Multiligament knee injury (MLKI): an expert consensus statement on nomenclature, diagnosis, treatment and rehabilitation

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Abstract

Multiligament knee injuries (MLKIs) represent a broad spectrum of pathology with potentially devastating consequences. Currently, disagreement in the terminology, diagnosis and treatment of these injuries limits clinical care and research. This study aimed to develop consensus on the nomenclature, diagnosis, treatment and rehabilitation strategies for patients with MLKI, while identifying important research priorities for further study. An international consensus process was conducted using validated Delphi methodology in line with *British Journal of Sports Medicine* guidelines. A multidisciplinary panel of 39 members from 14 countries, completed 3 rounds of online surveys exploring aspects of nomenclature, diagnosis, treatment, rehabilitation and future research priorities. Levels of agreement (LoA) with each statement were rated anonymously on a 5-point Likert scale, with experts encouraged to suggest modifications or additional statements. LoA for consensus in the final round were defined 'a priori' if >75% of respondents agreed and fewer than 10% disagreed, and dissenting viewpoints were recorded and discussed. After three Delphi rounds, 50 items (92.6%) reached consensus. Key statements that reached consensus within nomenclature included a clear definition for MLKI (LoA 97.4%) and the need for an updated MLKI classification system that classifies injury mechanism, extent of non-ligamentous structures injured and the presence or absence of dislocation. Within diagnosis, consensus was reached that there should be a low threshold for assessment with CT angiography for MLKI within a high-energy context and for certain injury patterns including bicruciate and PLC injuries (LoA 89.7%). The value of stress radiography or intraoperative fluoroscopy also reached consensus (LoA 89.7%). Within treatment, it was generally agreed that existing literature generally favours operative management of MLKI, particularly for young patients (LoA 100%), and that single-stage surgery should be performed whenever possible (LoA 92.3%). This consensus statement will facilitate clinical communication in MLKI, the care of these patients and future research within MLKI.

Key points

- Multiligament knee injuries (MLKI) encompass a wide spectrum of injuries with potentially devastating consequences.
- Despite this, there remains no current consensus on an accepted approach for terminology, classification, diagnosis and treatment of MLKI, which limits both clinical care and research.
- This study aimed to establish the first expert consensus on the nomenclature, diagnosis, treatment and rehabilitation strategies for the care of patients with MLKI, while also identifying important research priorities.
- An international, multidisciplinary consensus process was conducted, involving 39 experts in MLKI care from 14 countries, employing validated Delphi methodology.
- Specific attention was given to achieving a diverse, representative expert group using objective and reproducible methodology.
- In total, 50 items (92.6%) achieved consensus with >75% agreement and <10% disagreement and were included in the final consensus document.

- A consensus definition for MLKI has been developed and is recommended for all future studies on this subject.
- Importantly, experts agreed that most MLKIs are *not* caused by knee dislocations emphasising that there should not be assumed equivalence between the terms 'knee dislocation' and MLKI. 'Dislocation' should only be used within the context of MLKI when there is evidence for this injury.
- Although classification systems for MLKI have been updated and improved, consensus was reached that there is a need for a modern, comprehensive classification system.
- This comprehensive classification system should incorporate injury mechanism (high, low or ultra-low velocity), extent of non-ligamentous structures injured (including menisci, cartilage and neurovascular structures) and the presence or absence of knee dislocation.
- The purpose and categories of classification within this system should directly guide treatment decisions.
- Consensus has been reached on the preferred imaging adjuncts for investigation of suspected MLKI, which include MRI, CT angiography and stress radiographs where appropriate.
- A number of recommendations regarding surgical management strategies, timing of intervention and nature of intervention reached consensus, including early versus delayed intervention, reconstruction versus repair and staged intervention.
- The overarching recommendation was that decisions regarding surgical intervention should be made on an individual basis considering the pattern of injury (using an accepted classification system), associated injuries, patient factors and the best available evidence.
- The consensus group noted the heterogeneity and largely lower order evidence that currently informs diagnostic and treatment decisions regarding MLKI, with a wide variety of outcome measures employed in measurement, precluding meaningful comparisons and pooling of data.
- There is a clear need for a universally accepted core outcome set to allow for standardised data collection and outcome reporting for future studies of MLKI.
- The consensus group overwhelmingly agreed that there is a need for a multicentre registry of MLKI in order to permit high-quality, prospective data collection, and therefore high-quality research output that translates to meaningful improvements in the standard of clinical care provided to patients with MLKI.

Introduction

Multiligament knee injuries (MLKIs) have classically been 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) (including the medial collateral ligament (MCL)) and posterolateral corner (PLC) (which includes the lateral (fibular) collateral ligament).[1] These injuries can have life-changing consequences including chronic knee dysfunction,[2] neurovascular injury[3] and post-traumatic osteoarthritis.[4–6] If misdiagnosed or inappropriately treated, the prognosis is poor, with persistent pain, impaired function, continued instability and the need for multiple surgical procedures.[7] MLKIs represent a heterogeneous spectrum of pathology, which are less common than single ligament knee injuries. As such, it has been challenging to produce appropriately powered prospective studies to adequately answer research questions regarding diagnosis and management,[8] and no comprehensive consensus studies have been performed.

The objective of this study was to establish expert consensus on the diagnosis, treatment and rehabilitation of MLKI in adults, while informing future directions for research.

Methods

A modified Delphi consensus process was conducted, adhering to the *British Journal of Sports Medicine* (BJSM) consensus guidelines[9] and the ACcurate COnsensus Reporting Document (ACCORD) checklist for reporting of consensus methods,[10] guided by prior published frameworks.[11] The Delphi method is an iterative process that facilitates the generation of consensus among panel members on a given topic,[11] and has been widely used in sports medicine and orthopaedic research.[12–19] A series of anonymised surveys are performed, with the result of each round collated, analysed and presented back to the group. Participants from the expert panel are then invited to reassess their responses after considering the group's responses, and statements are modified or created in response to agreement and feedback from the panel. These steps of collating and presenting data with sequential iterations of re-optimised surveys continues until sufficient consensus is achieved.

Panel selection

A working group of six individuals (IRM, NSM, AGG, JC, GM, RFL) facilitated an iterative process to develop consensus among an objectively selected, multidisciplinary panel of experts (figure 1) in line with BJSM guidelines.[9, 20, 21] The 25 most published senior or first authors in the area of MLKI were identified as part of a recent scoping review.[22] As this group consisted exclusively of men, we sought to increase female representation by inviting the five most published females on the topic (minimum of two senior or first author publications, also identified through the scoping review). To further increase the diversity and multidisciplinary nature of the expert group, an international perspective was sought including representation from each of the 11 IOC Centres of Research Excellence. In total, 39 individuals (31 males, 8 females) were invited, all of whom completed the entire consensus process. Patients were not involved in the design of this study. A breakdown of the demographics and characteristics of included experts is provided in table 1.

