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Establishing the indications for temporising knee-spanning external fixation: A modified Delphi study of the International Knee Dislocation Study Group

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Abstract

Purpose: Knee dislocations (KDs) can be limb-threatening injuries that may require a temporising knee-spanning external fixator (KSEF) for stabilisation. Precise indications for this commonly utilised invasive immobilisation technique remain controversial and poorly defined. The purpose of this study was to establish consensus-driven indications for temporising KSEF use in the initial management of KDs.

Methods: A working group of fellowship-trained orthopaedic surgeons generated clinical scenarios reflecting commonly debated indications for temporising KSEF application. Utilising a modified Delphi technique, 23 surgeons from the International Knee Dislocation Study Group completed two anonymous online survey rounds. Consensus was defined a priori as ≥70% agreement or disagreement.

Results: Response rates were 100% for Round 1 and 96% for Round 2. Four scenarios achieved unanimous consensus: (1) KD without post-reduction instability (100% disagreement), (2) inability to maintain tibiofemoral reduction in the sagittal/coronal plane with non-invasive knee immobilisation (NIKI) after initial reduction (i.e., redislocation/subluxation) (100% agreement), (3) tibial plateau fracture-dislocation with post-reduction subluxation (100% agreement), and (4) in bilateral closed KDs where one limb is indicated and the other is NOT, span ONLY the indicated limb (100% agreement). Two scenarios achieved strong positive consensus (90%–99.9% agreement): (1) morbid obesity (BMI ≥ 40) without NIKI of sufficient size (91.3% agreement), and (2) extensor mechanism injury with

Abbreviations: ACCORD, ACcurate COnsensus Reporting Document; BMI, body mass index; IRB, Institutional review board; KD, knee dislocations; KSEF, knee-spanning external fixator; MRI, magnetic resonance imaging; NIKI, non-invasive knee immobilisation.

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post-reduction subluxation (91.3% agreement). Four and one additional scenarios achieved positive and negative consensus, respectively.
Conclusions: This modified Delphi study established consensus-driven indications for temporising KSEF application in the initial management of KDs, which advocate for more selective use than what is demonstrated in the literature.

Level of Evidence: Level V.

KEYWORDS
Delphi, external fixator, knee dislocation, knee-spanning external fixation, multiligament knee injury

INTRODUCTION

Knee dislocations (KD), defined as disruption of the normal articulating surfaces of the tibiofemoral joint verified clinically or radiographically, are potentially limb-threatening injuries that can arise from a variety of mechanisms [40, 64]. While the vast majority of KDs result in a multi-ligament knee injury (MLKI), most MLKIs do not occur as a result of a KD [47, 52]. While these terms are often used interchangeably, the distinction is critical, as there is an increased risk of vascular injury and peroneal nerve injury in the documented KD compared to the non-dislocated MLKI [25, 56]. The distinction has also been shown to have prognostic implications in comparing KD3-M injuries, with dislocated knees having worse outcome scores at a mean 6.5 years follow-up [21]. Patients may also have extensive orthopaedic and systemic injuries, making KDs a significant challenge for the healthcare system [9, 26, 28, 49].

In the acute setting, initial stabilisation of a KD after reduction may be achieved using non-invasive knee immobilisation (NIKI) in the form of a knee immobilizer, brace, or splint when a concentric reduction can be maintained and soft tissue conditions allow. Temporising knee-spanning external fixators (KSEF) offer a more rigid construct and are typically reserved for situations where NIKI fails to maintain reduction, when staged wound care is anticipated, or when vascular reconstruction requires additional protection. These devices are applied in up to 50% of KDs, despite their association with several postoperative complications, magnetic resonance imaging (MRI) compatibility concerns or image artifact, delay in diagnosis secondary to a lack of institutional MRI and KSEF policies precluding the imaging from occurring, and delay in definitive ligamentous reconstruction, among others [4, 8–10, 22, 36, 44, 45, 50, 51, 59, 63, 66]. The decision to apply a KSEF is complex but typically involves the consideration of injury severity, instability, comorbid injuries, patient adherence, and resource availability [8, 12, 19, 31, 33, 37, 42, 46, 53, 62]. Divergent views on the use of temporising KSEFs persist because KDs represent heterogeneous injury patterns with variable instability, vascular and soft tissue compromise, and resource constraints [49, 52]. Furthermore, comparative outcome data for clearly defined clinical scenarios are limited, and the theoretical benefits of KSEF use, such as improved maintenance of reduction or graft protection, must be balanced against the risks [18, 22, 36].

While risk factors for KSEF application have been identified [9], indications remain poorly defined and controversial [3, 30, 41]. Several broad indications have been described, including vascular injury, knee fracture-dislocation, open KD, soft tissue compromise, compartment syndrome, polytrauma, and morbid obesity [5, 2, 7, 8, 12, 24, 29, 31–33, 37, 42, 46, 49, 53, 62, 63]. However, there remains no high-level evidence to justify or discourage temporising KSEF use under defined circumstances, and international consensus is yet to be ascertained. Thus, there is an unmet need for guidelines on the utilisation of KSEFs in the initial management of KDs. Recent Delphi studies have successfully standardised indications for both rare and common orthopaedic interventions [16, 55, 58].

As such, the objectives of this modified Delphi study were to (1) identify clinical scenarios in which an expert panel supports temporising KSEF use following an acute, documented KD; (2) identify clinical scenarios in which temporising KSEF use is discouraged following an acute, documented KD; and (3) summarise areas of uncertainty requiring individualised decision-making and future study. These objectives are intended to support orthopaedic traumatologists, sports surgeons, and trauma teams involved in the initial management of acute KDs and are intended to be applicable across practice settings where temporising KSEF may be considered.

