Case Report

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“Multiligamentous” Injuries of the Skeletally Immature Knee: A Case Series and Literature Review

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Abstract

Multiligamentous knee injuries occur rarely in the pediatric population. Few reports are available in the existing literature; furthermore, no longitudinal studies regarding the choice of treatment and long-term outcomes for this unique population have been published. To fill this knowledge gap, the literature on multiligamentous injuries of the knee in the adult population is commonly used as a guideline in clinical decision making for children and adolescents. However, the developing bone and physis are often weaker than the ligamentous structures of the knee—particularly during periods of rapid growth—and may be the first to fail in the event of injury or trauma. Bony avulsion fractures and peri-physeal fractures, rather than mid-substance ligamentous ruptures, may result. Patients with skeletal immaturity may therefore present with different patterns of multiligamentous injury after acute trauma to the knee. This article describes the clinical presentation, our treatment approach, and short-term outcomes for three pediatric patients with multiligamentous injuries of the knee and reviews the current literature relating to these uncommon injuries.

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Multiligamentous knee injuries (MKIs) occur rarely in the skeletally immature population; however, the true incidence is unknown. Little information is available to guide treatment of pediatric patients who sustain MKIs; data concerning the clinical outcomes for this unique population are similarly lacking.[1-5] As a result, no consensus exists among healthcare providers regarding the optimal treatment of patients with MKIs and open physes.

The adult literature concerning MKIs is commonly used as a guideline in clinical decision making for children and adolescents. However, because of their unique anatomy, patients with skeletal immaturity may present with different patterns of multiligamentous injury after acute trauma to the knee.[6] The developing bone and physis are weaker than ligamentous structures and are often the first to fail in the event of injury;[7] traumatic knee injuries in skeletally immature patients may therefore result in avulsion fractures of the ligament attachment sites. In addition to bony avulsion fractures, ligament injury in young patients may alternatively manifest as a ligamentous avulsion from bone without associated fracture or as an intrasubstance tear through the body of the ligament itself. In the setting of MKI, these patterns of ligamentous injury may exist in combination.

Differences between children and adults with MKIs regarding clinical presentation, injury patterns, and physical and psychologic development have the potential to affect treatment decisions and functional outcomes. Surgical timing parameters, techniques, and postoperative rehabilitation strategies that yield successful outcomes in mature adults may not be safe or effective for developing children and adolescents. For example, both children and adults may present with pain, instability, and difficulty with ambulation after an acute traumatic MKI; however, it is not known whether rates of vascular injury and peroneal nerve dysfunction—complications associated with knee dislocation, of which MKIs are a subset—are comparable between the two populations. Similarly, although chronic instability is a well-described sequela of MKI in adults, the incidence of long-term functional instability in the pediatric population has not been established. Additionally, skeletally immature patients are vulnerable to traumatic and/or iatrogenic physeal injury with resultant angular deformity or limb length discrepancy; surgical techniques may be tailored to avoid such physeal arrest. By contrast, growth disturbance is of no concern for older adolescent and adult patients whose physes are physiologically fused.

Furthering our understanding of MKIs in the skeletally immature population is essential for improving the musculoskeletal care we provide. Here, we retrospectively report on our experience with three pediatric patients with MKIs and open physes and review the existing literature relating to this uncommon injury.

This study was performed in accordance with Institutional Review Board regulations.

Case 1 is a male patient aged 13 years 1 month, who presented with multiple musculoskeletal injuries after being struck by a car while using a motorized scooter. In addition to a subdural hematoma, he had sustained an open left transverse femoral diaphyseal fracture with two 30-cm associated wounds, an open left ankle fracture dislocation, and open fractures of the third, fourth, and fifth left metatarsals managed with urgent surgical irrigation and débridement (I + D) and stabilization. Distal pulses could not be palpated on presentation but returned after reduction of the ankle. Preoperative imaging included a CT angiogram, which demonstrated intact vasculature of the left lower extremity; the consulting vascular surgery service did not recommend additional imaging or intervention. Additionally noted on the initial CT angiogram were multiple bony avulsion fractures about the left knee, including from the lateral femoral condyle and posterior cruciate ligament (PCL) tibial insertion site. Multiligamentous knee injury was suspected, and he was immobilized in a hinged knee brace (HKB) while being treated for his myriad injuries.

