Indications for internal fixation of fractures in children

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Summary
The nature of most fractures in children makes them suitable for closed management. However, functional outcomes are not uniformly good and there is evidence that poorer outcomes may be under-reported in children. The role for internal fixation is becoming better-defined. Most Salter Harris type I and II fractures are treated by closed methods while Salter Harris type III and IV fractures almost always require internal fixation. Metaphyseal fractures can be managed as Salter Harris II fractures, but are more likely to require some form of internal fixation. The management of long bone diaphyseal fractures is more controversial. The specific management depends on the bone that is fractured and generalisations regarding treatment are difficult to make. While closed management remains appropriate in most situations, the use of intramedullary fixation has been shown to be effective and safe in a variety of fractures. Care is necessary to avoid rotational malalignment which will restrict range of movement. Both external fixation and plate osteosynthesis have a valuable role in the management of some children’s fractures.

Introduction
The purpose of this article is to review the current indications for the internal fixation of pelvic and long-bone fractures in children with particular reference to recently published studies. The management of the more common fractures has been included but for comprehensive coverage of fractures in children the reader is referred to the standard texts. Whilst in adults the place for operative treatment of fractures has become well established, the view that operative treatment in children should be avoided wherever possible has been more persistent. The study of fractures in children is hampered because of the relative infrequency of many injuries and the observation that the skeletal age of the child often has a profound influence over both the management and final outcome. Useful comparisons of treatment need to include practical classifications of fractures and accurate comparisons between children of similar skeletal age. There is a need for better-controlled multicentre prospective studies.

Although the vast majority of fractures in children continue to be managed non-operatively, internal fixation is increasingly being advocated in a range of situations...
(Table 1). Factors which influence this include rising patient and parental expectations, a desire to rehabilitate the child back into society as soon as possible and the increasing popularity of less invasive techniques such as flexible intramedullary nailing.

Upper limb

Proximal humerus fractures

Paediatric fractures involving the proximal humerus follow characteristic patterns depending on the child’s age. Young children and infants tend to present with Salter Harris type I injuries with metaphyseal fractures becoming more common in school age children up to the age of 10. After the age of 10, Salter Harris type II fractures predominate. The periosteum is tougher posteriorly and tends to tear anteriorly. This may explain the typical fracture pattern with anterior displacement of the humeral shaft.

Neer and Horowitz classified proximal humeral fractures according to the degree of displacement. Fractures with <5 mm displacement were classified as grade I, grade II included displacement of up to one third shaft diameter and grade III up to two thirds of the shaft diameter. Fractures with displacement of greater than two thirds of the humeral shaft diameter, including completely displaced fractures, were classed as grade IV.

Neer grade I and grade II fractures, which make up the majority of proximal humerus fractures in children, usually have little angulation, are relatively stable because of the intact soft tissues and can be treated conservatively. Neer grade III and IV fractures are associated with higher energy injury with more extensive soft tissue damage. The distal humerus may button-hole through the periosteum or the shoulder joint capsule into the deltoid muscle and interposition of soft tissues can occur. Both of these factors may make reduction difficult and increase the risk of re-displacement. Nevertheless, the majority of these fractures can usually be reduced by closed manipulation (Fig. 1). In children under 7 or 8 years of age with isolated injuries, treatment in a hanging cast is usually satisfactory. Some loss of position is acceptable since healing in as much as 70° angulation is consistent with a good outcome. Because of the capacity of the proximal humerus to remodel operative

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<th>Table 1 Suggested relative indications for internal fixation of paediatric fractures.</th>
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<td>Relative indications for internal fixation</td>
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<td>Intra-articular fracture with &gt;2 mm displacement</td>
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<td>Conservative management socially unacceptable</td>
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<td>(shoulder/hip spica)</td>
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<td>Multiple trauma</td>
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<td>Floating joints</td>
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<td>Open fractures</td>
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<td>Inadequate closed reduction</td>
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<td>Older child</td>
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<tr>
<td>Inability to maintain reduction</td>
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<td>Surgeon’s expertise</td>
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Figure 1 Type IV proximal humerus fracture that has been manipulated to a satisfactory position.
treatment in older children, up to age 12 in girls and 14 in boys, is rarely indicated.

The correct management of severely displaced fractures in older children remains controversial. The extent of soft tissue damage renders these fractures unstable and while the majority can be satisfactory reduced, the reported incidence of loss of reduction is up to 50%.

