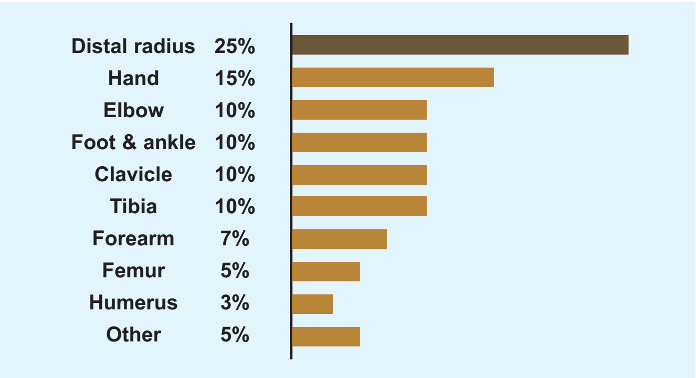
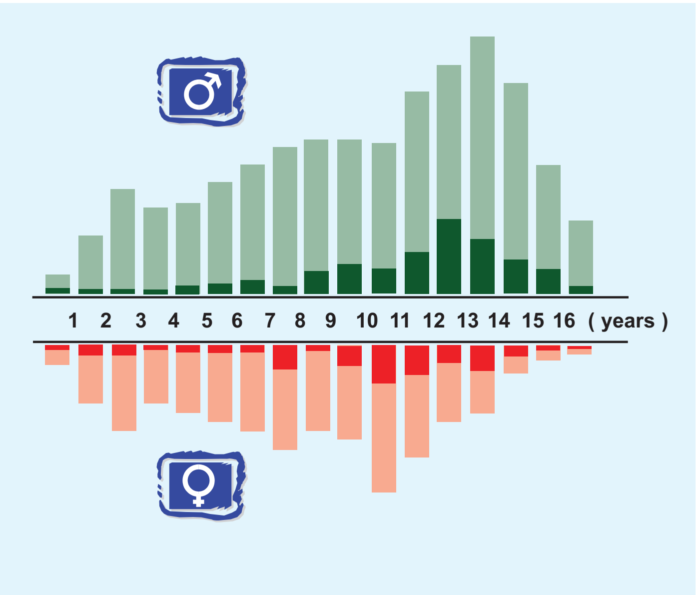
CHAPTER 7

Trauma

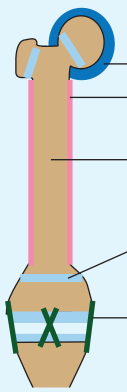
Trauma is the leading cause of death in children. It is second to infection as a cause of morbidity. Fractures peak during lunch play in school and in late afternoon during sports. Three-fourths of fractures occur outdoors. One-fourth of fractures are of the radius [A]. The most common operated fracture is of the supracondylar humeral region. The school playground is the richest source of fractures. Boys sustain more fractures than do girls [B]. Annual fracture incidence in children is 2%. Refracture rate averages 0.5%, higher for some (e.g., of radius and ulna), and lower for others



A Distribution of fractures by location Numbers have been simplified to aid comparisons.



B Distribution of fractures by gender and age Boys (*green*) have a peak 3 years after girls (*red*). Physial fractures (*dark*) represent 1/5 of children's fractures.



Feature	Management
Chondral model	Less visible on röntgenogramme
Peri-osteum	Healing Internal stability
Bone	Less mineral, more cancellous: ductile—yield not break less comminution
Physis	Point of weakness Growth disturbance Remodeling
Ligaments	Last to fail Joint stability Fracture before ligament tear

C Structural features of a child's bone The distinctive features significantly affect management.

and lower for others. Increasing sports participation is shifting the number of fractures to younger patients. Most pædiatric fractures are isolated and of the appendicular skeleton, which form the subject of this chapter.

PHYSIOLOGY

Children's bones differ from those of adults [C]. The differences and consequences diminish with age, so that during adolescence, treatment approaches that of the adult.