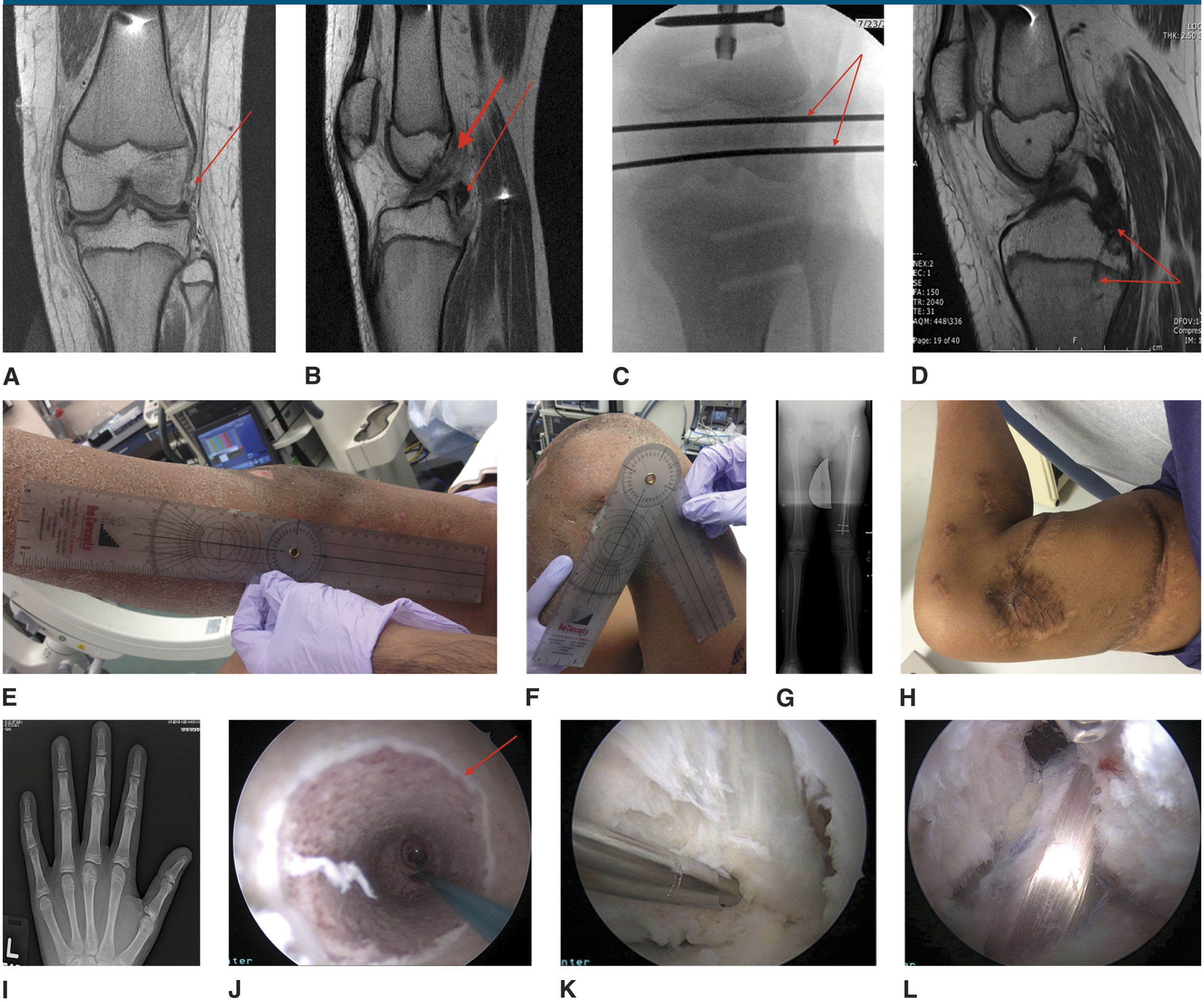
Over the first week postinjury, he underwent three additional I + D procedures to manage his heavily contaminated wounds and exchange of the femoral external fixator for a lateral-entry rigid intramedullary nail. MRI of the left knee performed on day 5 of hospital stay demonstrated a displaced bony avulsion fracture of the PCL from the tibia, bony avulsion fractures of the lateral collateral ligament (LCL) and popliteus tendon from their insertions on the femur with associated disruption of the lateral capsule, and complete intrasubstance tearing of the anterior cruciate ligament (ACL) (Figure 1, A and B).