Table 1 Participant characteristics of the expert panel

Characteristic	Categories	Experts
Sex	M:F	31:8
Age (years)	30–39	2
	40–49	9
	50–59	12
	60–69	13
	70	3
Areas of expertise	Clinical only	3
	Research only	2
	Clinical and research	34
Specific role of those with clinical expertise	Sports medicine physician	1
	Orthopaedic surgeon	28
	Physical therapist	7
	Sports scientist	2
	Other	1
Region of practice	North America	25
	Europe	9
	Middle East/Africa	2
	South America	1
	Southeast Asia	1
	Australasia	1
MLKI cases per year	0–9	8
	10–19	6
	20–29	9
	30 or more	16
Highest academic achievement	MD	23
	PhD	9
	MD/PhD	7

F, females; M, males; MLKI, multiligament knee injury.

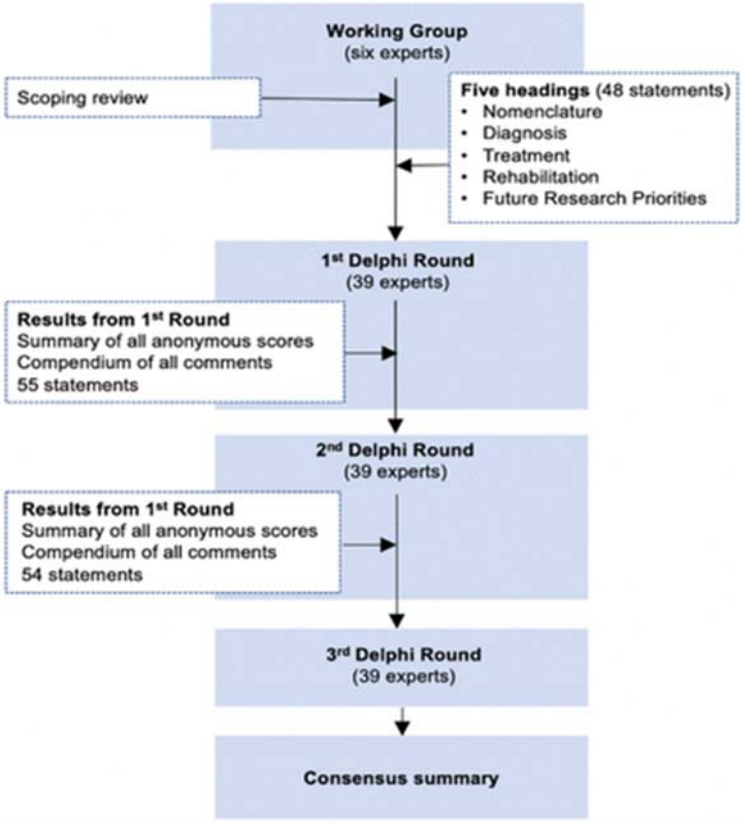

Figure 1. Flow diagram of consensus process.

Equality, diversity and inclusion statement

As mentioned above, we sought to increase both female and geographic representation of our expert panel while maintaining objective selection. We achieved this first, by inviting the five most published females on the topic (minimum of two senior or first author publications also identified through the scoping review). Second, to further increase the diversity and multidisciplinary nature of the expert group, an international perspective was sought including representation from each of the 11 IOC Centres of Research Excellence. In total, 39 individuals (31 males, 8 females) were invited across 6 continents, all of whom completed the entire consensus process. We endeavoured to employ a robust method to gain a diverse, inclusive and globally representative view while maintaining an objective level of expertise in our consensus, however we recognise that this process still resulted in the majority of the panel consisting of male orthopaedic surgeons from North America. We have recognised that this may have biased our results towards the perspective of this group, and this should be borne in mind in future consensus processes.

Evidence review and development of first round survey

A recent scoping review on MLKI diagnosis, treatment and rehabilitation[22] highlighted the pressing need for consensus in this area and the findings informed the content of the first round survey. Formal methods of evidence synthesis such as scoping reviews have similarly been used as a basis of prior Delphi studies[18, 23–25] in sports medicine and are considered best practice

methodology.[20, 21] Draft statements were formulated into categories: nomenclature, diagnosis, treatment, rehabilitation and future research priorities.

Consensus process

An online survey (Survey Monkey, San Mateo, California) was created allowing experts to rate agreement using a 5-point Likert scale (strongly agree, agree, neither agree nor disagree, disagree or strongly disagree). Given the diverse range of MLKI-related topics, participants were given the opportunity to opt out of a given question if it was felt out of their area of expertise. A free-text comments section was included to enable suggestions of modifications or additional items. The initial survey was pilot tested by members of the working group for face validity, understanding and acceptability, with subsequent modifications made prior to circulation to the wider panel.

In the second round, experts were asked to review the anonymised results from round 1 and score all items within the second survey. As with round 1, a free-text comments section was included to allow for suggestions of modifications or additional items. Questionnaires were re-analysed and the cycle repeated until consensus was reached (as defined below) for all items or for a maximum of three rounds.

Standard setting and statistical analysis

Levels of agreement (LoA) were expressed as a percentage of those responding to each individual question. The level of consensus was defined *a priori*. In the first and second round of the survey, statements were retained for the subsequent round if both ≥70% of respondents agreed (either agree or strongly agree) *and* <20% disagreed (either disagree or strongly disagree).[13, 18, 26, 27] Items not meeting these criteria were discarded or modified according to responders' suggestions. In the third round, responses were analysed with stricter cut-off criteria: items were only considered to have reached consensus if >75% of respondents agreed and fewer than 10% disagreed. Divergent opinions are presented in the 'Results and recommendations' section under 'Areas of disagreement'. Agreement among ≥75% of the participants has previously been noted to be the most frequently specified determination of a consensus for Delphi studies.[28]

Results and recommendations

Delphi process and overall consensus

Forty-eight initial statements were identified from the scoping review of existing literature for consideration by the expert group in the first-round survey. Thirty-nine participants completed all three rounds of surveys, representing a 100% response rate. The results of each survey round are summarised in table 2, with a summary of LoA for statements in each of the three rounds summarised in figures 2–4. Of the 54 items included in the final round survey, consensus was achieved for 50 items (92.6%) (table 2). LoA for items not reaching criteria for consensus in each round are reported in online supplemental table A1.

Table 2 Summary of results at completion of each survey round in the Delphi process to establish consensus in MKLI

Delphi round	No. of responses	Total no. of items included in survey	Items reaching threshold for retention in subsequent round*
1	39	48	52.1%*
2	39	55	69.1%*
3	39	54	92.6%†

*Items from rounds 1 and 2 were included for subsequent rounds if >70% of agreement agreed that an item should be included, with <20% disagreeing.
†Items were considered to have reached consensus if >75% of agreement experts agreed that an item should be included, with <10% disagreeing.

