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PEDIATRIC ORTHOPEDICS (B HEYWORTH, SECTION EDITOR)

Physeal fractures about the knee

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Abstract While some fractures may be managed similarly in adults and children, physeal fractures are uniquely limited to the pediatric population and require special consideration. Although physeal fractures about the knee are relatively rare, they are occurring more frequently due to increasing youth participation in sports and high-energy recreational activities. The evaluation and management of distal femoral and proximal tibial physeal fractures are similar to one another, but fractures of the tibial spine and tibial tubercle are approached somewhat differently. A thorough understanding of the pertinent developmental anatomy is critical for correlating the clinical findings with the imaging work-up, and for anticipating the most common and the most serious complications of each fracture. Diagnosis is usually made with appropriate plain radiographs with advanced imaging often used for preoperative planning. In general, fracture pattern and degree of displacement determine the need for surgical intervention and the overall outcome. While a variety of fixation techniques or constructs may be used, because of the importance of restoring physeal and articular anatomy for avoidance of growth disturbance and degenerative joint disease, respectively, achieving anatomic, rigid fixation is of greater importance than with many other fracture locations in the growing skeleton.

Keywords Distal femoral epiphysis · Pediatric fracture · Pediatric trauma · Physeal fracture · Proximal tibial epiphysis · Tibial tubercle avulsion

Introduction

Although physeal fractures about the knee are relatively rare, they are occurring more frequently due to increasing youth participation in sports and high-energy recreational activities. Whereas evaluation and management of distal femoral and proximal tibial physeal fractures are similar, the tibial spine and tibial tubercle fractures are approached somewhat differently. We will review the pertinent anatomy, clinical signs, imaging work-up, and treatment principles of each of these injuries, along with their most common and most serious complications.

Distal femoral physeal fractures

Isolated distal femoral physeal injuries are rarely seen [1, 2]. They represent 5 % of all physeal injuries [3]. Salter-Harris II fractures are the most common type [1, 2, 4, 5]. They may be uncommon fractures, but they frequently have long-term complications, such as growth disturbance, with subsequent development of leg length discrepancy and/or angular deformities [1, 2]. Growth arrest can occur as a result of direct physeal injury, epiphyseal bone bridge formation, or nonanatomic reduction [1].

Traditional assumptions are that girls achieve skeletal maturity at age 14 and that growth continues until 16 years in

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boys. Skeletal growth of the overall leg is about 23 mm per year. The distal femoral physis grows the fastest of all physes and is the main growth center of the lower leg, contributing approximately 40 % of lower extremity growth [1, 2, 6]. Overall, the knee contributes ~15 mm, since the distal femoral physis grows at a rate of about 9–10 mm per year and the proximal tibia physis grows 5–6 mm per year [6]. The proximal femur contributes approximately 3 mm per year, and the distal tibia approximately 5 mm per year.

Clinical presentation

Most distal femoral physeal fractures are caused by sports trauma, traffic accidents, and horse riding accidents [4]. The primary symptoms are knee pain and inability to walk or bear weight on the injured leg [6]. Physical exam in patients with displaced fractures reveals a swollen, sometimes tense knee, with tenderness along the physis [6]. Special attention must be paid to a thorough vascular examination of the affected lower extremity as vascular injuries are a serious complication related to displaced distal femoral physeal injuries.

Radiographic findings

Standard anteroposterior (AP) and lateral radiographs should be obtained. The imaging diagnosis of an entrapped periosteum can be suspected on radiographs with persistent physeal widening >3 mm [7•]. Stress radiographs were historically suggested as an option to look for opening of the physis if there was a suspicion of physeal injury without appreciable displacement at the time of presentation, but could be quite painful for the patient. Therefore, stress radiographs have become less popular in the evaluation of physeal fractures and are not typically used in clinical practice. MRI or ultrasound provide better visualization when limited ossification complicates the radiographic evaluation, such as in infants with a relatively unossified femoral epiphysis [6]. Urgent MRI is recommended to establish a definitive diagnosis when entrapped periosteum is suspected [7•].

Treatment

Stable, truly nondisplaced fractures can be treated nonoperatively with long leg casting [6]. Fixation is not required as long as the fracture does not lose reduction in the cast; therefore, close clinical follow-up is mandatory, and if any displacement develops, there should be a low threshold to employ closed reduction and percutaneous pinning. The diagnosis of a Salter-Harris I fracture of the distal femur may not be identifiable on injury films. Empiric treatment with 2–3 weeks cast immobilization and follow-up radiographs is reasonable if the exam demonstrates significant tenderness directly over the physis rather than the medial collateral ligament (MCL), particularly in younger adolescents in whom true MCL injuries are exceedingly rare.

