction (ACLR). Early repair is recommended for Stener-type injuries and avulsion fractures, while a 6-week waiting period is advised for other injuries [40, 41].

Shultz et al. [40] provide a comprehensive treatment algorithm for these injuries. Young athletes with Grade 2 and 3 injuries might require repair if associated with avulsion fractures, and reconstruction if torn at mid-substance. For persistent medial instability at 6 weeks in Grade 2 and 3 injuries, reconstruction is recommended. In Grade 2 injuries, reconstruction is advised if the Slocum test is positive; otherwise, the ACL is fixed and the MCL treated conservatively [40].

Arthrofibrosis is a significant complication with both conservative and operative management of combined ACL and MCL injuries. However, reoperation rates for these two management groups were not statistically significant in another study [42]. Patellofemoral pain is also a notable complication [38, 43]. MCL repair has a slower recovery rate and a lower likelihood of return to play compared to nonoperative management. The rates of stiffness were reported to be 16–25% in studies from 30 years ago, but only 0–10% in the last 10 years [36, 44].

Van Der List et al. [36] recommend early ACL surgery in the setting of combined ACL and MCL injuries to reduce valgus laxity. They found higher residual valgus laxity when the ACL was treated conservatively initially. However, they did not define the terms "early" or "delayed" in their study. The laxity is thought to result from the failure to maintain an isometric point during MCL healing. Once ACL stability is restored, MCL treated by repair or reconstruction performed equally well. For distal MCL injuries, they recommend MCL repair and ACL reconstruction. They noted selection and publication bias in the reviewed articles.

Wright et al. [39] investigated Grade 3 MCL injuries combined with ACL injuries. They identified seven combinations of management and concluded that those undergoing MCL reconstruction have high rates of return to sport (85–90%) and a low risk of recurrent valgus instability. Tissue quality is crucial for predicting repair success. These patients often had less flexion than those with isolated ACLR. Recent techniques like augmentation with fibre wire or fibre tape were not included in the SRs due to limited experience with these methods. Randomized controlled trials (RCTs) were few (0–25% of studies) and showed significant variability in techniques and quality [38, 39].

MCL in MLKI

MRI and stress X-rays are recommended for confirming the diagnosis [45]. Until 2009, no significant differences were noted in outcomes between repair and reconstruction, with limited evidence available [46]. Many reports advocated initial conservative management for MCL injuries, with surgery recommended for failed conservative treatment [47]. The decision to repair or reconstruct depends on the quality of the residual ligament and the duration since injury [47]. Outcomes for the MCL + ACL combination were significantly better than for the MCL + PCL combination.

Allografts (Achilles and semitendinosus) have shown good results in MLKI, though most surgeons prefer semitendinosus autografts [47]. Fixation methods vary, but recommendations include using an interference screw with or without an endo-button for proximal femoral fixation and a staple or screw washer in osteopenic bone for distal fixation [47]. MCL reconstruction improves valgus laxity, ROM, and outcome scores (IKDC and Lysholm) without significant differences when performed with concomitant reconstructions [47]. Of those who had surgery, 61% returned to sports compared to only 31% who had conservative management [45].

Key findings and recommendations for MCL injuries include:

- Grade 2 and 3 MCL injuries are equal in incidence [41].
- MCL avulsion fractures may be fixed early. The clinical and functional effects of valgus laxity are not well understood and cannot be directly evaluated by PROMs [41].
- ACLR improves outcomes related to MCL, whether treated conservatively, repaired, or reconstructed [41].
- ACL tunnels were made, but fixed on the tibial side only after addressing the MCL [41].
- Sirisena [48] reviewed methods to test the MCL clinically and found no easily applicable method.

PLC + Cruciates

Rochecongar [49] reviewed 13 studies on PLC + (ACL or PCL injuries), finding a 10% complication rate. PLC injuries occur in 43–80% of patients. There were a greater number of patients in the PLC + PCL group (nine studies, 300 patients) than in the PLC + ACL group (four studies, 90 patients). ACL injuries had shorter times to surgery due to easier diagnosis. Failure to address PLC leads to cruciate reconstruction failure. Autografts were common in the ACL group, and allografts in the PCL group. Rehabilitation programmes varied between studies, but it is recommended to defer weight-bearing for 6 weeks in patients with PCL injury. The final Lysholm scores were similar after reconstruction, but more variable in the PCL + PLC group. Long-term outcomes were lacking, with poorer outcomes more common in the PCL group. Conservatively managed patients had the poorest results, and residual posterior laxity ranged from 2 to 6 mm after PCLR.