The attachment of the rotator cuff muscles proximal to the fracture tends to cause the humeral head to rotate into flexion, abduction and some external rotation. Maintenance of reduction may be better in a cast with the shoulder abducted to 90° ("Stop the Bus" shoulder spica cast). However, the application of this type of cast is technically demanding and may be unacceptable to the parents and child. The remodelling potential in older children is less and therefore a loss of position is less tolerable in adolescents. The great majority of authors have recommended conservative management of all proximal humeral fractures; however, there are relatively few functional outcome studies and those that exist suggest poorer results in older children. Over the age of 12, severe displacement, multiple trauma and a requirement for an open reduction are all relative indications for internal fixation. Hence grade III or IV fractures in adolescents should be considered for closed reduction and internal fixation with Kirschner wires or flexible intramedullary nailing. In children present with severely displaced fractures. This indicates substantial periosteal stripping and soft tissue tearing. In the absence of complicating factors most can still be treated by closed manipulation under general anaesthesia and application of a U slab or hanging cast. Since 80% of humeral growth occurs at the shoulder, the closer the fracture is to the shoulder and the younger the child, the greater the degree of angulation that can be accepted. Whilst angulation of 30° in a 10-year-old with a proximal humeral fracture will remodel well, the same angulation in the distal diaphysis of a 12-year-old girl is likely to result in a cosmetically unacceptable malunion. Although many humeral fractures will heal in some degree of internal rotation because of the position adopted by the arm when in a sling, this rarely appears to cause any functional problem.

In common with other diaphyseal long-bone fractures, the indications for internal fixation include an inability to obtain or maintain a satisfactory reduction, multiple trauma, a floating elbow joint, open fractures and fractures associated with vascular injuries. The choice of fixation is primarily between flexible intramedullary nailing and plate osteosynthesis. This choice depends upon the indication for fixation, fracture configuration and local expertise. Plating remains a safe choice and has regained popularity over intramedullary nailing in the management of most adult diaphyseal fractures of the humerus. The use of flexible intramedullary nails is not a recent advance in humeral fractures. Brumback et al. described 63 adult fractures managed with Rush pins or Enders nails in 1986. There is no evidence in the literature to guide the treating surgeon as to which technique is preferable in paediatric fractures. Whereas, radial nerve palsy associated with a closed humeral fracture (treated non-operatively) usually resolves spontaneously over a period of 8–12 weeks and can be observed, palsy associated with open fractures or presenting post-operatively require exploration.

**Elbow: lateral condyle fractures**

Lateral mass fractures constitute up to one fifth of elbow fractures in children. The mechanism of injury is said to result from a fall on the outstretched hand resulting in either compression through the radio-capitellar joint or avulsion during a varus strain at the elbow. At surgical exploration of displaced fractures, extensive disruption of the lateral soft tissues is normally found.

These fractures have a propensity for late displacement and delayed healing even when the initial displacement is slight. Rutherford classified this injury according to the degree of displacement: grade I including up to 1 mm, grade II between 1 and 2 mm and Grade III >2 mm of opening of the lateral cortex. This is a useful classification system as it guides treatment. Grade I fractures in children who have minimal swelling or bruising may be treated conservatively but will require weekly X-ray review until there is clear evidence of bone healing without displacement. Displaced fractures (Grade III) require an open reduction avoiding soft tissue stripping from the posterior aspect of the lateral condyle. Internal fixation can be achieved with two diverging K-wires or a screw. The management of minimally displaced fractures (Grade II) is controversial. Attempts to assess the risk of late displacement using further imaging such as MRI or contrast arthrography have been inconclusive. In our experience, the presence of an intact articular cartilage hinge does not prevent progressive lateral opening of these fractures, presumably caused by tension from the lateral wrist extensors. Closed reduction and percutaneous pinning of minimally displaced fractures has only a small risk of morbidity and avoids the problems associated with late treatment of displaced fractures which include delayed healing, non-union, cubitus valgus, tardy ulnar nerve palsy and loss of function. The accuracy of reduction can be confirmed by air or contrast arthrography.

**Elbow: medial epicondyle fractures**

Fractures of the medial epicondyle are generally avulsion injuries resulting from forced valgus applied to the extended elbow with the wrist dorsiflexed. As a result, they are associated with extensive soft tissue damage to the medial aspect of the elbow joint with resulting instability. They often become very swollen, and with prolonged immobilisation, recovery of function can be slow with persisting stiffness. The only absolute indication for fixation is incarceration of the fragment within the elbow joint, which may occur if there has been an associated dislocation of the elbow joint. Minimally displaced fractures (<5 mm) can be treated by cast immobilisation. It is debatable how much displacement is acceptable. If the epicondyle is displaced
more than 5 mm, it is likely to heal with a pseudarthrosis. Whether this is clinically important is unknown. Farsetti et al. examined the long-term outcome of operative and non-operative treatment of fractures displaced 5–15 mm and found no difference in outcome. Our practice is to internally fix fractures displaced more than 5 mm using a single cannulated screw, to rehabilitate the patient more quickly and reduce the risk of elbow stiffness. There may also be a benefit in terms of grip strength.

