Review Article

Pediatric Knee Dislocations and Physeal Fractures About the Knee

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Abstract

Given the high incidence of vascular and neurologic injury associated with pediatric knee dislocations and displaced physeal injuries about the knee, a thorough understanding of the clinical and radiographic signs associated with these injuries, relevant anatomy, workup, reduction techniques, and surgical management is crucial. A higher incidence of these injuries in children is anticipated because of increased participation in high-energy activities that result in contact or collision during sports or recreation. Complications, such as vascular and nerve injuries and compartment syndrome, can be diagnosed early in the workup to prevent catastrophic outcomes. The clinical examination should include evaluation of the motor and sensory status of the limb, palpation of pulses, and measurement of ankle brachial indices. Radiographic examination should include plain radiography and supplemental advanced imaging, if indicated. Vascular imaging or expert consultation should be considered when the pulse or ankle brachial index is abnormal on clinical examination. Selection of nonsurgical or surgical treatment depends on the fracture pattern and stability.

JAAOS Plus Webinar

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The incidence of knee dislocations, multiligamentous knee injuries (MLKIs), and physeal fractures about the knee in children and adolescents will likely continue to increase as more children participate in sports activities year-round. Complications associated with these injuries can be catastrophic; therefore, an understanding of the relevant anatomy and the necessary physical examination and diagnostic workup is critical when evaluating and treating these conditions.

Knee Dislocations and Multiligamentous Knee Injuries

Incidence

Knee dislocations are extremely rare, accounting for approximately 0.02% of orthopaedic injuries.[1] The true incidence is likely higher because some dislocations spontaneously reduce before presentation.[1,2] The incidence of knee dislocation in the pediatric and adolescent population is unknown. Only limited case reports and small case series pertaining to pediatric knee dislocations exist.[3-5] In a report of three patients who suffered knee dislocations in trampoline accidents, each patient also had a popliteal artery injury, highlighting the potential severity of this injury.[4] The reported incidence of injury to the popliteal artery associated with knee dislocation ranges from 1.6% to 30%.[2,6] Because knee dislocations commonly result in MLKIs, a dislocation should prompt an evaluation of the vascular status of the limb. In a study of 71 patients with MLKIs, 12.5% of patients had an associated injury to the popliteal artery.[7]

Table 1

Kennedy Classification of Knee Dislocations Based on the Position of the Tibia Relative to the Femur[8]

Position of Tibia	Incidence (%)	Mechanism	Notes
Anterior	40	Hyperextension	Vascular injury
Posterior	33	Dashboard, fall on flexed knee	—
Lateral	18	Varus	—
Medial	4	Valgus	—
Rotatory	4	Twisting	Posterolateral most common; may be irreducible

Table 2

Classification of Knee Dislocations Based on Ligamentous Injury Pattern[a]

Class	Ligaments Involved
KD I	ACL or PCL with PMC and/or PLC
KD II	ACL and PCL only
KD III	ACL and PCL with PMC or PLC
KD IV	ACL, PCL, PMC, and PLC
KD V	MLKI with periarticular fracture

ACL = anterior cruciate ligament, KD = knee dislocation, MLKI = multiligamentous knee injury, PCL = posterior cruciate ligament, PLC = posterolateral corner, PMC = posteromedial corner
[a] Classification developed by Schenck and modified by Wascher[9]

Classification and Presentation

In general, a sports injury or high-energy trauma can produce a MLKI or knee dislocation. The force vector and the position of the limb determine the ligamentous injury and the direction of the dislocation. Classification of dislocations is based on the position of the tibia relative to the femur: anterior, posterior, lateral, medial, and rotatory (Table 1).[8] Wascher[9] modified Schenk's classification of knee dislocations, which is based on the pattern of injury to the cruciate ligaments and posteromedial and posterolateral corners (Table 2).

Patients who present with a dislocated knee have significant pain, soft-tissue swelling, ecchymosis, and ligamentous instability and may have an obvious deformity.[1] A dimple in the soft tissues should alert the examiner to the possibility of femoral condyle entrapment within the medial or lateral soft tissues. Some dislocations may spontaneously reduce and present with ligamentous instability and swelling alone; therefore, the initial workup for a MLKI should be the same as that for a dislocation[7] (Figures 1 and 2).

Evaluation and Imaging

With high-velocity trauma, there is a high incidence of associated injuries to the head, chest, and abdomen (27%) as well as fractures (50% to 60%).[9] Patients with these injuries should be evaluated using standard trauma protocols. A thorough examination should be performed promptly after presentation, including inspection and palpation of the entire limb; ligamentous examination; evaluation of vascular status, with examination of pulses and ankle brachial indices (ABIs); evaluation of compartments of the leg; and neurologic testing.

