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Bony Knee Injuries in Pediatric Patients

AUTHORS

Jillian Merica, MD, Attending Emergency Medicine Physician, UNC Southeastern, Lumberton, NC; Core Faculty Member, Emergency Medicine Residency, Campbell University Affiliate

Daniel Migliaccio, MD, Clinical Assistant Professor, Department of Emergency Medicine, University of North Carolina, Chapel Hill

PEER REVIEWER

Robert W. Schafermeyer, MD, FACEP, FAAP, FIFEM, Owner, Schafermeyer Consulting, LLC, Charlotte, North Carolina; Past President, American College of Emergency Physicians

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Pediatric knee injuries can vary greatly, from acute traumatic injuries to subacute and chronic overuse injuries. With approximately 2.5 million sports-related knee injuries presenting to the emergency department (ED) yearly, this works out to approximately 2.29 knee injuries per 1,000 pediatric patients seen. Knee injuries are most common in patients between the ages of 15 and 24 years, with the lowest rate among children younger than 5 years old. The most common causes of knee injuries among all ages are sports and recreation (which account for almost 50% of injuries), home structures, and home furnishings. The sports posing the greatest risk for knee injury in the United States are football, soccer, and basketball.[1]

Although emergency physicians are skilled at identifying limb- and life-threatening injuries, it is important to note that the most commonly encountered diagnoses associated with knee injury are "strains and sprains (42.1%), contusions and abrasions (27.1%), and lacerations and punctures (10.5%)."[1] While these injuries are not limb- or life-threatening, their diagnosis and referral for appropriate follow-up and treatment can have a significant impact. Even after returning to full sport participation, it has been shown that adolescent athletes with previous knee injuries have reduced physical, school, and social functioning, in addition to lower overall health-related quality of life, than their peers.[2] Treatment primarily focuses on return to baseline function, anatomy preservation, and prevention of long-term sequelae.[3]

Anatomy Review

The knee is built from two joints: the patellar articulation with the femoral trochlear groove and the tibial articulation with the femur.[4]

The patella, which is embedded in the quadriceps tendon, is a sesamoid bone that increases the mechanical advantage of the quadriceps.[5] Although the fibula is involved with knee movement, it does not articulate within the knee joint; it articulates distally on the lateral condyle of the tibia, also known as the fibular notch.

The knee "joint line" is defined by the femoral condyles and tibial plateaus. This becomes important when attempting to narrow the differential by physical exam. As a pivotal hinge (trocho-ginglymus) joint, the knee allows for flexion, extension, and partial internal and external rotation.[4] It is stabilized primarily by anterior, posterior, medial, and lateral collateral ligaments in their respective planes, in addition to the iliotibial band, which runs from the tensor fasciae latae and the gluteus maximus to the lateral tibia.[5]

The most important tendons in the knee, in addition to the iliotibial band, are the patellar tendon (inserts on the tibial tuberosity) and the quadriceps tendon (four quadricep muscle tendons that coalesce on the patella). These tendons are essential to the extensor mechanism of the knee, and although they rarely are injured, their injury can be severe and debilitating.[4,6,7]

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EXECUTIVE SUMMARY

- Within the popliteal fossa is a neurovascular bundle containing the popliteal artery, common peroneal nerve (lateral division of the sciatic nerve), and the tibial nerve (continuation of the sciatic nerve). Consider injury to these structures when evaluating a patient with a hyperextension injury and/or posterior knee dislocation.
- Pediatric bones have distinct segments: the diaphysis (shaft), metaphysis (flared segment between diaphysis and physis), physis (growth plate), and epiphysis (ossification center). The weakest of these segments is the growth plate, which reduces the overall tensile strength of the bone to be less than that of the ligaments, making fractures more common than ligamentous injuries.
- Once the physis closes, the tensile strength of the bone becomes greater than that of the ligament. Knees are skeletally mature (full physis closure) between 15.6 and 17.1 years of age in boys and between 15.0 and 16.9 years of age in girls.
- The Ottawa Knee Rule can be applied to patients from ages 2 to 16 years, with a 97% sensitivity and 27% specificity for fracture.
- Tibial tubercle fractures used to be historically rare, but they have increased with increased engagement in competitive sports at younger ages. The most common mechanism of injury involves jumping and landing, or any injury associated with violent quadriceps contraction. Pre-existing Osgood-Schlatter disease is found in 23% of tibial tubercle fractures.
- Proximal metaphyseal fractures are uncommon and usually occur between 3 and 6 years of age. One mechanism is associated with nonaccidental trauma and involves intentional pulling on the leg with rotational force (for example, grabbing a child by the ankle with rapid acceleration and deceleration force). These are identified as corner or bucket handle fractures on imaging.
- Complications associated with knee dislocation include deep venous thrombosis, significant functional instability, and vascular injury in 2.4% of patients.
- About 50% of popliteal artery injuries are associated with dislocation or fracture of the femur, tibia, and/or fibula. When the popliteal artery is injured, other concomitant injuries include popliteal vein injury in 12.1% of cases, posterior tibial nerve injury in 3.4% of cases, and peroneal nerve injury in 3.4% of cases.
- Patients with acute slipped capital femoral epiphysis are unable to bear weight and have severe pain on passive and active movement. There often is associated joint effusion and limb shortening with external rotation, although this is not always seen. More chronic presentations may have similar findings, but patients may tolerate weight bearing with an antalgic or altered gait, including taking shorter steps on the painful leg and turning the affected foot outward.
- Patellofemoral instability is one of the most common pediatric and adolescent knee conditions. The majority of patellar dislocations and subluxations are lateral.

Hyaline cartilage and menisci (fibrous cartilage) are soft tissues that act as shock absorbers in the knee joint and distribute force.[5] The hyaline cartilage lies along the articular bone surfaces to allow for smooth movement. The two menisci are located only along the tibial plateau within the medial and lateral fossae, appropriately named the medial meniscus and lateral meniscus, respectively. The menisci have great tensile strength, allowing them to be excellent shock absorbers and protect bones while simultaneously better defining the reciprocal depressions for femur articulation.[5]

Along the posterior aspect of the knee, also called the popliteal fossa, is a neurovascular bundle containing the popliteal artery, common peroneal nerve (lateral division of the sciatic nerve), and the tibial nerve (continuation of the sciatic nerve). These structures are especially important to consider when evaluating a patient with hyperextension and/or posterior knee dislocation or injury.[5,8] The knee has poor collateral vascular circulation, so injury to this neurovascular bundle can be devastating and lead to loss of limb viability.[8] Lastly, the knee has three compartments: the medial tibiofemoral, lateral tibiofemoral, and patellofemoral, which all share the same synovial cavity.[5]

Special anatomical considerations in the pediatric population involve the bone's ability to grow. Pediatric bones have distinct segments: the diaphysis (shaft), metaphysis (flared segment between diaphysis and physis), physis (growth plate), and epiphysis (ossification center). The weakest of these segments is the growth plate, which reduces the overall tensile strength of the bone to be less than that of the ligaments. This reduced tensile strength of bone, in comparison to ligaments, causes pediatric knees to experience fractures more often than ligamentous injuries.[7,9] Although this dynamic changes once the physis closes, the tensile strength of the bone becomes greater than that of the ligament.[7] Keep in mind, the age for physeal closure can vary by individual, by gender, and by anatomical location.[10] Typically, knees are skeletally mature (full physis closure) between 15.6 and 17.1 years of age in boys and between 15.0 and 16.9 years of age in girls.[11]

Another feature specific to the pediatric knee is the varus and valgus progression that occurs during development. Although significant varus (bow-legged) or valgus (knock-knee) deformities can be associated with injury and chronic discomfort in adults, they are considered normal in the development of children younger than 7 years old. Before 1 year of age, it is expected for knees to have a varus angulation. This changes to a neutral position around 1 year of age, then transitions to a valgus angulation (peaking at about 20 degrees) at 3 years old. Children usually reach a normal knee orientation by 7 years old, which is neutral or less than 12 degrees valgus. Normal knee growth will continue until about 14 years of age in females and about 16 years of age in males.[10]