Elbow: supracondylar fractures

Extension supracondylar fractures account for nearly two thirds of elbow fractures seen in children. Over half are undisplaced, Gartland grade I. These are defined as having <1 mm of opening anteriorly with no comminution or deformity of either medial or lateral columns. These can be treated with confidence by simple immobilisation using a non-circumferential cast. While all Gartland grade III fractures require reduction and internal fixation, the literature is divided regarding the management of Gartland grade II fractures. These have a persisting posterior periosteal hinge but there may be significant comminution and displacement of one column, usually on the medial side. We have found that if the elbow is not grossly swollen, it is often possible to assess these fractures in the Accident and Emergency department. After simple analgesia the child is encouraged to extend the elbow sufficiently for the carrying angle to be assessed. If the carrying angle is similar to the normal side, the injury can be treated as for a grade I fracture. If there is clinical doubt or if the X-ray films suggest significant angulation and particularly medial comminution, then we prefer to perform an examination under anaesthesia. If the initial alignment is found to be satisfactory, the fracture is gently manipulated to achieve the best position and is subsequently treated as for a grade I fracture with a back-slab. If there is significant loss of the carrying angle or substantial hyperextension (centre of capitellum behind the anterior humeral line), we prefer to reduce and stabilise the fracture with two K-wires.

There has been extensive review of the merits of laterally placed parallel wires compared with crossed lateral and medial K-wire insertion (Fig. 2). The use of crossed wires is associated with a small but significant incidence of iatrogenic ulnar nerve injury of up to 7%. Lee et al. found that crossed K-wires provided greater resistance to axial rotation. They also recommended that if two lateral K-wires are used, they should be divergent and not parallel. It is important to place the pins so that they cross the fracture as far apart as possible and equidistant from the respective medial and lateral extremities of the fracture.

Rarely, there may be an intra-articular extension to the supracondylar fracture, which does not fit the Gartland classification easily. Abraham et al. has suggested that these fractures be classified separately as a new type IV and has recommended that fixation with one or two medial wires in addition to two parallel or divergent lateral wires is associated with improved stability and long-term functional outcome.

Flexion supracondylar fractures are much less common. They are usually more difficult to manage conservatively, possibly because the intact soft tissues are anterior and cannot easily be used as a fulcrum to maintain reduction unless the arm is immobilised with the elbow fully extended. For this reason, we pin all angulated and displaced flexion supracondylar fractures.

Elbow: radial neck fractures

Fractures of the radial neck make up approximately 10% of fractures of the elbow in children. They are caused by falls on the out-stretched arm with the forearm in supination and are the corollary of medial epicondylar avulsions. These are usually Salter Harris type I or II fractures in which the radial head is depressed and angulated in relation to the neck of the radius. There may have been a posterior dislocation of the elbow at the time of injury. Examination may demonstrate significant elbow joint instability, indicating possible medial soft tissue injury. These fractures are frequently associated with other injuries around the elbow such as fractures of the proximal ulna, and avulsions of the medial epicondylo. Restriction of forearm rotation is often apparent. Traditional teaching has been to accept up to 30° of angulation although it can be difficult to measure this accurately, particularly from standard X-ray films obtained in the emergency department. There is no agreement in the literature regarding the acceptable degree of displacement. Up to 50° of angulation may be expected to remodel in children under 5 years of age, but here is a risk of significant loss of forearm rotation in children over 10 years of age when the angulation is 30° or more.

Various techniques for closed manipulation have been described in the literature. While open reduction has been associated with poor outcomes, this may reflect the severity of the original injury. More recently percutaneous pin reduction (with fixation only if the fracture remains unstable) has been popularised. We have found this technique to give good results in the majority of cases. However, open reduction is occasionally required and is preferred to significant residual displacement as judged by instability or restriction of forearm rotation during EUA. Care should be taken to avoid any additional damage to the periosteal attachment of the radial head and it is usually possible to steer the head back into position with minimal soft tissue surgery, where it is often remarkably stable. Internal fixation is achieved with a fine oblique K-wire. A protruding wire will prevent early mobilisation but localises surgical trauma to the site of injury. Alternatively a retrograde flexible intramedullary nail can be used to reduce and stabilise the fracture.

Elbow: olecranon fractures

The great majority of olecranon fractures in children have a largely intact periosteum and can be treated conservatively. Displacement of up to 2 mm is acceptable and associated with a good long-term outcome. In younger children with significant displacement, fixation with parallel longitudinal pins and tension band using a bio-absorbable suture such as PDS is satisfactory and allows easy removal of the metal without further surgery (Fig. 3). In older children the
Figure 2  (a) Type III supracondylar fracture. (b) A provisional reduction was obtained in the Emergency department, as there was vascular compromise. (c,d) Following Brachial artery exploration, the fracture was fixed with two lateral K-Wires.