The popliteal artery is tethered proximal to the knee at the adductor hiatus and distal to the joint at the arch of the soleus muscle.[1,10,11] The genicular arteries provide poor collateral circulation for distal flow and are often injured in a knee dislocation. Therefore, occlusion of the popliteal artery at the level of the knee can be catastrophic. Although arteriography has historically been the standard of care for diagnosis of arterial injury following knee dislocation, it is expensive and invasive, exposes the patient to radiation, requires anesthesia, and carries an overall complication rate of 1.7%.[10]

Several authors have found excellent correlation between significant vascular injury and asymmetry on pulse examination and have proposed that an abnormal physical examination serves as a guide to selective vascular imaging. In a prospective study of 35 patients with knee dislocations, 8 patients presented with or developed abnormal pulses, and 7 of these had an abnormality found on subsequent arteriography.[12] None of the 27 patients who had normal pulse examinations had abnormal vascular imaging. Another series reported on prospective data from 116 patients with

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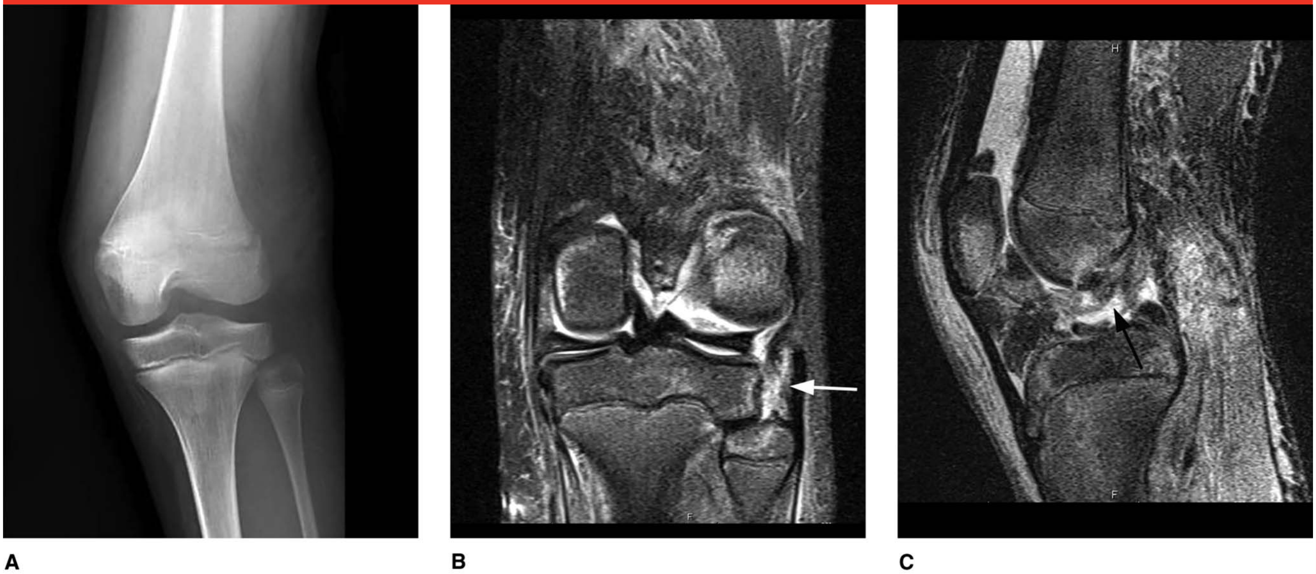
Figure 1