Surgical treatment included subacute, staged open repairs of the PCL using transphyseal sutures and of the posterolateral corner injury using all-epiphyseal suture tunnels (Figure 1, C and D). Specifically, he underwent open reduction and suture fixation of the PCL using a posterior approach to the knee 10 days after initial injury. Transosseous (and transphyseal) tunnels were made using an ACL guide from the PCL insertion site on the posterior tibia distally and anteriorly; sutures were placed through the PCL and its bony fragment, shuttled through the tibia, and tied over an anterior bone bridge. The posterolateral corner injury was managed with open repair of the bony avulsion fracture 16 days after injury.

Despite initiation of knee motion under the supervision of in-patient physical therapy services, within 3 weeks of surgery arthrofibrosis developed in him, and he then underwent manipulation under anesthesia 2.5 months after his initial injury (Figure 1, E and F). Child psychiatry became a critical component of his care team, and because of increasing anxiety and aggression regarding medical and surgical treatment, ACL reconstruction was deferred. Three months after his initial injury, he was transferred to an acute pediatric rehabilitation facility.

Six months following hospital discharge, he had returned to home and school and re-presented as an outpatient, reporting symptoms of knee instability while "doing tricks" on his bicycle. Preoperative evaluation was notable for a positive pivot shift and 2B Lachman tests, a bone age of 14 + 0 years, no notable malalignment of the lower extremity, and notable scarring over the hamstrings of the affected left lower extremity (Figure 1, G–I). He reported feeling better adjusted at home and school and ready to undergo additional

Figure 1



Representative images from case 1, a male motor scooterist of age 13 years 1 month, who was struck by a car. **A**, A coronal MRI of the left knee demonstrating an avulsion fracture of the LCL from the femur (arrow). **B**, A sagittal MRI demonstrating intrasubstance tearing of the ACL (thick arrow) and bony avulsion fracture of the PCL (thin arrow). **C**, An intraoperative fluoroscopy image demonstrating creation of epiphyseal suture tunnels (arrows); sutures were placed into the avulsed LCL fragment, passed medially through the tunnels, and tied over a medial bone bridge. **D**, A postoperative sagittal MRI demonstrating reduction of the PCL using transphyseal suture tunnels (arrows). **E** and **F**, Intraoperative photographs following manipulation under anesthesia. Preoperative images including (**G**) a preoperative limb-alignment radiograph, (**H**) a photograph demonstrating notable scarring over the ipsilateral hamstrings, and (**I**) a bone age study, consistent with that of a 14-year-old male patient. Arthroscopic images depicting (**J**) skeletonization of the PCL, (**K**) an intraosseous view of the femoral tunnel (arrow points to physis), and (**L**) final appearance of the ACL graft. ACL = anterior cruciate ligament, LCL = lateral collateral ligament, PCL = posterior cruciate ligament

surgery. So, he underwent transphyseal ACL reconstruction using contralateral quadrupled hamstring autograft and "physeal-respecting" techniques (eg, use of soft-tissue graft, slight verticalization of the tunnels, and fixation away from the physes and avoidance of graft overtensioning; Figure 1, J–L). In addition to in-patient physical therapy services, a continuous passive motion machine was used after ACL reconstruction to prevent re-occurrence of arthrofibrosis. At 11 months from his most recent surgery, physical examination demonstrated symmetric limb length and alignment, passive knee motion of zero to 130°, negative drawer testing, and stability of the collateral ligaments. He denied mechanical or instability symptoms and had returned to unrestricted activity. He was subsequently lost to follow-up.

Case 2 is a male patient aged 13 years 8 months, who presented with acute knee pain after a contact-type football injury. Pertinent positives on his physical examination included a large effusion, 2B Lachman, positive supine dial testing, and >10 mm opening with varus stress performed at 30° of flexion. Radiographs and MRI of the knee demonstrated a displaced tibial spine fracture with an associated Segond fracture, ligamentous avulsion of the distal LCL, and partial avulsion of the biceps femoris tendon at their insertions onto the fibular head; the remainder of the posterolateral corner structures were intact (Figure 2, A and B).

He underwent arthroscopic-assisted reduction and fixation of the tibial spine fracture using all-epiphyseal screws and concomitant open repair of lateral injuries using all-epiphyseal suture anchors (Figure 2, C–I) 13 days after initial injury. Specifically for the open repair, a Krackow-type suture was placed through the soft tissues that remained attached to the lateral tibial condylar avulsion fracture, and this was used to tension the avulsed fragment prior to fixing it securely to the tibia with a suture anchor. The LCL and biceps avulsion injuries were similarly reapproximated to the fibular footprint and secured with a suture anchor.