Figure 3  A displaced olecranon fracture with fracture of the radial head, treated by open reduction and pin fixation.
fracture should be treated as for the adult equivalent with longitudinal K-wires and a wire tension band.

**Forearm diaphyseal fractures**

The majority of forearm fractures in children present few therapeutic problems. The thick periosteum makes significant loss of rotation unlikely and the soft tissue hinge facilitates reduction and maintenance of alignment. Even completely displaced fractures in younger children may retain adequate soft tissues to allow accurate reduction and management in a cast with little risk of malunion or functional impairment. Careful radiological follow-up is needed to ensure acceptable alignment and rotation is maintained to union.

There is little consensus in the literature regarding the degree of angulation or rotational malalignment that can be accepted. Children up to the age of 8 can be expected to correct up to 20° of angulation with growth but remodelling potential in children older than 10 years is unpredictable. Similarly, there is little agreement regarding the functional outcome in children with residual malalignment. Whereas some authors report satisfactory results despite residual angulation, it has been suggested that the true incidence of poor outcomes may be widely under-reported and other authors have stressed the risk of loss of rotation. The advice of Evans is that for complete fractures of the radius “there is nearly always a rotational deformity ... and its correction is a dominant factor in the treatment”. Tarr showed that for distal and middle third fractures loss of up to 18° of forearm rotation occurred with 10° of angular deformity. Additionally, rotational deformity of the radius produced a loss of rotation equal to the degree of the rotatory deformity. Since there exists little or no capacity for rotational remodelling, this suggests that even in young children accurate rotational alignment is important if normal function is to be maintained.

There is therefore good evidence to support the recommendation that no more than 10° of angulation and minimal rotation in the diaphysis should be accepted, particularly in children over 10 years of age. Pronation of the forearm for the distal diaphyseal fracture, and supination of the proximal fracture helps to correct the underlying rotational deformity.

Open reduction and internal fixation (ORIF) has been the mainstay of operative treatment for many years. More recently, intramedullary fixation of forearm diaphyseal fractures has been popularised. Lascombes recommended fixation of both bones using pre-bent nails. However, other authors have suggested that the use of a single nail may be sufficient if, following reduction of both bones and pinning of one, the second bone is stable. Yung et al. reported a technique of fixation of the radius using an intramedullary K-wire and then assessment of the stability of the ulna fracture. In his series, nearly 50% of ulna fractures were not nailed and this did not affect the outcome. While intramedullary fixation can provide reliable maintenance of alignment, it does not of itself guarantee correct rotational alignment. Luhmann et al. reported that 30% of children treated with intramedullary K-wires or Rush rods had an average loss of forearm rotation of 13° of supination and 9° of pronation. Other complications associated with the use of intramedullary nails include skin irritation, pin site infection and injury to extensor tendons. Careful attention to surgical technique is necessary to avoid these problems. In situations where closed nailing cannot be achieved and where there is doubt regarding residual rotational malalignment, open reduction and plate fixation remains the treatment of choice.

Our current practice is to carry out a closed manipulation and assessment in theatre. If a satisfactory stable reduction is obtained and the forearm can be rotated through a full range of movement an above elbow cast is applied. If there is doubt about the reduction or the fracture is unstable, surgical stabilisation is indicated (Figs. 4 and 5). In the rare cases where closed reduction is not possible, surgical exposure frequently reveals interposed soft tissues and mal-rotation.

Monteggia described a subset of forearm fractures involving dislocation of the radial head. Bado’s classification is based on the direction of dislocation of the radial head and is helpful in determining treatment.

**Type I** anterior
**Type II** posterior
**Type III** lateral
**Type IV** anterior+fracture of the radius

Many Monteggia fractures can be treated by closed manipulation provided reduction of the radial head is confirmed. Weekly X-ray review is required until the ulnar fracture is consolidated. The radial head may be felt to reduce and become stable, presumably becoming fully relocated within an intact annular ligament in which case some instability or residual deformity of the ulna can be accepted. Where there is any doubt about the stability of the reduction of the radial head, the ulna fracture should be stabilised either with a plate or intramedullary fixation. In type IV fractures, stabilisation of the radius either by ORIF or occasionally by intramedullary nail is generally recommended converting the injury to a type I configuration.