Growth Plate

The growth plate, or physis, is the most distinctive feature of a child's skeleton. It adds to the risk of growth disturbance. It is weaker than bone, which is weaker than ligament [D]. It is most vulnerable during periods of growth acceleration, such as puberty. It enables remodeling [E].

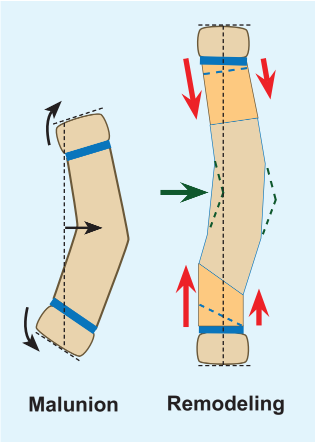
Remodeling This refers to correction of a malaligned bone with growth [E]. This consists of two principal components:

- Differential growth at the physis, which accelerates on the concave side
- Differential growth at the fracture, which shows periosteal laying down of bone by apposition in the concavity and bone resorption on the convexity of the apex of deformity

Remodeling rectifies epiphysial and articular orientation, as well as the mechanical axis. Several factors influence remodeling:

- Growth of the child. This is determined by maturity, which may be measured by Tanner stage or years of growth remaining based upon the arithmetic method that states girls stop growing significantly around 14 years and boys around 16 years.

D The physis is weak Force of fracture travels along the path of least resistance, the distal femoral physis (*red*).



E Mechanism for remodeling Differential growth occurs at physis (*red*) and periosteum (*green*). As remodeling proceeds, mechanical axis (*black*) centers toward the longitudinal axis of the bone, and the epiphysis become horizontal to rectify the adjacent joints.

While 2 years of growth remaining may be regarded as a requirement for remodeling, the process is more predictable for fractures occurring in the first decade than in the second decade.

- Growth of the bone. Physis that are more active are more potent. The greatest percent growth of bone occurs at proximal humerus more than distal radius more than distal femur [F]. As a result, greater displacement of fractures of proximal humerus and distal radius may be accepted: remodeling substitutes for reduction [G].
- Location of fracture within a bone. More remodeling is required in the diaphysis than in the metaphysis [H]
- Plane of joint motion. Forces that stimulate new bone formation are greatest in the plane of motion (Wolff law). In addition, an enarthrodial joint can accommodate greater residual deformity than a more restricted joint, such as a ginglymus, which can accommodate only in the sagittal plane of motion.

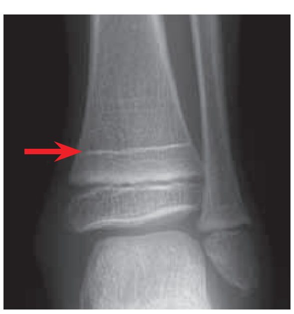
Duration of acute remodeling, which is the period of observation before intervention for malunion, is typically 1 year but occasionally up to 2 years, for example, proximal metaphysis of tibia fracture.

Injury Physis are located adjacent to an epiphysis, which is a secondary ossification center that forms the articular surface of a bone "on top" (Greek επι−) of the physis, and an apophysis, which grows "away" (Greek απο−) from the physis to serve as a site of attachment of a muscle. Injuries to and displacement of the former are less tolerated than are the latter. Ligaments attach to epiphysis, thereby concentrating force during joint motion at the physis, which increases risk of injury.