MATERIALS AND METHODS

This consensus study was conducted in accordance with the ACcurate COnsensus Reporting Document (ACCORD) (Supporting Information: Appendix 10), as well as the consensus statement guidelines by Murray et al. [14, 43]. Institutional review board (IRB) approval through the Yale University IRB was obtained prior to initiation of the study (protocol number: 2000039395). No external funding was utilised, nor was the study registered prior to its initiation.

Participant selection

Ten members of the International Knee Dislocation Study Group (IKDSG), which was established in 2023 as a collaboration of academic orthopaedic surgeons and researchers with a focused research interest in KDs, served as a working group to create a series of clinical scenarios to be investigated as potential indications for the application of a temporising KSEF in the setting of an acute KD. Scenario development was informed by a targeted, non-systematic review of the literature and the collective clinical experience of the fellowship-trained orthopaedic surgeons that made up the working group. The working group consisted of several authors of the current study: Michael J. Medvecky, Michael J. Alaia, Túlio V.O. Campos, Michael F.G. Held, Bruce A. Levy, Volker Musahl, Dustin L. Richter, Brian R. Waterman, Daniel B. Whelan, Robert C. Schenck Jr. Members of the working group were eligible to participate as panellists.

A panel size of approximately 20–30 experts was targeted, consistent with common Delphi practice and sufficient to capture diverse viewpoints while maintaining feasibility for iterative rounds. A total of 26 orthopaedic surgeon members of the IKDSG were contacted via email to serve as panellists. Selection criteria included a publication record, an active clinical practice in the treatment of KDs, and a commitment to participate for the study duration. The goal was to include international participants to enable a wide variety of experiences, viewpoints, clinical resources, and treatment strategies. Respondents represented an internationally diverse cohort with broad geographic distribution across five continents and a wide range of clinical experience. A total of 23 internationally recognised experts ultimately agreed to participate. No patients or members of the public were involved in the design, conduct, reporting, or dissemination plans of the study.

Modified Delphi technique

A modified Delphi method was utilised, which is an accepted process that is widely implemented in orthopaedic research. This process involves a structured focus group session to synthesise expert opinion where empirical guidance is limited through anonymous, iterative feedback and systematic aggregation of responses [13, 16, 20, 23, 34, 39, 54, 55, 58]. The working group served as the focus group, overseeing the initial scenario generation, while the lead authors [MJM, EMA and JMS] assessed the responses and provided item refinement for Round 2 questions, with only one of the lead authors performing the survey. Working group members who were also panellists participated in voting. Item revisions were finalised before redistribution of the subsequent round based on aggregated, anonymized feedback.

Next, the panellists participated in a series of two sequential survey rounds to reach consensus on each of the posed scenarios. The objective of Round 1 was to determine whether each scenario met a priori consensus for or against temporising KSEF application, while the objective of Round 2 was to re-rate scenarios that did not reach consensus in Round 1 or to clarify select indications based on aggregated panel feedback. Closed-ended questions and action-oriented statements predominated in the survey, with some open-ended questions included to gain further perspective and potentially generate additional questions for successive rounds. In each survey, the participants were presented with a series of hypothetical clinical scenarios involving a closed, documented (confirmed clinically or radiographically) tibiofemoral KD. Scenario-based items were preceded by the following standardised instructions: "For the below clinical scenarios in the setting of a closed, documented (proven) tibiofemoral knee dislocation, please use the Likert scale to indicate if you would place a knee-spanning external fixator (KSEF) associated with …" Accordingly, a 5-point Likert scale (strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, strongly agree) was used wherein participants were asked to determine whether they would apply a KSEF in each clinical scenario. For each statement, an optional free-text box was provided with encouragement for respondents to support their decision or provide additional information for the successive round(s). Responses were mandatory for each query. Results of each round were anonymously summarised and those reaching consensus were removed.

Consensus was defined a priori as ≥ 70% agreement, with responses of either 'strongly agree' or 'somewhat agree' corresponding to agreement with the statement, or 'strongly disagree' or 'somewhat disagree' corresponding to disagreement with the statement. The response of 'neither agree nor disagree' was treated as neutral and not included in either category to preserve the validity of consensus thresholds. A 70% threshold was chosen to balance methodological rigour with recognition of the inherent heterogeneity of KD presentations and practice environments, and is consistent with several published consensus statements in this field [13, 20, 23, 39, 54, 60]. Consistent with Hurley et al., 90%–99.9% agreement was considered 'strong consensus' and 100% agreement was considered 'unanimous consensus' [23]. In this context, unanimous consensus reflects uniform agreement within this panel and suggests high confidence that the scenario should (or should not) prompt temporising KSEF use. 'Strong consensus' reflects broad support with limited dissent. Thus, these scenarios should be treated as recommended indications while recognising that dissenting viewpoints may reflect meaningful clinical heterogeneity. In contrast, scenarios without consensus should be interpreted as areas where individualised judgement and local resource considerations should take precedence.

After each round, a summary of the anonymized results was evaluated by the lead authors [MJM, EMA and JMS]. Items that reached consensus were excluded after the first round. Scenarios for which substantial clarification was requested in free-text responses were retained, modified for clarity, or split into more specific scenarios for Round 2. Panellists were permitted to revise their responses considering the results of Round 1. All ratings were anonymous to other panellists throughout all rounds. After Round 2, the study was concluded, as no additional clarification was required at this stage.

Data capture and analysis

Prospective participants were first contacted and invited via email, and the final cohort received the survey electronically through the Yale University Qualtrics® platform. No pilot study was conducted prior to survey distribution. Non-respondents received up to three weekly reminders via an integrated reminder function. Level of agreement is presented as percentages, which were calculated after each round.