**Distal radial fractures**

Fractures of the distal radius fall into two common groups. Salter Harris II fractures are almost always inherently stable once reduced and almost never require internal fixation. If an open reduction is required, then internal fixation is warranted. Fractures of the distal radial metaphysis may be unstable after reduction, particularly if the reduction is not complete. Up to 20% of completely displaced metaphyseal fractures will re-displace in cast. The use of a percutaneous K-wire in these children is effective in preventing re-displacement. Percutaneous K-wiring may also be indicated if there is extensive soft tissue damage, in the presence of an ipsilateral proximal fracture and following remanipulation.
Lower limb

Pelvic and acetabular fractures

It requires a significant force to fracture the pelvis or acetabulum of a child. In pelvic ring disruptions there is a high incidence of injury to other body systems. Severe blood loss from a child’s pelvic fracture is less common than in the adult. This may be due to the more elastic nature of the blood vessels in a child or the greater ability of arteries to vasoconstrict after injury. It is usually the injury to the other organs in the body that accounts for deaths due to paediatric pelvic fractures. The emergency stabilisation of the pelvis using an external fixator is therefore less often indicated in a child.

Whilst the deforming forces in paediatric pelvic fractures are similar to adults, the resulting anatomy of the fracture may be quite different. These differences are due to the
Table 2 Key and Conwell classification of pelvic fractures.

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<th>Group</th>
<th>Examples</th>
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<tr>
<td>1. No break in pelvic ring</td>
<td>Avulsions fractures (of apophysis)</td>
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<tr>
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<td>Iliac wing fracture</td>
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<td></td>
<td>Fracture of pubis or ischium</td>
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<td></td>
<td>Fracture of sacrum or coccyx</td>
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<td>2. Single break in pelvic ring</td>
<td>Fracture of two ipsilateral pubic rami</td>
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<td>Symphysys pubis disruption</td>
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<td></td>
<td>Sacroiliac joint disruption</td>
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<tr>
<td>3. Double break in pelvic ring</td>
<td>&quot;Straddle&quot; fracture</td>
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<td>Complex fractures</td>
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Paediatric hip fractures

Paediatric hip fractures are rare (<1% all childhood fractures) and are frequently associated with high-energy injuries. The Delbet classification is most commonly used, with Type 2 (transcervical) and Type 3 (basicervical) accounting for over 90% of fractures. Type 1 (transepiphyseal) and Type 4 (intertrochanteric) fractures are extremely rare. Paediatric hip fractures have a high incidence of complications. Avascular Necrosis (AVN) has been reported in up to 50% of Type 2 fractures and is the leading cause of a poor outcome. Other common complications include physal growth arrest, non-union, coxa vara, chondrolysis and late degenerative changes. The rationale for the use of internal fixation is to minimise these complications. Completely undisplaced hip fractures are uncommon. They have been managed successfully by non-operative methods (traction and/or hip spica). The use of internal fixation for undisplaced fractures is unproven. Displaced hip fractures treated with closed reduction and spica cast immobilisation may be appropriate for the young child. In older children the early literature reported poor results for the management of hip fractures with or without internal fixation. It was thought that the outcome was determined at the time of injury by the degree of fracture displacement and age of the child. Both of these factors are important determinants of the final outcome; however, recent studies have reported reduced complication rates with the use of internal fixation. The improved results from these small series are likely to be multifactorial. Modern internal fixation devices are stronger and less likely to fail. Anatomic reduction is strongly associated with a reduced risk of AVN, coxa vara and non-union. Decompression of the intraarticular haematoma may further reduce the risk of AVN. The timing of surgery has not been the subject of a separate study; however, there is indirect evidence that surgery within 24 h of injury is desirable. It is impossible to state with certainty which of these factors is the most important. Internal fixation is the most reliable means of ensuring maintenance of an anatomic reduction and therefore should be associated with a reduced risk of AVN, coxa vara and non-union.

For displaced fractures the treatment should consist of early anatomic reduction (closed or open), decompression of the hip joint and stable internal fixation (Fig. 6). A hip spica is commonly used to immobilise the joint for 4-6 weeks post-operatively. Open reduction may be achieved by a Watson–Jones approach. Internal fixation is frequently with cannulated screws, although smooth Steinmann pins may be used in the young child (age under 3). Type 4 fractures will require a dynamic hip screw device of appropriate size. If possible, penetration of the physis by metalwork should be avoided (except in Type 1 fractures) as it increases the probability of early physisal closure. However, fracture stability is the primary concern and if necessary the physis may be crossed.

Femoral diaphyseal fractures

Femoral shaft fractures are common, with the majority of fractures occurring in the diaphysis. The choice of treatment depends on the age of the patient, fracture configuration and location in the bone, soft tissue damage, associated injuries and local expertise.

In a child under the age of 6, most surgeons would opt for non-operative management in most patients. In children up
to 24 months, gallows traction may be utilised, depending on the weight of the child. From the age of two, in-line skin traction with the use of a Thomas splint is the preferred method. After an initial period of traction, a spica cast can be applied to allow the child to return home. However in a young patient, when healing is rapid and the time in traction is short this is not as useful.