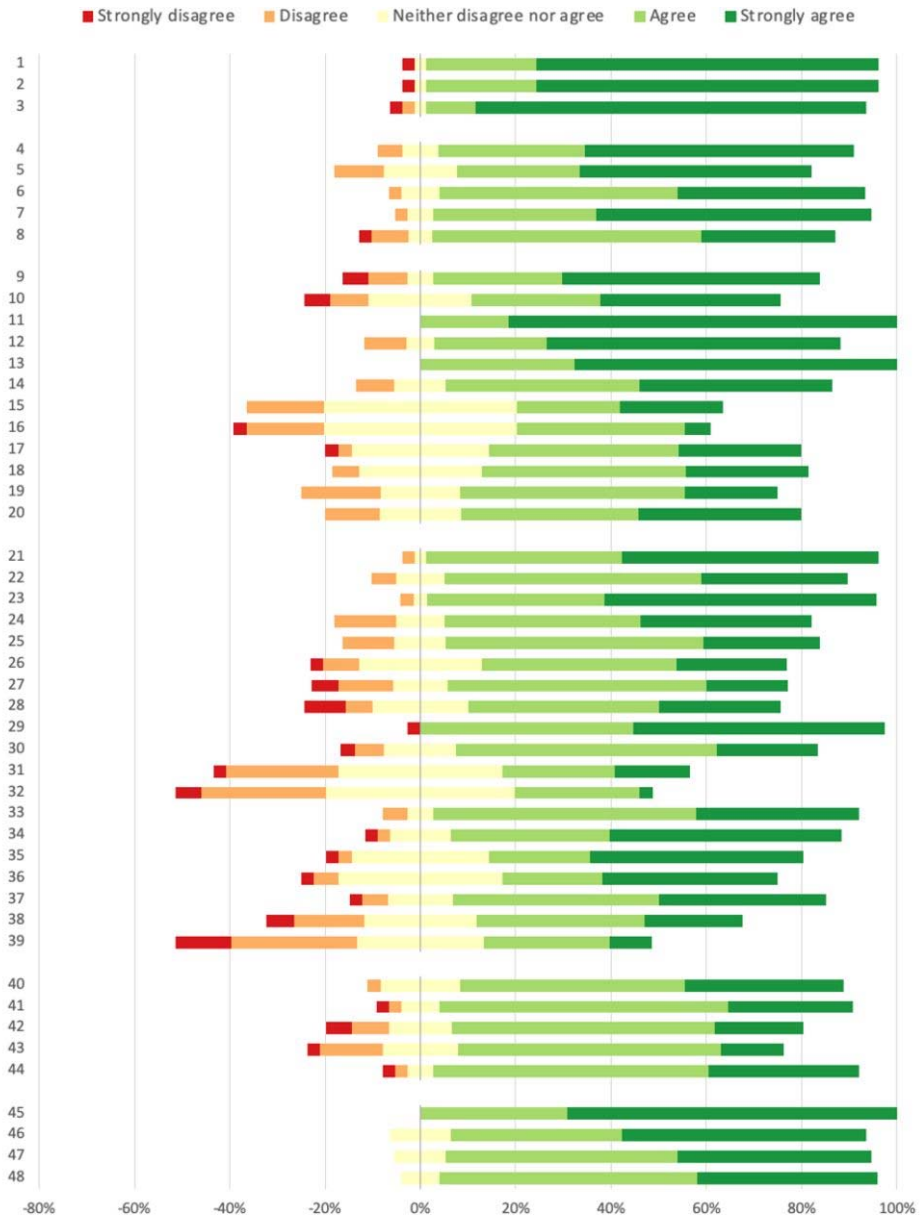

Figure 2. Levels of agreement for statements included within the first-round survey. Full statements and values are available in online supplemental table A1.

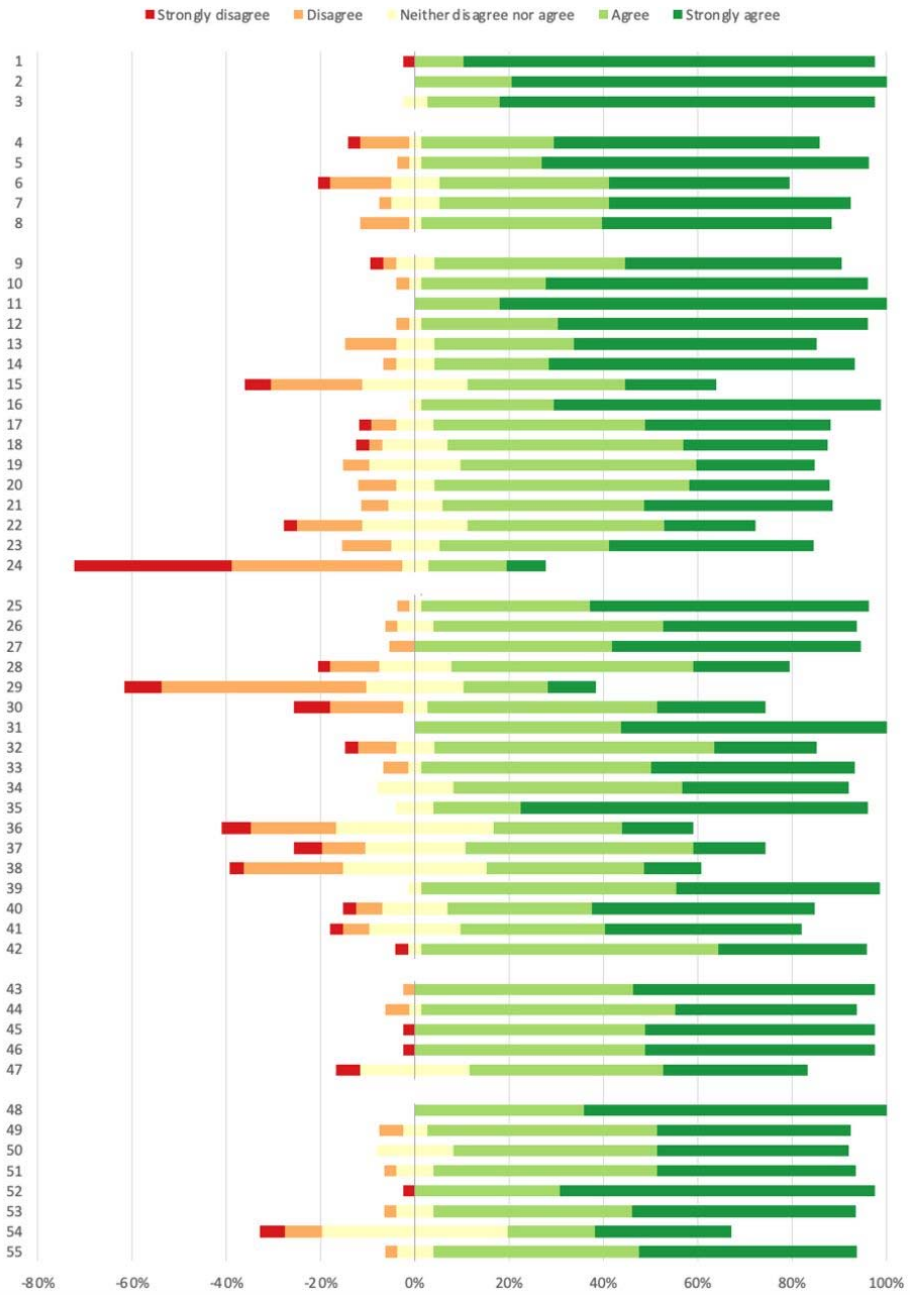

Figure 3. Levels of agreement for statements included within the second-round survey. Full statements and values are available in online supplemental table A2.