Because members of the working group were involved in generating the initial clinical scenarios, a sensitivity analysis was also performed to evaluate whether inclusion of working group members influenced the consensus findings. Consensus calculations were repeated after excluding these individuals from the analysis.

Free-text responses to open-ended queries were exported from Qualtrics® into Microsoft® Excel and analysed using inductive content analysis [35]. Two investigators independently categorised responses, utilising a third reviewer to resolve discrepancies. Multi-coding was permitted, but each category was counted once per respondent to avoid overweighting verbose answers. Numeric responses were grouped into clinically meaningful bins and summarised descriptively in rank-order by frequency of mentions. The exact responses from each of the panellists to each open-ended question are included in Supporting Information: Appendices 2–9 which are provided to allow for a more detailed review of the coding and theme development process.

Operational definitions

For the purposes of this study, MLKI was defined as an acute knee injury involving injury to at least two of the four major ligamentous structures of the knee (anterior cruciate ligament, posterior cruciate ligament, medial collateral ligament, lateral collateral ligament, posteromedial corner or posterolateral corner), with or without frank tibiofemoral dislocation. KD was defined as disruption of the normal articulating surfaces of the tibiofemoral joint, confirmed clinically or radiographically, regardless of whether the joint was reduced prior to definitive imaging. In this study, KDs are considered a subset of MLKIs. Concentric reduction was defined as restoration of tibiofemoral alignment without persistent tibial translation on post-reduction imaging. Post-reduction subluxation was defined as persistent tibiofemoral malalignment or translation after reduction confirmed on imaging. Inability to maintain reduction was defined as recurrent subluxation or dislocation in NIKI after an initially acceptable reduction. Severe soft tissue injury was defined as soft tissue compromise anticipated to require staged wound management, including serial debridement, negative-pressure wound therapy, skin grafting, or flap coverage, and where non-invasive immobilisation is not feasible or risks skin viability. Morbid obesity was defined as a BMI ≥ 40 kg/m². Open KD was defined as a KD associated with an overlying soft tissue wound that communicates with the joint or fracture site. Closed KD was defined as a KD without such a communicating wound. Vascular injury was defined as an arterial injury of the limb (popliteal artery) that necessitated any surgical intervention, including stent placement, interposition grafting, bypass or primary repair.

RESULTS

Demographic characteristics

Panellists were predominantly sports medicine fellowship-trained orthopaedic surgeons from high-resource, academic, Level I trauma centres in the United States. These characteristics likely reflect high access to operating room resources, advanced imaging, and subspecialty support, which may influence the perceived feasibility of temporising KSEF application and staged management pathways. A detailed summary of the demographic characteristics of the panellists is provided in Table 1.

Degree of consensus

Round 1 was initiated on 2/1/2025, and Round 2 was initiated on 6/24/2025 and finalised on 7/21/2025.

TABLE 1 Summary of demographic characteristics of panellists.

Characteristic	Details
Mean time in clinical practice (range)	17.8 (2–35) years
Mean annual MLKI surgical volume (inpatient)	20.4 (0–75) cases/yr
Mean annual MLKI clinic volume (outpatient)	19.5 (2–45) cases/yr
High-resource practice setting	21/23 (91%)
Academic practice setting	22/23 (96%)
Any ER on-call responsibilities	18/23 (78%) Average monthly on-call (range): 2.9 days (0–8)
Trauma center level*	Level I: 14 (93%) Level II: 0 (0%) Level III: 1 (7%)
Countries represented	United States: 15 (65.2%) Canada: 3 (13%) South Africa: 1 (4%) Brazil: 1 (4%) Norway: 1 (4%) Denmark: 1 (4%) Qatar: 1 (4%)
Fellowship training	Sports Medicine: 22 (96%) Trauma: 3 (13%) Arthroplasty: 1 (4%) Foot & Ankle: 1 (4%) Shoulder & Elbow: 1 (4%)

Note: MLKI volumes reflect both dislocated and non-dislocated MLKI presentations and are reported as a proxy for panellist experience.

*Trauma center level only included respondents practicing in the United States ($n = 15$).

Abbreviations: ER, emergency room; MLKI, multiligament knee injury.

Response rate was 100% in Round 1 and 96% in Round 2. No item-level missingness occurred within submitted surveys, and no delays were encountered. Round 1 consisted of 17 clinical scenarios and nine open-ended queries. After Round 1, eight clinical scenarios achieved positive consensus (≥70% agreement) for the application of a temporising KSEF, one achieved negative consensus (≥70% disagreement), and eight failed to achieve consensus (<70% agreement or disagreement). Overall, four scenarios achieved unanimous consensus (100% agreement) and two achieved strong consensus (90%–99.9% agreement).

Three scenarios progressed to Round 2, including scenario 12 (bilateral closed KDs: if NEITHER limb independently meets the indication, apply bilateral KSEF), scenario 13 (morbid obesity (BMI ≥ 40) WITH an adequate fit NIKI available), and scenario 15 (open KD). The bilateral closed tibiofemoral KD scenario progressed to Round 2 because Round 1 responses demonstrated clinically meaningful dispersion, suggesting persistent uncertainty regarding whether bilaterality alone should modify an otherwise 'no-KSEF' recommendation. The Round 2 re-rating clarified that bilaterality alone does not justify temporising KSEF in the absence of limb-specific indications, and the scenario achieved negative consensus after panellists reviewed group feedback. The BMI > 40 despite availability of adequately fitting NIKI scenario progressed to Round 2 because Round 1 responses were split nearly equally, reflecting uncertainty regarding whether obesity increases risk of failure of noninvasive immobilisation versus frame-related morbidity. The Round 2 re-rating confirmed sustained practice variation, as the scenario did not reach consensus despite structured feedback. Finally, open KD progressed to Round 2 because Round 1 responses demonstrated significant variability and did not meet the consensus threshold despite being frequently cited as an indication in open-ended responses. The Round 2 re-rating further emphasised the variability in practice patterns, as responses were split equally.