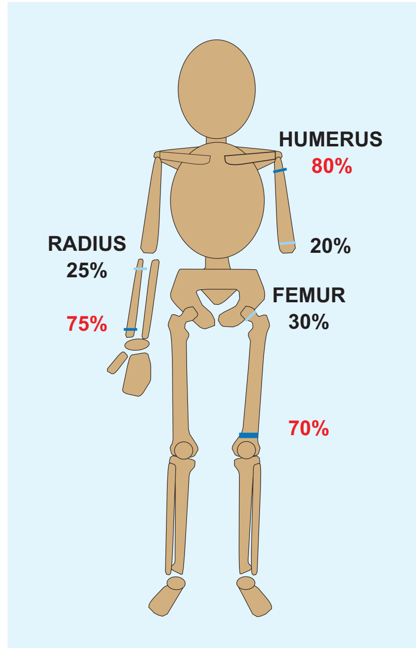
Growth disturbance occurs most frequently from trauma and infection. Infection typically results in a diffuse zone of injury. Trauma may do the same, as in a crush mechanism, or it may produce a discrete bridge of bone: displacement brings metaphysis from one side into contact with epiphysis on the other side, which unite. Injury also may stimulate a growth plate to overgrow. This is most striking in the femur and may be related to hyperæmia.

Force of fracture travels through the hypertrophic zone, because this is the level of highest stress concentration between the zone of provisional calcification adjacent to metaphysis and the proliferative and germinal zones adjacent to epiphysis. Growth will resume after fracture provided the blood supply is preserved, and there is no mechanical disruption of the rest of the physis. The latter may occur at an undulating or otherwise irregular physis, such as the distal femur or distal tibia, where "Poland hump" may act as a spike to tear across the proliferative and germinal zones. The distal physis of tibia also is vulnerable due to force concentration of body weight over a relatively small area. This may explain injury to the tibial apophysis, where force of quadriceps is concentrated.

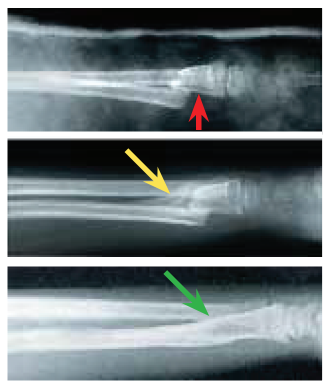
Injury may be marked on bone by a growth arrest line (Harris) [I]. This represents condensation of mineral due to temporary growth arrest locally after fracture or diffusely after a generalized severe illness. Date of injury may be calculated based upon distance from physis and physial rate of growth. Slowing or arrest of growth is indicated by a reduction of distance. Partial growth disturbance is suggested by obliquity of the line relative to the physis, suggesting asymmetric growth by an unhealthy physis.

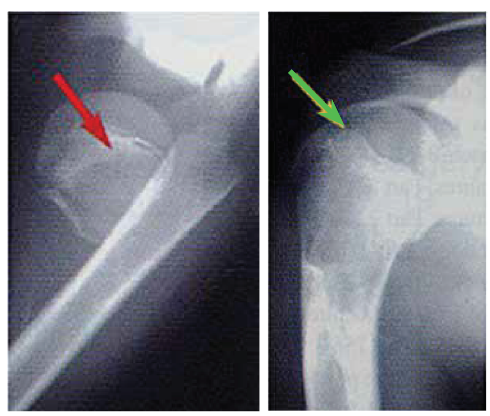


I Growth arrest line This (*red*) is parallel to the distal physis of tibia, suggesting symmetric growth. The distance of 5 mm after 1 year is consistent with normal growth rate of an uninjured physis.

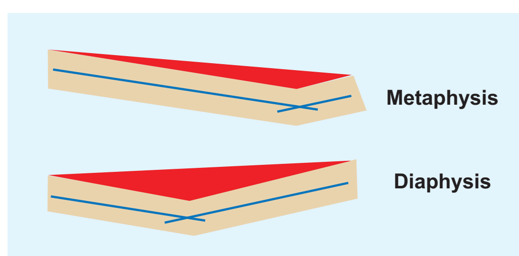


F Remodeling at physis This is proportional to % of total bone growth. Proximal humerus, distal radius, and distal femur have best remodeling potential.