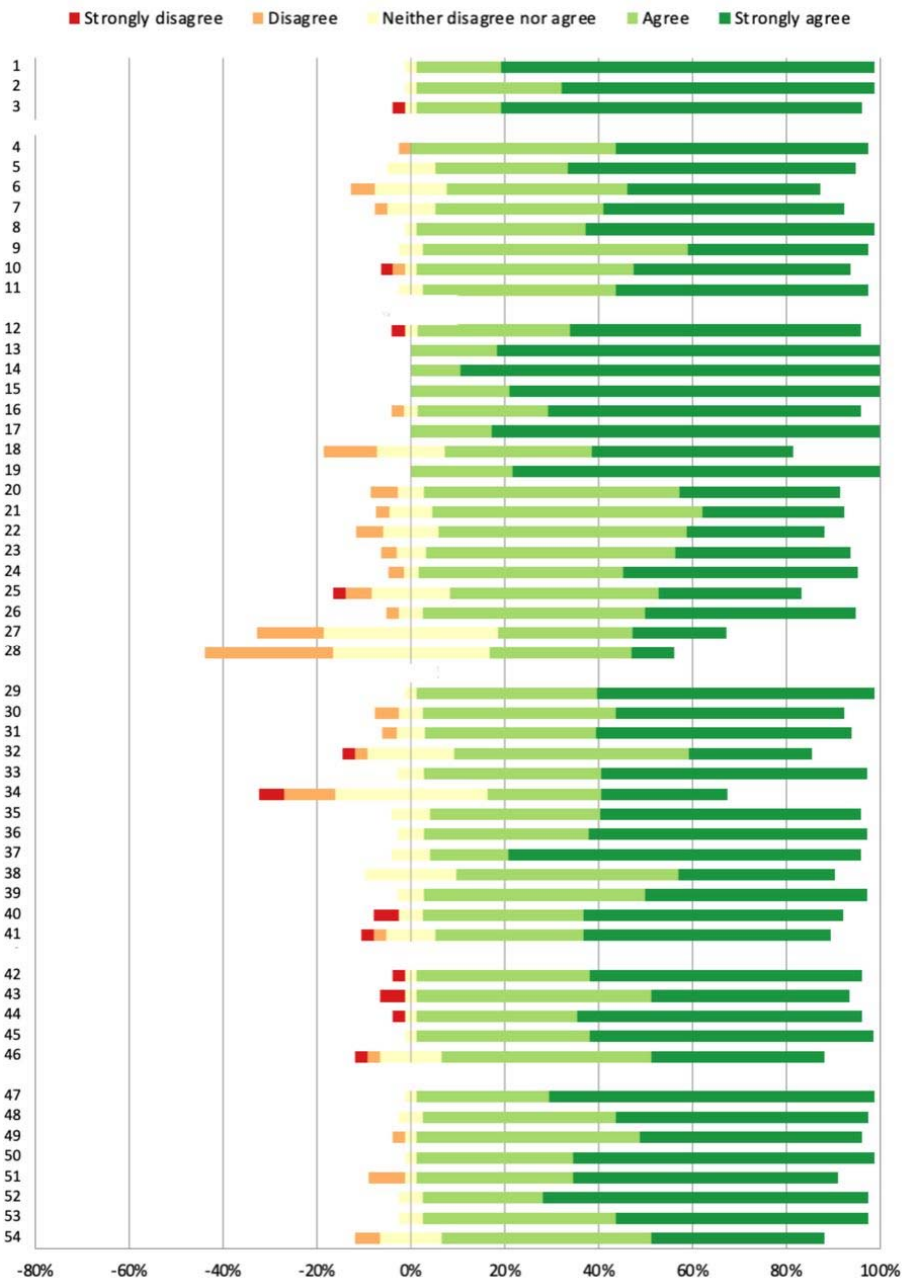

Figure 4. Levels of agreement for statements included within the final-round survey. Full statements and values are available in online supplemental table A3.

Consensus findings

The outcome of the consensus process, including dissenting viewpoints and areas of disagreement and recommendations are outlined below. The key clinical recommendations from this Delphi process are summarised in figure 5.