One scenario was introduced in Round 2 (after vascular bypass, use KSEF for tibiofemoral stabilisation to protect the graft during staged wound procedures) because Round 1 consensus supporting KSEF in the setting of bypass warranted a more granular, mechanistic framing that distinguished graft protection during staged wound procedures from the broader category of vascular injury. This addition improved interpretability of the vascular indication by operationalizing the rationale for KSEF use after bypass. This scenario achieved positive consensus in Round 2.

In general, unanimous consensus largely reflected decision points with minimal clinical ambiguity, most notably the presence or absence of post-reduction instability and failure of NIKI. Furthermore, patterns that consistently influenced agreement levels were associated with post-reduction instability, vascular injury, and severe soft tissue injury. Post-reduction instability also represented the most influential modifier of consensus outcomes. For example, tibial plateau fracture-dislocation achieved unanimous positive consensus for temporising KSEF use in the presence of post-reduction instability but no consensus in the absence of it. Similarly, extensor mechanism disruption achieved strong positive consensus in the presence of post-reduction instability but no consensus in the absence of it.

A complete summary of the consensus findings is presented in Table 2, and examples of scenarios that achieved unanimous or strong consensus are illustrated

TABLE 2 Summary of consensus findings for temporising knee-spanning external fixator application.

Clinical scenario	Agreement	Consensus
1. KD without post-reduction instability		
a. Round 1 b. Round 2	23/23 (100%) No N/A	Unanimous negative consensus
2. Vascular injury requiring bypass		
a. Round 1 b. Round 2	20/23 (87.0%) Yes N/A	Positive consensus
3. After vascular bypass, use KSEF for tibiofemoral stabilisation to protect the graft during staged wound procedures		
a. Round 1 b. Round 2	N/A17/22 (77.3%) Yes	Positive consensus
4. Open fasciotomy wounds		
a. Round 1 b. Round 2	16/23 (69.6%) Yes N/A	No consensus
5. Morbid obesity (BMI ≥ 40) with NO NIKI of sufficient size		
a. Round 1 b. Round 2	21/23 (91.3%) Yes N/A	Strong consensus
6. Tibial plateau fracture-dislocation with post-reduction subluxation		
a. Round 1 b. Round 2	23/23 (100%) Yes N/A	Unanimous positive consensus
7. KD with severe soft tissue injury anticipated to require skin grafting or flap coverage		
a. Round 1 b. Round 2	19/23 (82.6%) Yes N/A	Positive consensus
8. Extensor mechanism injury with posterior (or anterior) subluxation after reduction		
a. Round 1 b. Round 2	21/23 (91.3%) Yes N/A	Strong positive consensus
9. Inability to maintain tibiofemoral reduction with NIKI in the sagittal or coronal plane after initial reduction (i.e. redislocation or subluxation)		
a. Round 1 b. Round 2	23/23 (100%) Yes N/A	Unanimous positive consensus
10. Persistent subluxation in the sagittal or coronal plane after initial reduction with NO evidence of skin compromise/impending necrosis		
a. Round 1 b. Round 2	20/23 (87.0%) Yes N/A	Positive consensus
11. Bilateral closed KDs: if one limb is indicated and the other is not, span ONLY the indicated limb		
a. Round 1 b. Round 2	23/23 (100%) Yes N/A	Unanimous positive consensus
12. Bilateral closed KDs: if NEITHER limb independently meets the indication, apply bilateral KSEF		
a. Round 1 b. Round 2	14/23 (60.9%) No 19/22 (81.8%) No	Negative consensus

TABLE 2 (Continued)

Clinical scenario	Agreement	Consensus
13. Morbid obesity (BMI ≥ 40) WITH adequately fitting NIKI available		
a. Round 1	12/23 (52.1%) Yes	No Consensus
b. Round 2	11/22 (50.0%) Yes	
14. Tibial plateau fracture-dislocation WITHOUT post-reduction subluxation		
a. Round 1	9/23 (39.1%) Yes	No consensus
b. Round 2	N/A	
15. Open KD		
a. Round 1	14/23 (60.9%) Yes	No consensus
b. Round 2	11/22 (50.0%) Yes	
16. Extensor mechanism injury with a reduced tibiofemoral joint after initial reduction		
a. Round 1	14/23 (60.9%) No	No consensus
b. Round 2	N/A	
17. Persistent sagittal or coronal plane subluxation that is taken to the OR for open reduction or soft tissue interposition and is NOW concentrically reduced		
a. Round 1	14/23 (60.9%) No	No consensus
b. Round 2	N/A	
18. Distal femoral condyle fracture-dislocation		
a. Round 1	13/23 (56.5%) Yes	No consensus
b. Round 2	N/A	

Note: Unanimous consensus = 100% agreement. Strong Consensus = 90%–99.9% agreement. Consensus = 70%–89.9% agreement. No Consensus = <70% agreement. N/A = the item did not reach Round 2.

Abbreviations: KD, knee dislocation; KSEF, knee-spanning external fixator; NIKI, non-invasive knee immobilisation.

in Figure 1. The full distributions of agreement, disagreement, and neutral responses for all scenarios are provided in Supporting Information: Appendix 1.