History, Exam, and Initial Workup

In addition to routine "OLD CARTS" (onset, location/radiation, duration, character, aggravating factors, relieving factors, timing, and severity) history, it is important to ask about previous knee injuries or congenital abnormalities, the ability to walk or play after injury, knee functionality after injury (range of motion, ability to bear weight), mechanism of injury, mechanical symptoms, and chronicity of symptoms.[4,12,13]

The exact mechanism of the injury should be clearly understood. Common mechanisms include rotational injury (direction change, pivoting), blunt trauma, start/stop injury, jumping, and powerful muscle contractions. The directionality of blunt trauma can help determine possible ligaments involved, since anterior blows are more closely associated with posterior cruciate ligament (PCL) injury; valgus forces are associated with medial cruciate ligament (MCL) injury; varus forces are associated with lateral cruciate ligament (LCL) injuries; and abrupt deceleration, hyperextension, and/or rotational mechanisms are associated with anterior cruciate ligament (ACL) injuries. Rotational mechanisms also can be associated with meniscal injuries or patella subluxation.[4,13]

Any mechanical symptoms also should be explored, since they can help elucidate which structure in the knee may be injured. "Locking" often is associated with meniscal or plica injuries, "popping" is associated with ligamentous injury, and the knee "giving out" can be associated with ligamentous injury, patellar subluxation or dislocation, or quadriceps injury.[4,13]

Lastly, a clear understanding of the chronicity of symptoms is essential to narrowing the differential diagnosis among acute injuries, subacute conditions, and chronic conditions, although this often can be difficult in pediatric populations, depending on their age and developmental status.[4,13]

On exam, start by examining the hip to evaluate for signs of referred pain, and always compare the unaffected knee to the painful knee. Complete a visual inspection for swelling, effusion, bruising, and cutaneous injury. Check for symmetric knee musculature or signs of atrophy, as this can indicate a more chronic injury or condition. Complete a focused exam for tenderness, with special attention to tenderness of the tibial tubercle, patella, joint line, femoral condyle while in flexion, and growth plates. Check if the patella is ballotable, since increased or decreased mobility can reflect tendinous tears or underlying effusion, respectively. Examine for full range of motion, and specifically watch the patella through full extension and flexion for appropriate tracking and crepitus. Evaluate for straight leg raise, knee extension, locking or catching of the knee, giving way, or stiffness.[4,12,13] Examine for neurovascular injury distal to the fracture site, which includes palpating distal pulses, measuring capillary refill, testing motor function, testing sensation, and measuring two-point discrimination. Specifically for knee injuries, examine for common peroneal (fibular) and tibial nerve deficits. (*See Table 1.*) Further details on specific examination techniques and findings are described with the respective knee injuries. When determining whether imaging is necessary, in addition to clinical gestalt, clinical tools, such as the Ottawa Knee and Pittsburgh rules, can help.

The Ottawa Knee Rule has been shown to reduce the number of radiographs ordered, patient wait times, and costs without increased incidence of missed fractures.[14] The rule recommends imaging patients who are older than 2 years of age with traumatic knee pain and/or tenderness on exam and one or more of the following:

- age older than 55 years;
- tenderness to palpation of the fibular head;
- isolated tenderness to palpation of the patella;
- inability to flex knee 90 degrees; and
- inability to bear weight both immediately and in the ED (i.e., ambulate more than four steps; limping is OK and does not require heel to toe steps).

In applying the Ottawa Knee Rule to pediatric populations, there is some discrepancy in the data for patients younger than the age of 5 years, but meta-analyses have shown high sensitivity and adequate specificity for children older than 5 years of age.[15,16] According to Bulloch et al, the Ottawa Knee Rule can be applied to patients from ages 2 to 16 years. They found a 97% sensitivity and 27% specificity for fracture in this age group and estimated that implementation of this rule could reduce radiographs by 31.2%.[17]

The Pittsburgh Decision Rules can be applied to all patients on initial presentation who suffered knee injury from a fall or blunt trauma within one week prior to presentation and who are without prior knee surgical history. Imaging is recommended if the previous criteria are met, in addition to at least one of the following:

- age younger than 12 years or older than 50 years; and
- inability to take four steps and patient must engage both the toes and heels of each foot with each step, regardless of age.

Studies comparing the Ottawa and Pittsburgh rules showed similar sensitivities, but higher specificity in the Pittsburgh rules,[18,19] although the Bulloch paper stated concerns that the confidence intervals associated with the Pittsburgh rules were poor and did not recommend their use in children.[17]

If imaging is warranted, plain films should be obtained. It is generally recommended to start with anteroposterior and lateral films, with or without oblique views or a sunrise view. Oblique views can help identify subtle plateau fractures. When gross fractures are not evident, lateral films may show lipohemarthrosis (fat-fluid levels) suggestive of intra-articular fracture. Weight-bearing films also can help assess functionality, if the patient is able to tolerate them.[4,19] Additional views specific to particular fractures are listed in the summary table and in their respective sections.

If further imaging is warranted as the result of concerning radiographic findings or negative/inconclusive radiographs in the setting of persistent clinical concern, magnetic resonance imaging (MRI) is usually the next modality of choice, since it reduces exposure to radiation and better assesses soft tissue. MRI also can diagnose patellar dislocations that have spontaneously reduced.[7,12] Computed tomography (CT) may be superior in delineating the extent of tibial plateau fractures, but it should be considered on a case-by-case basis, and the risk of increased radiation exposure in a pediatric patient should be considered.[19]

If further imaging is warranted, and the clinician is unskilled in knee examination, it should be completed in consultation with a specialist to ensure the appropriate imaging is obtained.[7] If MRI is

Table 1. Nerve Deficits in the Knee[51-53]

Nerve	Motor Deficits	Sensory Deficit	Associated Knee Injury
Tibial nerve	Loss of plantar flexion of ankle and weakened foot inversion; associated with shuffling gait	Lateral and plantar foot and posterior lower leg	Compartment syndrome, posterior knee dislocation, or any fracture posteriorly displaced into the popliteal fossa
Common peroneal (fibular) nerve	Loss of dorsiflexion of ankle ("foot drop") and unable to evert the foot ("steppage gait")*	Foot dorsum and lateral shin	Knee dislocation or fracture or compression injury from direct trauma (usually where it wraps around the fibular neck)

*Weakness is more obvious when observing the patient walking while attempting to hold the foot in dorsiflexion, although gait demonstration is often intolerable or inappropriate in the setting of traumatic injury.

unavailable, the decision for transfer to a facility with MRI or close follow-up with MRI must be made on a case-by-case basis in regard to the severity of injury, clinical concern, and available resources. Consulting an orthopedic specialist may be beneficial in assisting with making this decision.

The most common pediatric knee injuries identified by MRI include patellar injury, patellar tendon injury, physeal fractures, osteochondral abnormalities, ligament tears, and meniscal injury.[9]

The Western Australia Department of Health developed the following evidence-based flowchart to assist in clinical decision making for children presenting with knee pain. It is available at https://bit.ly/3767PwE .

Bony Knee Injuries

As noted in the anatomy section, pediatric patients experience fractures more often than ligamentous injury, since the tensile strength of their ligaments is greater than that of the pediatric bone.[7] Despite bony injuries being more common than ligamentous injuries, knee fractures are relatively rare in the context of all knee injuries incurred by children. Possible physeal injuries and tibia fractures can cause the greatest threats to the limb, since they may be associated with devastating consequences. Physeal fractures are often associated with vascular injuries[21] and can impede growth, leading to limb length discrepancies and deformity.[3] Tibia fractures, especially tubercle fractures, are associated with compartment syndrome.[21]

All knee fractures warrant prompt orthopedic consultation. The immediacy depends on the severity of injury, the availability of appropriate imaging, hospital policy, availability of specialists, and the discretion of the clinician. In general, patients can be appropriately splinted with follow-up the next morning or admitted to the hospital with orthopedic consult in the morning if the patient is neurovascularly intact and the fracture is closed, nondisplaced, or mildly displaced and easily reducible.[21] If any of these criteria are not met, the patient should receive emergent orthopedic evaluation and be transferred to a facility with specialty care, if necessary. Open fractures should receive emergent intravenous antibiotics and admission. See the open fracture section for details.[22,23]

The majority of nondisplaced and/or reducible fractures can be managed nonoperatively, while displaced/nonreducible or complex fractures typically will require surgical intervention.[21] (*See Table 2, available online at* https://bit.ly/3KEWHbN.) Ultimately, this decision depends on the type and extent of the fracture, which is discussed in more detail later.

