Extensor Mechanism Disruption Impacts Treatment of Dislocated and Multiligament Injured Knees

Treatment and Schenck Classification Recommendations Based on a Global Delphi Method

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Background: Multiligament knee injury (MLKI) with associated extensor mechanism (EM) involvement is a rare injury, with limited evidence to guide optimal treatment. The purpose of this study was to identify areas of consensus among a group of international experts regarding the treatment of patients with MLKI and concomitant EM injury.

Methods: Utilizing a classic Delphi technique, an international group of 46 surgeons from 6 continents with expertise in MLKI undertook 3 rounds of online surveys. Participants were presented with clinical scenarios involving EM disruption in association with MLKI, classified using the Schenck Knee-Dislocation (KD) Classification. Positive consensus was defined as ≥70% agreement with responses of either "strongly agree" or "agree," and negative consensus was defined as ≥70% agreement with "strongly disagree" or "disagree."

Results: There was a 100% response rate for rounds 1 and 2 and a 96% response rate for round 3. There was strong positive consensus (87%) that an EM injury in combination with MLKI significantly alters the treatment algorithm. For an EM injury in conjunction with a KD2, KD3M, or KD3L injury, there was positive consensus to repair the EM injury only and negative consensus regarding performing concurrent ligamentous reconstruction at the time of initial surgery.

Conclusions: In the setting of bicruciate MLKI, there was overall agreement on the significant impact of EM injury on the treatment algorithm. We therefore recommend that the Schenck KD Classification be updated with the addition of the modifier suffix "-EM" to highlight this impact. Treatment of the EM injury was judged to have the highest priority, and there was consensus to treat the EM injury only. However, given the lack of clinical outcome data, treatment decisions need to be made on a case-by-case basis with consideration of the numerous clinical factors that are encountered.

Clinical Relevance: Little clinical evidence exists to guide the surgeon on the management of EM injury in the setting of a multiligament injured or dislocated knee. This survey highlights the impact that EM injury has on the treatment algorithm and provides some guidance for management until a further large case series or prospective studies are undertaken.

Multiligament knee injury (MLKI) encompasses a heterogeneous grouping of injuries involving the cruciate and/or collateral ligaments. The injury can be accompanied by a true dislocation of the tibiofemoral joint with various degrees of injury to the surrounding neurovascular structures, soft tissue, and osseous architecture of the knee[1-3]. Isolated injury to the extensor mechanism (EM), involving quadriceps tendon injury, patellar fracture, patellar tendon injury, or avulsion of the tibial tubercle, often occurs in the setting of high-energy trauma[4-6]. In rare cases, MLKIs may present with concomitant injury to the EM. One study found that 12 (5%) of a cohort of 237 patients with MLKI presented with concomitant EM injury[7].

Given the rarity of these injuries, there is a paucity of literature to guide optimal treatment strategies for MLKI with concomitant EM injury[7-11]. One study reported on a series of 15 patients, most of whom achieved favorable outcomes after undergoing staged EM repair followed by ligament reconstruction[10], whereas another study reported a 90% rate of return to

*A list of the Knee Fracture-Dislocation Study Group members is included in a note at the end of the article.

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the prior activity level after single-stage MLKI treatment combined with EM repair[11]. However, both studies were limited by small patient cohorts with various knee injuries and lacked clinical comparison with a control group. Mojica et al. compared outcomes in patients with MLKI who did and did not have a concomitant patellar tendon rupture and found worse functional outcomes in the patients who had patellar tendon rupture[7]. While that study included a control group, it was still limited by a small sample size of 12 patients per group, thereby making it difficult to draw conclusions regarding treatment strategies.

There is currently no clear consensus regarding the optimal treatment of these injuries. The purpose of this study was to identify areas of consensus among a group of international experts regarding the treatment of patients with MLKI and concomitant EM injury.