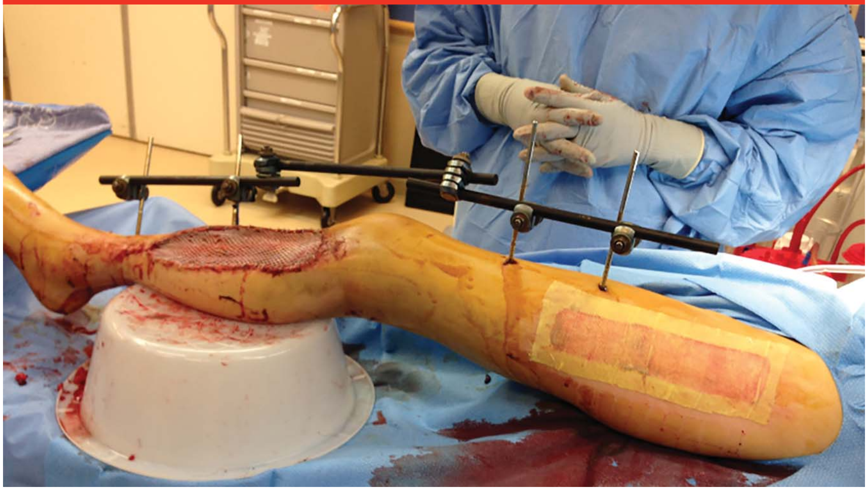


A, Preoperative AP radiograph of the knee in a 12-year-old boy who presented with a spontaneously reduced knee dislocation, compartment syndrome of the leg, and a pulseless and insensate foot. Immediate reverse saphenous vein bypass grafting was performed for a popliteal artery laceration, spanning external fixation was applied, and four-compartment fasciotomy was performed. **B**, Coronal proton density-weighted fat-saturated MRI scan of the knee demonstrating evidence of posterolateral corner injury (arrow). **C,** Sagittal proton density-weighted fat-saturated MRI scan of the knee showing an anterior cruciate ligament tear (arrow) and a nondisplaced Salter-Harris type III fracture.

knee dislocations who underwent selective arteriography.[6] Nine of the 10 patients with abnormal pulse examinations had arterial damage. Seventeen patients who had normal examinations underwent arteriography. No vascular lesions requiring surgery (ie, surgical vascular lesions) were found, but one patient had a small intimal tear. However, in a meta-analysis of the accuracy of pulse examination in predicting arterial injury, Barnes et al[13] reported that surgical vascular lesions were found on imaging in some patients who had a normal initial vascular examination. Furthermore, the incidence of vascular lesions that do not require surgery (ie, nonsurgical vascular lesions), such as non-flow–limiting intimal tears, may go undiagnosed without vascular imaging.[14] Barnes et al[13] also found that an abnormal pulse examination had a sensitivity of 79% and a specificity of 91% for diagnosis of a surgical vascular lesion. Of 140 patients who had a normal pulse examination and an arteriogram, 13 had nonsurgical, nonocclusive intimal injuries. In a study of 67 patients with vascular lesions associated with bicruciate injuries of the knee, 1 patient had an intimal flap tear of the popliteal artery that required surgical management.[14]

Careful examination of the peripheral pulse and the ABI or ankle-arm index (if the contralateral leg is unavailable) should be performed in all patients with a suspected knee dislocation or MLKI. Several studies have shown that the ABI is also a strong predictor of vascular status.[15,16] In a study of 38 patients aged 15 to 74 years, Mills et al[15] reported that an ABI of <0.9 had a sensitivity and specificity of 100% in predicting a significant arterial injury; 11 patients with an ABI <0.9 had a vascular lesion.[15] One patient aged 16 years had an injury to the popliteal artery. In patients with an ABI >0.9, no vascular lesions were found on clinical examination or ultrasonography. In a study of 55 patients aged 12 to 63 years with knee dislocations, 12 (48%) with an ABI <0.8 had a vascular lesion (surgical or nonsurgical); no vascular lesions were found on angiography or follow-up examination in patients with an ABI >0.8.[16] This study found that the pulse examination had a specificity of 100% and a positive predictive value of 1.0 when an ABI of >0.8 was used as a threshold for potential arterial injury and selective arteriography. Patients in these studies were typically older adolescents and adults. Because no dedicated reports exist on the predictors of ABI following knee dislocations in skeletally immature patients, the ABI threshold following knee dislocations in children is unknown.

Figure 2



Intraoperative photograph of the patient shown in Figure 1 demonstrating the limb following external fixation and split-thickness skin grafting to close the lateral fasciotomy wound.

Neurologic examination performed before and after reduction is important, as well. The peroneal nerve is most commonly injured in a posterolateral dislocation and the reported incidence of peroneal nerve injury ranges from 14% to 40%.[11] When a neurologic injury is present, the incidence of vascular injury is higher, highlighting the importance of both neurologic and vascular examinations.[15]

Although arteriography has been the preferred technique for diagnosis of vascular injury, other modalities are now available and widely used. CT angiography has the advantage of being better coordinated with other CT imaging, which many trauma patients may require. Results of CT angiography have been correlated with intraoperative arteriography results. Seamon et al[17] reported that 21 of 22 patients (95%) with abnormal results on CT angiography were confirmed on arteriography. Duplex sonography is a noninvasive procedure that can be performed quickly and relatively inexpensively in the emergency setting. Good sensitivity and accuracy have been reported.[18]

The noninvasive nature and relative availability of magnetic resonance arteriography as well as the ability to evaluate ligamentous structures are among the advantages of this modality.[11,19] Magnetic resonance arteriography has been shown to be as accurate as conventional arteriography for diagnosis of injury to the popliteal artery.[20] This modality also allows the clinician to visualize distal runoff vessels and correlates well with intraoperative findings.[20]