Proximal Tibial Fractures

Tibial Eminence (Spine) Fracture.

The tibial eminence is the elevated region of bone between the condyles of the tibia. Tibial eminence fractures are categorized as avulsion fractures at the anterior portion of the tibial eminence where the ACL inserts deeply on the subchondral plate. They result from increased traction on the ACL and are considered ACL-equivalent injuries.[21,24] These fractures are relatively uncommon injuries in children, affecting three in every 100,000 children.[25] The mechanism of this fracture usually occurs when the knee is flexed and experiences an internal rotation movement of the tibia, classically associated with falls off a bicycle, but it also is seen in young athletes or patients in motor vehicle accidents.[24]

On exam, patients will be unable to bear weight and will have a painful, swollen knee. The workup should include plain films in the lateral, anterior/posterior, and intracondylar views. Lateral plain films are generally diagnostic.[4] These fractures often are associated with meniscal injuries, collateral ligament injuries, capsular injuries, and/or osteochondral fragment injuries in about 40% of cases. A meta-analysis of ACL injuries by Buckle et al found that associated meniscal or additional ligament injuries occurred in 27% to 75% of cases.[26] Given the likelihood of associated soft-tissue injuries, thorough examination for other ligamentous and meniscal injuries is recommended, and further nonemergent imaging with MRI is warranted for their diagnosis if suspected on exam.[27] Soft-tissue injuries do not require emergent orthopedic evaluation, but proper imaging of these injuries can assist with treatment, planning, and approach by specialists.[4,24,27]

In the ED, treatment involves placement of a long-leg splint with the need for emergent orthopedic evaluation depending on the nature of the fracture. The Meyers & McKeever classification system is used to stratify tibial eminence fractures by severity and can be used to help determine a treatment plan.[27] Generally speaking, nondisplaced or reducible type I and II fractures can be managed nonoperatively in a long-leg splint in extension with urgent orthopedic evaluation, whereas type III and IV or displaced fractures require surgical intervention and emergent orthopedic evaluation.[4,27]

For definitive treatment of these fractures, the orthopedic community is generally in agreement that displaced eminence fractures in pediatric patients should be fixed operatively, although there are multiple modalities of treatment, and surgical techniques are continuing to evolve in skeletally immature patients.[11,21,25,26] If left untreated, tibial eminence fractures can result in instability, biomechanical functional loss, valgus deformity, and growth disturbance.[24,26,27]

Tibial Tubercle Fractures. Tibial tubercle fractures were historically rare, causing 0.4% to 2.7% of pediatric knee injuries, but they have increased with increased engagement in competitive sports at younger ages.[28] They are seen almost exclusively in males because of developmental differences in males and females. Male bones complete development at an older age than females, causing a heavier and stronger force on a weaker apophysis.

The most common mechanism of injury involves jumping and landing, or any injury associated with violent quadriceps contraction. This fracture is associated with existing Osgood-Schlatter (OS) disease, since 23% of tibial tubercle fracture cases have preexisiting OS. Although the incidence of tubercle fracture among all patients with OS is unclear, it is reasonable to discuss the risk for future fracture in patients diagnosed with this condition.[29] On exam, look for tenderness of the tibial tuberosity, severe swelling, pain with extension, and reduced ability or complete inability to extend.[21,28] Generally, diagnosis can be made with AP and lateral plain films, but in some cases further imaging with CT may be warranted if there is concern for articular involvement.

In the ED, place the affected limb in a long-leg splint. The need for emergent orthopedic evaluation depends on the severity of the fracture, which is classified using the Ogden Criteria. The Ogden Criteria is a modified and more specific version of the previously used Watson-Jones criteria. Generally, type IV and V fractures or significantly displaced fractures require operative treatment with emergent orthopedic evaluation while others can be managed nonoperatively with a long-leg cast in extension for approximately six weeks and urgent orthopedic evaluation.[28] It is important to note that, despite this classification system, there are significant discussion and variation in practice among orthopedists for definitive treatment. These variations likely are because of the uniqueness of each fracture regarding the extension of the fracture line and the amount of displacement.[28,29]

Complications include bursitis, refracture, and compartment syndrome. The most common complication was bursitis associated with surgical implant, which accounted for more than half of the complications, while refracture represented only 6% of total complications. Compartment syndrome occurred in 3.57% of tibial tubercle fractures.[21,29] A recent literature review showed that 98% of patients returned to their previous level of activity, regardless of fracture type.

Proximal Tibial Epiphyseal Fracture. Fractures of the proximal tibia epiphysis are very rare, since the knee anatomy protects this portion of the bone very well. The semitendinosus muscle tendon covers the epiphysis and inserts on the metaphysis. Similarly, the fibular ligament and medial collateral ligaments insert on the metaphysis, putting the epiphysis at low risk for avulsions and varus-vulgus forces, as these are transmitted to the metaphysis.[30] Of all bone epiphysis injuries, these account for only 0.5% to 3.1% overall.[31] Given the rarity of these fractures, there is little new evidence regarding them, and the majority of literature published is in the form of case reports. On exam, palpate for tenderness at the epiphysis and inspect for deformity. Plain films in the AP and lateral views generally are diagnostic.[30-32]

In the ED, these fractures can be categorized using the Salter-Harris classification to help determine the treatment plan. As with other Salter-Harris fractures, reducible types I and II fractures generally can be handled nonoperatively with long-leg splinting and urgent orthopedic evaluation, while types III and IV usually require operative repair and emergent orthopedic evaluation. These fractures generally have a good prognosis with treatment.[32,33]

Proximal Tibial Metaphyseal Fracture. Proximal metaphyseal fractures are uncommon and usually occur between 3 and 6 years of age, but they also can be seen in infants and adolescents. Their diagnosis and treatment depend greatly on their mechanism of action. The mechanism of action for proximal tibial metaphyseal fractures can be broken down into two categories: low-energy and high-energy mechanisms.

The low-energy mechanisms generally occur in children younger than the age of 9 years. In children ages 3 to 6 years old, one mechanism is associated with nonaccidental trauma and involves intentional pulling on the leg with rotational force (for example, grabbing a child by the ankle with rapid acceleration and deceleration force, or violent shaking of an infant). These are identified as corner or bucket handle fractures on imaging. Another common low-energy mechanism seen in children ages 3 to 9 years is medial (varus) or lateral (valgus) force to the leg. This kind of injury is associated with activities like jumping on a trampoline and are identified as nondisplaced incomplete fractures called buckle or greenstick fractures.[20,34] Although the fibula tends to remain intact in these injuries, the presence of a fibula fracture can indicate a more unstable fracture pattern.[20]

High-energy mechanisms generally occur in adolescents and are associated with sports activities or motor vehicle accidents.[34] They involve complete transverse fractures of the metaphysis with displacement. They require admission for repeat careful examination for compartment syndrome, vascular injury, and surgical stabilization.

On exam, patients with low-energy mechanisms will refuse to bear weight, but there will be little to no localized swelling or deformity. These patients should be examined for other signs of physical abuse. High-energy mechanisms are more likely to show deformity and tenderness on exam.[34] Imaging should include plain films in the AP and lateral views, and bilateral films often are recommended to help determine abnormalities from baseline anatomy. On imaging, abusive injuries will appear as a triangular-shaped avulsion of the bone or a "c-shape" of a bucket handle in the oblique view. This view extenuates that the subperiosteal layer has pulled away from the bone. Examine closely for signs of compartment syndrome, as this would warrant admission for frequent evaluation.