Operative treatment includes closed vs open reduction with hardware stabilization. Most patients are treated with closed reduction and percutaneous fixation, followed by casting immobilization [6]. There is a general consensus that displaced fractures should be operatively stabilized with internal fixation, including displaced Salter-Harris [8] I or II fractures, even if they have been successfully reduced with closed methods. The undulating physis remains unstable following reduction and should still be pinned since it cannot be fully stabilized with casting alone [9].

Ideally, all reduction maneuvers should be a single attempt with adequate relaxation and without undue force [6]. Prior publications have demonstrated an association between reduction attempts and the risk to physeal arrest in other anatomical locations [10, 11]. It is therefore possible that repeated attempts at distal femoral physeal reduction that are forceful or without adequate muscle relaxation could also cause additional injury to the growth plate. This would increase the overall risk of physeal arrest above that which is attributable to the original injury.

Physeal growth can be inhibited if the surgical fixation crosses the physis [3, 12•]. Therefore, Salter-Harris II fractures with Thurston-Holland fragments sizeable enough to accommodate screws should be reduced and fixed with lag screws in the metaphysis, so that the internal fixation can avoid the physis if possible [3, 6, 13]. Smooth pins are thought to be less likely to cause further physeal injury. So if the physis must be crossed to stabilize the fracture, such as Salter-Harris I and Salter-Harris II fractures with small Thurston-Holland fragments smooth k-wires are used [3, 12•]. However, damage to the physis, even with percutaneous smooth wire fixation, can lead to potential bar formation and growth disturbance [1]. It was previously suggested that hardware crossing the physis was relatively safe if it involved a small portion of the physis, but recent animal study confirmed physeal bar formation despite involvement of <10 % of the cross-sectional area [12•].

Displaced Salter-Harris III and IV fractures and irreducible displaced Salter-Harris I or II fractures generally require open reduction [6]. An open surgical approach allows for a precise, anatomic reduction of the articular surface of the type III and IV fractures, minimizing the risk of complications [1, 14, 15]. Periosteum infolding into the fracture site is what usually blocks the closed reduction in the irreducible Salter-Harris I and II fractures [6, 16]. Preoperative MRI can confirm entrapped periosteum, which, even if removed during open reduction of the physeal fracture, may be associated with an increased risk for premature physeal arrest [17].

Complications

Late complications are more common than acute complications [6], and overall, growth arrest is the most commonly observed complication [1–3]. Growth disturbances, in the form of either leg length discrepancy and/or angular deformity, result from physeal arrest. Multiple studies have shown a fairly high rate following physeal injuries to the distal femur; although the reported rates for physeal arrest are variable among individual studies, it can be greater than 60 % [1–3, 5, 15]. Although there is a greater incidence of absolute growth disturbance in patients treated with fixation, there is a decreased incidence of clinically significant growth disturbance, defined as a leg length discrepancy ≥1.5 cm and/or 5° of varus or valgus deformity [2]. High-energy distal femur growth plate fractures have a significantly higher rate of growth disturbance compared with low-energy fractures [3]. Physeal arrest correlates with increasing severity based on the Salter-Harris classification [1–3]. Displaced fractures have a four times greater risk of growth arrest than nondisplaced fractures, and undesirable outcomes after distal femoral physeal fractures are more common in younger patients [2]. The development of deformity is also related to the exactness of the reduction—the further from anatomic reduction, the greater the chance of deformity or other complications [5]. Thomson et al.'s retrospective analysis showed the best results occurred with anatomic reduction and internal fixation; 43 % of their fractures reduced without fixation subsequently displaced during cast treatment [9].

A physeal bridge may develop after either operative or nonoperative treatment. Premature physeal arrest may not be clinically evident until years after the injury, although MRI could facilitate the diagnosis sooner [17]. Physeal bar excision is recommended when less than 50 % of the physis is involved, and there is adequate growth remaining (at least 2 cm or at least 2 years) [18]. Traditionally, fat has been used for interposition after bar resection, but polymethylmethacrylate may be utilized as an alternative to fat interposition, as it will not necrose or degenerate, and may have less of a recurrence rate [18]. Physeal bar resection in isolation can lead to incomplete correction as the injured physis may still cease growing earlier than a healthy physis. A contralateral hemiepiphysiodesis or ipsilateral osteotomy may be needed later to obtain complete correction. Therefore, patients must be followed closely with serial leg length and alignment assessments in the years leading up to skeletal maturity.