Management

When a patient presents to the emergency department with a dislocation that has not spontaneously reduced, reduction should be a priority following resuscitation. Documentation of pulses, ABI, and neurologic status should be done before and after reduction. Adequate sedation is necessary for ease of reduction and patient comfort. Gentle re-creation of the deformity, traction, and manipulation of the tibia relative to the femur will generally reduce the knee. Forceful hyperextension or posterior translation of the tibia should be avoided to prevent further injury to the popliteal neurovascular bundle. Any puckering of the skin, especially in the setting of a rotatory dislocation, should alert the clinician to the possibility of an irreducible dislocation caused by femoral condyle entrapment in the soft tissues.[1] If no vascular injury is present and the knee is stable following reduction, the knee should be immobilized in extension in a knee immobilizer or a hinged knee brace. We prefer to use a knee immobilizer because of the ease of application, availability, and ability to monitor compartments of the leg and perform radiography without significant image disruption.

Immediate vascular surgical intervention is indicated in cases of arterial transection or occlusion. Immediate orthopaedic surgical intervention is indicated when the dislocation is irreducible, open, or unstable after reduction. When vascular repair is necessary, an external fixator can be used to stabilize the joint and protect the vascular repair. If open reduction is needed, a midline incision with either a medial or lateral parapatellar arthrotomy can be used to visualize the joint. In the case of an open dislocation, the principles of wound management guide the placement of incisions. When surgical intervention is indicated, a spanning external fixator should be used to maintain the reduction. Controversy exists regarding acute versus delayed reconstruction of ligaments in the setting of MLKI.

Physeal Fractures About the Knee

The physes of the distal femur and proximal tibia contribute 70% of the overall length of the lower extremities.[21] The average growth of the distal femur and proximal tibia is approximately 9 to 10 mm and 6 mm per year, respectively. Additionally, the apophysis of the tibial tubercle on the anterior proximal tibia contributes to appositional and angular growth, and the proximal fibular physis contributes to angular and longitudinal growth. Disturbance of these physes can cause growth arrest and limb-length discrepancy or angular deformity.

The medial collateral ligament (MCL) and the lateral collateral ligament (LCL) originate on the distal femoral epiphysis. The MCL bifurcates into a deep branch, which inserts onto the proximal tibial epiphysis, and a superficial branch, which inserts onto the tibial metaphysis. The LCL inserts onto the proximal fibular epiphysis. Loading across the physis causes stress on the ligaments initially, and this stress is transferred to the physis, which is weaker than the ligaments. The Salter-Harris classification is used to categorize physeal fractures of the distal femur and proximal tibia.[21]

Distal Femoral Fractures

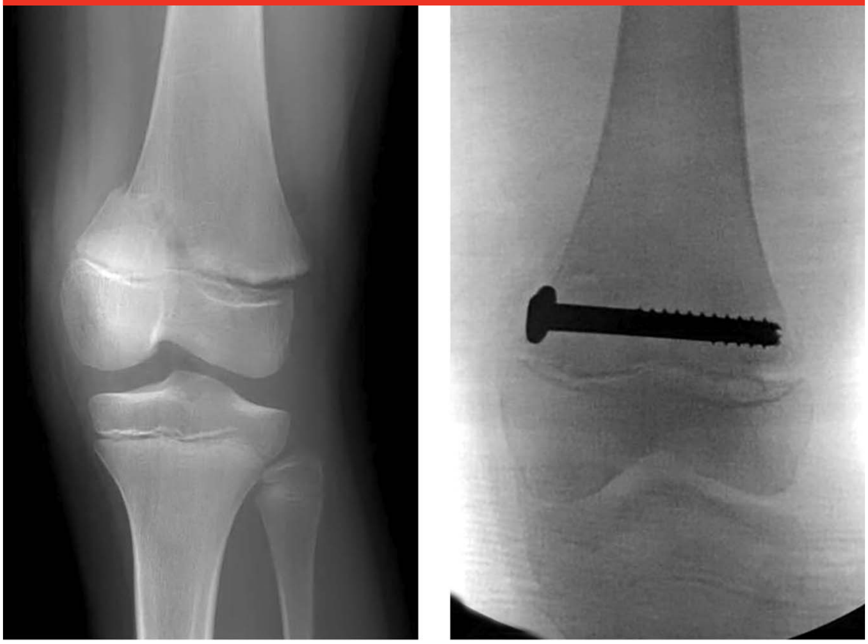
Distal femoral fractures comprise 2% to 5% of physeal fractures.[22-24] These fractures may result from high- or low-energy mechanisms of injury and commonly occur in motor vehicle accidents or with sports participation. A varus or valgus load applied across the knee is the common mechanism of injury that causes failure of the periosteum on the tension side of the physis and results in a metaphyseal fragment on the compression side.[24] Anteriorly displaced fractures are typically caused by a hyperextension mechanism, and posteriorly displaced fractures are often the result of a posteriorly directed force on a flexed knee.[25]