Motion was initiated and advanced 3 weeks after surgery, with protected weight bearing in a HKB for 6 weeks. At final follow-up 10 months after surgery, physical examination demonstrated passive knee motion ranging from 2° to 135°, a 2A Lachman test, and negative pivot shift, dial and varus/valgus testing. Radiographs demonstrated healing of his fractures without evidence of physeal compromise (Figure 2, J and K). He denied pain and instability symptoms and was actively participating in competitive basketball.

Case 3 is a perimenarchal female patient aged 12 years 11 months, who sustained acute injuries of both lower extremities after being struck by a car while waiting for school bus. A closed right femoral shaft fracture was managed by the on-call surgeon with urgent reduction and stabilization using a lateral-entry intramedullary nail. Examination of the left knee under anesthesia at the time was notable for effusion, 2B Lachman testing, and >10 mm lateral gapping with varus stress at 30° of flexion; neurovascular function was intact. Radiographs, CT, and MRI of the left knee demonstrated a comminuted tibial spine avulsion fracture with concomitant displaced bony avulsion of the femoral attachments of the LCL and popliteus tendon and nondisplaced Segond fracture (Figure 3, A); the PCL, MCL, extensor mechanism, and the remainder of the posterolateral corner were noted to be intact.

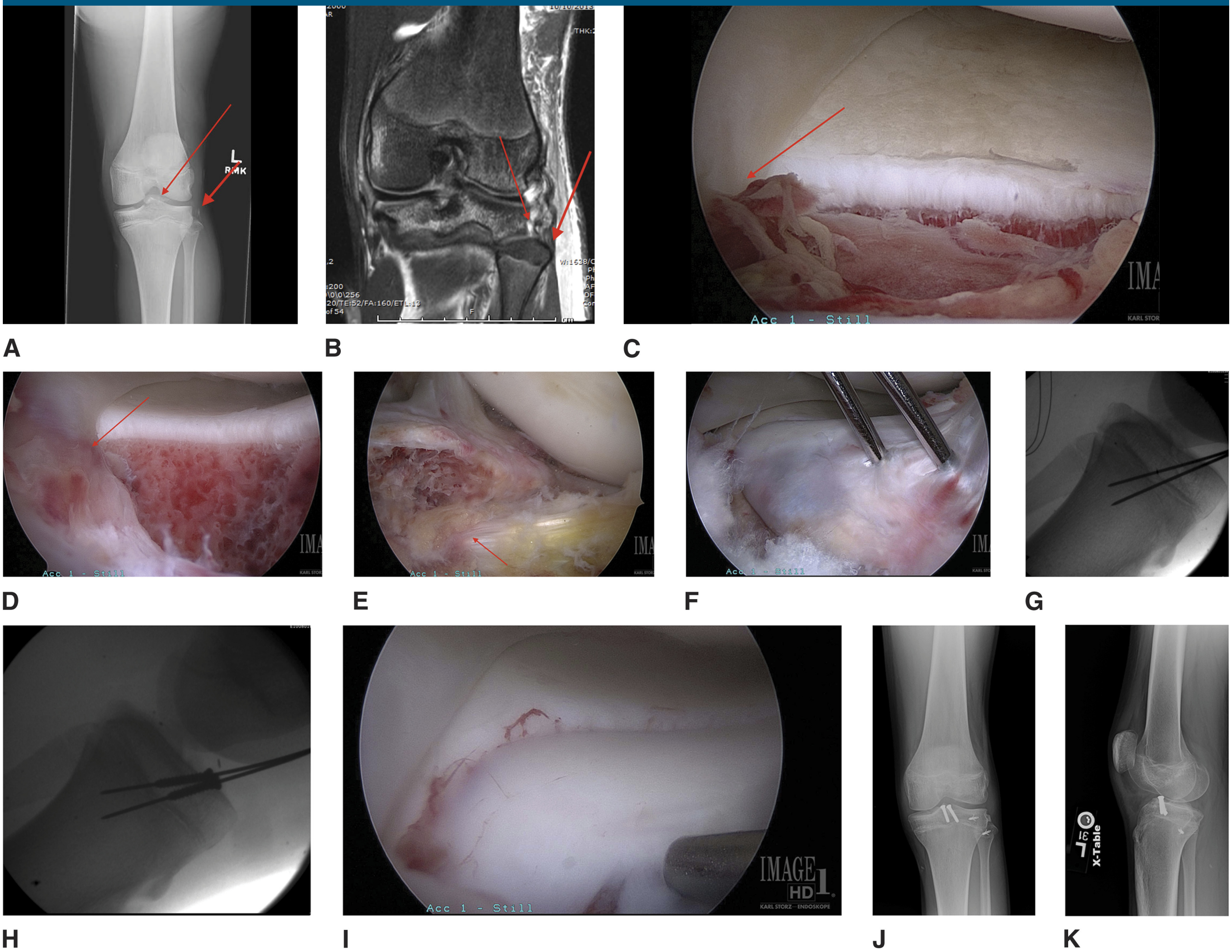
She was referred to the sports medicine service for management of her knee injuries, She subsequently underwent arthroscopic-assisted reduction and suture fixation of the tibial spine fracture (Figure 3, B–D) and open repair of the posterolateral corner injuries using a lateral "hockey-stick" incision and all-epiphyseal suture tunnels 20 days after initial injury (Figure 3, E). Postoperatively, her weight-bearing status was limited to touchdown only for 6 weeks in a HKB. Knee motion was initiated immediately at zero to 30°, advanced to zero to 90° for weeks 2 to 4, and then was unrestricted after 4 weeks. Six weeks after surgery, she had a demonstrable motion deficit, with a passive motion arc of 5 to 75°. Intensive physical therapy was initiated four times weekly under close supervision. By 10 weeks postoperative, her motion had improved to 1 to 135° under this regimen. At her most recent visit, 14 months from surgery, she had regained both motion and strength throughout the kinetic chain, had a clinically stable knee (2A Lachman, negative drawer, pivot shift, dial and collateral stress testing), and had returned to unrestricted physical activities. A limb alignment radiograph (Figure 3, F) and radiographs of the left knee demonstrated symmetrically closing physes and healed bony avulsion fractures.