Neurovascular complications are rare, but a popliteal artery injury would most likely be associated with a hyperextension injury with anterior displacement of the epiphysis. Malunion, infection, recurrent displacement, instability, and restricted range of motion with knee stiffness have also been noted [1–3].

Proximal tibial physeal fractures

The incidence of proximal tibial physeal fractures is <1 % of all pediatric fractures [19]. There may be a direct or indirect mechanism of injury [6]. The most common mechanism involves indirect trauma to a hyperextended knee; valgus or varus indirect trauma, or high-energy direct trauma can also result in these injuries [19]. Bilateral simultaneous nondisplaced proximal tibial Salter-Harris type II fractures were recently reported in a healthy 14-year-old athlete with vitamin D deficiency prompting Harb et al. to recommend a thorough evaluation, including a metabolic work-up, with any unusual presentation of these fractures [20•].

Clinical presentation

The primary complaint of patients with a proximal tibial physeal fracture is knee pain, and the physical exam reveals focal tenderness along the physis, soft tissue swelling, and usually a knee effusion [6]. Depending on mechanism of injury, valgus or varus knee instability may be present [6]. A careful neurovascular exam is important. The physis is at the same level as the trifurcation of the popliteal artery where the three major branches (peroneal, anterior tibial, and posterior tibial arteries) divide off distal to the soleus muscle [6, 19]. This explains the risk of vascular compromise with displacement. These fractures may also be associated with type III tibial tubercle fractures, so there is also a risk of compartment syndrome due to disruption of the anterior tibial recurrent artery.

Radiographic findings

AP and lateral radiographs are required with optional oblique views. Salter-Harris classification can be assessed with plain films along with displacement of fracture fragments. CT is indicated to further document fracture displacement and is the best modality to evaluate Salter-Harris III and IV fractures. Although the mid and distal tibia are the most common site of stress fractures in the skeletally immature patient [21], Tony et al. recently described purely intra-epiphyseal stress injuries of the incompletely ossified proximal tibial epiphysis, using MRI as the principal imaging modality [22•].

Treatment

Nonoperative treatment is indicated for a nondisplaced fracture as well as for a minimally displaced Salter-Harris type I or II fracture that can be reduced and is stable with external immobilization [6]. Reduction maneuvers combine manual traction with anteriorly directed translation of the metaphyseal fragment [6]. The knee should be casted in slight flexion for 4 to 6 weeks [6]. Re-displacement is common without internal fixation.

Indications for operative treatment (closed reduction and percutaneous pinning) include Salter-Harris I and II fractures that are unstable or have failed closed reduction, or failure to maintain reduction in a long leg cast with less than 60° of knee flexion [6]. To determine stability, assess range of motion under fluoroscopy after reduction. If the fracture re-displaces, then it is considered unstable. For metaphyseal fixation, percutaneous pins should run parallel to the physis, but if transphyseal fixation is needed for stability, the smooth nonthreaded pins should cross as perpendicular as possible to the physis. Open reduction with internal fixation is required for displaced Salter-Harris III or IV fractures. Percutaneous screw fixation runs parallel to the physis in the epiphysis for type III injuries or the metaphyseal fragment in type IV injuries [6]. Postoperatively, the knee should be casted in slight flexion for 6 weeks [6].

Complications

Several complications have been reported including loss of reduction, ligamentous instability, and compartment syndrome. The rate of acute neurologic and vascular injuries is approximately 14 % [19]. Growth disturbances are the most common complication, occurring in 25 %, and can lead to limb length discrepancy and/or angular deformities. When significant enough, these growth disturbances may be treated with bar resection and interpositional free fat, but one third experience a recurrent bar formation and as many as 60 % have fair to poor results [23]. In a recent pilot animal study, PLGA scaffolds were shown to increase the amount of cartilage and reduce the amount of bony bar reformation in simulated proximal tibial physeal injuries when compared with the use of the traditional fat graft [24•]. Contralateral epiphysiodesis may also be indicated as treatment for leg length discrepancies, present or anticipated.