An obvious deformity is visible in patients with a displaced fracture. However, nondisplaced fractures may result in focal tenderness to palpation, pain, swelling about the knee, and the inability to bear weight.[26] Neurovascular examination is crucial in patients with these fractures because the popliteal artery and the tibial and peroneal nerves are at risk of injury. AP and lateral radiographs of the knee should be obtained. Nondisplaced Salter-Harris type I fractures may show a small fleck of bone from the metaphysis or physeal widening but can be radiographically unremarkable. The use of stress radiographs has fallen out of favor because of patient discomfort and the potential need for sedation.[26] Oblique views may be useful to further quantify displacement or to classify the fracture pattern.[26] When the diagnosis cannot be made based on plain radiography, CT or MRI can be used.[27,28] These scans are costly and may require sedation; therefore, they should not be part of the routine imaging series. In the setting of Salter-Harris type III or IV fractures, CT is helpful for more accurate determination of the amount of articular displacement, which is often deceptive on plain radiography.[26-28] Medial Salter-Harris type III fractures and terrible triad injuries of the knee (ie, tears of the anterior cruciate ligament, MCL, and meniscus) are commonly caused by the application of a valgus load to the knee; therefore, some authors recommend MRI to evaluate for possible injury to the soft tissue in addition to the fracture.[29]

Typically, reduction of displaced Salter-Harris type I and II fractures is possible with closed manipulation. There should be <2 mm of residual physeal displacement to decrease the risk of growth disturbance.[24] If a stable reduction is achieved, a bivalved long leg cast can be applied. Close follow-up is recommended, with radiographs obtained within 5 to 7 days to evaluate for any redisplacement.[26] If the fracture is reducible but unstable, two crossed transphyseal smooth pins may be inserted percutaneously (antegrade or retrograde) and are either cut under the skin or left percutaneous. They should be removed in the office within 4 weeks to prevent pin-tract infection. Typically, the fracture is sufficiently healed for pin removal at that time. A Salter-Harris type II fracture with a large metaphyseal fragment (Thurston-Holland fragment) can also be stabilized with a screw inserted percutaneously into the metaphysis parallel to the physis and perpendicular to the fracture line (Figure 3). A long leg cast is used for 4 to 6 weeks, and range of motion can begin following cast removal. A graduated return to full weight bearing can begin at approximately 4 to 6 weeks, when there is sufficient bony union noted on plain radiography.

Salter-Harris type III and IV fractures, which are completely nondisplaced and stable, can be treated with initial immobilization in either a well-padded posterior splint or a bivalved long leg cast; however, most authors advocate the use of internal fixation because of the propensity for late displacement.[26] These fractures are intra-articular and require reduction of the physis and the articular surface (within 2 mm); internal fixation is often necessary.[26-28] Manual manipulation and percutaneous placement of reduction clamps may be helpful for reduction, but if there is residual displacement >2 mm at the physis or the articular surface, direct visualization of this region is needed to remove soft tissue or periosteum from the fracture site. Depending on the patient's size, 4.5- to 7.3-mm cannulated screws are placed parallel to the articular surface of the epiphysis and/or metaphysis to avoid crossing the physis and to compress the fracture site.[26,27,29] If open reduction is not required or the incision does not allow for device placement, the screws can be inserted percutaneously. Immobilization in a hinged knee brace or

Figure 3



A B

A, Preoperative AP radiograph of the knee demonstrating a Salter-Harris type II distal femoral fracture in a 10-year-old girl following a skiing accident. **B**, AP fluoroscopic image of the knee demonstrating fracture fixation with two 6.5-mm cannulated screws percutaneously inserted into the metaphyseal fragment.

a bivalved long leg cast is continued for no longer than 4 weeks to allow range of motion and to prevent the development of arthrofibrosis.[24]

The incidence of growth disturbance is higher in the distal femur than in other locations because of the high energy that is required to cause a distal femoral physeal fracture, the large amount of growth from this portion of the femur, and the undulating pattern of the physis in this area. The risk of growth arrest ranges from 40% to 90%.[23,26,30-32] Risks of growth arrest include younger age (more growth remaining), amount of displacement, and comminution.[23,30] Transphyseal fixation with smooth pins has not been shown to correlate with an increased risk of angular deformity.[30,32] Long-standing radiographs of the lower extremities should be obtained at 6- to 12-month intervals to evaluate for angular deformity or growth arrest. In a recent meta-analysis of growth disturbance following distal femoral physeal fractures, the incidence of growth disturbance associated with Salter-Harris fractures was highest for type IV fractures (64%) followed by 58% for type II, 49% for type III, and 36% for type I.[23] Of 506 patients with distal femoral physeal fractures, 112 (22%) had a limb-length discrepancy >1.5 cm.