Materials and Methods

Participant Selection

A working group of 8 surgeons (M.J.M., D.L.R., M.D.M., D.C.W., G.P.T., T.V.O.C., M.H., R.C.S.) with clinical and academic experience in treating MLKI convened to facilitate the development of consensus statements. Two members of the working group (M.J.M., D.L.R.) performed separate PubMed searches to identify first authors and senior authors of publications regarding MLKI, knee dislocation, or EM injury within the last 5 years. Additionally, national and international MLKI taskforces were reviewed to identify participants. A total of 65 orthopaedic surgeons were identified and contacted via email to participate in the study. Selection criteria included a publication record, an active clinical practice involving treatment of MLKI, and a commitment to participate for the duration of the study. We sought to obtain a diverse group that included international participants to allow for a wide variety of experiences, clinical resources, and treatment strategies. A total of 46 knee surgeons from 19 countries across 6 continents participated in this survey. Twenty were from the U.S., and 27 were from 18 countries outside the U.S. (Table I).

Institutional review board approval for the study (protocol no. 2000028912) was obtained before the start of the study.

Establishing Consensus Using a Classic Delphi Technique

The Delphi technique was originally developed by the RAND Corporation as a method for obtaining consensus regarding international affairs[12]. It has been widely used in orthopaedic surgery to achieve consensus on certain topics on which no agreement had previously existed, by employing an iterative process of feedback from experts in the field[13-20]. The Delphi technique begins with open-ended questions to generate ideas for further inquiry. This is followed by a series of survey rounds that may include both open- and closed-ended questions to generate additional questions for the following rounds, until consensus is reached or lack of progression toward consensus is apparent.

In each survey round, the participants were presented with a series of clinical scenarios or treatment strategies regarding MLKI with concomitant EM injury and asked to respond using a 5-point Likert scale: "strongly agree," "agree," "neither agree nor disagree," "disagree," or "strongly disagree." Each question included an opportunity to provide additional clarification that would be utilized for the generation of additional questions in the succeeding round. Based on prior orthopaedic studies utilizing a Delphi technique, positive consensus was defined as ≥70% agreement with responses of either "strongly agree" or "agree," and negative consensus was defined as ≥70% agreement with "strongly disagree" or "disagree."[14,16-20]

After each round, a summary of the results was evaluated. Items that reached either positive or negative consensus were then excluded from the subsequent round, while questions that did not reach consensus were included or clarified in the form of new questions. The Delphi process was completed after the third round, as no additional discordance was encountered at this stage.

In round 1, the group was surveyed with 2 open-ended questions and 4 closed-ended questions to gather initial thoughts and opinions on the clinical importance of EM injuries to the expected treatment algorithm for knees with MLKI and dislocation (Table II).

In round 2, participants were asked to consider the management of a displaced transverse patellar body fracture in the setting of MLKI (Fig. 1). This fracture was selected to provide an EM injury that would mandate open exposure via an arthrotomy and yield a stabler construct, in comparison with a soft-tissue EM injury, but would need to be factored into the postoperative rehabilitation plan. Ligamentous injury was classified using the modified Schenck Knee-Dislocation (KD) Classification[21,22]. Three scenarios were presented: KD2, KD3L, and KD3M. A total of 12 questions (4 for each scenario) were presented. These asked the participants to consider whether

TABLE I Participants from Outside the United States

Country	No.
Argentina	1
Australia	2
Belgium	1
Brazil	5
Canada	1
Chile	1
Colombia	1
Denmark	1
England	1
Germany	1
Greece	1
Japan	1
Norway	2
Scotland	1
South Africa	2
Spain	3
Sweden	1
Switzerland	1