Bonanzinga et al. [50] reviewed six studies involving 95 patients, highlighting variability in treatment and outcomes. They concluded that combined ACL and PLC reconstruction is the most effective treatment, but emphasized the need for more research on long-term outcomes.

Rehabilitation

Early mobility after acute surgery resulted in fewer ROM deficits without causing joint instability [12]. Acute and staged surgeries benefit from early and aggressive rehabilitation protocols, increasing return-to-work rates. However, surgery within 3 weeks is associated with higher ROM complications and procedures for stiffness and anterior instability. Newer rehabilitation techniques could improve outcomes and reduce stiffness in combined ACL and MCL injuries [49].

No standardized rehabilitation protocol exists in the literature. Rehabilitation principles include restoring ROM, protecting reconstructed ligaments, and gradually progressive strengthening exercises. The commonly cited protocol is by Fanelli and Edson [19, 51]. Open kinetic chain exercises are recommended between 30 and 60 degrees of flexion, and hamstring activation is delayed for 6 weeks following PCL reconstruction. Consensus on returning to sport post-MLKI surgery ranges from 8 to 12 months, with decisions on weight-bearing, running, and returning to work and sport often based on surgeon preference rather than robust data [52].

Complications

Vascular Injury

Vascular injury in knee dislocations is a significant complication, with a frequency of 10.7% and an amputation rate of

2.2% [53]. Identifying vascular injury using pulse palpation is inaccurate [49]. Angiography is recommended for patients with equivocal findings or absent pulses; those with palpable pulses should be closely monitored [54]. An abnormal pedal pulse has a sensitivity of 0.79, specificity of 0.91, positive predictive value of 0.75, and negative predictive value of 0.93. Liberal use of angiography is advised [54].

An ankle-brachial index (ABI) of 0.9 or less indicates the need for a CT angiogram, which is more sensitive and specific than conventional angiography [53, 55]. The types of dislocations predisposing to vascular injury include KDIV and posterior KD [53]. Ischaemia time should be considered a relative measure rather than an absolute predictor of amputation [56]. An ischaemia time under 6 h salvages the limb in 90% of cases, whereas over 12 h saves less than 50% [56]. The amputation rate is 86% if repair occurs more than 8 h after injury [54]. The risk of amputation increases with the severity of soft tissue and neurological injuries rather than ischaemia time [56]. The amputation rate is 51.8% in limbs with an ischaemia time of more than 6 h, and 81.4% and 85.2% in limbs with extensive soft tissue injury and open injuries, respectively, indicating that soft tissue problems significantly increase the chances of amputation [56].

In the presence of vascular injury, if an external fixator improves stability, it should be considered before vascular repair, as the application of a fixator is rapid and provides a stable skeleton for the repair. Procedures for vascular injuries include surgical bypass, embolectomy, vascular repair, and interposition grafting [53].

Neurologic Injury

The prevalence of nerve injury in knee dislocations (KD) ranges from 15 to 19% [53, 57]. Common peroneal nerve (CPN) palsy occurs in 5–40% of cases after KD. Woodmass et al. [58] found that functional recovery after complete CPN palsy was 38.4%, compared to 87.3% for incomplete palsy. Post-intervention recovery rates range widely from 0 to 30%. Management options include conservative measures, neurolysis, direct nerve repair, nerve grafting (NG), tibialis posterior tendon transfer (TPTT), and combined TPTT with NG.

Nerve grafts longer than 6 cm have generally yielded unsatisfactory results in KD, where injuries can extend up to 15 cm [58]. Younger age is a positive prognostic factor for nerve recovery. Routine neurolysis does not improve outcomes after CPN palsy [26, 53]. Kim et al. [25] use nerve conduction studies (NCS) and electromyography (EMG) to guide decisions, reporting a 75% recovery rate for CPN grafts under 6 cm, but only 38% for grafts of 6–12 cm. Given that the extent of injury in KD involves a long segment, the expected recovery is only 38% or lower. Some authors suggest that combined TPTT and NG offer superior outcomes [58, 59]. Tibialis posterior tendon transfer is recommended for persistent motor deficits after 1 year of no recovery following CPN palsy.