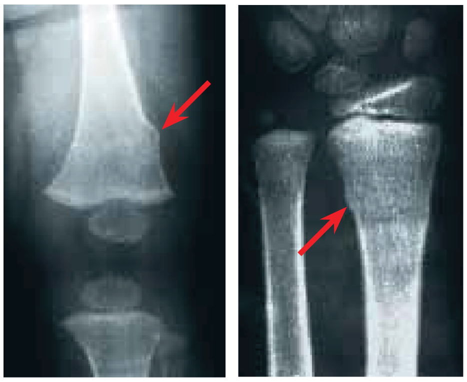




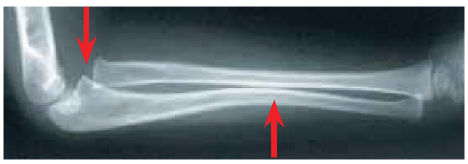
G Remodeling of forearm In the radius, the distal fragment is apposed to the proximal fragment like a bayonet on the barrel of a rifle. Callus is laid down in the concavity on the dorsum, thereby straightening the fracture over several months (*green*). In the proximal humerus, a completely displaced fracture (*red*), including angulation >60 degrees and significant shortening, remodels completely (*green*). Both children are <10 years.



H Remodeling according to site For the same angular deformity, more correction (area in *red*) is required for midshaft than distal deformity.

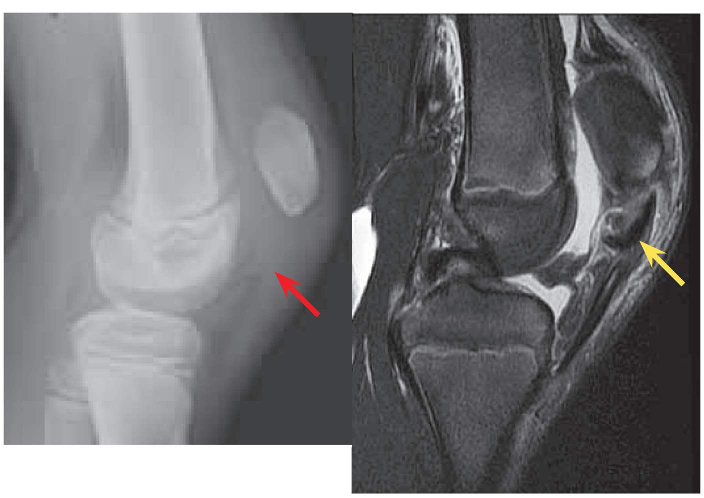


J Buckle fracture This is characteristic of immature bone.



K Plastic deformation The fixed deformity drives the head of radius out of joint and prevents it from relocating. A more brittle bone would break, which would increase displacement and the chance of spontaneous reduction of radial head.

L Ligament avulsion The intercondylar eminence of tibia fails before the anterior cruciate ligament, which may stretch but does not tear.



M Chondral model The apex of patella pulls off with a sleeve of cartilage that is barely visible on röntgenogramme (*red*) yet represents a large semilunar fragment when viewed by MRI (*yellow*).

Bone

Reduction in mineralization with a more collagenous extracellular matrix, and a larger proportion of cellular component, result in a more ductile material that can buckle when stressed [J] or plastically deform [K] and that resists fragmenting into multiple pieces. The lag in mineralization behind longitudinal growth renders immature bone more porous and thereby more susceptible to injury.

Periosteum

This is more metabolically active in the child than in the adult. It does not tear as readily, leaving continuity for new bone formation. This explains the exuberant callus seen in the infant and the rapid union and increased potential for remodeling seen throughout childhood. The periosteum is thick. The structural integrity of a child's periosteum adds internal stability to fractures. However, it also may interfere with reduction and growth if it becomes entrapped within a fracture.