TABLE II Questions in Delphi Round 1*

	Consensus Positive	Consensus Negative
Closed-ended questions		
I believe that a patellar tendon rupture (or extensor mechanism injury) with a MLKI significantly alters the treatment algorithm such that it should be included as a modifier suffix in the Schenck KD Classification (e.g., KD3M-EM), like C for arterial injury or N for nerve injury.	**87%**	13%
A mid-substance patellar tendon rupture alters my treatment algorithm regarding timing of the cruciate ligaments in a MLKI.	58%	42%
I would opt to treat the cruciate ligament injuries at the time of the open patellar tendon repair.	39%	50%
Among the 3 zones of injury of a patellar tendon rupture (proximal, midsubstance or distal) is there any particular zone of injury that would alter your treatment algorithm more than the other?	23%	**77%**
Open-ended questions		
What technical challenges does a complete patellar tendon injury or extensor mechanism disruption impose on your treatment plan or strategy in the MLKI or dislocated knee?		
Please elaborate on how any EM injury would change your treatment algorithm, surgical timing, graft options, rehabilitation, or any other factors.		

*Responses that reached at least 70% agreement are bolded. MLKI = multiligament knee injury, KD = Knee-Dislocation, EM = extensor mechanism.

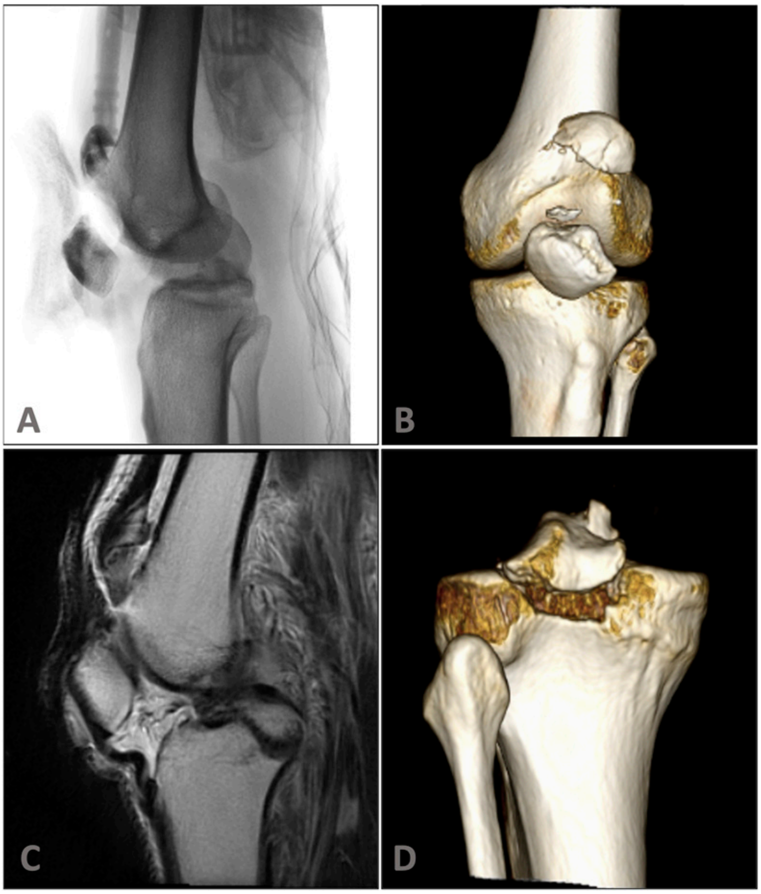

Fig. 1
An open KD3L injury involving a displaced, minimally comminuted transverse patellar fracture and a displaced PCL avulsion fracture from the tibial plateau. **Fig. 1-A** Lateral radiograph. **Fig. 1-B** Three-dimensional computed tomography (CT) reconstruction demonstrating the patellar fracture. **Fig. 1-C** Proton-density-weighted sagittal magnetic resonance image demonstrating a redundant patellar tendon secondary to the patellar fracture. **Fig. 1-D** Three-dimensional CT reconstruction demonstrating the PCL tibial avulsion fracture.

