MINI-SYMPOSIUM: CHILDREN’S ORTHOPAEDIC SURGERY

(ii) Paediatric epiphyseal fractures around the knee

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Paediatric; Knee; Fracture; Osteochondral injury

Summary
Physeal fractures around the knee are most common in children aged 9–14. The majority of these fractures will have a good outcome if they are adequately treated initially. There is a fairly clear consensus on how these fractures should be managed. Undisplaced fractures are treated with cast immobilisation and almost universally have a good outcome. Displaced Salter Harris I and II fractures of the proximal tibia and distal femur can usually be treated with closed reduction and fixation. Intraarticular fractures often require open reduction prior to internal fixation. Displaced fractures of the tibial spine, tibial tuberosity and patella are more difficult to reduce closed and an open reduction is frequently required. Most osteochondral fractures are simply excised arthroscopically. There are well recognised complications associated with paediatric knee fractures. Early complications include popliteal artery damage, ligament damage and compartment syndrome. Late complications are usually related to damage to the physis with leg length discrepancies and angular deformity.

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Introduction
As the child ages the incidence of physeal fractures around the knee increases with a corresponding decrease in the incidence of metaphyseal fractures. Isolated ligament injuries also become more common in the teenager (Fig. 1). With growth, the epiphysis becomes less cartilaginous and the secondary ossification centre increases in size. This relative rigidity of the epiphysis reduces its ability to absorb energy and there is a tendency for applied forces to be transmitted to the physis. This may account for the shift in fracture distribution. Most physeal knee fractures therefore occur over the age of 10. The distal femoral and proximal tibial growth plates are responsible for the majority of longitudinal growth of the lower limb (Table 1). Fractures affecting these physes are associated with a risk of late angulation and limb shortening. It is fortunate that the majority of these fractures do occur in the older child with less remaining growth potential. The treating surgeon should be aware of the risk of injury to the soft tissues surrounding the knee. Injury to the popliteal vessels, compartment syndrome and ligament damage are all seen in association with paediatric knee fractures.

Radiological investigations
In many circumstances plain anteroposterior and lateral radiographs are all that are required. A Merchant or skyline...
A view of the patella is helpful in the diagnosis of medial and lateral patellar avulsions. Tunnel views can be used to visualise the intercondylar area, for example when looking for loose osteochondral fragments. Further imaging is useful if there is doubt about the diagnosis or to delineate complex fracture patterns prior to surgery. Tomograms and stress radiographs have largely been replaced by the use of MRI and CT scanning. If stress radiographs are performed care should be taken not to further displace the fracture fragments. In general, when trying to delineate a complex fracture pattern, CT is the most useful investigation. MRI is helpful in tibial spine and patellar fractures with a very small bone fragment, to examine the integrity of the attached ligament. MRI is also used in the diagnosis of undisplaced fractures, particularly Salter Harris I fractures. Ultrasound is occasionally helpful in the assessment of the integrity of the patella tendon in sleeve fractures with a small bony avulsion.

**Distal femoral epiphysial fractures**

**Aetiology and anatomy**

The distal femoral epiphysis contributes 40\% to total limb length, growing at a rate of approximately 1 cm per year (Table 1). Nearly 75\% of all epiphyseal fractures are Salter Harris Type II. Fractures of the distal femoral epiphysis account for just 1\% of all paediatric long bone fractures.

**Classification**

The Salter Harris classification is used to classify distal femoral fractures. Type II fractures are the most common, accounting for over 80\% of distal femoral physeal fractures. Displacement usually occurs in the direction of the metaphyseal fragment. In type III fractures the split in the epiphysis is usually in the midline. Type V fractures are rare and often diagnosed late (Fig. 2).

**Mechanism of injury**

The mechanism of injury is either hyperextension or varus/valgus stress. Historically, hyperextension injuries were most common (Fig. 3). These were often caused by a child’s leg becoming caught in the moving wheel of a horse-drawn cart. These injuries were associated with a high risk of vascular complications and hence amputation. Varus/valgus injuries are now much more common, usually sustained during sport or in road traffic accidents. The risk of vascular

**Table 1** Approximate relative contribution of lower limb growth plates to leg length.

<table>
<thead>
<tr>
<th>Growth/periosteal (mm)</th>
<th>Percent contribution to length bone</th>
<th>Percent contribution to leg length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal femur</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>Distal femur</td>
<td>9</td>
<td>70</td>
</tr>
<tr>
<td>Proximal tibia</td>
<td>6</td>
<td>66</td>
</tr>
<tr>
<td>Distal tibia</td>
<td>3</td>
<td>33</td>
</tr>
</tbody>
</table>

**Figure 1** Graph of distribution of knee injuries by age.

**Figure 2** Asymmetric growth arrest following Salter Harris Type V distal femur fracture.
complications in these injuries is lower. Type I injuries can occasionally occur in the neonate, during delivery.