Between the ages of 6 and skeletal maturity, there are a number of management options, all of which have their own merits and problems. In this age group, there is little literature to guide the treating surgeon as to which method is best. As a child gets older, non-operative management becomes more problematic. The potential of the bone to remodel a malunion reduces and the risk of significant shortening is increased. Healing time increases and so the time needed in traction is longer. The effectiveness of traction in obtaining and maintaining reduction is also reduced. The use of a spica cast is less acceptable. A prolonged break from schooling is often necessary.

Dissatisfaction with non-operative methods of managing femoral shaft fractures in this age group has resulted in a trend towards the use of operative methods, in particular flexible nailing (Fig. 7). In a non-randomised comparison of flexible nailing and skeletal traction/spica cast management all fractures healed primarily and function scores at 1 year were similar. However, out of 35 fractures treated in traction/spica, there were three malunions and in a further two cases loss of reduction required re-operation. Children undergoing flexible nailing had reduced hospital stay and time off school. The most common complication in the flexible nailing group was irritation from the nails at the insertion site. Certain factors make flexible nailing a less attractive option. These are very proximal or distal fractures, highly comminuted or long spiral fractures. Heavier children may bend the non-rigid nails and therefore a supplementary cast may be required until callus formation has occurred.

External fixation is an effective method of treating femoral shaft fractures. It is particularly useful in open fractures, very comminuted fractures and fractures in the distal femur, where bone healing is more rapid. The external fixator construct is rigid and there are concerns that it is associated with a longer time to union and less callus production. Dynamisation of the external fixator may not overcome this problem. The two major complications that occur with external fixation are pin track infections and refracture after frame removal. The risk of refracture is between 5% and 20%. A recent study published in the Lancet randomised children to External Fixation or Hip spica. At 2 years there were significantly more malunions in the hip spica group, although patient and parent satisfaction were similar as were functional outcomes. There is a single study comparing flexible nailing and external fixation. Recovery and return to school were quicker in the flexible nailing group. Additionally, parent satisfaction was greater and there were fewer complications.

ORIF using a 4.5 mm plate is useful in proximal and distal femoral fractures. In addition, if a vascular repair is carried out, plate fixation is the treatment of choice. Pulmonary complications are rare in children with isolated femur fractures. However, the presence of a severe head injury and a femoral fracture increases the risk of pulmonary problems considerably. There is little guidance on the method of operative fixation that is preferable in the head-injured child. Children with a head injury or other multiple injuries can be safely managed with plate osteosynthesis (or external fixation) once they are adequately resuscitated. The timing of surgery may be less critical than in adults. Plate fixation is the only operative
method that does not necessarily require image intensifier screening intraoperatively. The large incision, increased blood loss, fixation failure, plate removal and risk of refracture mean that plate fixation has largely been superseded by other methods, except in the circumstances mentioned above. Minimally invasive plating methods may expand the indications for plate fixation in children.

Rigid intramedullary nailing has been used for the treatment of femoral shaft fractures in the skeletally immature patient. Most series report a small but significant risk of AVN of the femoral head, even with a greater trochanteric entry point. This complication is so severe that most surgeons have abandoned this technique, particularly as there are other effective treatment methods available. The use of rigid cephalo-medullary nailing is the treatment of choice in skeletally mature adolescents.

In common with other joints, “floating” knee joint injuries are best treated operatively. As a minimum, the femur should be operatively stabilised. Non-operative management is associated with an increased risk of leg length discrepancy, malunion and secondary operative procedures.

**Proximal tibial metaphyseal fractures**

Fractures of the proximal tibial metaphysis typically occur in children aged between 2 and 8. If displaced, the tibia is usually in valgus. Displaced fractures are managed by closed manipulation and a long leg cast. If a closed reduction cannot be achieved, there may be intervening periosteum or the tendons of the pes anserinus can become interposed in the fracture. In this circumstance an open reduction is necessary. When accurate reduction is obtained it is rare for these fractures to be sufficiently unstable to require internal fixation. Even following a perfect reduction, however, a valgus deformity of the tibia can occur with growth of the child. The rate of progression of this is maximal in the first year and then diminishes. The natural history of the valgus deformity is spontaneous correction by years 3–5, so early surgery is not indicated (Fig. 8). In the rare situation that the valgus does not correct sufficiently, it can be managed by hemiepiphiyseodesis in early adolescence, or by proximal tibial osteotomy.

**Tibial diaphyseal fractures**

Tibial shaft fractures are common in children, occurring most often in the distal tibial diaphysis and metaphysis. In contrast to tibial fractures in adults, paediatric tibial fractures are more commonly undisplaced, the fibula is often intact, open fractures are less common and so is the incidence of compartment syndrome.