Discussion

Adults who sustain MKIs commonly do so as a result of sports-related injury (a moderate energy injury mechanism) or motor vehicle–related injury (a high-energy mechanism); the adolescents with MKI in this series similarly sustained injuries as a result of moderate-to-high-energy trauma.[8-10] Specifically, two patients were involved in motor vehicle accidents and the third was injured as a result of a forceful tackle playing football. This pattern is also consistent with the few cases of MKIs reported in the pediatric literature, which were largely because of motor vehicle accidents and athletics.[1-5] Additionally, one case report describes MKI in an obese 15-year-old female patient, sustained in a low-velocity fall from standing.[11] This ultra–low-energy injury mechanism coupled with obesity have also been described in adults with MKIs.[12]

Examining the patterns of knee injury as detailed previously, two patients in this study had exclusively ligamentous avulsion injuries (bony ligamentous avulsions of the ACL, with a combination of bony and insertional ligamentous avulsions of the LCL), whereas the third patient had a combination of bony avulsion fractures of the LCL and PCL in concert with a mid-substance injury of the ACL. Bony ligamentous avulsion injuries were by far the

Figure 2

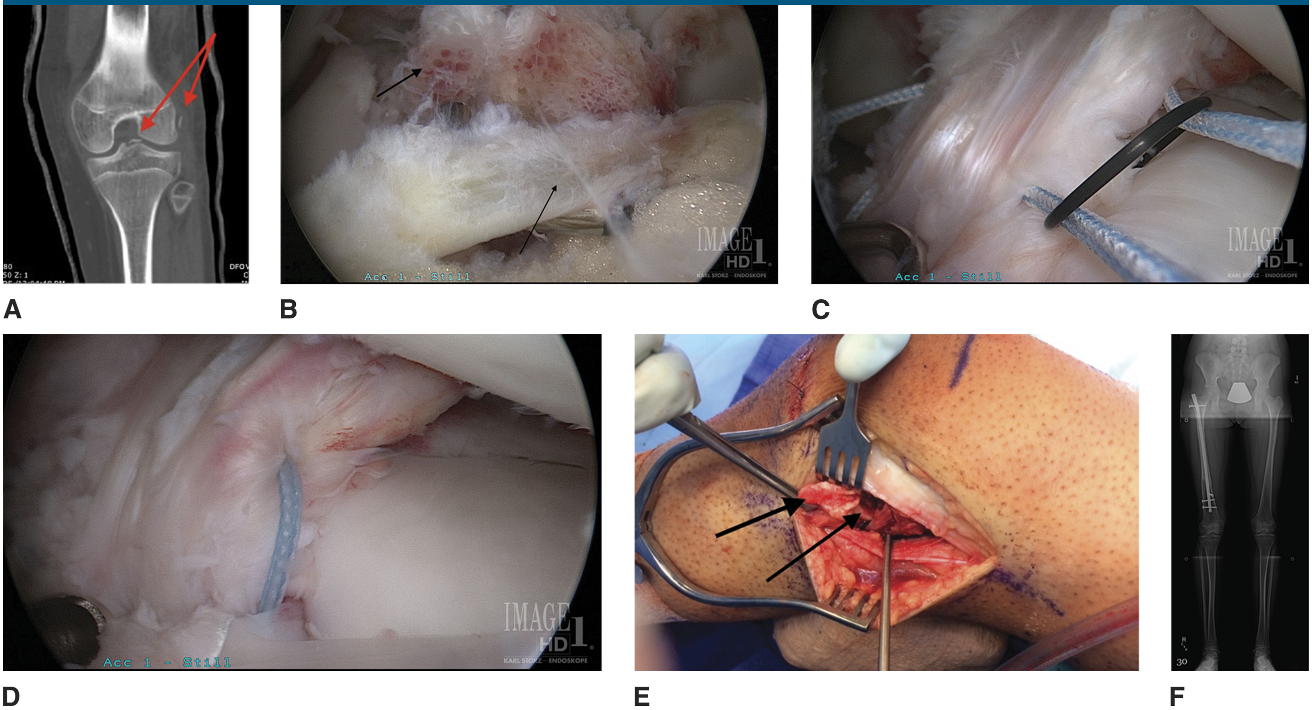


Illustrative images from case 2, a male football player of age 13 years 8 months. **A**, An AP radiograph demonstrating a displaced tibial spine fracture (thin arrow) with concomitant Segond fracture. **B**, A coronal MRI demonstrating distal ligamentous avulsion of the LCL (thin arrow) and partial tendinous avulsion of the distal biceps femoris from the fibular head. Arthroscopic images demonstrating entrapment (**C**) and removal (**D**) of the anterior horn medial meniscus from the fracture site. **E**, Image demonstrating entrapment of the intermeniscal ligament (arrow) within the fracture site. **F** and **G**, Image illustrating fracture reduction and provisional fixation with smooth K-wires placed across the physis. **H** and **I**, Image depicting final fracture alignment after placement of two all-epiphyseal cannulated screws. **J** and **K**, Three-month postoperative AP and lateral radiographs demonstrating all-epiphyseal anchors for fixation of the capsular and posterolateral corner injuries.