**Presentation**

In displaced fractures pain and deformity are the presenting features. The femoral epiphysis is displaced along with the tibia, so the femoral and tibial condyles are in normal alignment with each other. Arterial injury is rare (1%) in varus/valgus injuries.

**Treatment**

Undisplaced fractures can be managed in a long leg cast for 4–6 weeks. Displaced type I and II fractures may be treated by closed reduction. An assessment of stability can be made at the time of reduction. The reduction can then be held with a long leg cast, with or without internal fixation. In larger and heavier children it is more difficult to maintain a reduction with a plaster alone with a risk of redisplacement if the fracture is not internally fixed. In one series 3 out of 7 fractures redisplaced after cast immobilization. Internal fixation is usually carried out with crossed smooth Kirschner wires, inserted from distal to proximal (Fig. 4). Type II fractures with a large metaphyseal fragment can alternatively be managed by transverse percutaneous cannulated screw fixation of the metaphyseal fragment to the rest of the femur. Irreducible Type I and II fractures and all displaced type III and IV fractures require open reduction and internal fixation with cannulated screws or pins.

**Outcome**

The final outcome is related to the initial displacement of the fracture. The irregular femoral epiphysis provides resistance to shear. Because of this irregularity, when a fracture does occur it is more likely to be associated with damage to the physis. Salter Harris type I and II fractures of the distal femoral epiphysis are more commonly associated with growth arrest and subsequent angulatory deformity than these patterns of fracture at other locations. In type II fractures the physis underlying the metaphyseal fragment is
spared and the fracture angulates away from the side of the metaphyseal piece i.e. a medial metaphyseal fragment results in a valgus deformity. As the force required to fracture the epiphysis in a younger child is greater and therefore the energy imparted to the growth plate is more than in an adolescent fracture, it can therefore be expected that the initial damage to the physis is greater in a younger child. In addition the younger child has more potential for future growth therefore any damage to the growth plate resulting in shortening and/or angulation will be exaggerated. Angulatory problems that develop may be managed with hemiepiphysiodesis or osteotomy. The degree of predicted Leg Length Discrepancy (LLD) will influence treatment of shortening. A significant LLD (>2 cm or requiring contralateral epiphysiodesis) has been variably reported in 10–50% of patients. This is usually related to physeal bar formation. If children are followed to skeletal maturity, problems with LLD and angulation can be detected and treated at an early stage.

**Proximal tibial epiphysial fractures**

**Aetiology and anatomy**

Proximal tibial physeal fractures have similarities to distal femoral fractures in terms of classification, mechanisms of injury and treatment. They are approximately 3 times less common than fractures of the distal femoral epiphysis. This is thought to be due to protection of the physis arising from the sites of insertion of the collateral ligaments. Both medial and lateral collateral ligaments attach to the femoral epiphysis. However, the medial collateral ligament attaches to the tibial metaphysis and the lateral ligament is inserted into the fibula (Fig. 5). When a deforming force is applied to the knee the collateral ligaments will therefore transmit force to the femoral epiphysis but spare the tibial epiphysis. At the level of the proximal tibia the popliteal artery is relatively fixed in position, due to its numerous branches. It is therefore at significant risk of injury in fractures of the proximal tibia.

**Classification**

The Salter Harris classification is most widely used for proximal tibial physeal fractures. Type II and IV fractures are the most common. Type II fractures are usually due to valgus stress and the metaphyseal fragment is therefore usually lateral, with a corresponding valgus deformity. Type III fractures are often associated with avulsion of the tibial tuberosity (described below).

**Mechanism of injury**

Hyperextension or varus/valgus strains are the most common mechanism of injury. Fractures may also occur at birth or during vaginal breach delivery. Periarticular knee fractures have been reported following manipulation of a child’s knee.

**Presentation**

A tense haemarthrosis is usually present. Because of the shape of the proximal tibial physis, the tibial metaphysis displaces posteriorly (Fig. 6). This is particularly so in hyperextension injuries. There is a significant risk of injury to the popliteal neurovascular structures. A careful examination of the neurovascular structures in the lower limb must be made.