TABLE III List of Statements Reaching Consensus After Delphi Round 2*

	Consensus	
	Yes	No
A patient sustained a bicruciate injury (KD2) & displaced transverse patella body fracture.		
I would perform patella ORIF only.	**81%**	19%
I would perform patella ORIF & reconstruct the PCL.	23%	**77%**
I would perform patella ORIF & reconstruct the ACL.	3%	**97%**
I would perform patella ORIF & reconstruct the PCL & ACL.	24%	**76%**
A patient sustained a KD3L injury and a displaced patella body fracture.		
I would perform patella ORIF only.	**72%**	28%
I would perform patella ORIF & reconstruct the PCL.	14%	**86%**
I would perform patella ORIF & reconstruct the PCL & LCL.	28%	**72%**
I would perform patella ORIF & reconstruct the PCL, ACL & LCL.	23%	**77%**
A patient sustained a KD3M injury and a displaced patella body fracture.		
I would perform patella ORIF only.	**81%**	19%
I would perform patella ORIF & reconstruct the PCL.	24%	**76%**
I would perform patella ORIF & reconstruct the PCL & MCL	23%	**77%**
I would perform patella ORIF & reconstruct the PCL, ACL & MCL.	26%	**74%**

*Responses that reached at least 70% agreement are bolded. KD = Schenck Knee-Dislocation Classification, KD2 = bicruciate ligament injury, KD3L = bicruciate + lateral collateral ligament injury, ORIF = open reduction and internal fixation, KD3M = bicruciate + medial collateral ligament injury, PCL = posterior cruciate ligament, ACL = anterior cruciate ligament, LCL = lateral collateral ligament, MCL = medial collateral ligament.

isolated patellar open reduction and internal fixation (ORIF) or various combinations of ORIF and corresponding cruciate and/or collateral ligament reconstruction should be performed (Table III). Only isolated bicruciate ligamentous knee injuries (injuries of the posterior cruciate ligament [PCL] and anterior cruciate ligament [ACL]) and bicruciate injuries involving each respective collateral ligament (medial collateral ligament [MCL] and lateral collateral ligament [LCL]) were included in these clinical scenarios.

The purpose of round 3 was to evaluate the treatment of 3 EM injuries that would result in relatively less secure fixation than the previously described clinical injury (transverse patellar fracture) and would impact the postoperative rehabilitation plan: patellar tendon rupture, displaced tibial tubercle fracture, and displaced inferior-pole patellar fracture. A question about quadriceps tendon rupture was not included because of the extreme rarity of its presentation, but it could be considered a part of this soft-tissue EM injury spectrum. Participants were asked to consider the 3 EM injuries in the context of patients with KD2, KD3L, and KD3M injury, resulting in a total of 9 questions (Table IV).

Data Capture and Analysis

Initial invitations were sent via email. After the survey group was established, surveys were conducted using the Yale Qualtrics Research Suite, an online survey platform. Reminders were sent via email on a weekly basis, up to 3 times, if a participant had not returned the survey within the first week.

Source of Funding

No external funding was received for this work.

Results

Demographics

The mean time in clinical practice was 15.3 years (range, 1 to 35 years), and the mean annual case volume of MLKI surgeries was 19.8 (range, 3 to 75) (Fig. 2). Of the 46 respondents, 100% participated in rounds 1 and 2 and 96% (44 of 46) participated in round 3.

Round 1 Results

Round 1 consisted of 4 closed-ended and 2 open-ended questions (Table II). Two of the closed-ended questions reached >70% consensus. There was strong positive consensus (87%) that EM injury in combination with MLKI significantly alters the treatment algorithm and EM injury should therefore be added as a modifying suffix in the Schenck classification. Additionally, there was 77% positive consensus that the zone of injury of a patellar tendon rupture (proximal, midsubstance, or tubercle avulsion) does not influence the treatment algorithm. No consensus was reached regarding the recommendations for treating the cruciate ligaments at the time of the open EM surgery or regarding timing of surgical treatment of the cruciate ligament injury.