most common type of injury in this series of adolescents. Adults, by contrast, are more likely to experience ligamentous failure within the substance of the ligament (particularly the ACL), although ligamentous avulsion injuries and avulsion fractures do also occur in the adult population.[2,10]

All three patients sustained avulsions of the LCL (both bony and insertional ligamentous avulsions) with a combination of proximal and distal avulsion sites. This pattern is similar to that described in adults, where 84% of MKI-related LCL injuries are ligament avulsions that may be managed with repair or delayed reconstruction.[10] Interestingly, no patient in this study had injury of the MCL by examination or MRI, although MCL injury has been identified in nearly half of adult-type MKIs[10] and combined ACL-MCL injuries have been reported in the pediatric literature.[2] Finally, whereas none of the patients reviewed here experienced neurovascular injury, Twaddle et al[10] reported a 14% rate of both vascular disruption and peroneal nerve injury in their prospective study of 63 patients with MKIs (aged 14 to 67 years).

Figure 3



Illustrative images from case 3, a female pedestrian of age 12 years 11 months, who was struck by a car. **A**, A coronal CT of the left knee demonstrating displaced avulsion fractures of the tibial spine and lateral collateral ligament (arrows). Arthroscopic images depicting interposition of the intermeniscal ligament within the fracture site (**B**), reduction and suture shuttling through the comminuted tibial spine fragment (**C**), and the final fixation construct (**D**). **E**, An intraoperative photograph demonstrating the lateral collateral ligament/popliteus avulsion fragment (thick arrow) and donor site (thin arrow). **F**, A limb alignment radiograph taken 15 months after surgery, with no evidence of growth disturbance.