**Treatment**

Treatment options are similar to those used for fractures of the distal femoral epiphysis. Non-displaced Salter and Harris type I to IV fractures can be treated by cast immobilisation for 4–6 weeks. Displaced type I and II fractures may be reduced closed and then stabilised using smooth Steinmann pins. A large metaphyseal fracture may lend itself to cannulated screw fixation. Displaced type III and IV fractures will need open reduction and fixation, as will type I and II fractures that are not reducible by closed means.

**Outcome**

These fractures usually occur in adolescents and the prognosis is generally good. Type IV fractures are at a higher risk of developing problems with angulation or limb length
A discrepancy than other fracture patterns. Burkhart and Peterson described a series of open proximal physeal tibial fractures. These were all caused by lawnmowers and occurred in younger children. They had a universally poor outcome with a high incidence of problems with limb growth and angulation.\textsuperscript{7} Arterial injury is a well-recognised complication of proximal tibial physeal fractures, occurring in up to 10\% of patients.

Tibial tuberosity avulsions

Aetiology and anatomy

The tibial tuberosity develops from the anterior portion of the proximal tibial epiphysis. From the age of 8 years the secondary ossification centre of the tuberosity begins to appear, distinct from the main secondary ossification centre of the proximal tibia (which appears at 2 months). By age 17 the two ossification centres have merged.

Classification

The initial classification of these fractures was by Watson–Jones (Table 2). He recognised that the fracture starts at the distal tip of the physis of the tibial tuberosity. The extent to which the fracture propagates towards the knee joint surface determines the group into which the fracture falls. In type I fractures the fracture stops before the ossification centres of the tuberosity and proximal tibia meet. Type II fractures run up to the ossification centre of the proximal tibia (i.e. involve the whole tuberosity). Type III fractures are intra-articular. Ogden has subsequently modified this classification (Fig. 7).\textsuperscript{8}

Mechanism of injury

Fracture of the tibial tuberosity typically affects teenagers involved in sport. There is either forced flexion of the knee or a contraction of the quadriceps, which pulls off the tuberosity.\textsuperscript{9}

Presentation

There is a history of acute injury to the knee, which helps to distinguish this from Osgood–Schlatter’s disease. Osgood–Schlatter’s is a traction apophysitis affecting the superficial portion of the growth plate. Cases of fracture of the tuberosity have been reported in patients with pre-existing Osgood–Schlatter’s disease. It is uncertain as to whether pre-existing Osgood–Schlatter’s is a risk factor for tibial tuberosity fracture. In type I fractures it may still be possible to perform a straight leg raise. There is a risk of compartment syndrome in Type III fractures.

Treatment

Undisplaced fractures may be treated in a long leg cast with the knee in extension. Displaced fractures are best treated by open reduction and internal fixation as it is important that intervening periosteum is removed from the fracture. In Type III fractures the menisci may become interposed in the fracture site or torn. Small bone fragments of the tibial tuberosity may need to be sutured back into place. Larger fragments can be held with screws or K-wires. Following removal of the cast physiotherapy is useful to regain movement and rebuild muscle strength. Typically sports may restart at 3–6 months post-injury.
Outcome

The fracture typically occurs close to skeletal maturity and therefore the prognosis is good. In younger patients genu recurvatum is a possible complication. Retained metalwork may cause irritation as it often lies superficially. Patients with type III fractures should be closely monitored for compartment syndrome.

Table 2  Watson–Jones and Ogden classification of tibial tuberosity fractures.

<table>
<thead>
<tr>
<th>Watson–Jones</th>
<th>Ogden</th>
</tr>
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<tbody>
<tr>
<td>I  Fracture occurs through tibial tuberosity ossification centre</td>
<td>Ia  Undisplaced</td>
</tr>
<tr>
<td>II Fracture occurs between ossification centres of tibial tuberosity and proximal tibia</td>
<td>Ib  Displaced</td>
</tr>
<tr>
<td>III Fracture extends through proximal tibial ossification centre into knee joint</td>
<td>IIIa Not comminuted</td>
</tr>
</tbody>
</table>

Intercondylar eminence (tibial spine) fractures

Aetiology and anatomy

The intercondylar eminence is the central non-articulating part of the tibial plateau. The anterior tibial spine is most commonly avulsed, along with the insertion of the Anterior Cruciate Ligament (ACL). Rarely the posterior spine and insertion of the Posterior Cruciate Ligament (PCL) may be pulled off.