Nonunion associated with distal femoral fractures is rare given the presence of an abundant blood supply and adequate soft-tissue envelope. Neurologic injury, vascular injury, and compartment syndrome are also less commonly associated with these fractures than with proximal tibial fractures.

Proximal Tibial Fractures

Proximal tibial physeal fractures are relatively uncommon, comprising <1% of all physeal fractures.[22] The superficial MCL, LCL, tibial tubercle, and fibula provide structural support to prevent displacement; therefore, a significant force is required to cause a widely displaced proximal tibial fracture.[33] The fracture pattern varies based on the mechanism of injury, with Salter-Harris type II fractures being the most common.[34] Posterior displacement of the metaphyseal fragment occurs with a hyperextension mechanism of injury, whereas posterior displacement of the epiphyseal fragment occurs with a flexion-type mechanism.[25,34] Laceration of the popliteal artery or thrombosis associated with proximal tibial fractures is more of a concern than with a distal femoral fracture because the artery is tethered to the posterior tibia just below the physis.[25,33] Additionally, the trifurcation of the popliteal artery is at this level; the posterior tibial artery passes under the soleal arch, and the anterior tibial artery passes over the interosseous membrane.[35] A thorough neurologic and vascular examination should be done, including an evaluation of the compartments of the leg regardless of the amount of displacement at the time of presentation. The level of suspicion for vascular injury should be on par with that for a knee dislocation or MLKI.[25]

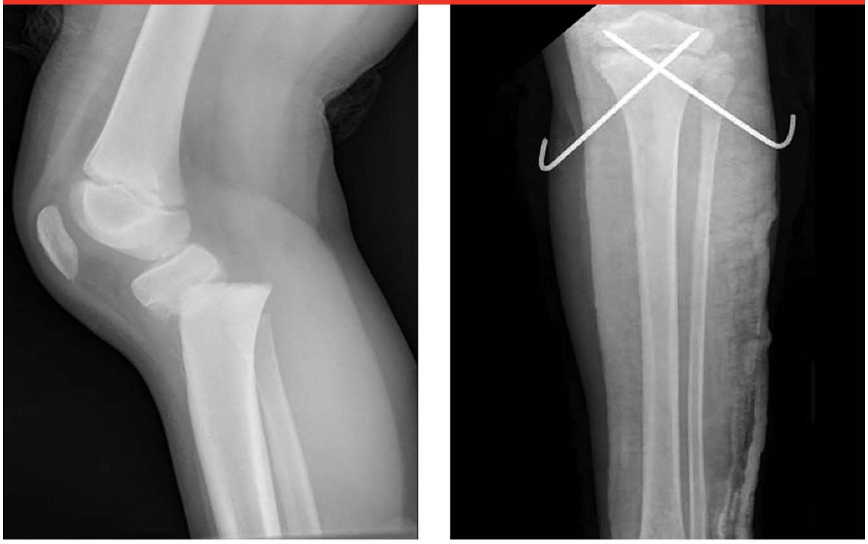
Initial radiography should include AP and lateral views of the knee. The use of stress radiographs has fallen out of favor. CT and MRI are not routinely obtained for initial diagnosis. However, CT is helpful for determining the fracture pattern and the amount of articular displacement in Salter-Harris type III and IV fractures, and MRI can aid in the diagnosis of associated ligamentous injuries.[24] Medial displacement of an epiphyseal fragment may indicate a MCL injury, and tibial spine avulsions (equivalent to rupture of the anterior cruciate ligament in adults) have been associated with Salter-Harris type III fractures.[36]

Nondisplaced Salter-Harris type I and II fractures can be managed with immobilization in a long leg cast for 4 to 6 weeks.[25,33,34] Displaced Salter-Harris type I and II fractures often can be reduced with closed manipulation and immobilized in a long leg cast.[34] Extreme hyperextension during closed reduction as well as extreme flexion in the cast should be avoided. Internal or percutaneous fixation is indicated in this situation to allow a more neutral degree of flexion in the cast.[24,25] Neurovascular examination following reduction should be recorded; any persistent asymmetry warrants further vascular imaging or expert vascular consultation. Failure to achieve reduction via closed manipulation with <2 mm of residual displacement at the physis is an indication for open reduction and exploration for an entrapped ligament, pes tendon, or periosteum. If internal fixation is necessary for stability or positioning in a cast, two 2- to 3.5-mm transphyseal smooth pins can be placed percutaneously in a crossed antegrade or retrograde fashion (Figure 4). Pins placed in a retrograde fashion are farther from the knee joint, decreasing the risk of septic arthritis.[25] Pins placed in an antegrade fashion, however, are less technically challenging to insert, and they can be left bent outside of the skin or buried. In general, the fracture is healed sufficiently at 4 weeks that the percutaneous pins can be removed to avoid pin-tract infection. If a large metaphyseal fragment is present, it can be stabilized with a percutaneous pin or screw placed perpendicular to the fracture and parallel to the joint.