Sensitivity analysis

A sensitivity analysis excluding working group members (n = 13 panellists) demonstrated a similar overall pattern of agreement compared with the primary analysis (Supporting Information: Appendix 11). One scenario that achieved consensus in the primary analysis fell just below (69.2%) the predefined 70% threshold in the restricted analysis (KD with severe soft tissue injury anticipated to require skin grafting or flap coverage). All remaining scenarios retained consensus, although scenario 11 shifted from unanimous to strong consensus.

Open-ended queries

An inductive content analysis was performed to summarise the responses to open-ended queries related to the use of temporising KSEFs in the initial management of KDs. The responses are synthesised and presented in Table 3.

Decision-making algorithm

To facilitate translation of these consensus findings into bedside practice, scenarios that achieved positive or negative consensus were thematically synthesised into a decision-making algorithm for temporising KSEF application after an acute, documented tibiofemoral KD (Figure 2). The algorithm prioritises post-reduction alignment and maintainability with adequately fitting NIKI, while incorporating consensus-supported modifiers that warrant escalation to temporising KSEF, including vascular injury requiring bypass/graft protection and severe soft tissue compromise requiring staged wound management. Themes from scenarios that failed to reach consensus are grouped as 'Individualised Decision-Making' to reflect ongoing clinical uncertainty. The algorithm applies specifically to the decision of whether to apply a

FIGURE 1 Examples of the clinical scenarios that achieved unanimous or strong consensus for the utilisation of a temporising knee-spanning external fixator: morbid obesity (BMI ≥ 40) with NO knee immobilizer/brace of sufficient size (91.3% Yes) (Figure 1a), extensor mechanism injury with posterior (or anterior) subluxation after reduction (91.3% Yes) (Figure 1b), tibial plateau fracture-dislocation with post-reduction subluxation (100% Yes) (Figure 1c), inability to maintain tibiofemoral reduction in the sagittal or coronal plane with non-invasive knee immobilisation after initial reduction (i.e., redislocation or subluxation) (100% Yes) (Figure 1d). BMI, body mass index.

temporising KSEF in the setting of an acute, documented tibiofemoral KD.

DISCUSSION

In the management of an acute documented KD, consensus findings support NIKI when a concentric reduction can be maintained and soft tissue conditions allow, reserving temporising KSEF for situations where the reduction cannot be maintained, there are limb- or skin-threatening associated injuries, or where NIKI is not feasible due to body habitus. Within this framework, these findings support a selective rather than routine approach to temporising KSEF use. The default strategy in the initial management of KDs should be immobilisation with adequately fitting NIKI for a stable and maintainable reduction, with escalation to a temporising KSEF when specific injury-related modifiers are present, including persistent post-reduction instability, vascular injury/reconstruction requiring protection, major soft tissue compromise requiring repeated access or periarticular fractures that magnify the deficiency of the soft tissue restraints.

In practice, following tibiofemoral reduction and immediate neurovascular and soft tissue assessment, orthopaedic surgeons should first establish whether the knee is concentrically reduced and maintained with NIKI. From there, consensus discourages routine KSEF application and favours non-invasive immobilisation with close surveillance and early planning for advanced imaging and definitive ligamentous strategy. In contrast, when the knee demonstrates persistent post-reduction instability, consensus supports escalation to temporising KSEF to maintain alignment while definitive planning proceeds. This approach is consistent with the broader literature emphasising that the principal indication for KSEF is failure of non-invasive methods to achieve or maintain a stable reduction, with additional consideration given in the setting of vascular injury, soft tissue constraints and body habitus.

Knee dislocations with severe soft tissue compromise

In the setting of a KD with severe soft tissue compromise, a temporising KSEF aims to maintain reduction, assist in hospitalisation and nursing care, and facilitate staged soft tissue management (serial debridement, negative pressure wound therapy and definitive coverage). The consensus findings are congruent with

TABLE 3 Inductive content analysis of open-ended responses to queries related to the use of knee-spanning external fixation in the treatment of knee dislocations.