Classification

Myers and McKeever have classified anterior tibial spine fractures. Type I fractures are minimally displaced. Type II fractures have an intact posterior hinge, however the anterior portion of the tibial spine is elevated. Type III fractures are completely displaced. Type III fractures may be further classified. Illa fractures are displaced but not rotated and Illb fractures are displaced and rotated. Most fractures are Type II or III. Radiographs often underestimate the size of the avulsed fragment, which is largely cartilaginous. The medial and lateral extents of the avulsed fragment have the appearance of “bat wings” and tissue can easily become interposed, blocking reduction.

Mechanism of injury

Avulsions of the tibial spine are relatively common in children. The mechanism is similar to that of ACL injury in the adult. There is a valgus stress to the flexed knee or the knee is forcibly hyperextended. This usually occurs during sport or in a fall from a bicycle.

Presentation

The knee is acutely swollen and it may not be possible to fully extend or flex it. Laxity is often evident, if the child allows clinical examination. Weight-bearing on the injured leg may not be possible.

Treatment

Undisplaced fractures can be treated in a long leg cast with the knee in 20° of flexion (ACL maximally relaxed).
fractures should reduce when the knee is extended. They may therefore be managed in a long leg cast with the knee extended (not hyperextended). The cast is retained for 6 weeks. Type II fractures that do not reduce closed should be treated as type III injuries.

Type IIIa injuries may reduce closed, but Type IIIb fractures will not. In practice Type III fractures are managed with arthroscopic reduction and fixation or with an open anteromedial arthrotomy, reduction and fixation (Fig. 8). Transosseous sutures, screws or direct suture may be used to secure fixation. Post-operatively repair is protected by immobilisation of the knee in a long leg cast in slight flexion. A recent study has shown that it may only be necessary to perform an arthroscopic reduction (removing the transverse meniscal ligament from the fracture site). The reduction can then be maintained by casting the leg in hyperextension.  

There is very little information available on the management of PCL avulsions. If they are displaced the senior author’s practice is to perform an open reduction with internal fixation via a posterior approach (Fig. 9).

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**Figure 8** AP and lateral views of an anterior tibial spine fracture (8a) which has been internally fixed with a cannulated screw inserted into the epiphysis (8b). The physis has not been breached by the screw.

**Figure 9** Posterior spine avulsion internally fixed via a posterior approach to the knee joint.
Outcome

If the fracture is reduced adequately the prognosis is good. Proximal migration of the fracture can result in a block to extension. Following tibial spine avulsion, even after anatomic fixation, the ACL is often stretched. A positive anterior draw is common but the pivot shift test is almost always negative. In the long term this does not seem to be symptomatic, although the laxity does not recover. The children that are symptomatic following tibial spine fracture seem to suffer from activity-related pain rather than instability.

Patellar fracture

Aetiology and anatomy

Adolescents approaching skeletal maturity may suffer the same spectrum of patella fractures as adults. Adult pattern fractures are much less common in the younger child, as the patella is largely cartilagenous. Children more frequently suffer from peripheral osteochondral fractures of the patella, of which the inferior “sleeve” fracture is the most common. The fracture occurs through the zone of osseo-chondrous transformation, where the patella tendon collagen fibres blend directly into cartilage. Radiographs often give the appearance of a small bony fragment, however as the bulk of the avulsed fragment is cartilagenous the true size of the fragment is generally much larger (Fig. 10).

A superior sleeve fracture has also been described. In addition to sleeve fractures, medial or lateral osteochondral avulsions may also occur.

Classification

The patella is wholly cartilaginous until the age of 3. Ossification begins centrally. It is common for there to be more than one ossification centre, which can add to diagnostic problems in younger children. As there is no specific classification system the fractures are described by their appearance and anatomical location. Avulsion fractures may be inferior, superior, medial or lateral. The inferior “sleeve” fracture is the most well known variant. These fractures usually present acutely following a definite injury are often displaced and require fixation. A more chronic problem may present with no specific recollection of injury due to repetitive tension on the inferior pole (the Sinding-Larsen-Johansson lesion). Medial avulsions are also common. As the avulsion is largely cartilagenous they may not be diagnosed at the time of initial patella dislocation. It is only as the fragment ossifies that its full extent becomes evident. Superior avulsions are much less common. The extensor mechanism is not often compromised with superior avulsions. A chronic traction, similar to Sinding-Larsen-Johansson can also occur at the superior patella pole. Lateral avulsions are a chronic superolateral separation due to the tensile pull of vastus lateralis. These are equivalent to a bipartite patella.

Mechanism of injury

Sleeve fractures occur when the quadriceps are contracted against a flexed knee, such as in jumping. Both a fixed flexion deformity and restricted flexion of the knee joint can predispose to patella fractures. Medial fractures are usually the result of an acute lateral patella dislocation. As many as 40% of lateral patellar dislocations may be complicated by a medial patella avulsion or osteochondral fracture (from the patella or lateral femoral condyle).