In the ED, low-energy mechanisms can be handled routinely with reduction, long-leg splinting, and urgent orthopedic follow-up.[34] When splinting, be sure to keep the knee in extension with a varus mold to prevent the common complication of tibial metaphyseal fractures of progressive valgus angulation.[20] If this valgus angulation complication occurs, it may or may not improve with time. If performing closed reduction and splinting, it is recommended to obtain plain films of both tibias for comparison to ensure adequate alignment of the injured tibia.[34]

Any child with a corner or bucket handle fracture requires evaluation for child abuse. The appropriate evaluation for nonaccidental trauma per hospital policy should be pursued, including a mandatory report to appropriate government authorities, if applicable in that jurisdiction.

Treatment for high-energy mechanisms requires admission for frequent repeat evaluation for compartment syndrome or vascular injury. Emergent orthopedic evaluation is recommended, and surgical stabilization often is required.[34]

Common complications include valgus deformity, which can occur in up to 50% to 90% of cases, with maximum deformity taking 18 months to develop. Limb length discrepancy also can occur, with the affected leg averaging 9 mm longer than the unaffected leg.

Displaced Femoral Physeal Fracture

Distal femoral fractures account for 12% to 18% of femur fractures in pediatric patients.[8,35] Unlike the tibia, which has unique fracture patterns due to its anatomy, distal femoral fractures generally can be categorized by the Salter-Harris classification system.

The mechanism of injury usually is high-energy, and the direction of the force applied to the knee can help determine fracture location and type:[8]

• Breech delivery is associated with Salter-Harris I fractures in neonates.[8]

• Valgus force (medial force applied to the lateral aspect of the knee) causes Salter-Harris II and III fractures. These fractures classically are seen in football players.[8]

• Varus force (lateral force applied to the medial aspect of the knee) leads to lateral displacement.

• Knee hyperextension can cause displacement of the epiphysis anteriorly. In these injuries, it is important to examine closely for neurovascular injury — specifically examine for foot drop and sensory deficits on the dorsal and plantar foot — as the proximal segment of the femur can be pushed into the popliteal fossa and injure the popliteal vessels, common peroneal nerve, and posterior tibial nerve.[8]

• Knee hyperflexion leads to posterior displacement.

• Minimal-force mechanisms are associated with growth plate weakening disorders, such as osteomyelitis, leukemia, and myelodysplasia.[20]

On exam, as mentioned, evaluate for limb shortening, limb angulation, and neurovascular compromise, including foot drop, decreased sensation along the dorsal and plantar foot surfaces, and distal pulses. Hamstring spasm causing knee flexion may be present.[20] Diagnosis can be confirmed by imaging, with plain films usually being sufficient for diagnosis. The knee should be imaged in the AP, lateral, and oblique views, in addition to AP imaging of the full femur and the hip.[8] If there is concern for vascular compromise, obtain CT with angiography or conventional arteriography and emergently consult orthopedics. Note that stress radiographs evaluating for physis opening are no longer recommended because of the risk of physeal damage.

In the ED, treatment should include reduction, if applicable, and a high long-leg splint with the knee in extension and with strict nonweightbearing recommendations. The Salter-Harris classification system can be used to help direct management. Arrange urgent orthopedic follow-up for patients who are neurovascularly intact and have either nondisplaced or mildly displaced fractures (Salter-Harris I or II) with successful reduction and splinting.[8] Emergent orthopedic evaluation is required for any patient with distal neurovascular deficits, signs of compartment syndrome, irreducibly displaced Salter-Harris I or II fractures, and all Salter-Harris III, IV, and V fractures.

Splinting is most effective if it also can involve the hip and ankle, although this may require the addition of stirrups.[8] Be aware that multiple attempts at reduction can further injure the physis.[20] If one has difficulty with reduction, proceed with caution. In neonates, a soft cotton roll and tongue depressor often are sufficient for padding and splinting.[8] If the patient arrives by ambulance in skeletal traction performed by emergency medical services, it is recommended to remove the traction to prevent the development of pressure ulcers. Although this is a common practice in adults, it is uncommon for orthopedists to place traction pins in pediatric patients in the ED due to possible improper pin placement, which can harm growth plates. To assist with pain control, multiple studies have shown that ultrasound-guided femoral nerve blocks and fascia iliaca compartment blocks have provided pain control with lower pain scores and longer durations than traditional oral and intravenous medications.[8,36,37]

Any high-energy mechanism injury or femoral fracture in a nonambulatory infant or child should warrant examination for additional injuries. Femoral fractures require significant force; thus, any femoral injury in a nonambulatory child warrants evaluation for nonaccidental trauma and alerting Child Protective Services. Additionally, patients who underwent a high-energy mechanism likely will require a full trauma evaluation.[8]

Definitive treatment and prognosis vary by age and premorbid functionality. Neonates generally heal within one month without long-term complications if properly splinted. In children younger than 6 years of age, splinting usually is sufficient for treatment. In children older than 6 years of age, surgical intervention is more likely to be needed, but it is case- and surgeon-dependent. Regardless of surgical intervention, patients must maintain strict nonweightbearing on the affected leg for six weeks. After three months, patients can begin transitioning to normal activity, with full activity at six months status post injury.[8]

Overall, complications are uncommon, with exception of angular deformity, growth arrest, or leg-length discrepancy. One meta-analysis reported that 52% of all distal femoral growth plate fractures were associated with limb-length discrepancy, with 22% of patients experiencing > 1.5 cm leg-length discrepancy.[38] These discrepancies may resolve with growth, or they may require shoe inserts or, possibly, surgical intervention if there is a > 2 cm difference between limbs at bone maturity. Other complications include neurovascular compromise and compartment syndrome, as described earlier, which are rare and are associated more with higher energy trauma (high falls or vehicle accidents).[8] If incurred, most nerve palsies resolve with time.[8,20] Nonunion is very uncommon and should prompt evaluation for infection. Workup should include complete blood count, erythrocyte sedimentation rate, and c-reactive protein testing. Patients also may experience stiffness upon cast removal, although most children regain full range of motion over time without intervention.[8]

Supracondylar Distal Femur Fractures

Supracondylar fractures occur just above the knee joint and involve transverse or oblique fractures proximal to the distal femoral epicondyles. They compose 12% of femoral fractures in children. Of supracondylar fractures, approximately 57% are displaced. They are caused most commonly by a fall, usually greater than 1 meter of height, and are very uncommon before the age of 4 years.[39] If suspected in plain films, nondisplaced fractures generally heal well with conservative management. In nondisplaced fractures, the affected leg can be splinted/cast with a hip spica and closely followed by an orthopedist. Displaced supracondylar fractures usually require surgery, although the best techniques are still under investigation. In a recent study using K-wire fixation, Li et al found good results and minimal complications.[39] Within 10 weeks, all patients were able to return to normal activity without pain, maintained full range of motion of the knee, and had an average limb-length discrepancy of 0.4 cm. Common complications include psychosocial issues due to prolonged immobilization, limb-length discrepancy, and valgus deformity due to the unbalanced pull of the gastrocnemius or adductus muscles, making alignment difficult to control.[39]

Knee Dislocation (Tibiofemoral Dislocation)/Popliteal Artery Injury

Knee dislocation is a complex injury resulting from the rupture of multiple ligaments. It is associated with high rates of vascular and nerve injury.[40] These dislocations are defined by the movement of the tibia in relation to the femur and are usually, but not exclusively, in the AP plane. Knee dislocations involve at least two tendons and are associated with multidirectional instability. Although they classically involve ACL and/or PCL injury, it is possible for these ligaments to remain intact and for dislocation to occur due to other ligamentous injury.