Tibial spine fractures

While tibial spine fractures can occur in adolescents, they are more commonly seen in school-age children and pre-adolescents. Bicycle injuries are a classically described mechanism, accounting for greater than 50 % of tibial avulsion fractures [34, 35]. However, athletic injuries may also result from either contact or noncontact injuries [25]. The mechanism of injury is similar to an anterior cruciate ligament (ACL) rupture and may occur during a rotational injury while playing sports such as soccer or skiing, or with extension and rotation during a fall [6, 25].

Anatomy

The tibial spine, also known as the tibial intercondylar eminence, is the elevated region between the articular portions of the medial and lateral tibial plateaus [6, 26, 27]. The ACL attaches between the lateral aspect of the medial tibial spine and the tibial eminence, 10–14 mm behind the anterior border of the tibia [6, 27]. Both mid-substance ACL tears and tibial spine fractures may occur in skeletally immature patients, but the intercondylar eminence is more prone to failure than the ligamentous structures that attach to it due to the relatively weak, incompletely ossified tibial epiphysis [6, 25].

Classification

The original classification system described by Meyers and McKeever in 1959 established three types of fracture pattern [27]. Type I is nondisplaced from its bed, type II is minimally or mildly displaced with an intact posterior hinge while the anterior third is elevated, and type III is completely elevated from its bed with disruption of the posterior cortex [6]. Later, a type IV fracture pattern was described that involved comminution and rotation of the fragments [28].

Clinical presentation

Patients with tibial spine fractures present with a primary complaint of knee pain with motion [25, 29]. A large immediate knee effusion is usually noted, and the knee is flexed with limited range of motion secondary to pain and muscle spasm [6, 25, 27]. Extension can be blocked by the fragment also. It is difficult to assess knee stability because of pain-mediated muscular spasm and guarding, but an anterior drawer test or Lachman's exam may be positive [6, 25].

Radiographic findings

Standard knee radiographs [27, 30] are recommended and are key to preventing a missed diagnosis [31•]. The lateral radiograph is usually key to making this diagnosis. CT may be used for preoperative planning and to better quantify the amount of displacement of the fragment [6, 32]. MRI, which, unlike CT does not involve radiation, is useful in evaluating this injury since the incidence of concomitant intra-articular injuries is high, and this modality is better at identifying associated collateral ligament and meniscal involvement than CT or radiographs [25, 33].

Treatment

Nondisplaced type I and reducible type II fractures are amenable to nonsurgical management [25, 27, 34]. This consists of closed reduction, possible aspiration of the hemarthrosis [27, 30, 33, 34], and immobilization in 0–20° of extension [4, 34–37]. When closed reduction is attempted, good quality post-reduction radiographs or CT are helpful to assess the adequacy of the reduction. Surgical fixation of tibial eminence fractures is indicated for all displaced fractures including all type III fractures, type II fractures that cannot be adequately reduced in extension, and late displacement of type I fractures [25].

Surgical techniques

Arthroscopic management is now the most common approach, having evolved from traditional open or mini-open techniques [38]. Standard arthroscopic portals are used [30] for this technique, which begins with debriding the fracture [29]. Meniscal entrapment is common in patients with displaced tibial eminence fractures. Removing the incarcerated meniscus, or entrapped intermeniscal ligament, allows for anatomic reduction [39–41]. The medial meniscus is the most common cause of a blocked reduction; Lafrance et al. noted this at the time of arthroscopy in more than half their patients with residual displacement after closed reduction [25].

Suture and cannulated screw fixation are the most common fixation techniques, and both have yielded satisfactory results [25, 38, 42]. Suture fixation has the advantage of avoiding the physis. Biomechanical studies have shown that sutures may also be stronger in strength than screw fixation [43]. Ultra-high-molecular-weight polyethelene (UHMWPE) suture fixation was found to be stronger than PDS or screw fixation [44]. This procedure is technically demanding, which a disadvantage of arthroscopic suture fixation [25, 42]. Nonetheless, suture fixation techniques appear to be the most popular among orthopedic surgeons [25]. A curved suture passer may be used to arthroscopically pass sutures into the distal ACL. An ACL guide can assist with reduction of the fragment, and to drill one or two 2 mm holes, similar to an ACL tunnel. The sutures can be pulled out the tibia through the transosseous tunnels and tied over a button or bony bridge, respectively [45].