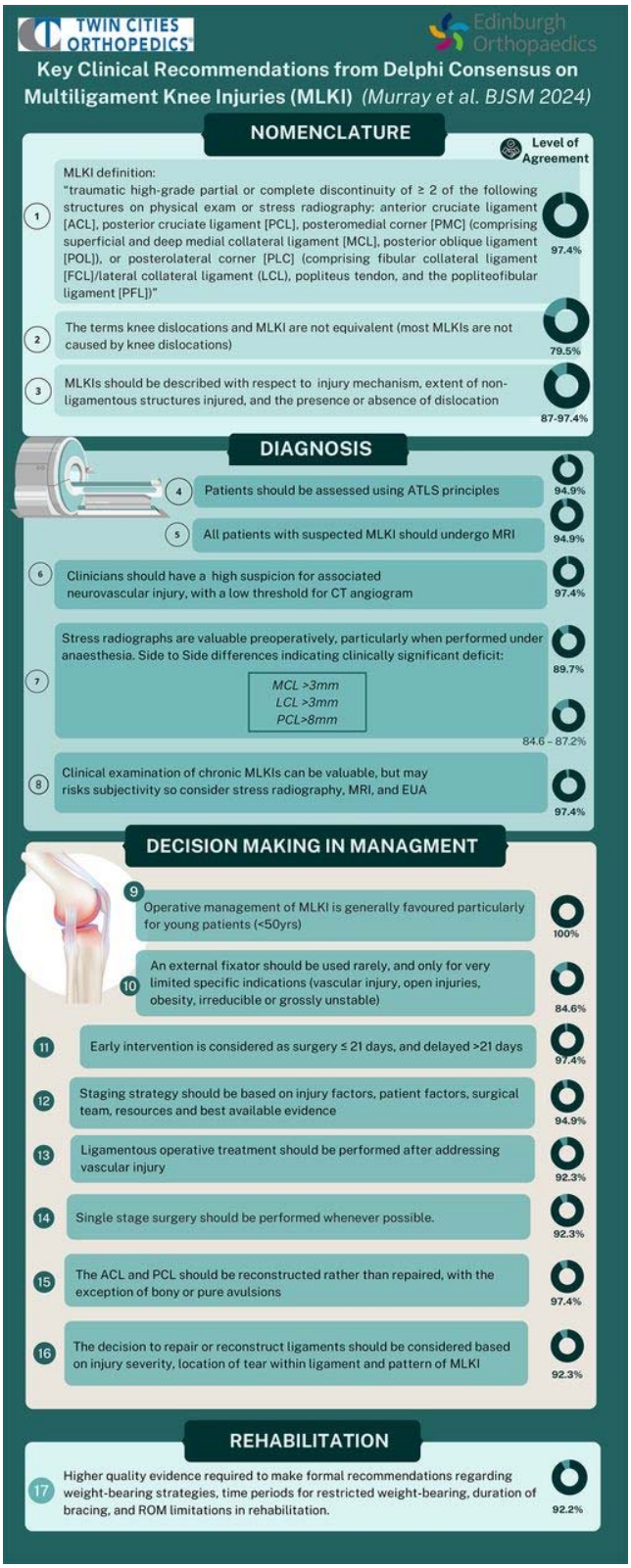

Figure 5. Summary infographic illustrating the key clinical recommendations of our Delphi process and associated levels of agreement (LoA). ATLS, advanced trauma life support; EUA, examination under anaesthesia; ROM, range of motion.

Domain 1: existing literature

Results and recommendations

Within this domain, consensus was sought on the current landscape of the literature regarding the diagnosis and treatment of MLKI, and the perceived need for an expert consensus. A total of three statements were considered with all achieving the threshold for consensus, although agreement was not unanimous (table 3). The expert panel re-affirmed the findings of the scoping review, noting the heterogeneity and largely lower order evidence that currently informs diagnostic and treatment decisions regarding MLKI. Importantly, the experts agreed that heterogeneity in the outcome measures used for evaluating MLKI precludes meaningful comparisons and pooling of data within this rare injury pattern. Most experts expressed a need to produce an accepted and standardised approach for diagnosing and treating MLKI that could be considered 'best practice'.

Table 3 Statements achieving consensus after three Delphi rounds under the heading *'existing literature'*

Statement	% within expertise	% agreement	% disagreement
The literature relating to outcomes following treatment of MLKIs is heterogeneous with a variety of diagnostic and treatment protocols being advocated, mostly based on small retrospective studies or pooled analyses of these studies.	100.0	97.4	0.0
Significant heterogeneity in reporting of variables that may influence outcome following MKLI limits comparisons between studies and adequate pooling of data.	100.0	97.4	0.0
Given the limitations in existing literature, there is a need to develop consensus among experts to guide best practice in the diagnosis and management strategies for MLKIs.	100.0	94.9	2.6

MLKI, multiligament knee injury.

Dissenting viewpoints and areas of disagreement

A range of suggestions of how the field could overcome clear limitations in the literature were made, including developing a 'core outcome set' to encourage uniform reporting criteria, and standardised outcome measures. A number of other suggestions proposed are discussed below in the section 'Domain 6: future research priorities'.

Domain 2: nomenclature

Results and recommendations

This domain aimed to establish consensus regarding definitions for MLKI and the need for a standardised method of communication when describing MLKI, including an appropriate classification system. Of the 17 statements discussed across all rounds, 8 reached agreement with none being unanimous. Statements achieving consensus are outlined in table 4.

Table 4 Statements achieving consensus after three Delphi rounds under the heading *'nomenclature'*

Statement	% within expertise	% agreement	% disagreement
MLKIs can be defined as a traumatic high-grade partial or complete discontinuity of at least two of the following structures verified on physical examination or stress radiography: ACL, posterior cruciate ligament, posteromedial corner (comprising superficial and deep medial collateral ligament, posterior oblique ligament or posterolateral corner) (comprising fibular collateral ligament/lateral collateral ligament, popliteus tendon, popliteofibular ligament).	100.0	97.4	2.6
There is a need to establish consensus on standardised nomenclature relating to MLKIs.	100.0	89.8	0.0
Most MLKIs are not caused by knee dislocations and use of the term knee dislocation should be discouraged unless referring specifically to this mechanism of injury.	100.0	79.5	5.1
There is a need for improving classification systems for MLKI, specifically a system that incorporates MLKI that are not caused by a knee dislocation.	100.0	87.2	2.6
A classification system for MLKIs should reflect the range of possible injuries and their severity.	100.0	97.4	0.0
In classifying MLKIs, the anatomical structures involved, the location of injury within these structures and the injury mechanism (including velocity such as high vs low vs ultra-low velocity) should be described separately.	100.0	94.9	0.0
An MLKI classification system should facilitate treatment decisions for each categorised injury.	100.0	92.3	5.1
An MLKI classification system should take into consideration associated non-ligamentous structures injured in addition to the ligamentous components.	100.0	94.9	0.0

MLKI, multiligament knee injury.

Importantly, there was overwhelming agreement (LoA: 97.4%) regarding the following definition of MLKI: '*a traumatic high-grade partial or complete discontinuity of at least two of the following structures verified on physical examination or stress radiography: ACL, PCL, PMC (comprising superficial and deep MCL, posterior oblique ligament (POL)), or PLC (comprising fibular collateral ligament (FCL)/lateral collateral ligament (LCL), popliteus tendon and the popliteofibular ligament (PFL))'*. Experts agreed that most MLKIs are *not* caused by knee dislocations (LoA 79.5%), emphasising that there should not be assumed equivalence between the terms 'knee dislocation' and MLKI. 'Dislocation' should only be used within the context of MLKI when there is evidence for this injury.

A separate emerging theme from these statements was the need for an updated MLKI classification system, distinct from the current Schenck Knee Dislocation Classification.[29] Experts agreed that an updated system based on the structures involved, and severity of their injury would be of value. There should not be an implied assumption of knee dislocation. Instead, this should be stated separately in association with the nature of the injury mechanism (high, low or ultra-low velocity). Furthermore, the classification system should consider the extent of associated non-ligamentous structures injured (including menisci, cartilage and neurovascular structures). The purpose and categories of classification within this system should directly guide treatment decisions.

Dissenting viewpoints and areas of disagreement

The most contentious points centred around the appropriateness of the term 'knee dislocation' in the context of MLKI and the characteristics of an ideal classification system. While most experts felt that the majority of MLKI injuries do not result from a knee dislocation, several individuals emphasised that dislocations are frequently unproven or transient. The authors have previously defined knee dislocation as 'total disruption of the tibiofemoral joint verified clinically or radiographically'.[22] Ultimately, it was agreed that the term knee dislocation should not be used in equivalence with MLKI, but may be of value if a true tibiofemoral dislocation is confirmed.

Experts noted limitations in the Schenck Knee Dislocation Classification, agreeing that an updated classification system is required. However, a minority of the expert panel felt the recently published pathoanatomic MLKI classification system[30]—based on the knee dislocation classification—was sufficiently practical. While some felt that any updated

classification system should be based purely on the anatomical structures injured and their degree of injury, others felt that injury mechanism, for example, whether a knee dislocation occurred, was relevant and should be considered. Ultimately, consensus was reached that injury mechanism, anatomical structures involved and location of injury within these structures should all be part of an updated classification system but should be considered in separate sections of the updated classification system.