In skeletally immature patients, dislocation caused by ligamentous failure is relatively uncommon, as the physis is more likely to fracture before the ligament disrupts.[7,20] Therefore, avulsion fractures, growth plate injury, and cartilage injury are seen more often with dislocations in children.[40,41] When dislocated in the AP plane, they commonly disrupt the neurovascular bundle running along the popliteal fossa, which includes the popliteal artery, tibial nerve, and common peroneal nerve.[7,20] The rarity of dislocation may also be related to its high rate of spontaneous reduction, with an estimated 50% of cases unreported due to spontaneous reduction.[42]

Common mechanisms of injury include hyperextension and valgus and varus rotary stress. Hyperextension injuries are associated with popliteal artery stretch and rupture.[43] Forceful posterior displacement of the tibia while the knee is flexed at 90 degrees leads to arterial contusion and damaged intima.[40] Since many knee dislocations spontaneously reduce, a thorough history is very important, including the leg position during injury, the knee and leg appearance immediately following the injury, and whether it subsequently changed.[7]

Although knee dislocations were previously thought to be associated with high-velocity trauma mechanisms, recent data have shown nearly equivalent distribution between high- and low-velocity trauma.[42] Regardless, knee dislocation often is associated with tibia, patella, pelvis, spine, and head injuries, and all patients should receive a complete trauma examination.[40]

On exam, knee dislocations often are clinically obvious, with gross deformity and large hemarthrosis or ecchymosis, but some can be subtle, with little visible deformity, if they have spontaneously reduced.[43] If no gross deformity is noted, but dislocation is suspected by the history, complete a thorough ligamentous exam for knee stability, although pain and swelling may limit this examination. If two or more ligamentous deficits are noted, a dislocation is likely to have occurred.[7,44]

Skin should be inspected for the "dimple sign," which indicates a manually unreducible posterolateral dislocation. To identify this "dimple," examine the medial joint line for a transverse groove on the skin. If present, the medial capsule has been invaginated into the dislocation, preventing manual reduction.[44]

In the case of gross deformity or suspicious exam, a neurovascular exam and emergent plain films should be completed to confirm the dislocation. Plain films in the AP and lateral views can be especially helpful in knee dislocations because displaced fractures in adolescents and children can misleadingly appear similar to dislocation on visual inspection.[7]

In the ED, if dislocation is the primary concern and imaging cannot be obtained emergently, a reduction should be performed immediately, because the risk for neurovascular insult outweighs the benefits of waiting for imaging. After reduction, a repeat neurovascular exam should be completed.[7] The exam should include an ankle brachial index (ABI), and a vascular surgery consultation should be pursued if the ABI is less than 0.9 and/or if there are abnormal or asymmetric distal pulses.[43] The patient also should be examined for signs of deep vein thrombosis.[40]

After reduction, immobilize the joint in a knee immobilizer at 15 to 20 degrees and obtain repeat AP and lateral plain films to confirm reduction.[44] It is reasonable to obtain a CT angiogram to evaluate for vascular compromise and patency, although these are usually unnecessary if the patient's vascular exam and ABI are normal.[43] Note that intimal flaps of the popliteal artery are a possible complication and can cause delayed vascular occlusion,[40] thus, admission for serial examination (every two to four hours by nursing staff) is recommended.[43] The patient should be evaluated emergently by an orthopedic surgeon and a vascular surgeon or transferred to a facility with those specialists.[7] Imaging should not delay transfer.

The definitive treatment is emergent surgical intervention, pending patient stabilization of life-threatening injury. To avoid permanent damage, vascular repair needs to be initiated within six to eight hours of injury, if indicated.[20] As stated, all patients with knee dislocations should be admitted for serial vascular exams, regardless of the need for surgical intervention.[43]

Complications associated with knee dislocation include deep venous thrombosis, significant functional instability,[40] and vascular injury in 2.4% of patients.[7] Excellent evaluation for vascular injury in knee dislocations is essential, since delays in the diagnosis of popliteal artery injuries can lead to lifelong disability and limb loss. Popliteal artery injury has a greater than 10% amputation rate in pediatric patients, since the knee has poor collateral circulation.[8,45]

Adjacent to the popliteal artery are the posterior tibial nerve and the common peroneal nerve, which are also at risk of injury.[8] One study looking at the association of popliteal artery injury with various knee injuries found that about 50% of popliteal artery injuries were associated with dislocation or fracture of the femur, tibia, and/or fibula.[45] It also found that when the popliteal artery was injured, other concomitant injuries included popliteal vein injury in 12.1% of cases, posterior tibial nerve injury in 3.4% of cases, and peroneal nerve injury in 3.4% of cases.

Referred Pain and SCFE

A slipped capital femoral epiphysis, often referred to as SCFE (pronounced "skiffy"), occurs when the epiphysis is displaced or "slips" from the proximal femoral neck along the physeal plate. It is one of the most common hip pathologies in adolescents. Although this is primarily a hip pathology, it is important to consider when discussing knee injuries because 15% of patients present with knee pain.[46] This referred pain from the hip to the knee is likely due to innervation of pathways of the anterior branch of the obturator nerve and branches of the articular femoral, common peroneal, and saphenous nerves.[4] This injury typically occurs between the ages of 10 and 16 years, which aligns with the peak time of linear bone growth. There is a slight increase in incidence among males compared to females (male to female ratio of 1.5:1). Patients who have reached menarche or passed the fourth Tanner stage are far less likely to incur this injury.

Obesity is the greatest risk factor associated with SCFE, even in the absence of other medical conditions, with patients in the 90th percentile of weight at greatest risk, and the risk continuing to increase with the severity of obesity. Endocrine disorders and certain genetic disorders also can increase the risk of SCFE. The most common associations are thyroid disorders, growth hormone disorders, Down syndrome, and Rubenstein-Taybi syndrome. Patients with unilateral SCFE and concurrent endocrine disorders have a 100% chance of developing bilateral SCFE, while the other populations have a 30% to 60% chance of developing bilateral SCFE.[46]

The mechanism and presentation can vary from acute traumatic injury within the past three weeks to chronic vague symptoms spanning many weeks or months — the latter typically occurring in obese patients, although a thin patient who has recently undergone a significant growth spurt also can fall into this category.[46]

On exam, patients with acute presentations are unable to bear weight and have severe pain on passive and active movement. There often is associated joint effusion and limb shortening with external rotation, although this is not always seen. More chronic presentations may have similar findings, but patients may tolerate weight bearing with an antalgic or altered gait, including taking shorter steps on the painful leg and turning the affected foot outward. In severe slips, the patient may have a Trendelenberg gait.

In bilateral injury, a waddling gait can be seen. Examination may reveal atrophy of the upper thigh and gluteal muscle of the affected leg due to disuse. Knee palpation and examination should be nontender and normal, despite the patient localizing pain to the knee, but palpation of the anterior hip may reveal tenderness. Passive range of motion will likely, but not necessarily, be painful, with decreased motion primarily with internal rotation, abduction, and flexion. Range of motion may be painful in other directions if an atypical displacement has occurred, such as a valgus slip.

During passive motion examination, watch for a natural tendency of the thigh to abduct and externally rotate, as this finding is very concerning for SCFE.[46]

During the workup, keep in mind that 20% to 40% of SCFE cases are bilateral on initial presentation, and unilateral slips happen more frequently on the left.[46] Thus, bilateral imaging generally is recommended. Plain films are vastly diagnostic, although MRI can be useful for symptomatic preslips or if clinical suspicion is high and plain films are nondiagnostic. MRI also is helpful in evaluating for the extent of osteonecrosis, if present. Plain films should be taken in the AP and lateral views, with lateral projections in frog-leg or cross-table views. True lateral radiographs can be used in place of frog-leg or cross-table views if the patient underwent a traumatic mechanism and there is concern that leg movement will worsen the injury. The classic finding on plain film is described as "ice cream slipping off a cone." More subtle finds include widening and irregularity of the physis with thinning of the proximal epiphysis. When reviewing the plain films, also consider avascular necrosis of the hip (Legg-Calve-Perthes disease), as it presents very similarly. Currently, CT and ultrasound play little to no role in SCFE diagnosis.