Salter-Harris type III or IV fractures, which are completely nondisplaced, may be treated with long leg immobilization and close follow-up. If this method of initial immobilization is chosen, a well-padded posterior splint or a bivalved cast is applied. Given the propensity for displacement and the need for maintenance of reduction of both the physis and the articular surface, the use of percutaneous screws is recommended.[24] For displaced fractures, open reduction and internal fixation (ORIF) should be performed under direct visualization to restore the articular surface and the physis. Screws or pins are placed parallel to the joint surface within the epiphysis and metaphysis for fracture site compression and to avoid crossing the physis, if possible.

Growth disturbance following proximal tibial physeal fractures has been reported in approximately 25% of patients.[37] Long-standing radiographs of the lower extremities should be obtained every 6 to 12 months for the first 2 years, and follow-up should continue until the patient reaches skeletal maturity. Ligamentous injury associated with proximal tibial fractures has also been reported and should be assessed following stabilization.[36] Nonunion is rare in proximal tibial fractures. Neurologic and vascular injuries are noted in approximately 14% of cases.[35] Thus, the neurovascular examination is particularly important, and signs of compartment syndrome should be closely monitored. Patients with these injuries should be admitted for 24 to 48 hours following definitive treatment to monitor for these potential complications.

Figure 4



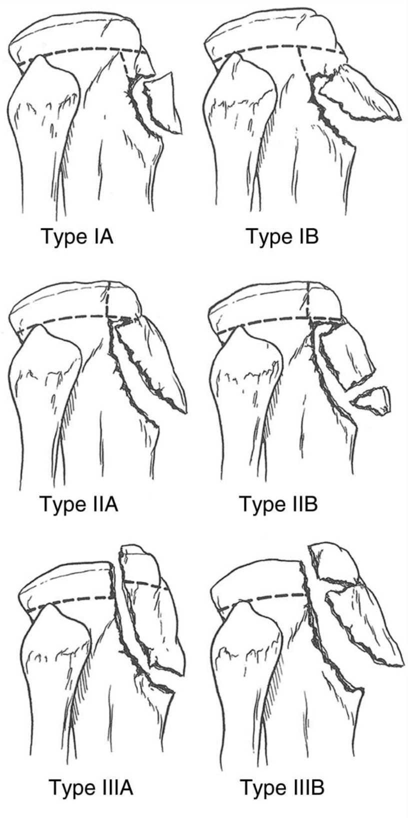
A B

A, Lateral radiograph of the knee in a 10-year-old boy showing a Salter-Harris type II proximal tibial fracture with posterior displacement of the metaphyseal fragment, which is concerning for a vascular injury. **B,** AP radiograph of the knee following closed reduction and internal fixation with retrograde crossed Kirschner wires. (Reproduced from Edwards PH, Grana WA: Physeal fractures about the knee. *J Am Acad Orthop Surg* 1995;3[2]:63-69.)

Tibial Tubercle Fractures

Tibial tubercle fractures comprise <1% of physeal fractures. Most of these fractures occur in adolescent boys aged 12 to 17 years.[33,38] The apophysis closes from proximal to distal during adolescence, resulting in a vulnerable area as it closes distally.[33,39] A violent contraction of the quadriceps, which can occur with jumping or forced flexion against

Figure 5



Ogden modification of the Watson-Jones classification of tibial tubercle fractures. Type IA fractures are distal to the junction between the proximal tibia and the apophysis and are nondisplaced or minimally displaced, whereas type IB fractures are hinged in this location. Type IIA fractures are at the junction of the proximal tibia and tubercle, and type IIB fractures are comminuted with anterior translation of the distal fragment. Type IIIA fractures extend into the articular surface, and type IIIB fractures are intra-articular and comminuted. (Adapted from Edwards PH, Jr, Grana WA: Physeal fractures about the knee. *J Am Acad Orthop Surg* 1995;3[2]:63-69.)

a contracted quadriceps muscle, is the mechanism of injury.[33,38-40] Patients with these fractures present with focal soft-tissue swelling and tenderness on palpation at the tibial tubercle anteriorly. Intra-articular fractures can cause a hemarthrosis.