The issues raised by the responses to the open-ended questions were categorized to establish common themes (Table V). Although there is no tibiofemoral fracture involvement, which can markedly impact stability, some participants felt that any osseous or soft-tissue disruption of the EM contributes to posterior instability and alters the treatment options and timing of surgery. Other concerns raised included the staging of treatment, arthrofibrosis and/or heterotopic ossification, and the effect on postoperative rehabilitation. The issues raised in the open-

TABLE IV List of Statements Reaching Consensus After Delphi Round 3*

	Consensus	
	Yes	No
A patient sustained a bicruciate injury (KD2) & patellar tendon rupture. I would perform patellar tendon repair only.	**89%**	11%
A patient sustained a bicruciate injury (KD2) & displaced tibial tubercle fracture. I would perform tibial tubercle ORIF only.	**91%**	9%
A patient sustained a bicruciate injury (KD2) & displaced inferior pole patella fracture. I would perform ORIF of the inferior pole patella fracture only.	**93%**	7%
A patient sustained a KD3L & patellar tendon rupture. I would perform patellar tendon repair only	**91%**	9%
A patient sustained a KD3L & displaced tibial tubercle fracture. I would perform tibial tubercle ORIF only	**93%**	7%
A patient sustained a KD3L & displaced inferior pole patella fracture. I would perform ORIF of the inferior pole patella fracture only.	**95%**	5%
A patient sustained a KD3M & patellar tendon rupture. I would perform patellar tendon repair only	**91%**	9%
A patient sustained a KD3M & displaced tibial tubercle fracture. I would perform tibial tubercle ORIF only	**92%**	8%
A patient sustained a KD3M & displaced inferior pole patella fracture. I would perform ORIF of the inferior pole patella fracture only.	**95%**	5%

*Responses that reached at least 70% agreement are bolded. KD = Schenck Knee-Dislocation Classification, KD2 = bicruciate ligament injury, ORIF = open reduction and internal fixation, KD3L = bicruciate + lateral collateral ligament injury, KD3M = bicruciate + medial collateral ligament injury.

ended questions were used to generate additional closed-ended inquiries for subsequent rounds.

Treatment of Patellar Fracture Only Versus Concurrent Ligamentous Reconstruction

Of the 12 scenarios presented in the second round, 3 reached >70% positive consensus and the remaining 9 reached >70% negative consensus. In the setting of a displaced patellar body fracture with a KD2 injury, there was 81% agreement on performing ORIF of the patellar fracture only and >70% agreement on not performing a concurrent isolated cruciate or bicruciate ligament reconstruction at the time of initial surgery. Similarly, in the context of a KD3L or KD3M injury, there was >70% agreement to repair the patellar fracture only and not treat the cruciate or collateral ligaments concurrently (Table III).

Treatment of Other EM injuries

In round 3, participants were asked to consider other EM injuries that would result in less secure fixation: patellar tendon rupture, displaced tibial tubercle fracture, and displaced inferior-pole patellar fracture (Fig. 3). All 9 of the presented scenarios reached >70% positive consensus. For a patient with KD2 injury, there was strong agreement (89% to 93%) to initially treat only the 3 types of EM