Ligaments

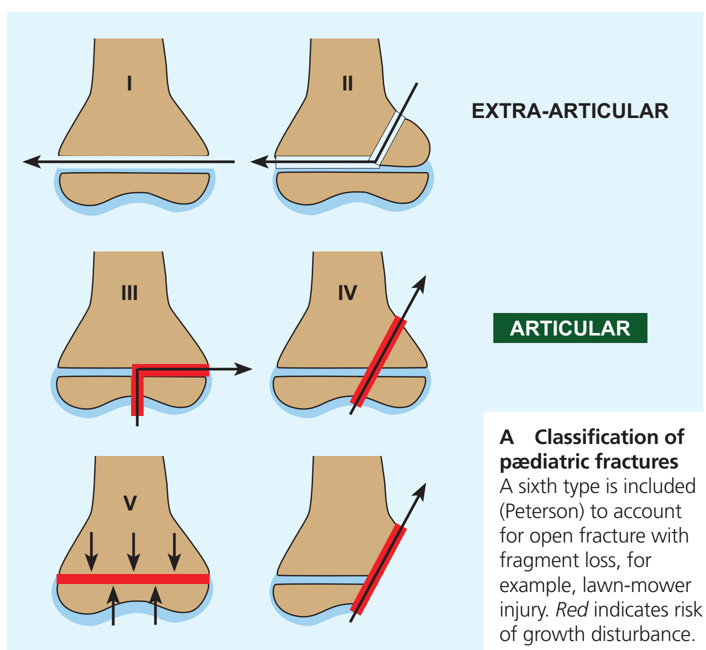
In a child, ligament is stronger than bone, which is stronger than physis [L]. Ligaments, and perichondrium, protect a physis they span from displacement. Ligaments resist failure such that they do not tear but rather transmit force to dissipate in an avulsion fracture [M].

Chondral Model

An increasing proportion of the skeleton, growing by endochondral ossification, is invisible on röntgenogramme with decreasing age. Early on, landmarks may be absent. Later, articular fragment size may be underestimated, as typified by the patellar sleeve fracture [M].

CLASSIFICATION

There are several classifications of pædiatric fractures. In the most accepted system [A], fractures are divided into five categories based upon pattern and mechanism, as evaluated by röntgenogramme. Type V is rare and identifiable only in retrospect, when compression of the physis has led to growth disturbance. The first four types may be divided into two groups, extra-articular or articular, thereby dividing fractures into those which risk growth and those which risk growth and osteoarthritis. The two groups also may be distinguished by operative rate. Physial fractures are managed according to criteria for acceptable displacement that vary according to site; most are treated nonoperatively. Articular fractures are treated according to universal principles, which do not accept >2-mm step-off in order to minimize risk of osteoarthritis; as a result, most are treated operatively.



A Classification of pædiatric fractures A sixth type is included (Peterson) to account for open fracture with fragment loss, for example, lawn-mower injury. *Red* indicates risk of growth disturbance.

EVALUATION

Up to 15% of fractures in children are missed or misdiagnosed at first evaluation. Individual fractures will be addressed separately.

History

Infants do not speak. Falls and other mechanisms may be unwitnessed. Children, who are in pain and scared, may not be able or willing to answer questions. Caregivers of abused children will be evasive or lie.

Physical Examination

Pseudoparalysis refers to refusal to use a limb because of pain. The upper limb is held suspended as if paralyzed. The child refuses to bear weight on the lower limb. Because the child comes with parents, and both may be distressed, there is pressure not to disturb the child any more than already has been done, by injury, by those enlisted to help at the scene, by transportation to a medical facility, and by others who already have examined the child. Be thorough, for example, do not miss an open wound covered by a splint. Be persistent: management of a postoperative neural deficit after reduction and fixation of a supracondylar humerus fracture is predicated on knowledge of the preoperative function.