During the physical examination, pain can be elicited with a straight leg raise or by extending the knee against gravity; these tests can be helpful tools when the diagnosis is unclear or unknown (eg, in the setting of a nondisplaced fracture). Neurovascular examination, with a particular focus on the anterior compartment, is an important part of the initial evaluation. Disruption of the anterior tibial recurrent artery can result in bleeding into the anterior compartment of the leg, leading to compression of the anterior tibial artery and the deep peroneal nerve.[38,39] This can be an evolving phenomenon; therefore, serial examinations are warranted.[25] Radiography should include AP and lateral views of the knee. A perfect lateral view of the tibial tubercle apophysis is needed; because the apophysis is just lateral to the midline, slight internal rotation of the leg may be helpful.[39] The Ogden modification of the Watson-Jones classification system is most commonly used to categorize tibial tubercle fractures[41] (Figure 5). In a study of 41 tibial tubercle fractures, classification based on plain radiography underestimated the severity of the fracture in 50% of injuries.[39] CT may help to delineate intra-articular involvement or extension of the fracture into the metaphysis. MRI may also be useful to identify meniscal tears, osteochondral defects, or an associated patellar or quadriceps tendon rupture, which was reported in up to 15.7% of injuries.[39]

Nondisplaced or minimally displaced (<2 to 3 mm) type I fractures can be immobilized in a well-padded, long leg posterior splint or a bivalved cylinder cast with the knee in full extension for 4 to 6 weeks.[38,40] Displaced type I fractures and most type II and III fractures require ORIF[25,38,40] (Figure 6). A midline anterior incision is used. Interposed soft tissue can be removed from the fracture, and the reduction can be visualized.[40] For intra-articular fractures, visualization of the articular surface and the menisci can be achieved through a parapatellar arthrotomy or with an arthroscope.[40] Generally, fixation is performed using two or three 4.0-mm cannulated cancellous screws inserted through the tubercle into the metaphysis.[25,40] Washers can be useful to prevent cortical penetration into the relatively soft apophyseal and metaphyseal bone and can facilitate device removal.[25] Additional suture fixation can be used as backup fixation for disrupted retinacular tissue or periosteum along the patellar tendon and/or an associated patellar tendon rupture; this can also help to secure small comminuted fragments beneath the tendon.[25,40] A prophylactic anterior compartment fascial release can be performed using Metzenbaum scissors directed inferiorly down the fascia through the surgical incision; alternatively, intraoperative decompression of the hematoma within the anterior compartment can also be considered.[38,40] Intraoperative monitoring of compartment pressure should be performed if there is clinical concern for increased swelling following reduction and fixation. Immobilization in a long leg cast or brace in full extension for 4 to 6 weeks is recommended after surgical fixation and is followed by progressive range of motion and quadriceps strengthening.[25,38,40] Admission for 24 to 48 hours to monitor the patient's neurovascular status and evolving compartment syndrome is prudent.

Growth arrest resulting in genu recurvatum following tibial tubercle fractures is uncommon because these fractures tend to occur in teenagers (ages 13 to 17 years).[25,38-41] When a patient aged <13 years sustains this injury, longer term follow-up is warranted.[38] The reported incidence of compartment syndrome is between

Figure 6

A, Preoperative lateral radiograph of the knee demonstrating a type III tibial tubercle fracture in a 16-year-old boy. Intraoperative AP (**B**) and lateral (**C**) fluoroscopic images of the knee following open reduction and internal fixation of the fracture.

2% and 20% in the literature.[40,41] Device prominence can cause painful bursitis, especially in thin patients, and may require removal.[39] Nonunion is a rare complication associated with this type of fracture.

Summary

In the setting of knee dislocation and MLKI as well as fractures of the distal femur, proximal tibia, and tibial tubercle, a thorough physical examination, with a special focus on the neurovascular status, should be performed. Careful monitoring of pulses and ABIs is paramount and, if the examination is abnormal, prompt vascular imaging and consultation with a vascular surgeon are required. Knee dislocations and displaced distal femoral or proximal tibial fractures should be reduced as soon as possible to remove tension from the neurovascular structures. Many Salter-Harris type I and II fractures can be stabilized, anatomically reduced, and treated with immobilization. Many Salter-Harris type III and IV fractures require internal fixation because of instability or persistent joint or physeal incongruency >2 mm following reduction. Open reduction is indicated for these fractures if the articular surface or physis is not reducible to within 2 mm through closed or percutaneous means. Knee dislocations that are not reducible must undergo open reduction. Dislocations that are unstable following closed reduction require open reduction. If a vascular repair is required, a spanning external fixator can be used to stabilize the joint and protect the repair. Tibial tubercle fractures, which are nondisplaced, are treated with immobilization, but type II and III fractures require ORIF. Regardless whether closed or open management methods are used for fracture management, close monitoring for any neurovascular signs or compartment syndrome is crucial.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 2, 13, and 23 are level I studies. References 6, 12, 14, 15, and 17-19 are level II studies References 3-5, 7, 8, 16, 20, 22, and 27-41 are level IV studies.

References printed in **bold type** are those published within the past 5 years.

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