Stiffness/Arthrofibrosis (AF)

The overall complication rate in the literature varies widely, ranging from 6 to 75%. Arthrofibrosis (AF) is the most prevalent complication, with an absolute risk of 12% across studies [60]. In MLKI, AF occurs in 9.8% (range 4.5–28.9%) [57]. Risk factors for stiffness include surgery within 3 weeks of injury, involvement of three or more ligaments, and high-grade injuries like Schenck III and IV [55]. Factors such as age, gender, BMI, energy of injury, and neurovascular damage do not significantly correlate with increased stiffness.

External fixation and staged surgical approaches have been suggested as potential risks for stiffness; however, these could not be conclusively tested in the systematic review by Ozbek due to data heterogeneity. External fixations are employed in 8–15% of cases, typically for a period of 23–30 days in MLKI [57].

Fahlbusch et al. [55] investigated the incidence of stiffness, identifying high-grade injuries such as Schenck III and IV, acute treatment, and range of motion (ROM) limiting rehabilitation programmes as risk factors. They noted that the average time from the index operation to manipulation under anaesthesia (MUA) was 14.3 weeks, and to arthroscopic adhesiolysis was 27.7 weeks. Additionally, large incisions and scarring crossing the joint were identified as contributing factors. Other frequently reported complications include infection and deep vein thrombosis (DVT) [60].

Fahlbusch defined AF by criteria including flexion < 90 degrees at 4 weeks postop, > 20 degrees flexion loss compared to the normal limb, and > 10 degrees extension deficiency with > 20 degrees flexion deficiency [61–63]. Furthermore, Shelbourne et al. defined as ROM loss occurring after 3 months postoperatively in the absence of mechanical blockage and no satisfactory improvement following aggressive physiotherapy. AF management often involved lysis of adhesions (LOA) (78.5%) more frequently than MUA (21.5%). The timing of LOA was advised to be within 6 months, as the risk of fractures increases for MUA performed after 3 months postoperatively [60].

HTO and Ligament Instabilities

The literature on high tibial osteotomy (HTO) related to knee instability predominantly addresses single ligament injuries combined with malalignment. However, there is data on combined ligament injuries such as ACL and PLC or PCL and PLC with malalignment, where HTO may be considered. Both single-stage and staged procedures have been documented, with staged procedures preferred for the benefit of correcting malalignment with HTO in the first stage, followed by ligament reconstruction if instability persists [64].

Return to Sports/Work

Everhart et al. [65] studied outcomes regarding return to work and sport after MLKI. A return to high-level sport was observed in 23% of cases; return to any level of sport was 53.6%, with a higher percentage of surgically treated patients returning than those treated non-surgically. Return to work with little or no modification was reported in 62%, while return to any kind of work was reported in 88.4% of patients. Obese patients exhibited lower outcome scores, and those with higher Schenck grades or vascular injuries showed lower rates of return to work [65].

Limitations Reported by the SRs

All systematic reviews this study examined reported low evidence of included studies. The following limitations were reported by the SRs.

- Validity of most studies is limited by heterogeneity in definitions (especially for stiffness and Grade 3 MCL injuries), injury mechanisms, assessment protocols, diagnosis, surgery timings, management by different surgical techniques, and postoperative rehabilitation protocols.
- Predominantly retrospective study designs, small sample sizes hindering data analysis and patient qualification, and short follow-ups.
- Some studies did not report associated chondral or meniscal injuries [30].
- Inclusion of low-quality evidence studies; in fact, the number of RCTs seen in each study is very low, with some studies not having any RCTs.
- Inclusion/exclusion of vascular and neurologic injuries affects outcomes.
- IKDC and Lysholm scores have not been validated for MLKI, but utilized by many studies

Recommendations

Papalia [45] recommended six guidelines for future studies related to ACL and MCL injuries, which could also be applied to future studies on MLKI. These guidelines include conducting prospective studies or RCTs for stronger evidence, utilizing better diagnostic protocols with MRI and stress radiographs to quantify instability, clearly stating inclusion and exclusion criteria, standardizing rehabilitation protocols and monitoring compliance, and standardizing outcome assessments with a minimum follow-up of 24 months. There is a need to conduct multicentre randomized trials due to the rarity and heterogeneity of the condition. Key areas of study include validating and selecting the best outcome scores for reporting MLKIs, evaluating new surgical techniques and technologies such as internal bracing, and developing new bracing and rehabilitation techniques. More research is needed to evaluate variations among these injuries, tunnel convergence, and fixation techniques.