Question	Participant comment summary for inductive content analysis of all the comments (see Supporting Information: Appendix 2–9 for complete free-text responses)
At your institution, what patient receives external fixation when presenting with a multiligament knee injury? (Appendix 2)	Four respondents (17%) reported that all or the majority of closed KDs are treated with a temporising KSEF. 21 respondents provided a percentage for the proportion of KD patients treated with a temporising KSEF at their institution (median 15.0%, mean 26.7%, SD 28.7%, range 5-100%), indicating marked inter-institutional variability. The most consistently cited indications were inability to maintain a reduced/concentric knee after closed reduction (gross instability, recurrent subluxation, or loss of reduction via NIKI) (14 mentions); vascular injury or protection of a vascular repair/bypass (13 mentions); and open knee injury or major soft tissue compromise (large defects, skin loss/burns/wounds/fasciotomies) (13 mentions).
Following external fixation, when is the next time (in days) a follow-up radiograph is obtained? (Appendix 3)	The most frequently cited timing was either ≤24 hours (6 mentions) or 8–14 days (6 mentions). Mentioned often but less consistently was 3–7 days (4 mentions). Barely mentioned were 24–72 hours (2 mentions) and ≥15 days (2 mentions).
If an external fixator is used, what is your preferred timeframe for removal? (Appendix 4)	The most frequently cited removal windows were ≤2 weeks (9 mentions) and 4–6 weeks (7 mentions). Mentioned often but less consistently were 3–4 weeks (4 mentions) and non-numeric statements to remove "ASAP/when clinically safe" (4 mentions).
Do you give a pin site "holiday" after external fixator removal prior to definitive ligament reconstruction? If yes, what is the established time period (in weeks)? (Appendix 5)	78% of respondents answered yes to whether they give a pin site holiday after KSEF removal.The most frequently cited duration was about 2 weeks (5 mentions). The next most common window was 4–6 weeks (4 mentions).
Is there an MRI protocol at your emergency room or institution for a patient with a KSEF in place? Please provide obstacles encountered with a KSEF and MRI staff, colleagues, or hospital institution. What is done if the initial MRI is of insufficient quality? (Appendix 6)	43% of respondents reported that there is an MRI protocol at their emergency room or institution for a patient with a KSEF. The main obstacles reported were MRI-compatibility verification and staff comfort (12 mentions), such as needing documented proof that a specific frame is MRI-compatible, uncertainty despite having "MRI-compatible" fixators, discomfort among MRI technologists, transferred patients with unknown hardware, and occasionally having to change a non-compatible frame. Less frequent themes included variable staff knowledge/interpretation (3 mentions), image-quality/technique issues (3 mentions), and logistics/coordination (3 mentions). Other themes included policies to avoid MRI until KSEF removal (2 mentions) and patient-related constraints such as obesity or DVT/PE/infection risk (2 mentions). Only one respondent reported no obstacles. Two respondents described the presence of a formal protocol, and two reported a policy to defer MRI until after KSEF removal. 50% of respondents reported that they would repeat the MRI if the initial MRI were of insufficient quality. 27% reported that they would remove the KSEF entirely, and 32% reported that they would remove the pins, clamps, or bars that are deemed to be creating the artifact. 14% reported that they would perform a CT arthrogram. In addition, singular responses included being unable to repeat the MRI at their institution, using EUA to further evaluate the knee, repeating immediately after KSEF removal and then performing definitive fixation, and using the soft tissue window of a CT scan for further evaluation.
Preferred KSEF construct: • Pin size and placement relative to the joint line? • Anterior or lateral thigh placement? • Medial tibial placement? • Rods & number of bridging rods?(Appendix 7)	Most respondents prefer 5 mm pins (12 mentions), followed by 6 mm (4 mentions), 4.5 mm (4 mentions), and occasionally 5.5 mm (1 mention). Relative to the joint line, respondents most often specified placement ≥ 10 cm away (7 mentions). Fewer cited ~5 cm (2 mentions) or used non-numeric descriptors such as "far" (3 mentions) or "close" (2 mentions).Lateral thigh placement was most common (9 mentions), followed by anterior (7 mentions) and anterolateral (5 mentions).Medial tibial placement was endorsed by the large majority (Yes = 20, No = 1, Unclear = 2). For rod placement, the base configuration was usually two rods (14 mentions), with some using

(Continues)

TABLE 3 (Continued)

Question	Participant comment summary for inductive content analysis of all the comments (see Supporting Information: Appendix 2–9 for complete free-text responses)
	one rod (3 mentions) or ≥3/variable (6 mentions). Where bridging rods were specified, most reported use of two bridging rods (2 mentions) and 1–2 bridging rods (2 mentions) were common; others described conditional/as-needed use (2 mentions) or referenced implied bridging constructs (2 mentions), with one unspecified bridging mention (1 mention). Overall, the pattern favours 5 mm pins placed ≥10 cm away from the joint line, lateral, anterior, or anterolateral thigh vectors, anteromedial tibial pins, a two-rod base, and 1–2 bridging rods added for stability as needed.
What obstacles do you face when managing an acute knee dislocation requiring external fixation? (Appendix 8)	MRI-related barriers dominated (11 mentions), including compatibility verification and staff comfort, scheduling delays, artifact requiring repeat scans, and occasional frame changes before imaging. Communication/coordination problems (6 mentions) and protocol/timing/logistics gaps (6 mentions) were common, including handoffs between services, unclear post-KSEF protocols, difficulty securing OR time, and delays to removal/rehab. Stiffness/ROM problems were also common (6 mentions). Technical issues including pin placement/reduction quality (5 mentions) were also frequently reported. Other obstacles included pin-site infection/care challenges (4 mentions) and vascular-related constraints for reconstruction (3 mentions).
Are there any associated ipsilateral lower extremity fractures that you feel lead you to more likely indicate knee-spanning external fixation for a closed, reduced tibiofemoral dislocation? (Appendix 9)	The most frequently cited ipsilateral injuries prompting KSEF were displaced tibial plateau fractures requiring operative intervention (8 mentions). Knee fracture-dislocation and distal femoral articular fractures appeared 4 times. Less frequent were shaft-level fractures (tibial/femoral) (2 mentions) and ankle/pilon fractures (2 mentions). 7 entries indicated no automatic indication/case-by-case use.

Abbreviations: CT, computed tomography; DVT, deep vein thrombosis; EUA, examination under anaesthesia; KD, knee dislocation; KSEF, knee-spanning external fixator; MRI, magnetic resonance imaging; OR, operating room; PE, pulmonary embolism; ROM, range of motion.

staged KD protocols that recommend temporising KSEF application when soft tissue compromise precludes safe NIKI and definitive reconstruction [31, 37]. Our recommendation is to apply a KSEF in situations where staged soft tissue management is needed, with removal once soft tissue goals are met and the reduction can be safely maintained non-invasively.

Open knee dislocation

While open KD failed to achieve consensus, this injury is consistently described as a primary indication for temporising KSEF application in the literature [8, 11, 29, 31, 37, 42, 53, 62]. Open KDs are complex injuries due to high infection rates and wound healing challenges [27, 31, 67]. In this scenario, temporising KSEFs aim to stabilise the limb, minimise internal and external forces on the soft tissue envelope, facilitate hospitalisation and nursing care, and allow visual access to the wounds. While failure to achieve consensus may suggest only selective use of a KSEF for open KDs, the diverse nature of the potential cutaneous and associated soft tissue injuries would require a multitude of clinical scenarios to be presented and evaluated. Thus, the use of temporising KSEFs in this scenario represents an opportunity for additional focused research.