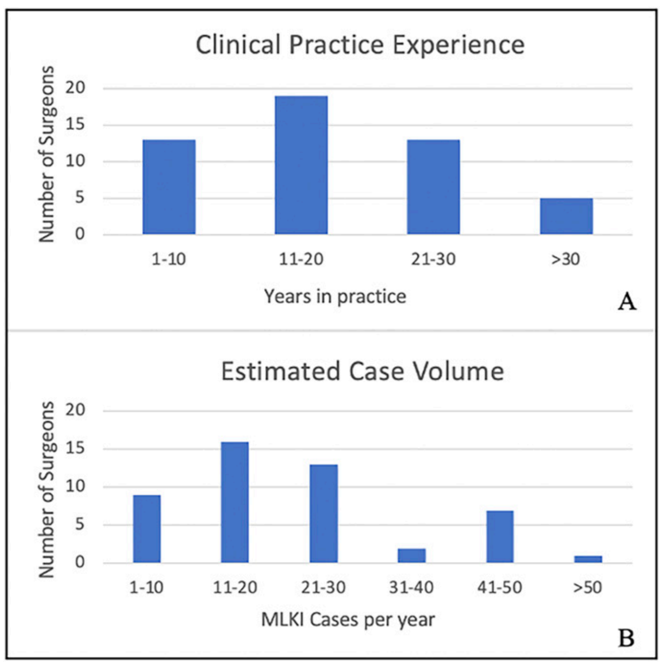

Fig. 2
Clinical practice experience and estimated annual MLKI (multiligament knee injury) volume of the survey respondents.

TABLE V Summary of Treatment Issues Raised by Round 1 Inquiries*

- Relative urgency of the treatment for the EM injury
- Uncertain impact of the magnified posterior stress that the disrupted EM has on a PCL-deficient knee
- Consideration of staged treatment of the EM and ligamentous injuries
- Concern for arthrofibrosis and/or heterotopic ossification secondary to the diffuse soft-tissue injury
- Consideration of augmenting the EM repair
- Consideration of reconstructing 1 or both cruciate ligament injuries at the time of the arthrotomy needed for the EM repair
- Effect on the rehabilitation options given the EM repair

*EM = extensor mechanism, PCL = posterior cruciate ligament.

injuries. Similarly, for KD3M or KD3L, there was strong agreement (>90%) to initially treat only the EM injuries (Table IV).

Discussion

There was consistent agreement among the surgeons participating in this study that EM injury in the setting of MLKI significantly alters the treatment algorithm, and for treating EM injuries only at the time of initial surgery and not concurrently reconstructing the cruciate or collateral ligaments.

The EM contributes significantly to posterior knee stability, such that it could be considered one of the primary stabilizing "ligaments" of the knee. We recommend the addition of a modifier suffix such as "-EM" to the Schenck KD Classification. The Schenck KD Classification was initially described in 1994 and was modified by Wascher et al. in 1997 to include vascular injuries as well as to specify medial versus lateral injuries[21-24]. In the context of KD5 injuries (KD + periarticular fracture), Stannard et al. recommended modifying the classification further to delineate ligament damage by adding a suffix to indicate which classification would be appropriate if the fracture was not present[25]. Similarly, a recent Delphi panel suggested the inclusion of an additional "-O" modifier to indicate open injuries[26]. Adding EM injuries as a "sixth stratified level" has been previously suggested by Mojica et al.[7]. The widely used Schenck KD Classification captures a heterogeneous group of injuries, and adding such a modifier can improve our ability to communicate and guide treatment for concurrent EM injury.

Treating MLKI associated with concomitant EM injury presents a logistical challenge regarding the timing and