We identified several common mistakes in these studies that led to their lower scores and recommendations to improve the quality of evidence (Table 5).

Conclusions

MLKIs are an uncommon and heterogeneous group of injuries and standardizing reporting on these injuries is a challenge. The systematic reviews of MLKIs exhibit numerous critical and non-critical biases that raise concerns about the strength and credibility of their evidence base. The absence of pre-registered protocols and risk of bias assessments in included studies can overestimate treatment effects and underestimate study variability, misleading clinical decisions and policy recommendations. Additionally, inadequate assessments of publication bias and heterogeneity in study design, treatment modalities, and outcome measures hinder the interpretation of conclusions and limit the ability to make robust clinical recommendations. These findings highlight a need for improved methodological quality in systematic reviews of MLKIs. There is a need to conduct multicentre trials due to the rarity and heterogeneity of the condition. Future systematic reviews should strive for rigorous adherence to methodological standards, including comprehensive risk of bias assessment and protocol pre-registration.

Table 5 Critical flaws identified according to AMSTAR2 criteria and recommendations to improve the quality of evidence

Identified flaws	Recommendations
• Most studies did not mention whether a protocol was pre-registered. Lack of pre-registration can introduce post hoc decisions in inclusion criteria and outcome measures, leading to selective reporting and publication bias	• Protocol writing and registration: Writing and adhering to a detailed protocol is essential to reduce bias. Clearly defining the research questions and review methods before starting the review ensures a uniform analysis by all the authors. Any deviations from the protocol should be justified by the authors. Unexplained changes can result in a lower-quality rating
• Many reviews did not provide a clear rationale for their selections of study types, which should not be arbitrary in systematic reviews. This lack of clarity can result in inclusion bias, where only certain types of studies are selected based on their results or qualities	• Study selection strategy: Authors should specify their strategy for selecting study types. If only RCTs or non-randomized studies are included, a rationale should be provided to show how these studies comprehensively address the research topic. Including both RCTs and non-randomized studies may be necessary to fully answer the research question, which again has to be clarified by the authors
• Most reviews did not comprehensively assess the risk of bias within the included studies. Failure to evaluate and discuss the implications of this risk can lead to overestimations of treatment effects or incorrect conclusions, as the quality of the evidence remains unclear	• Risk of Bias Assessment: It is crucial to not only assess the risk of bias, but also to discuss its implications on the results. The importance of risk of bias assessment cannot be overstated in appraising any systematic review. The discussion should include how these biases might influence the study results and consider whether they may account for differences between individual study results, especially for recommendations that may impact clinical practice or policy
• The reviews frequently lacked a thorough examination and discussion of heterogeneity among the studies' results. This is critical because understanding the variability among studies helps in determining the generalizability and applicability of the review's conclusions	• Heterogeneity: Review authors should explore the possibilities of heterogeneity and discuss its impact on the results, conclusions, and any recommendations. This discussion should be comprehensive to ensure a clear understanding of how variability affects the overall findings
• In instances where meta-analyses were conducted, there was often no clear description of the methods used for data synthesis, particularly in handling heterogeneity. Inappropriate methods can lead to misleading pooled results	• Authors should first define research question and protocol for study selection and data extraction. Appropriate statistics to calculate effect sizes from each study, pooling of data (fixed effects or random effects), and heterogeneity should be applied. Finally, results have to be interpreted cautiously, considering potential biases and conducting sensitivity analyses as necessary

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Data availability The data is provided on request to the corresponding author.

Declarations

Conflicts of Interest The authors declare that they have no conflict of interest.

Ethical Approval This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed Consent For this type of study informed consent is not required.

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