Vascular injury requiring bypass

In the setting of vascular injury requiring surgical intervention, temporising KSEFs add more definitive stability to a ligamentously compromised tibiofemoral joint where repeat subluxation or dislocation could have detrimental effects on the vascular surgery, and also facilitate fasciotomy wound or negative-pressure therapy device access. This guidance mirrors prior studies listing significant vascular injury among the primary indications for temporising KSEF application [8, 11, 29, 31, 33, 37, 42, 46, 62]. Contemporary evidence likewise notes that a KSEF is utilised in the majority of KDs with vascular injury, while highlighting ongoing debate regarding the comparative benefit and the exact sequencing of application relative to revascularization [49]. Our recommendation is for an open communication with the vascular surgeon to coordinate KSEF application timing, anatomical awareness of vascular graft positioning, planning and positioning of fasciotomy wounds which could impact future ligamentous

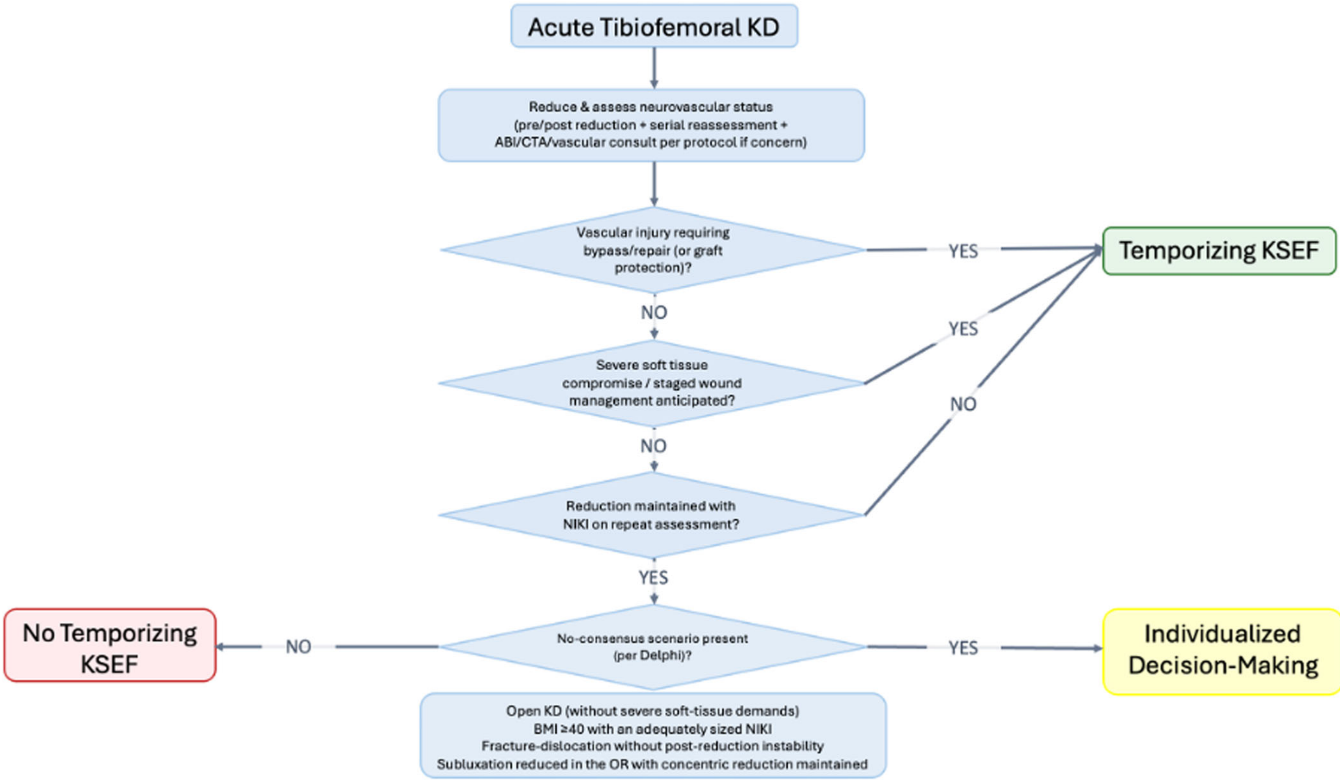

FIGURE 2 Consensus-driven decision-making algorithm for temporising knee-spanning external fixation (KSEF) after an acute, documented tibiofemoral knee dislocation (KD). The algorithm reflects scenarios evaluated in this modified Delphi study. Decision nodes leading to 'Temporising KSEF' or 'No Temporising KSEF' represent clinically significant themes across scenarios reaching a priori consensus, whereas the 'Individualised Decision-Making' branch aggregates themes from scenarios that did not reach consensus and may require case-by-case judgement. ABI, ankle-brachial index; CTA, computed tomography angiography; KD, knee dislocation; KSEF, knee-spanning external fixator; NIKI, non-invasive knee immobilisation; OR, operating room.

surgical treatment, and early frame removal once graft protection and soft tissue goals are met. Importantly, the scenario of vascular repair as opposed to bypass grafting was not assessed. In a vascular repair, there is a concern for more tension on the artery and less laxity that can be introduced than through a vascular bypass graft. Thus, it is suggested that the need for a KSEF in vascular repairs may be even greater.