The vast majority of these fractures can be managed with closed manipulation and a long leg cast. Acceptable limits
The indications for internal fixation are: failure to achieve and maintain a reduction within the above limits, open tibial fractures, polytrauma, compartment syndrome and a "floating knee". The techniques available include external fixation, flexible nailing, plate osteosynthesis, percutaneous pinning and rigid intramedullary nailing. Because fixation of tibial fractures is uncommon, there is a paucity of literature on the subject. The pros and cons of the various methods are similar to their use in femoral shaft fractures.

External fixation is historically the most common technique used to stabilise tibial fractures. The most common reason to stabilise the tibia surgically is an open fracture and so most series include a large proportion of open fractures. External fixation is an effective method of stabilising tibial shaft fractures, particularly those with extensive soft tissue damage. There is a relationship between the incidence of complications and the severity of the open wound. The main disadvantages of external fixation are delayed or non-union (approximately 10%), pin track infection (25%), refracture and tibial overgrowth.

There is a single retrospective comparison of external fixation and flexible nailing in the management of tibial fractures. Approximately half of the fractures were open. External fixation was associated with a much longer time to union (18 versus 7 weeks). There were three non-unions and two delayed unions in the external fixator group (out of 15 patients). The non-unions required conversion to a ring fixator and healed eventually. Unlike femoral shaft fractures, the functional outcome at 3 years was poorer in the external fixation group. On the basis of this study there is evidence that flexible nailing is superior to external fixation. Further studies have shown flexible nailing to be a safe technique in the management of tibial shaft fractures.

Figure 8  Proximal metaphyseal fracture. Significant valgus resulted which partially corrected by 2 years post-fracture.
Union is usually achieved within 3 months and the incidence of refracture, fixation failure and malunion is low. Flexible nailing has been used successfully in open fractures of the tibia, although its role in Type III open fractures is not clear. The very occasional use of rigid intramedullary nailing of the tibia in the skeletally immature has been reported. However, the proximal tibial growth plate is violated and it is therefore not recommended. Plate osteosynthesis is a viable option for the management of displaced, closed fractures of the tibial diaphysis. An attempt should be made to achieve maximal soft tissue cover for the plate, so that it is protected from superficial wound infections.

The principles of treating an open tibial fracture in children are similar to those in adults. However, it has been suggested that the initial wound excision in children may be less extensive. In particular, apparently devascularised bone has been seen to survive and new bone may form from retained periosteum. Whilst primary closure of an adult open wound is inadvisable, a child’s tissues may tolerate this more readily.

Fractures around the ankle

Paediatric ankle fractures are common as the ligamentous structures in the child are stronger than the open physis. Attempts have been made to classify paediatric ankle fractures using anatomical schemes (Salter Harris) and also systems that relate the mechanism of injury (e.g. Dias-Tachdjian modification of the Lauge-Hansen classification). The Salter Harris system is easily remembered, prognostic and gives some guidance to treatment. Systems describing the mechanism of injury provide a guide to reduction (reversal of the deforming forces); however, they have poor interobserver agreement and can be confusing.

Fibular fractures

Isolated fractures of the fibula are common and are usually Salter Harris I or II. These rarely require anything other than immobilisation in plaster. Displaced isolated Salter Harris III or IV fibula fractures are rare and can usually be managed non-operatively. Occasionally, the degree of displacement warrants fixation. Fibular fractures associated with a distal tibial fracture usually reduce and are stable with reduction of the tibial fracture and do not often require fixation.

Tibial fractures

Undisplaced distal tibial fractures can be managed in a cast with a period of restricted weight bearing. Most displaced tibial fractures are Salter Harris I or II and can be treated with closed manipulation and a cast. If there is any suspicion of an incomplete reduction, for example with significant gapping medially, then the fracture site should be opened (Fig. 9). As with proximal fractures, soft tissue may become trapped in the fracture site and this needs to be removed to minimise the risk of late growth disturbance. Most fractures are stable once reduced; however, if the fracture is unstable then internal fixation is warranted. A large metaphyseal fragment in a Salter Harris II fracture can be secured with a transverse interfragmentary screw parallel to the joint. If the metaphyseal fragment is too small, or in a Salter Harris I fracture, K-wires can be inserted across the physis but need to be removed when the fracture has united.

Salter Harris III fractures fall into two main groups. The Tillaux fracture is a Salter Harris III fracture of the anterolateral portion of the distal tibial epiphysis, caused

Figure 9  Following an attempted closed reduction, the fibula required ORIF. A gap persists medially, which required open reduction to remove interposed soft tissues from the fracture site.
by forced external rotation. It typically occurs in children aged 12–14, when the distal tibial physis is beginning to close. The physis closes over a period of 18 months, starting centrally, then medial and finally laterally. It may be possible to reduce a Tillaux fracture percutaneously, using a K-wire to manipulate the displaced fragment into position. Arthroscopically assisted reduction has also been described. The second common Salter Harris III fracture involves the medial malleolus. In common with other articular fractures, a maximum displacement of 2 mm can be accepted. CT or MR imaging is useful in the accurate assessment of articular disruption in distal tibial fractures and the images frequently suggest that the extent of articular damage may be greater than is apparent on plain X-ray films. If displacement is greater than 2 mm, an anatomic reduction (open or closed) and internal fixation is carried out.