Domain 3: diagnosis

Results and recommendations

This domain set out to establish consensus regarding 'best practice' in evaluating and investigating MLKI. Of 34 statements considered, only 14 reached sufficient agreement for consensus, 5 statements were unanimously agreed upon (table 5) and several clear recommendations were made.

Table 5 Statements achieving consensus after three Delphi rounds under the heading *'diagnosis'*

Statement	% within expertise	% agreement	% disagreement
MLKIs occurring in the setting of high-energy trauma, should be assessed using advanced trauma life support principles.	94.9	94.6	2.7
Each suspected MLKI should be assessed as a true knee dislocation with a high suspicion for associated neurovascular injury until proven otherwise.	97.4	100.0	0.0
All patients should undergo a careful assessment of the neurological and vascular status of the affected limb.	97.4	100.0	0.0
Clinicians should have a particularly high index of suspicion for associated neurovascular injury following diagnosis of MLKIs associated with PCL or PLC.	97.4	100.0	0.0
Clinical examination of pedal pulses alone is insufficient for the accurate diagnosis of vascular injury associated with acute MLKIs involving a higher energy mechanism.	92.3	94.4	2.8
There should be a low threshold for proceeding to vascular assessment with CT angiography in patients presenting with acute high-energy MLKI, knee dislocation, suspected bicruciate ligament or PLC injury and equivocal clinical examination and ABI findings.	89.7	100.0	0.0
All patients with suspected MLKI should undergo MRI if available.	94.9	100.0	0.0
Stress radiographs are valuable in the pre-operative phase as an adjunct to MRI in decision making by quantifying the degree of ligament competence, particularly when performed under anaesthesia.	89.7	88.6	5.7
For the LCL, an increase in lateral joint space of >3 mm in side-to-side difference on manual varus stress radiographs (with the knee at 20° of flexion) can be a useful adjunct to indicate a clinically significant LCL rupture which may require surgical intervention, when combined with suitable MRI findings.	84.6	87.9	3.0
For the MCL, an increase in medial joint space of >3 mm in side-to-side difference on manual valgus stress radiographs (with the knee at 20° of flexion) is a useful adjunct to support the diagnosis of a clinically significant MCL rupture that may require surgical intervention.	87.2	82.4	5.9
For the PCL, an increase in posterior tibial translation of >8 mm in side-to-side difference (with the knee at 90° of flexion) on manual stress radiographs or intraoperative fluoroscopy is a useful adjunct to support the diagnosis of a complete rupture of the PCL that may require surgical intervention.	82.1	90.6	3.1
Posterior manual stress radiographs at 90° knee flexion with >12 mm of posterior tibial displacement and a grade 3 posterior drawer test are a useful adjunct to support a diagnosis of a combined PCL and PLC or PMC injury or a PCL tear with reduced posterior tibial slope.	82.1	93.8	3.1
For the assessment of ACL injuries, a cut-off of >5 mm in side-to-side difference for anterior tibial translation on manual stress radiographs (with the knee at 20° of flexion) may be used as an adjunctive indication for surgical intervention in addition to suitable clinical examination findings (such as positive pivot shift, hyperextension).	92.3	75.0	8.3
Clinical examination of knee stability in the outpatient setting for chronic MLKIs can be valuable, but may risk subjectivity and should be followed up by stress radiography and/or examination under anaesthesia in combination with MRI where there is diagnostic uncertainty.	97.4	92.1	2.6

LCL, lateral collateral ligament; MCL, medial collateral ligament; MLKI, multiligament knee injury; PCL, posterior cruciate ligament; PLC, posterolateral corner; PMC, posteromedial corner.

Dissenting viewpoints and areas of disagreement

There were three main areas of contention: the use of advanced imaging for preoperative investigation of patients with nerve injury, ankle brachial index (ABI) readings in evaluating MLKI and the use of stress radiography. A substantial proportion of the expert panel felt that clinical assessment was the most appropriate method of evaluating a potential nerve injury. If further investigation of a potential nerve injury was required, the panel remained undecided regarding the best investigative modality.

The value of routine ABI measurements in initial assessment generated considerable debate. It was suggested that in the scenario of MLKI where history or clinical examination suggests a potential vascular injury, it would be more prudent to simply proceed to formal vascular investigation with MR or CT angiography, particularly given the potential consequences of missed vascular injuries. Some experts noted that investigation with ABI may be limited as a normal ABI would not contraindicate further imaging.

Almost 90% of experts agreed that stress radiography has value in the investigation of MLKI. Some experts questioned its value in the non-anaesthetised patient, while others felt this modality was too subjective to be relied on. The most appropriate technique (using adjunct devices such as Telos or KT-1000 vs manual stress) was also contentious. Some within the expert panel felt video fluoroscopy would be preferred, providing real-time feedback and a more 'global picture' regarding the functional consequences of ligamentous incompetence, whereas others felt formal radiography was essential. Consensus was ultimately reached with manual stress radiography comparing side to side differences deemed adequate. While some experts felt strongly that stress radiographs were highly valuable for monitoring recovery, others felt this may risk re-injury.

Domain 4: decision making in management

Results and recommendations

This domain aimed to establish consensus regarding best practice in managing MLKI. Specifically, this domain addressed the long-held controversies regarding the need for operative intervention, timing of surgery and surgical strategy (staging and repair vs reconstruction). Of 42 statements discussed across all rounds, 12 reached sufficient agreement for consensus, although none were unanimously agreed on (table 6). The areas of consensus and recommendations made within this broad category are discussed below.

Table 6 Results of final Delphi round under the heading '*decision making in management*'

Statement	% within expertise	% agreement	% disagreement
Objective comparisons of 'operative' and 'non-operative' management strategies are limited by variation in timing, ligament injuries studied, operative technique, returning level, type of activity desired and rehabilitation strategy.	100.0	97.40	0.0
Published pooled analyses of low-level evidence generally favour operative management of MLKI compared with non-operative management. Studies are particularly favourable of operative management in young patients (aged <50 years), reporting significantly higher rates of return to work or sport, and functional outcome following operative intervention.	100.0	89.70	5.1
An external fixator should be used rarely, and only for very limited specific indications (including but not limited to vascular injury, open injuries, obesity, an irreducible or grossly unstable joint not contained by a brace) and not routinely. If applied, particular care should be taken not to capture the quadriceps mechanism.	84.6	90.9	3.0
Early operative intervention is defined as occurring within 21 days of injury and delayed intervention is defined as surgery after 21 days.	97.4	76.3	5.3
The timing of operative intervention should be tailored to each individual ligament within MLKI and is determined by a range of factors including MLKI injury severity, pattern, associated neurovascular injury and patient factors.	94.9	94.6	0.0
The decision to pursue single or staged surgery for MLKI depends on a variety of factors including pattern of knee injury and associated injuries in polytrauma patients.	92.3	91.7	0.0
Recommendations regarding staging strategy should be based on injury factors, patient factors, surgical team, resources and best available evidence.	94.9	94.6	0.0
Ligamentous operative treatment should be performed only once vascular injury has been excluded or addressed.	92.3	91.7	0.00
Single-stage surgery should be performed whenever possible to facilitate early rehabilitation, reduce rehabilitation time and avoid overloading the reconstructed ligaments with staging.	92.3	80.6	0.0
The decision to repair or reconstruct ligaments in the context of MLKI should be considered, within the context of the severity of injury, location of tear within specific ligament (proximal, mid-substance, distal) and pattern of MLKI encountered.	92.3	94.4	0.0
Where possible, the ACL should be reconstructed rather than repaired, with the exception of bony or pure avulsions.	97.4	89.5	5.3
Where possible, the PCL should be reconstructed rather than repaired, with the exception of bony or pure avulsions (peel-off lesions).	97.4	84.2	5.3

MLKI, multiligament knee injury; PCL, posterior cruciate ligament.