Screw fixation is very stable, which allows for early range of motion [42, 46]. A variety of techniques may be used, but a 4.0 cannulated screw is usually inserted through a suprapatellar portal. There are several disadvantages of screw fixation, however. It can be challenging to place a screw perfectly perpendicular to the fragment. The screw may require removal if hardware irritation occurs with retained hardware in the joint; however, most people do not remove the screw prophylactically. Adequate screw purchase may be difficult with small fragments, and if not done correctly, screw use can cause fragmentation of the bony piece. An improperly placed or prominent screw may impinge, creating a block to extension and/or chondral damage. Physeal damage may result unless the screws are sufficiently short so as to not cross the physis [34].

Postoperatively, early range of motion is initiated to prevent loss of extension and regain flexion [6, 30, 38].

Complications

The most common complication of these fractures is stiffness. Arthrofibrosis is a risk following tibial spine avulsion treatment and is more common with surgical reconstruction [6]. Loss of motion may require a return to the operating room for lysis of adhesions and manipulation under anesthesia [4, 35, 46]. Residual ACL laxity, due to mid-substance attenuation of the ACL pre-fracture, can persist; however, it is often clinically insignificant and does not typically result in subjective instability [25, 27, 34]. Reconstruction of the ACL is rarely required, and Kocher et al. demonstrated an excellent clinical outcome after arthroscopic reduction and internal fixation of displaced fractures, despite persistent laxity [47]. Growth arrests have also been reported [48, 49].

Tibial tubercle fractures

Acute tibial tubercle avulsions are relatively uncommon, but severe apophyseal fractures are usually seen in adolescent males approaching skeletal maturity involved in jumping sports [50–53]. Christie and Dvonch reported that all of their cases occurred while playing basketball [51]. They may occur in isolation or be associated with additional injuries, such as patellar or quadriceps tendon avulsions, collateral or cruciate ligament tears, or lateral meniscal damage [6, 53, 54]. These fractures account for approximately 3 % of all proximal tibial fractures [53, 55].

Anatomy

The tibial tubercle is the most anterior aspect of the proximal tibial epiphysis and contributes to growth of the proximal tibia as it develops from a secondary ossification center between the ages of 10 and 12 years [6, 56]. In contrast, the primary ossification center of the proximal tibial physis is present at birth [56]. The extensor mechanism inserts on the tibial tubercle via the patellar tendon, which makes the tubercle an apophysis. The developmental anatomy of the tibial tuberosity is unique in that the tibial physis closes from posterior to anterior, so the energy from the fracture can travel up the apophysis and then exit up into the joint [53]. It also closes proximal to distal which predisposes the tibial tubercle to avulsion injury, especially in older children, between 13 and 16 years of age (just before the tibial tuberosity ossification center fuses with the metaphysis by the age of 15 to 17 years) [19, 53, 55, 56].

The anatomy of the proximal tibia and the tibial tubercle makes tibial tubercle fractures at relatively high risk for the development of compartment syndrome. The anterior tibial recurrent artery arises superiorly over the tibial tubercle and may be torn with displaced fractures of the tubercle [50, 57].

Classification

The most commonly used classification is Ogden's modification of the original Watson-Jones [58]. Type I is a fracture of the secondary ossification center near the insertion of the patellar tendon. A type II fracture propagates proximal to the junction with the primary ossification center. A type III fracture extends posteriorly to cross the primary ossification center. The Ogden modifiers include A for nondisplaced and B for displaced and/or comminuted [52]. Additional descriptions have now been added to the original system. The fracture can occasionally extend back out the posterior tibial metaphysis. This was described as a type IV by Ryu et al. [59]. Type V has a "Y" fracture configuration (Ogden 3B with a Salter-Harris IV fracture of the proximal tibia) [53].

Additionally, many variations of tibial tubercle fractures have been reported including combined tendon avulsions and tubercle fractures (type 1-C) [54], combined tibial tubercle avulsion fracture and patellar avulsion fracture [60•], and tibial tuberosity sleeve fracture [61•, 62]. A new classification system was recently proposed which utilizes CT scans since intra-articular involvement is often missed with the use of plain X-ray [63].

Clinical presentation

Patients classically report the sudden onset of knee pain during jumping activities, most often with onset during athletic participation, like basketball or football [6, 55, 58, 63]. Mosier et al. reported these fractures were the result of either a sudden contraction of the quadriceps during knee extension or passive flexion of the knee against rapid contraction of the quadriceps [55].