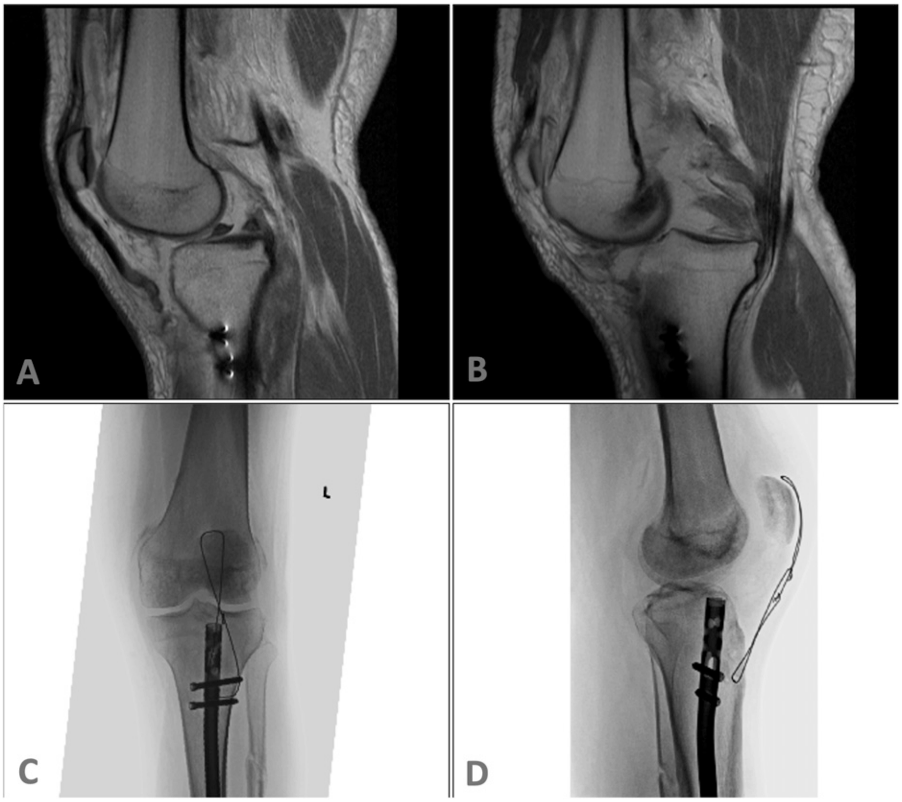

Fig. 3

KD3M injuries. **Fig. 3-A** Sagittal proton-density-weighted magnetic resonance image demonstrating distal avulsion of the patellar tendon and lateral compartment subluxation. **Fig. 3-B** Sagittal proton-density-weighted magnetic resonance image demonstrating medial compartment dislocation and an absent medial meniscus. Operative exploration showed a root tear of the anterior horn of the medial meniscus. **Fig. 3-C and Fig. 3-D** Postoperative radiographs showing a well-aligned tibiofemoral joint and cerclage wire augmentation of the patellar tendon repair.

prioritization of surgery. Single-stage surgery is tempting to theoretically expedite patient recovery and to increase procedural ease, given the access to the intercondylar notch using the exposure afforded by the arthrotomy needed for the EM repair. Two-stage surgery allows for a focus on protection of the EM repair, but it adds the increased morbidity risk of additional surgeries. If 2-stage treatment is elected, the surgeon needs to verify that a concentric tibiofemoral reduction is obtained and maintained acutely and in the follow-up phase of treatment, as the potential for tibiofemoral subluxation exists[27]. Depending on the clinical scenario, this may require immobilization with a range of options, including spanning external fixation, hinged external fixation, a cylindrical cast, a knee-ankle-foot orthosis, a hinged knee brace, or a knee immobilizer. Time to surgery is also important, as previous studies have reported better outcomes with earlier repair of the patellar tendon[28,29], whereas delayed repair may contribute to worse outcomes due to retraction of the ruptured tendon which could result in the possible need for grafting[30,31]. However, the initial swelling of the knee may increase the difficulty of early reconstruction of cruciate ligaments and contribute to arthrofibrosis and/or heterotopic ossification[32]. There are few clinical outcome studies or case studies to guide the decision-making process because of the rarity of the injury.

Furthermore, injuries to the EM, both soft-tissue and osseous, eliminate the option of patellar tendon or quadriceps tendon graft harvesting in both the acute and chronic settings. This factor can have significant implications in limited-resource settings in which allograft is less accessible. Repair of the EM requires an open arthrotomy and affects the ability to perform arthroscopic surgery, given the high potential for fluid extravasation into the anterior soft tissues. Participants also raised concern about using more extensive incisions and open reconstruction in an unstable, acute injury pattern with significant soft-tissue injury.