Operative versus non-operative management

The expert panel reached consensus that the current literature generally favours operative management of MLKI over non-operative management (LoA 89.7%), particularly in patients aged <50 years, where the majority of studies report significantly higher rates of return to work or sport and functional outcomes with operative intervention.[1, 31] Experts agreed (LoA 97.4%) that simple comparisons of 'operative versus non-operative' management strategies for MLKI may not be accurate, given considerable variation in surgical timing, ligaments injured, operative techniques, rehabilitation and level of returning activity.

Timing of surgical intervention

Experts agreed that early operative intervention should be defined as occurring within 21 days of injury with delayed intervention referring to beyond 21 days (LoA 76.3%)—consistent with the majority of published definitions.[1, 32–38] As the prior scoping review noted,[22] the original distinction appeared to come from a study by Levy *et al,* [1] who described 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 re-approximation and suture placement in the setting of repair.

Given the fairly arbitrary definitions of early and late operative intervention within current MLKI literature, it is perhaps not surprising that there was overwhelming consensus among the expert panel that timing of operative intervention should be tailored to each individual ligament and should be determined by a range of factors including MLKI injury severity, pattern, associated neurovascular injury and patient factors. The only statement within this domain that

failed to reach consensus was that 'early surgery (within 21 days) should be performed whenever possible depending on concomitant injuries and the resources available'.

Staging of surgery

Experts agreed that the decision to perform single or staged surgery should be made on an individual basis considering the pattern of injury (using an accepted classification system), associated injuries, patient factors and the best available evidence. Despite this it was suggested that where possible, single-stage surgery should be undertaken to facilitate early rehabilitation in keeping with previously published views in sport-related MLKI.[39] As noted from prior evidence, the literature comparing single-stage surgery with staged approaches remains of low quality.[22] Previously, cited advantages of staged interventions include better functional outcomes and less stiffness with staged procedures.[40] However, it remains unclear whether all patterns of MLKI act similarly and therefore should be managed singularly. For example, concomitant fracture or extensor mechanism injury in MLKI can influence selection of single versus staged surgery.[17]

Repair versus reconstruction

There was consensus that a decision to repair or reconstruct ligaments should be based on the severity of injury, tear location (proximal, mid-substance, distal) and pattern of MLKI. Regardless of the pattern of injury, it was recommended that the ACL and PCL should be reconstructed rather than repaired where possible,[41] with the exception of bony or pure avulsions (peel-off lesions).[42]

Dissenting viewpoints and areas of disagreement

There were two main areas of contention: timing of surgical intervention and repair versus reconstruction for the PMC and PLC. Despite the definition of 'early' and 'late' intervention reaching consensus, there was disagreement regarding whether such a distinction was of value. This is perhaps not surprising considering the relatively low-quality evidence on which these distinctions were made.1 However, some experts felt it was valuable to delineate between those injuries where clear tissue planes facilitate surgical access and those where scarring creates additional surgical challenges. There were strong views that a balance needed to be struck between early surgery, while tissue planes could be easily identified, and the risk of stiffness which is associated with early intervention.

Domain 5: rehabilitation

Results and recommendations

This domain aimed to establish consensus regarding rehabilitation and bracing strategies following surgical intervention for MLKI. Of 10 statements discussed across all rounds, 5 reached sufficient agreement for consensus, although none were unanimous (table 7). The two recommendations made by the expert panel for this domain were: first, that a period of restricted weightbearing in a hinged knee brace between 4 and 6 weeks is preferred, but this is based predominantly on expert opinion; second, in the case of posterior cruciate ligament reconstruction (PCLR), the use of daily prone knee range of motion exercises with immediate quadriceps activation is advocated, rather than delaying mobilisation.

Table 7 Results of final Delphi round under the heading '*rehabilitation*'

Statement	% within expertise	% agreement	% disagreement
Weightbearing strategies following surgical treatment of MLKI vary widely and do not have a robust evidence base, with current strategies based on expert opinion—most consider a period of non-weightbearing or touch-weightbearing within a hinged knee brace.	97.4	94.7%	2.6%
There is currently insufficient high-quality evidence to advocate a specific time-period of restricted weightbearing following surgical treatment of MLKI, however a period of 4–6 weeks can be considered acceptable based on current low-order evidence and expert opinion.	97.4	92.1%	5.3%
Further high-quality evidence is required to make specific recommendations regarding the duration of bracing following MLKI.	97.4	94.7%	2.6%
Further evidence is required to advocate specific ROM limitations following treatment for MLKI.	97.4	97.4%	0.0%
PCLR rehabilitation protocols that include early (within 1 week) daily prone knee range of motion exercises (0–90°) and immediate quadriceps activation appear to be more beneficial than rehabilitation strategies involving early immobilisation (a period of at least 3 weeks of immobilisation).	97.4	81.6%	5.3%

MLKI, multiligament knee injury; PCLR, Posterior Cruciate Ligament Reconstruction; ROM, Range of Motion.

Dissenting viewpoints and areas of disagreement

Three principal themes of contention emerged: first, what constitutes an appropriate period of weightbearing restriction; second, whether weightbearing restriction is required at all and third, whether bracing is required for all MLKIs. A proportion of the expert panel felt that daily prone knee range of motion exercises for PCLR rehabilitation should not involve active flexion to 90° and should only be performed passively by a trained therapist. The biomechanical rationale is that prone active knee flexion requires activation of the hamstring muscles, which has the potential to translate the tibia posteriorly, potentially stressing the reconstructed PCL. Others advocated the use of dynamic supportive bracing. Current best evidence indicates that early mobility achieves significantly better outcomes for stability, ROM and functional outcome compared with a period of initial immobilisation and delayed mobilisation.[40, 43, 44] However, significant variation in the rehabilitation protocols employed between studies limits further applicability of this evidence. Although attempts have been made to conduct high-quality randomised controlled trials, most have not been sufficiently powered to provide definitive answers to these questions.[45, 46] As we have previously noted, there are widely varying protocols for weightbearing, bracing, timing of initiation and types of physical therapy in the current evidence evaluating rehabilitation strategies following surgical intervention for MLKI, although most studies appear to follow rehabilitation protocols that are based on permutations of those originally described by Edson *et al* and Fanelli *et al*.[33, 47] An updated set of rehabilitation protocols, specific to the MLKI injury pattern encountered, is needed.