The adult literature on MKIs provides some evidentiary support for optimizing surgical timing and techniques.[13] In this series, surgery to address MKIs was performed in a subacute fashion, roughly 2 to 3 weeks after injury in each case. For case 1, the timing of surgeries was driven initially by the patient's readiness for OR given his associated musculoskeletal and neurologic injuries. The timing for case 3 was a result of her delayed presentation for treatment after referral. Determining the optimal timing of surgical treatment of case 2, however, presents an interesting conundrum: Given the amount of soft-tissue injury, swelling, and known capsular disruption this patient sustained at the time of injury, the adult MKI literature would suggest delaying arthroscopic treatment for at least 10 days to prevent intraoperative fluid extravasation, possible compartment syndrome, and arthrofibrosis. In direct contrast, data exist in the pediatric literature which suggest an association between increased time to surgery and arthrofibrosis development in children treated for isolated tibial spine fractures.[14] Additionally, performing surgical repair of an avulsed ligament (bony or no) in the first several days after injury generally allows for easier identification of anatomic structures and easier mobilization and reduction of injured structures. Balancing these competing rationales for early and delayed surgery in this population poses a challenge for the treating surgeon.

Furthermore, it is unclear whether early surgical treatment of children with MKIs would lessen the risk of arthrofibrosis: Another recent study demonstrated that initiating knee motion within 4 weeks of surgery for isolated tibial spine fractures was of primary importance in decreasing arthrofibrosis risk.[15] Extrapolating from this, perhaps the best approach is to perform surgery for pediatric and adolescent MKIs in a subacute fashion (10 to 14 days after injury), followed by early initiation of motion, a practice commonly used for adult MKIs. Yet, despite adoption of this strategy, arthrofibrosis developed in one patient in this series—case 1, who was treated with staged surgical repairs—requiring surgical treatment.

Because of the theoretical risk for iatrogenic physeal injury and resultant growth disturbance using traditional reconstruction techniques, the surgical techniques used for the patients described here were physeal sparing (eg, all-epiphyseal tunnels and fixation) whenever possible; when crossing a physis was considered necessary, "physeal-respecting" techniques were used (eg, small-diameter tunnels and use of soft-tissue graft). Clinical growth disturbance was not noted in this series, and the existing literature on this complication is scant and somewhat contradictory. Two early case series from 1979 reported no growth arrest after surgical management of ligamentous injuries in children.[4,5] More recently, Shiflett et al[16] reported retrospectively on four patients, with average age of 14.2 years, who underwent transphyseal ACL reconstruction and had a clinically notable growth disturbance (eg, distal femoral valgus and/or tibial recurvatum) develop postoperatively. In a related MRI study, Yoo et al[17] noted the formation of focal bone bridges across the open physis in 5 of 43 patients who underwent repeat MRI imaging after transphyseal ACL reconstruction; in this study, however, no patient went on to develop clinically notable deformity.

Sankar et al[2] reported good clinical outcomes for young athletes with ACL-MCL injuries managed with bracing treatment and delayed ACL reconstruction, similar to that in adults. The Sankar study is the first to investigate clinical outcomes in young patients with combined ligamentous knee injury; however, it is difficult to extrapolate their data (drawn from patients with midsubstance MCL and ACL injuries) to the patients described in this series. Clinical outcomes for other types of MKIs remain largely undescribed for pediatric patients. Outcomes in the adult population are variable.[13]

Ultimately, many unknowns remain in terms of structuring management plans for skeletally immature patients with MKIs, including appropriate surgical indications, optimal surgical timing, suitable surgical techniques, and effective rehabilitation guidelines. This small case series does not provide definitive data, but nevertheless it is useful because it indicates that (1) MKI does occur with some frequency in children and adolescents, (2) it is commonly the result of moderate-to-high-energy trauma, (3) ligamentous avulsion injuries—both bony and purely ligamentous—are particularly common in the skeletally immature population, (4) bony ligamentous avulsion injuries in this setting may be amenable to subacute repair, (5) arthrofibrosis after ligament surgery for MKI occurs in the pediatric population as it does in adults, and (6) surgical repair of ligamentous avulsion injuries in the pediatric population can be successful in restoring knee stability and clinical function.

By highlighting gaps in our knowledge about MKIs in skeletally immature patients, this series will ideally serve to stimulate research efforts to better characterize injury patterns, develop effective treatment algorithms, elucidate the incidence of associated complications, and optimize functional outcomes for this unique population.

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