In the ED, treatment is strict non-weightbearing restrictions with no specific splinting necessary. The choice of crutches, wheelchair, or bed rest is patient-dependent. Admission and emergent orthopedic consultation should be obtained with acute slips (also called "unstable slips") and often with bilateral slips, even if chronic, as the patient requires bed rest for bilateral slips. Other chronic slips (also called "stable slips") can be managed with urgent orthopedic evaluation. Definitive treatment is operative stabilization by an orthopedist.[46]

Complications include osteonecrosis, chondrolysis (joint space narrowing and loss of articular cartilage), femoroacetabular impingement that leads to premature arthritis, persistent symptoms, pain, and stiffness. Additionally, functional limitation may persist long term in up to one-third of patients.[46]

Patellar Subluxation and Dislocation

The patella is the largest sesamoid bone in the body. It is embedded in quadriceps tendon and lies in the trochlea of the femur. Dislocation or subluxation of the patella occurs when it moves out of its normal position in the trochlea. Patellofemoral instability is one of the most common pediatric and adolescent knee conditions. The majority of patellar dislocations and subluxations are lateral. Medial dislocations are rare, unless incited by trauma or surgery.

The classic mechanism described is internal rotation of the knee while the foot is planted (spinning, gymnastics, quick change of direction during athletic activity). Patients also may classically present describing the sensation of their knee "giving out."[4,6] On presentation, the patella may have already reduced spontaneously, but significant swelling, bruising, or effusion may be present. If not reduced, an obvious deformity should be noted with a mass to the medial or lateral aspect of the knee.[4]

On exam, specifically watch the patella through full extension and flexion for appropriate tracking, and palpate for crepitus.[4] Focal bony tenderness should not be present; if it is present, a fracture should be considered. Examine for hemarthrosis, as patellar dislocation is a common case of hemarthrosis in pediatric athletes. Additional findings, including enu valgum, increased femoral anteversion, external tibial torsion, trochlear dysplasia, patella alta, ligamentous laxity, and an increased quadriceps angle (Q angle) can increase the suspicion for patellar dislocation.[47] If the history is concerning for patella dislocation, but there is no apparent deformity, certain exam techniques can be used to evaluate the patella's predisposition for maltracking or subluxation.

One technique involves finding the Q angle. The Q angle is formed by two anatomical lines that meet at the center of the patella: one from the superior iliac crest to the center of the patella, and the other from the tibial tuberosity to the center of the patella. If the arc between these two lines, the Q angle, is greater than 15 degrees, there is a greater disposition for patella instability. The knee should be held in extension during this exam.[4,47]

Another exam maneuver is the patellar apprehension test. This test is divided into two components: Part 1 requires manual subluxation of the patella performed by placing a lateral force on the medial aspect of the patella with the examiner's thumb while moving the knee from extension to flexion at 90 degrees, then back to extension; part 2 is performed by placing a medial force on the lateral aspect of the patella with the examiner's index finger. If part 1 reproduces pain and part 2 does not, it is considered a positive test for increased patellar instability. This test has been found to have a sensitivity of 100%, a specificity of 88.4%, a positive predictive value of 89.2%, and a negative predictive value of 100%.[48]

The workup in the ED should include plain X-ray films in the AP, lateral, and merchant and/or tunnel views, which usually are sufficient for diagnosis.[47] Nonemergent MRI is indicated if soft tissue injury is suspected, such as chondral injury or osteochondral fractures, or if large medial patellar stabilizer defects are noted on exam.[4] MRI also can diagnose patellar dislocations that have reduced spontaneously.[12,47]

In the ED, treatment should include closed reduction and immobilization in a knee immobilizer. Reduced weightbearing with crutches is recommended. Limit walking, standing, repetitive bending, and frequent impact. Patients may use nonsteroidal anti-inflammatory drugs for pain control in addition to ice and elevation four times daily for 10 to 15 minutes each time. The majority of patellar dislocations are handled nonoperatively, with urgent orthopedic or primary care follow-up in two to three days. Early rehabilitation exercises are important to ensure proper recovery. Surgical intervention may be required if patellar dislocation recurs frequently or if there is an associated chondral injury, an osteochondral fracture, or significant medial patellar stabilizer defect, but these injuries do not require admission.[4,47]

The most common complications include recurrent knee pain or instability, with many studies showing more than 50% of patients with these symptoms.[4]

Patellar Fractures and Patellar Sleeve Fracture

Patellar fractures and patellar sleeve fractures have different definitions but have similar workups and treatments. Patellar sleeve (avulsion) fractures are defined as a separation of the cartilage sleeve from the patella. These are different from discrete fractures of the patellar bone itself.[4] Sleeve fractures are more common in children than adults[6] and generally occur between ages 8 and 12 years.[4] This is because the tendon strength is much greater than that of the bone in pediatric patients.

Approximately 1% of bony injuries are fractures of the patella.[4] The mechanism of injury is generally a direct force against the flexed knee or sudden quadriceps muscle contraction. This can range from falls or motor vehicle dashboard injuries to blunt object impacts or sudden start/stop injuries when sprinting or jumping during athletic activities.[7] Be sure to complete a full trauma exam, if warranted.

On exam, there is more likely to be focal bony tenderness with patellar fractures than with dislocations, which can help differentiate these two injuries. Inspect and palpate for joint effusion or hemarthrosis,[4] although this is not specific to patella fractures. Additionally, palpate for a gap in the extensor mechanism, which includes the quadriceps and patellar tendons. This can be associated with patellar fracture.[7] Examine the knee in full range of motion, making sure the patient is able to extend against gravity either by a straight leg raise or by sitting the patient at the edge of the bed and actively extending the knee against gravity.[4,7] Pain control may be necessary prior to the exam, which may include direct intra-articular injection of an analgesic like bupivacaine.[6] It is important to complete a thorough exam, since sleeve injuries often are misdiagnosed and can be missed on plain films.[21]

If blunt trauma is the primary mechanism, complete a thorough neurovascular exam. One study found that 25.9% of popliteal artery injuries were associated with closed fractures or dislocations of the patella due to blunt trauma.[45]

The workup should include plain films in the AP, lateral, and sunrise views. The need for MRI or CT is very uncommon, but they may be helpful if multiple injuries or soft tissue injuries are suspected. Ultrasound can be helpful to evaluate the quadriceps and patellar tendons for movement deficits or ruptures, which can be indicative of avulsion fractures. To perform the ultrasound, ask the patient to extend and flex the knee, then place the ultrasound in a long-axis position and move it in the rostral-caudal direction to visualize the entire extensor mechanism as the patient moves.[6]

When viewing plain films, it is important to keep in mind that bone fragments can be difficult to visualize, and an avulsion fracture cannot be completely ruled out with unremarkable plain films. Often, fractured fragments can be larger than they appear on X-ray because of their increased cartilage composition.[7] Additionally, a high-riding patella (patella alta) or low-riding patella (patella baja) can be suggestive of an avulsion fracture if fragments are not discretely seen.[4] If plain films are not conclusive, contralateral films can help determine changes from the patient's baseline anatomy, especially in conditions like bipartite patella, where the patella is congenitally formed from two bones.[6] If suspicion remains high, CT or MRI should be considered to confirm the diagnosis, as patellar sleeve injuries often are misdiagnosed.[7,21] If there is an overlying skin injury concerning for joint space involvement, observe for extravasation from the wound while injecting saline into the joint space from a different location. If there is

Table 3. Open Fracture Antibiotic Coverage Recommendations[23,49,50]

Gustilo Classification	Description of Open Fracture	Organism of Concern	Antibiotics
Type I	Skin wound < 1 cm and clean; minimal comminution	Gram-positive organisms only	First-generation cephalosporin alone (cefazolin) OR Clindamycin* OR Vancomycin** (if concern for methicillin-resistant *Staphylococcus aureus*)
Type II	Wound > 1 cm without extensive soft tissue damage, flaps, or avulsions; moderate comminution	Gram-positive AND gram-negative organisms	Type I antibiotic coverage ± aminoglycoside*** (gentamicin) or ceftrixone
Type IIIA-IIIC	Wound > 10 cm with extensive soft tissue injury or a traumatic amputation (includes special categories of gunshot fractures, open fractures caused by farm injuries, vascular injury that requires repair for limb preservation, and exposed bone requiring skin grafting for coverage)	Gram-positive AND gram-negative organisms	Type I antibiotic coverage AND Aminoglycoside**** (gentamicin preferred) or ceftriaxone
Additional Antibiotic Coverage Based on Wound in Contamination			
	Fecal or soil contamination (ex. farm-related injuries)	*Clostridium* coverage	High-dose penicillin or metronidazole
	Freshwater contamination	*Pseudomonas* and *Aeromonas* coverage	Piperacillin-tazobactam
	Seawater contamination	*Vibrio*, in addition to *Pseudomonas* and *Aeromonas* coverage	Piperacillin-tazobactam and doxycycline

*Recommendations for clindamycin are less robust than for first-generation cephalosporins, but clindamycin has been shown to have adequate coverage for type I and II open fractures.