Presentation

Sleeve fractures present with a traumatic haemarthrosis. There may be a palpable gap in the infrapatella region. Full active extension and a straight leg raise are usually not possible. There may be patella alta. In medial and lateral fractures the extensor mechanism is intact. Medial fractures are often recognised following patellar dislocation.

Treatment

Closed treatment in a long leg cast is appropriate for undisplaced fractures. Displaced fractures that involve the extensor mechanism (e.g. transverse and sleeve fractures) require open reduction and internal fixation. This is typically performed with a tension band technique. Medial avulsions are often best excised and the medial soft tissues repaired. If the fragment involves a significant amount of the joint surface it should be internally fixed. There is some evidence
that if these medial avulsions are not treated operatively there is a risk of recurrent subluxation or dislocation. Prolonged physiotherapy may be required after any patella fracture.

**Outcome**

Undisplaced and well-reduced fractures have a good prognosis. As might be expected displaced comminuted fractures do not have as good an outcome as undisplaced fractures. The presence of ipsilateral femoral or tibial fractures also predicts for a poorer outcome. Restoration of the pre-injury length of the extensor mechanism should minimise problems with restricted knee flexion, extensor lag and defunctioning of the quadriceps.

**Osteochondral fractures**

**Aetiology and anatomy**

Acute osteochondral fractures may arise from the patella or the medial or lateral femoral condyle. Even a large fragment may have only a small amount of ossified cartilage and their diagnosis can therefore be difficult.

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**Mechanism of injury**

The three mechanisms of injury are a direct blow, compression and rotation of the tibia against the femur and patella dislocation. Patella dislocation may produce both a medial patella fracture (Fig. 11) (pull off) and a lateral femoral condyle fracture (shear).

**Classification**

Beaty\(^\text{19}\) describes a classification of osteochondral fractures based on the work of Kennedy and Smillie. It is based on the anatomic location of the injury and the mechanism of injury (Table 3).

**Presentation**

There may be a history of patellar dislocation. The knee may be locked or there may be a history of mechanical symptoms due to a loose body within the knee. The knee is frequently swollen and a typical aspirate yields blood and fat.

**Treatment**

The management of an osteochondral fracture depends on the size of the fragment and the location of the fracture. Large fragments (1 cm\(^2\) or greater) from weight bearing surfaces warrant reduction and internal fixation. Fixation may be obtained using Herbert screws, however the majority of fragments are satisfactorily treated by arthroscopic removal from the joint. After simple excision of a fragment weight bearing can start immediately. The post-operative regime following fixation of an osteochondral fragment is considerably longer. Typically the knee is immobilised in a long leg cast or brace for 6 weeks, during which the patient is non-weight bearing. Prolonged physiotherapy will be required after this.

**Outcome**

As previously stated patellar dislocations associated with a medial patellar osteochondral fragment may be at a higher risk of future instability if the fracture is not treated operatively. There is little evidence available to calculate the risk of late osteoarthritic change with fragments involving weight-bearing surfaces.

**Conclusion**

Epiphyseal fractures around the knee are uncommon. Vigilance is required with displaced fractures as complications can be limb threatening. The risk of late limb growth problems is related to the initial displacement of the fracture and the age of the child at the time of injury. Undisplaced fractures can be managed in a long leg cast. Displaced fractures frequently require open or closed reduction and internal fixation. If an accurate reduction is achieved the results are usually favourable. Despite adequate and prompt treatment a permanent deficit may occur. The ACL is frequently lax following tibial spine avulsion,

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**Table 3** Classification of Osteochondral fractures of the knee.

<table>
<thead>
<tr>
<th>Site</th>
<th>Mechanism of injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial femoral condyle</td>
<td>Direct blow (fall)</td>
</tr>
<tr>
<td></td>
<td>Compression and rotation (tibiofemoral)</td>
</tr>
<tr>
<td>Lateral femoral condyle</td>
<td>Direct blow (kick)</td>
</tr>
<tr>
<td></td>
<td>Compression and rotation (tibiofemoral)</td>
</tr>
<tr>
<td>Patella (medial margin)</td>
<td>Acute patella dislocation</td>
</tr>
</tbody>
</table>

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**Figure 11** Medial patellar osteochondral avulsion.
although this does not seem to be clinically important in the medium to long-term. The risk of osteoarthritis after excision of osteochondral fracture fragments and articular cartilage fragments is not known.

References