The triplane fracture is a Salter Harris IV fracture that can occur in two, three or four parts. A detailed description is beyond the remit of this paper. The key to management is correction of rotation and restoration of the articular surface and this may be aided by cross-sectional imaging. Biplanar interfragmentary fixation is usually required. The second variation of a Salter Harris IV fracture is a shearing of the medial malleolus and metaphysis. There is evidence that residual displacement of >2 mm is associated with a poorer long-term outcome, with pain, stiffness and degenerative change. These adduction injuries should be reduced anatomically and stabilised with a transverse, intraepiphyseal screw.

The risk of growth disturbance following physal ankle fractures is greatest with Salter Harris IV and V fractures. The energy of injury, Salter Harris grade and quality of reduction are predictive of late growth problems at the ankle.

Discussion

The immature skeleton is characterised by tough, metabolically active periosteum, the open physis, relatively thick cartilage of the epiphysis and the rapidly remodelling metaphysis. These characteristics are most prominent in infants and progressively diminish throughout childhood and adolescence and are responsible for the typical morphology and behaviour seen in children's fractures. As a result most children's fractures occur with little disruption of the periosteum and are relatively stable. Satisfactory conservative fracture management depends upon the ability to obtain and maintain a sufficiently accurate reduction. Maintenance of a reduction is influenced by the quality of bone, configuration of fracture and the presence or absence of an intact soft tissue hinge that can be utilised in a cast or by traction.

Fractures in children heal rapidly, generally having satisfactory outcomes. This is in part because they rarely involve the articular surface and because of their potential to remodel and their more rapid rehabilitation. The pattern of fractures in children is different and it would be erroneous to apply uncritically lessons learnt from adult fracture management. This difference is most obviously seen in growth plate injuries that can carry long-term sequelae due to interruption in bone growth.

There is a paucity of quality evidence on which to base recommendations for the management of children's fractures. The bulk of the literature consists of case series and retrospective comparisons between techniques, which are both open to bias. Studies frequently include children of widely different ages when this may be the major factor determining outcome. Many of the controversial issues will need to be subjected to randomised trials to determine the most suitable method of management.

Fractures in children can undergo a degree of correction after healing. This remodelling occurs according to two principles. Wolff's law results in alterations in the form of bone in response to mechanical stresses upon it; after fracture healing resorption of bone which is mechanically redundant may allow some restoration of the original contour. According to the Heuter–Volkmann principle, asymmetrical growth may occur at the physisal plate, with compression of the physal inhibiting growth and tensile forces stimulating growth. Traditionally, reliance has been placed upon the potential for remodelling in the management of paediatric fractures. However, the ability of the child to adapt to deformity may disguise poor functional outcomes. Recent long-term follow-up studies have suggested that function may not always fully recover, despite apparent correction of deformity on X-ray. Even temporary loss of function during a child's formative years may have significant long-term implications.

In deciding on the indications for internal fixation, a number of factors need to be taken into consideration. The soft tissue envelope around a fracture is all important in the closed management of paediatric fractures. An intact soft tissue hinge can be used as a brace to stabilise the fracture, with the aid of a cast. The more displaced a fracture, the greater this soft tissue hinge is disrupted and the increasing likelihood of the fracture being unstable or irreducible by closed means.

For internal fixation to be useful, it must carry a demonstrable improvement in the end result of treatment. Additionally, the fixation must carry acceptable risks and minimal morbidity. Rigid cephalo-medullary nailing of paediatric femoral fractures is an excellent method of fracture stabilisation; however, the small risk of AVN has such serious consequences that most surgeons would consider it to be an unacceptable form of treatment in a skeletally immature patient.

Salter Harris I and II fractures are usually reduced closed and only occasionally require internal fixation. Salter Harris III and IV fractures frequently require open reduction and almost always require internal fixation. Metaphyseal fractures can be managed as Salter Harris II fractures, but are more likely to be unstable once reduced and hence may require some form of fixation (commonly with K-wires). The management of long-bone diaphyseal fractures can be simplified by asking a number of questions. Can the fracture be reasonably managed non-operatively? If not, is the fracture amenable to treatment with flexible intramedullary devices? If the fracture cannot be nailed, then the choice is between external fixation and plate osteosynthesis. This choice depends upon fracture morphology, soft tissue injury and surgical preference. Finally it is important to ask, can I manage this fracture? If not, then referral to a specialist centre is indicated.
Reference