**Vancomycin is likely appropriate gram-positive coverage in patients with penicillin allergies, although there is not significant literature on this topic.

***Aminoglycosides may be dosed once daily. Be aware that aminoglycosides carry a risk of nephrotoxicity and ototoxicity.

****Fluoroquinolones have been associated with nonunion and poor fracture healing and are not superior to the cephalosporin/aminoglycoside regimens above. They also have been associated with higher infection rates in type III open fractures.

positive leakage from the wound, emergent orthopedic consultation for washout is warranted.[6]

In the ED, treatment and management of sleeve fractures are similar to that of patellar and quadriceps tendon injuries. Patients should be placed in a knee immobilizer or splint in full extension, not hyperextension, with nonweightbearing instructions. To reduce swelling, elevation, ice, and compression with an elastic bandage can help. If effusion or hemarthrosis is causing significant discomfort, joint aspiration for pain relief is reasonable. Strength exercises while immobilized, including straight leg raises, should be started as early as possible.[6] Urgent orthopedic follow-up should be arranged for closed fractures. Open fractures require admission with emergent orthopedic evaluation. Definitive treatment depends on the extent of the injury. If the extensor mechanism is disrupted on exam, urgent surgical repair will be required.[7] Nondisplaced fractures with intact extensor mechanisms usually can be managed nonoperatively. The patient will remain in a knee immobilizer with a gradual increase in activity over four to six weeks.[6]

Complications include nonunion (rare), weakness, patellofemoral joint pain syndrome, osteoarthritis, osteonecrosis, and decreased range of motion.[6] Popliteal artery injuries have been associated with blunt patellar injuries.[45] Patients also may experience concomitant osteochondral fractures, which are osteochondral fragments arising from the initial fracture. They will present with continued catching or locking sensations, continued pain, and (sometimes) swelling. These osteochondral fractures can be diagnosed by MRI and outpatient orthopedic referral for treatment.[7]

Open Fractures

An open fracture occurs when the skin and soft tissue are completely disrupted at a fracture site, allowing for direct communication between the fracture and the environment.[22] It is important to identify open fractures on exam, as they have high rates of infection. It has been shown that early administration of antibiotics within the first six hours of injury have led to reduced infection — specifically, reduced osteomyelitis risk.[23] Risk of infection depends on wound size, severity of tissue and bone damage, extent of contamination, appropriate wound dressing, and patient's comorbid conditions. Comorbid conditions that increase infection are age of 80 years or older, nicotine use, diabetes, active malignancy, pulmonary insufficiency, and immunocompromised states — all conditions that cause impaired wound healing.[22] Infection risk is directly correlated with these comorbid factors: Patients with no risk factors have a 4% risk, those with one or two risk factors have a 15% risk, and those with three or more risk factors are associated with a 31% risk of infection.

On exam, carefully examine the skin to differentiate between the overlying abrasion and true disruption of the soft tissue leading to the fracture. A common misconception regarding open fractures is that the compartments have been decompressed. It is important to note that open fractures do not prevent compartment syndrome, as some compartments may still remain intact. Continue frequent checks for compartment syndrome if the patient has a concerning exam or a type of fracture that puts him or her at a greater risk of compartment syndrome.[22]

In the ED, treatment of open fractures is very similar regardless of fracture location. All open fractures require immobilization with splinting, antibiotics, tetanus prevention (depending on wound contamination and vaccination history), analgesia, and emergent orthopedic consultation for irrigation and possible debridement.[22] Antibiotic therapy is derived from adult data, and the choice of antibiotics is guided by the Gustilo classification of open fractures.[34,49] (*See Table 3.*) Tetanus vaccine and immunoglobulin administration are dependent on patient vaccination history and wound contamination.

Tetanus immunoglobulin: Give if the wound is contaminated or had a mechanism concerning for contamination and the patient has an unknown or incomplete tetanus vaccine history.[23]

Tetanus toxoid vaccine: Give if the patient has an unknown or incomplete tetanus vaccine history regardless of wound contamination. If the patient has been fully vaccinated previously, vaccination administration depends on wound contamination. In a clean wound, give if it has been more than 10 years since the last vaccination. In a dirty wound, give if it has been more than five years since the last vaccination.[23]

An incomplete tetanus vaccine history is defined as fewer than three previous tetanus toxoid vaccine doses.

Conclusion

The knee is the most commonly injured joint in pediatric patients, with approximately 2.5 million sports-related knee injuries seen in the ED annually.[1] Although the most commonly diagnosed injuries are sprains, strains, and cutaneous wounds, fractures can cause the most profound injuries with the greatest long-term deficits. Studies have shown that children have reduced physical, social, and school functioning in comparison to their peers after experiencing knee injury. Appropriate treatment of pediatric knee injuries can ameliorate these deficits.[2,3,11]

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The list of references is available online at: https://bit.ly/3vCni4V

CME/CE Questions

1. Pediatric patients are more likely to have a bone fracture than to disrupt a ligament.
   a. True
   b. False
2. An open fracture involves the complete disruption of the soft tissue above a fracture, allowing direct communication of the fracture with the environment. In an open fracture with a small wound that appears clean, which antibiotic(s) is/are recommended?
   a. Cefazolin
   b. Cefazolin and gentamicin
   c. Cefazolin and metronidazole
   d. Piperacillin-tazobactam and doxycycline
3. Which of the following fractures is an anterior cruciate ligament-equivalent injury?
   a. Tibial tubercle fracture
   b. Tibial metaphysis bucket handle fracture
   c. Tibial eminence fracture
   d. Patellar fracture
4. A football player presents with acute knee pain after being tackled below the knees. On exam, the knee does not show significant deformity, but it appears to be developing hemarthrosis. You complete a neurovascular exam, and the patient has isolated weakness on dorsiflexion of the affected limb. Which nerve are you concerned has been injured?
   a. Tibial nerve
   b. Common peroneal (fibular) nerve
   c. Sciatic nerve
   d Femoral nerve
5. Which criterion for imaging patients with knee pain is the same in both the Ottawa and the Pittsburgh decision rules?
   a. Age older than 50 years
   b. Inability to flex knee 90 degrees
   c. Tenderness of the fibular head
   d. Inability to ambulate four steps
6. Which fracture is associated with Osgood-Schlatter disease and is at risk for compartment syndrome?
   a. Tibial tubercle fracture
   b. Tibial metaphysis bucket handle fracture
   c. Tibial eminence fracture
   d. Patellar fracture
7. Which fracture is most concerning for nonaccidental trauma?
   a. Tibial tubercle fracture
   b. Tibial metaphysis bucket handle fracture
   c. Tibial eminence fracture
   d. Patellar fracture
8. Permanent bone deformity is one of the most serious complications of a proximal tibial metaphyseal fracture. When placing a splint, what can be done to help prevent this complication?
   a. Mold in hyperextension at the knee joint
   b. Mold in 90-degree flexion at the knee joint
   c. Mold with valgus stress
   d. Mold with varus stress

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Associate Editor: Mike Gates

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Accreditations Director: Amy M. Johnson, MSN, RN, CPN

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Bony Knee Injuries in Pediatric Patients

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Table 2. Classification and Treatment of Knee Fractures