Table 8 Results of final Delphi round under the heading '*future research priorities*'

Statement	% within expertise	% agreement	% disagreement
Minimum reporting standards are required to allow for accurate pooling of data and meaningful conclusions to be drawn regarding recommended strategies for diagnosis, management and rehabilitation of MLKI.	100.0	97.4	0.0
There is a need for more specific evidence on timing of intervention for MLKI, with a rationale for defining effective 'windows' for intervention, as current definitions of 'early' and 'late' intervention are arbitrary and based on expert opinion alone.	100.0	94.9	0.0
Further high-quality studies are required to assess the relative benefits of single versus staged surgery for MLKI stratified by knee dislocation classification, incorporating a policy of acute repair and delayed reconstruction when staged procedures are being undertaken.	97.4	94.7	2.6
A multicentre registry of MLKIs would be valuable.	100.0	97.4	0.0
Patient-reported outcomes specific for multiple ligament injured knee patients should be adopted by all researchers to better understand the unique patient population as opposed to scores which are not specific for MLKI.	100.0	89.7	7.7
Achieving standardisation of diagnosis, management and of outcome measures following MLKI would be of value.	100.0	94.9	0.0
Research studies are required to evaluate the effects of geographic location, socioeconomic factors and patient demographics (including sex and racial differences) on injury treatments and outcomes.	100.0	94.9	0.0
Research is required to assess stress radiographs in clinic and in the anaesthetised patient, to determine the relative accuracy and differences in findings regarding laxity/end points in these two settings.	97.4	81.6	5.3

MLKI, multiligament knee injury.

Domain 6: future research priorities

Results and recommendations

Of 12 statements discussed across all rounds, 8 reached sufficient agreement for consensus, although none were unanimous (table 8). Three main recommendations emerged. The most important recommendation was that minimum reporting standards were required for the diagnosis, management and rehabilitation of MLKI, to allow for accurate pooling and comparisons of data (LoA 97.4%). Second, a universally standardised set of outcome measures must be employed for MLKI, which uses harmonised MLKI-specific patient-reported outcome measures (PROMs). Third, a multicentre registry of MLKI would be immensely valuable. Such a registry could improve adherence to standardised recording of data points based on the core outcome set and minimum reporting standards among involved centres and allow for high-quality research output guiding best practice for the above themes. It could also be used to evaluate epidemiological data such as geographic location, socioeconomic factors and patient demographics, with MLKI outcomes. This was also deemed by the expert panel to be a research priority (LoA 94.5%).

Dissenting viewpoints and areas of disagreement

The most contentious topic between experts was the need for MLKI-specific PROMS, as opposed to generally accepted PROMs for knee injuries. Some within the expert panel felt that a combination of MLKI-specific and general PROMs should be collected, to allow for comparisons of the outcome of MLKI compared with other injuries. Others felt this was unnecessary as the aim is to compare outcomes for different injury patterns within the context of MLKI itself.

Strengths and limitations

The Delphi methods, as employed in this study, confer several advantages over group-based methods,[48] including the potential for anonymity within the expert panel,[48] which can mitigate the influence of dominant individuals. Online methods can enhance the consensus process due to subject anonymity.[48] Delphi panel surveys conducted entirely remotely have been shown to be as reliable as in-person panels, while also offering additional advantages such as cost reduction, faster execution and greater flexibility for participants.[49] The online nature of the survey ensured that we could maximise diversity and global representation on the panel.

A considerable strength of this study was the objective manner by which the panel was selected while taking care to ensure diversity in race, nationality, gender and professional background. As the 25 most published (first or senior) authors were male, we identified the most published senior or first author females including all those who published a minimum of two papers. To systematically incorporate international perspectives, we invited representatives with MLKI expertise from each of the 11 IOC research centres of research excellence. Our 100% response rate across all three survey rounds demonstrates engagement with the process by all experts. The views of the entire selected panel were therefore considered and represented throughout the consensus process.

This study has a number of limitations. First, despite efforts to ensure a diverse and inclusive expert panel, the panel remained weighted towards males. This appears to reflect a broader issue concerning the challenge of achieving adequate gender and ethnic diversity within the

field of orthopaedic sports surgery[50] and orthopaedics generally.[51] Although we collected the vast majority of relevant demographic information as recommended by the Cochrane Progress-plus framework[52] to aid with reporting the characteristics of our expert panel (table 1), we did not collect information on ethnicity or race of the expert panel members, which may limit the transparency of our reporting of characteristics of our expert panel. Future consensus studies should continue to work on improving the diversity of expert panels in this space. Furthermore, consensus studies should take into account the perspective of the patient and wider public. Second, when selecting our expert panel, we used the number of peer-reviewed MLKI publications as first or senior author as a proxy for expertise. We acknowledge that this may not objectively capture clinicians with clinical or surgical expertise in the care of MLKI and may introduce selection bias. However, we felt this was the most objective method of classifying expertise and note that authorship on peer-reviewed publications has previously been used either wholly or as a significant component of the definition of expertise in a number of recent consensus statements.[16, 17, 26, 53] Third, we recognise that our expert panel, although representative of several roles within a relevant multidisciplinary team for MLKI care, did not encompass the entire range of professional roles within a team that typically cares for patients with MLKI. Therefore, there remains a need for a balanced representation of currently practising members of the multidisciplinary team in future consensus statements, with more experts from allied health professions. Lastly, we recognise that several aspects of MLKI care surrounding rehabilitation, such as timelines or contents of rehabilitation programmes were not commented on in the current study. There is a dearth of literature in this regard due to the spectrum of injuries and range of treatment strategies encompassed by MLKI. We would suggest that future consensus studies may be considered exploring these areas specifically, following higher-order evidence being published.

Conclusion

In summary, this study employed Delphi methods to develop an international consensus in the nomenclature, diagnosis, treatment and rehabilitation of MLKI. Importantly, this study generated strong consensus on a definition for MLKIs, while identifying the requirement for a more comprehensive classification system. Participants agreed on key recommendations on clinical diagnosis, including the use of MRI for all patients, CT angiography for high-energy injuries, knee dislocations, bicruciate injuries or equivocal exam findings and stress radiographs for quantifying ligament competence. While there were ongoing areas of debate relating to treatment, experts agreed that single-stage surgery was preferable to facilitate early rehabilitation, and exercises to promote early range of motion are beneficial. Strategies to improve the reporting and standardisation of research studies pertaining to MLKI were identified as a key research priority.

Ethics statements

Patient consent for publication

Not applicable.

Ethics approval

Not applicable.

Footnotes

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