Physical exam reveals an acutely swollen knee (including a hemarthrosis with type 3 injuries) and tenderness at the tibial tubercle [54] The patient may be unable to extend the leg fully due to pain or weakness [6]. Pape et al. stress the importance of examining the soft tissue compartments of the leg, especially the anterior compartment [50]. Compartment syndrome is a potential complication, albeit not the most common, but should be considered nonetheless, especially in adolescent boys.

Radiographic findings

Using a lateral radiograph of the knee to identify the fracture and facilitate classification is standard practice [6, 63]. A lateral view of the contralateral knee may be helpful in skeletally immature patients [6]. Evaluate the level of the patella as disruption of the patellar tendon or tibial tubercle may be associated with patella alta [6, 54]. Pandya et al. advocate the use of preoperative CT scan or MRI as an adjunct to plain lateral radiographs to accurately determine fracture extension [63].

Treatment

Nondisplaced fractures are treated nonoperatively with 3 to 4 weeks of immobilization, either long leg casting or splinting in extension [53, 64]. Ogden type I fractures with minimal displacement and type II injuries with acceptable displacement after closed reduction have also been successfully treated with closed reduction and casting [6, 51, 52, 55].

Displaced tibial tuberosity fractures of any type require open reduction and internal fixation [53, 64]. Even in type III injuries, the outcome is usually good to excellent [53, 55]. Closed reduction can be attempted under anesthesia and, if adequately reduced, clamped and fixed with screws percutaneously [51]. If not adequately reduced, then open reduction would be performed. Pretell-Mazzini et al. performed a systematic review and found that 98 % were treated with ORIF [65•].

Cannulated screw fixation of the avulsed fragment is superior to percutaneous pinning for these displaced fractures. Screws offer better compression and rigid fixation without creating percutaneous pin sites. Screw fixation allows for earlier range of motion than casting alone, but hardware irritation from prominent screw heads can necessitate implant removal in over 50 % of cases [65•]. Periosteal sutures and casting can also be considered in very skeletally immature patients [53]. Abalo et al. and Riccio et al. have described the open technique [6, 64]. A medial or midline longitudinal incision is made to expose the fracture site. The fracture bed is cleared of any hematoma or soft tissue interposition including periosteum. Fracture fragments are anatomically reduced and internally fixed with one or two 4.0-mm cancellous, partially threaded screws. Larger 6.5-mm cancellous screws can be used but may be more likely to cause soft tissue irritation or more pain with kneeling in the long term.

Direct assessment of the articular reduction during open reduction and internal fixation is indicated in type III fractures. Anatomic reduction of the joint surface may be visualized arthroscopically or via a midline approach or median parapatellar open arthrotomy [52, 63]. The obvious advantage of the arthrotomy is the ability to address intra-articular extension and soft tissue injuries. The disadvantage however is that it may require longer immobilization and/or rehabilitation.

Postoperative care

Patients are made nonweight bearing and generally immobilized in a long leg or cylinder cast for 4 to 6 weeks [6, 54, 55]. Rehabilitation focuses on range-of-motion and progressive extensor mechanism strengthening [6, 54, 55]. Full motion and quadricep strength are required for return to sports, usually not sooner than 12 weeks [6, 63].

Complications

Numerous complications have been reported [51, 64] with an overall 28 % rate [65•]. Bursitis over the screw heads is the most common, occurring in 55 % [65•]. Growth disturbance (recurvatum deformity or leg length discrepancy) can occur when the growth arrests due to premature physeal closure [52, 63]. Anterior compartment syndrome is a potential risk, 3 % overall according to Pretell-Mazzini et al [65•], as the anterior tibial recurrent artery may be disrupted [50]. Stiffness, malunion, nonunion, patella baja, and secondary fracture through hardware have also been reported [52, 53, 55].

Conclusion

The evaluation and management of the distal femoral and proximal tibial physeal fractures have similar principles, while fractures of the tibial spine and tibial tubercle warrant somewhat unique considerations. A thorough understanding of the pertinent developmental anatomy is critical for correlating the clinical findings with the imaging work-up, and for anticipating the most common and serious complications of each fracture. Diagnosis is usually made with appropriate plain radiographs with advanced imaging often used for preoperative planning. In general, fracture pattern, degree of displacement, and associated injuries determine the need for surgical intervention and the overall outcome.

Compliance with ethical standards

Conflict of interest Rhianna M. Little declares that she has no conflict of interest.

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