Periarticular fracture-dislocation

For periarticular fracture-dislocations, consensus findings suggest that NIKI with close surveillance is appropriate unless there is persistent post-reduction instability, vascular injury or soft tissue demands. Several studies support a staged approach for tibial plateau fracture-dislocations with early temporising KSEF application [1, 48, 61]. These recommendations align with contemporary staged protocols for KDs and periarticular fractures, which reserve KSEF use for periarticular fracture-dislocations that remain subluxated, shortened, malaligned, or insufficiently stabilised by NIKI, or to facilitate soft tissue recovery before definitive osteosynthesis and/or ligament surgery [37, 42, 46, 48, 61, 65, 68].

Extensor mechanism injury

There is a strong basis to suggest that extensor mechanism injuries do not independently represent an indication for temporising KSEF unless there is persistent post-reduction subluxation. There can be a strong opinion of concern for higher risk of sagittal subluxation secondary to loss of the anterior restraint of the extensor mechanism, but the decision to apply a temporising KSEF in this scenario should instead be based on whether the knee remains subluxated or grossly unstable after NIKI [38].

Morbid obesity

Several studies have described morbid obesity as a primary indication for temporising KSEF use [6, 15, 17, 57, 64]. However, the consensus findings suggest that the decision to apply a KSEF should be based upon the inability to maintain a concentric reduction with NIKI rather than on body mass index (BMI) alone. Additionally, because patients with ultra-low velocity KDs are at higher risk for neurovascular injury [6], temporising KSEF may be needed more frequently in this population. However, BMI or ultra-low velocity mechanism of injury need not be the sole determinant for KSEF use. When there is NIKI of sufficient size for the patient, the decision to apply a KSEF should instead be based on the soft tissue condition, presence of vascular injury, and/or the ability to maintain the reduction.

Bilateral knee dislocations

In the setting of bilateral KDs, consensus findings discourage bilateral temporising KSEF application if each knee, when assessed independently, can be maintained in concentric reduction with NIKI. Clinically, this approach minimises unnecessary patient burden and potential KSEF-associated complications and reserves temporising KSEF use for limb-specific indications [8, 9, 22, 23, 51, 59, 63].

Limitations

There are several important limitations to this study, beginning with its reliance on anonymous online surveys, which limited real-time in-person debate but facilitated broad international participation. Second, the working group surgeons who generated the scenarios participated as panellists, potentially biasing the responses. Third, the isolated scenarios generated by the working group cannot comprehensively capture the heterogeneity of KDs and the potential for concomitant indications, particularly in terms of the dynamic elements of decision-making for KSEF application. The decision should ultimately be based on an assessment of post-reduction stability, vascular injury, soft tissue status, comorbid systemic injuries, and the overall clinical context. Fourth, vascular surgery stakeholders were not included as panellists, which may affect recommendations related to bypass protection and staged wound procedures. Fifth, these findings do not give recommendations on utilisation of manipulation under anaesthesia or lysis of adhesions upon KSEF removal, or, similarly, timing of definitive ligamentous reconstruction. Sixth, the absence of age, race, and ethnicity data may limit evaluation of how respondent demographics may have influenced responses. Seventh, generalisability may be limited in lower-resource settings where KSEF availability, imaging access, and multidisciplinary support differ. Finally, consensus findings reflect aggregated opinion rather than level 1 evidence, emphasising the ongoing need for prospective studies comparing KDs treated with and without a temporising KSEF for specific clinical scenarios.

CONCLUSION

This modified Delphi study supports the focused use of a temporising KSEF for an acute KD to: (1) maintain a concentric reduction that cannot be reliably achieved with NIKI, (2) protect vascular grafts, and (3) enable staged soft tissue management when needed. In contrast, the findings support avoiding the use of a temporising KSEF when: (1) the joint is reduced and can be safely maintained in reduction with NIKI and (2) soft tissue demands are limited. Additionally, bilateral KDs were not considered an indication for KSEF use, as each limb should be assessed individually. Scenarios that require individualised decision-making and further clarification include open KD, periarticular fracture-dislocation without subluxation, and morbid obesity with a stable reduction that can be maintained with NIKI. These findings offer guidance to standardise initial decision-making for the use of a temporising KSEF in the setting of an acute KD, with the goal of limiting its use to focused indications to minimise patient morbidity from this potentially limb-threatening injury.

AUTHOR CONTRIBUTIONS

Michael J. Medvecky and Ekrem M. Ayhan were the leading authors of the article. Michael J. Medvecky and Jonathan M. Salandra chaired the consensus and coordinated all correspondence between survey respondents and study participants. Jonathan M. Salandra was the primary designer of the study survey with support from Michael J. Medvecky. Ekrem M. Ayhan and Michael J. Medvecky drafted the initial manuscript with significant knowledge and writing contributions from Jonathan M. Salandra, Jay Moran, Meghana Nair, Michael J. Alaia, Túlio V. O. Campos, Michael F. G. Held, Bruce A. Levy, Volker Musahl, Dustin L. Richter, Brian R. Waterman, Daniel B. Whelan, and Robert C. Schenck Jr. Michael J. Medvecky, Michael J. Alaia, Túlio V. O. Campos, Michael F. G. Held, Bruce A. Levy, Volker Musahl, Dustin L. Richter, Brian R. Waterman, and Daniel B. Whelan served as the working group to create the series of clinical scenarios investigated in the survey. All members of the International Knee Dislocation Study Group (IKDSG) provided significant contributions to the knowledge and writing content of subsequent manuscript drafts. All authors, including members of the IKDSG, approved the submitted version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Institutional review board (IRB) approval was obtained from the Yale University IRB (protocol number: 2000039395).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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