Fracture Location	Classification	Imaging	Treatment	Tips
Tibia eminence	Meyers and McKeever (types I-IV)	• X-ray: AP/lateral/intercondylar	• Nondisplaced or reducible type I/II: nonoperative, long-leg cast in extension for three to four weeks; urgent orthopedic follow-up • Irreducible type III/IV: ORIF vs. all-arthroscopic fusion; emergent orthopedic evaluation • Nonweightbearing	• ACL-equivalent injury; risk of instability and functional loss • Evaluate for associated meniscal and ligamentous injury.[21]
Tibia tubercle	Ogden (modified Watson-Jones)	• X-ray: AP/lateral (optional internal rotation view) • CT if concerned for condylar involvement	• Type I or minimal displacement (< 2 mm) after closed reduction/cast application: nonoperative, long-leg cast in extension for six weeks; urgent orthopedic follow-up • Type II-V: open reduction and/or operative soft tissue repair; emergent orthopedic evaluation • Nonweightbearing	• Highest risk of compartment syndrome; admit if there is clinical concern[21] • Fracture line may extend proximally with variable distance posteriorly. • On imaging, widening or hinging open of the apophysis may indicate fracture. • Anterior swelling may be the only sign of a periosteal sleeve avulsion (type 5 injury). • Patella alta associated • Associated with Osgood-Schlatter disease
Proximal tibia epiphyseal	Salter-Harris	• X-ray: AP/lateral (optional oblique view) • Avoid varus/valgus stress due to physis injury risk	• Nondisplaced, stable Salter-Harris I/II: nonoperative, long-leg cast; urgent orthopedic follow-up • Unstable Salter-Harris I/II: closed reduction and pinning; emergent orthopedic evaluation • Salter-Harris III/IV: ORIF • Nonweightbearing	• Very rare due to protective anatomy • Rarity leads to scant data; information primarily is from case reports
Proximal tibia metaphyseal		• X-ray: AP/lateral views • Bilateral films recommended	• Nondisplaced or reducible: nonoperative, long-leg cast with varus molding and stirrups; urgent orthopedic follow-up • Irreducible: open reduction and casting; emergent orthopedic evaluation • Nonweightbearing	• Watch for concurrent proximal fibula fracture; it may indicate a more unstable fracture pattern. • Apply a varus mold when splinting to help prevent the complication of progressive valgus angulation; compare post-splint films against bilateral films to ensure appropriate splinting. • Evaluate for child abuse with avulsion (bucket handle or corner) fractures.
Distal femoral physeal	Salter-Harris	• X-ray: AP/lateral and oblique views of knee • Full femur and hip films recommended • CTA if there is concern for vascular compromise	• If nondisplaced or easily reducible: nonoperative, long-leg cast with stirrups to immobilized the hip, urgent orthopedic follow-up[14] • If displaced, irreducible Salter-Harris I/II, or Salter-Harris III/IV: likely requires percutaneous fixation or ORIF; emergent orthopedic evaluation • Nonweightbearing	• Evaluate for neurovascular compromise: foot drop, sensation along the dorsum and plantar foot, and distal pulses; if present, obtain CTA and emergent orthopedic consult. • Stress films are no longer recommended. • Evaluate for child abuse in nonambulatory children.
Knee dislocation		• X-ray: AP/lateral	• Reduction and knee immobilizer at 15 to 20 degrees • Emergent surgical fixation and orthopedic evaluation • Nonweightbearing	• Traumatic intimal flap of the popliteal artery can occur even if it appears vascularly intact; can diagnose via CTA. • Look for "dimple sign"; can indicate a posterior dislocation that will not be able to be manually reduced
Slipped capital femoral epiphysis		• X-ray: AP and lateral in frog-leg or cross-table view • Bilateral films recommended	• No specific splint recommended • Strict nonweightbearing with crutches, wheelchair, or bed rest • Admit if acute or bilateral • Urgent orthopedic follow-up if chronic	• If traumatic and concerned limb movement with worsen injury, true lateral films can replace frog-leg or cross-table
Patellar dislocation		• X-ray: AP/lateral and merchant views	• Knee immobilizer • Reduced weightbearing with crutches and limited activity • Urgent primary care or orthopedic follow-up	• These often spontaneously reduce; if you suspect spontaneous reduction, the quadriceps angle test and the patellar apprehension test can help determine patellar instability and likelihood of slip. • Common association of chondral or ligament injury; nonemergent MRI if concerned
Patellar fracture and patellar avulsion (sleeve) fracture		• X-ray: AP/lateral and sunrise views • Bilateral films recommended	• Knee immobilizer in full extension (not hyperextension) • Strict nonweightbearing • Urgent orthopedic follow-up	• Associated with patella alta and patella baja

AP: anteriorposterior; ORIF: open reduction and internal fixation; ACL: anterior cruciate ligament; CT: computed tomography; CTA: computed tomography angiography; MRI magnetic resonance imaging

Note: Emergent orthopedic evaluation requires evaluation while in the emergency department or transfer to a facility with an orthopedic specialist. Urgent orthopedic evaluation refers to outpatient follow-up within the next one to three days.

EMERGENCY MEDICINE REPORTS

Bony Knee Injuries in Pediatric Patients

Nerve Deficits in the Knee[51-53]

Nerve	Motor Deficits	Sensory Deficit	Associated Knee Injury
Tibial nerve	Loss of plantar flexion of ankle and weakened foot inversion; associated with shuffling gait	Lateral and plantar foot and posterior lower leg	Compartment syndrome, posterior knee dislocation, or any fracture posteriorly displaced into the popliteal fossa
Common peroneal (fibular) nerve	Loss of dorsiflexion of ankle ("foot drop") and unable to evert the foot ("steppage gait")*	Foot dorsum and lateral shin	Knee dislocation or fracture or compression injury from direct trauma (usually where it wraps around the fibular neck)

*Weakness is more obvious when observing the patient walking while attempting to hold the foot in dorsiflexion, although gait demonstration is often intolerable or inappropriate in the setting of traumatic injury.

Open Fracture Antibiotic Coverage Recommendations[23,49,50]

Gustilo Classification	Description of Open Fracture	Organism of Concern	Antibiotics
Type I	Skin wound < 1 cm and clean; minimal comminution	Gram-positive organisms only	First-generation cephalosporin alone (cefazolin) OR Clindamycin* OR Vancomycin** (if concern for methicillin-resistant *Staphylococcus aureus*)
Type II	Wound > 1 cm without extensive soft tissue damage, flaps, or avulsions; moderate comminution	Gram-positive AND gram-negative organisms	Type I antibiotic coverage ± aminoglycoside*** (gentamicin) or ceftrixone
Type IIIA-IIIC	Wound > 10 cm with extensive soft tissue injury or a traumatic amputation (includes special categories of gunshot fractures, open fractures caused by farm injuries, vascular injury that requires repair for limb preservation, and exposed bone requiring skin grafting for coverage)	Gram-positive AND gram-negative organisms	Type I antibiotic coverage AND Aminoglycoside**** (gentamicin preferred) or ceftriaxone
Additional Antibiotic Coverage Based on Wound in Contamination			
	Fecal or soil contamination (ex. farm-related injuries)	*Clostridium* coverage	High-dose penicillin or metronidazole
	Freshwater contamination	*Pseudomonas* and *Aeromonas* coverage	Piperacillin-tazobactam
	Seawater contamination	*Vibrio*, in addition to *Pseudomonas* and *Aeromonas* coverage	Piperacillin-tazobactam and doxycycline

*Recommendations for clindamycin are less robust than for first-generation cephalosporins, but clindamycin has been shown to have adequate coverage for type I and II open fractures.

**Vancomycin is likely appropriate gram-positive coverage in patients with penicillin allergies, although there is not significant literature on this topic.

***Aminoglycosides may be dosed once daily. Be aware that aminoglycosides carry a risk of nephrotoxicity and ototoxicity.

****Fluoroquinolones have been associated with nonunion and poor fracture healing and are not superior to the cephalosporin/aminoglycoside regimens above. They also have been associated with higher infection rates in type III open fractures.

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