There was consistent agreement among the surgeons in this study to treat only the EM injury at the time of initial surgery, and to not concurrently reconstruct the cruciate or collateral ligaments. This was consistent with the series reported by Liu et al., in which most of the 15 patients treated with 2-stage procedures (initial reduction and repair of the EM followed by multiple ligament reconstruction after at least 6 weeks) achieved a normal range of motion and knee stability[10]. On the other hand, Zhao et al. reported favorable outcomes in 10 patients after single-stage surgery for MLKI and concomitant EM injury[11]. However, they selected only active and young patients for ACL procedures and did not perform ACL reconstruction in patients who had posterolateral corner (PLC) or MCL injuries[11]. Further investigation is therefore warranted, given the few clinical outcome studies on this topic. The surgeon may deem single-stage surgery to have a relative benefit, but this decision must factor in the surgeon's clinical experience and assess patient factors such as associated injuries, social support, and estimation of rehabilitation compliance as well as the availability of local resources.

MLKI with concomitant EM injury raised certain issues regarding postoperative rehabilitation. Early postoperative joint mobilization is important to reduce the development of arthrofibrosis and knee stiffness, but it must be balanced against protection of the EM repair[9]. Mojica et al. reported that patients in their cohort were treated with a hinged knee brace locked in extension for a minimum of 3 weeks; however, the period of immobilization was dependent on the surgeon and was often based on the number of ligaments reconstructed[7]. Additionally, 75% of the patients in that study underwent staged treatment of the concomitant EM injury and MLKI[7]. In the present study, we did not specifically inquire about the postoperative rehabilitation protocol, but we believe that additional studies are needed to determine optimal rehabilitation strategies and to minimize complications.

Limitations

As with all Delphi studies, an inherent limitation is that the findings represent expert opinions and cannot match the level of evidence from randomized controlled trials, which would be challenging to conduct given the rarity of these injuries. Another limitation is that the process involved administering the surveys online, resulting in a lack of a face-to-face discussion and an ability to discuss the various opinions and evidence in more detail. However, the use of online surveys allowed us to include participants from a wide geographic area (6 continents), which would have been too logistically challenging to achieve in person. Additionally, recent authorship of applicable material was used as a proxy for expertise, but our quantification of clinical or surgical expertise may have introduced selection bias. However, we included surgeons from diverse geographic and clinical backgrounds to obtain a wide survey sample to lessen selection and sampling bias. Consensus was defined as ≥70% agreement in this study, based on prior Delphi studies, ranging from 70%-80%[13-20]. However, although 100% consensus was not reached for any of the clinical scenarios, >90% consensus was achieved for nearly all scenarios in round 3. Finally, the clinical vignettes were standardized to allow for systematic discussion. However, the idealized scenarios presented do not always represent the heterogeneity of injuries, patient factors, surgeon factors, and resource availability that must be considered in treating these injuries.

Conclusions

In the setting of bicruciate MLKI, there was overall agreement on the significant impact of EM injury on the treatment algorithm. We therefore recommend that the Schenck KD Classification be updated with the use of an "-EM" modifier suffix to highlight this impact. Treatment of the EM injury was judged to have the highest priority, and there was consensus to treat only the EM injury. However, given the lack of clinical outcome data, treatment decisions need to be made on a case-by-case basis with consideration of the numerous clinical factors that are encountered. ■

Note: The Knee Fracture-Dislocation Study Group participants include Geoffrey D. Abrams, MD; Robert A. Arciero, MD; Björn Barenius, MD, PhD; Jacqueline M. Brady, MD; Gonzalo Ferrer, MD; Carlos E. Franciozi, MD, PhD; Pablo E. Gelber Ghertner, MD, PhD; Alan Getgood, MD; Michael Hantes, MD; Christopher D. Harner, MD; Laith M. Jazrawi, MD; Aaron J. Krych, MD; Koen C. Lagae, MD; Robert F. LaPrade, MD; Bruce A. Levy, MD; Martin Lind, MD; Timothy Lording, MBBS, FRACS, FAOrthA; Rodrigo Maestu, MD; Matthew Matava, MD; Gilbert Moatshe, MD, PhD; Joan C. Monllau, MD, PhD; Iain R. Murray, FRCS, MFSEM, PhD; Volker Musahl, MD; Nelson

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