Divide type I open fractures into outside-in and inside-out [A]. The latter is produced by the osseous fragment pushing through the skin from a clean environment, rather than in the former case, where contamination from the outside may be introduced into the fracture. Inside-out open fractures may be washed in the emergency setting, treated with a single dose of antibiotics, and treated as though closed with close observation. After cast application, cut a window in the cast to make the lesion visible for follow-up. All other open fractures are managed according to general principles. The window for surgical débridement may be opened to 24 hours in children.

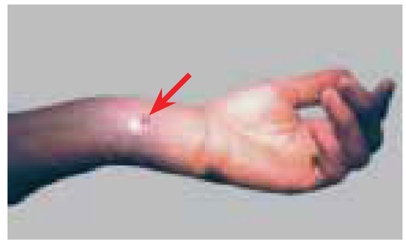
Compartment syndrome in children is not as fulminant as in adults. Bleeding raises compartment pressure, producing a tense limb that hurts. Increasing pressure, exacerbated by capillary leaking, first occludes venous outflow and only later occludes arterial flow to produce pallor, pulselessness, and paræsthesias. Have a high index of suspicion, for example, after supracondylar humerus fracture. While this is a clinical diagnosis first and foremost, data may be necessary in children when their presentation may be mild [B]. Delay in diagnosis is not unusual, but this is mitigated by the fact that full recovery may be expected up to 36 hours after injury. Distinguish exertional compartment syndrome (*cf.* Sports chapter).

Imaging

Röntgenogramme This is the mainstay of trauma imaging. In addition to anteroposterior and lateral projections, special views may be helpful, for example, oblique for condylar fractures [C] and mortise of the ankle. Beware of TRASH: The Radiologic Appearance Seemed Harmless. The term encompasses osteochondral lesions that may be incompletely visible on this imaging modality. These typically occur in the first decade. The elbow is a rich source, due to the multiple ossification centers with varying appearance, such as an epiphysial separation in the infant, a displaced intra-articular medial condyle fracture, or radiocapitular subluxation. Occult injuries may manifest secondarily in soft tissue, for example, the sail sign at the elbow [D]. Imaging the contralateral uninjured side may be helpful in the setting of atypia, such as a skeletal dysplasia.

Arthrogram This outlines the articular surface when affected by fracture and unossified [E]. In addition to aiding diagnosis, this modality may influence operative decision making and may be used to confirm acceptability of reduction of articular fractures, for example, of the lateral condyle of humerus (*q.v.*).

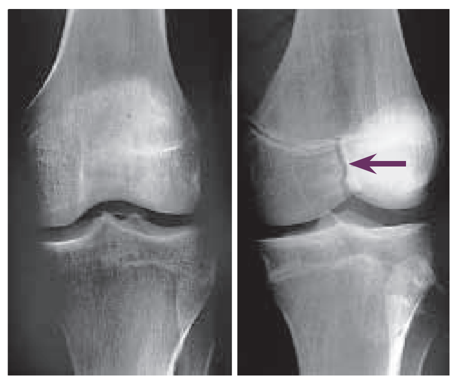
Scintigramme This also is useful for röntgenographically occult injury. In a child who refuses to bear weight on the lower limb or in whom the physical examination is nonlocalizing, scintigramme may reveal an injury and focus the evaluation.



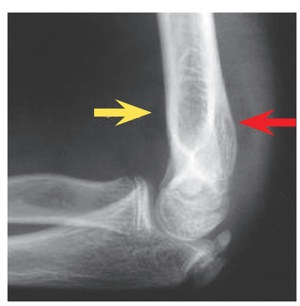
A Type I open fracture This inside-out subtype, resulting from a "poke" through the skin (*red*) by a bone fragment, may be treated with local care at initial encounter, after which it is managed as a closed fracture with close follow-up.

Pressure
Diastolic pressure—compartmental pressure ≤30 mm Hg
Compartment pressure ≥30 mm Hg
Mean arterial pressure—compartment pressure ≤40 mm Hg

B Compartment syndrome These data have been suggested to support the clinical diagnosis of compartment syndrome.

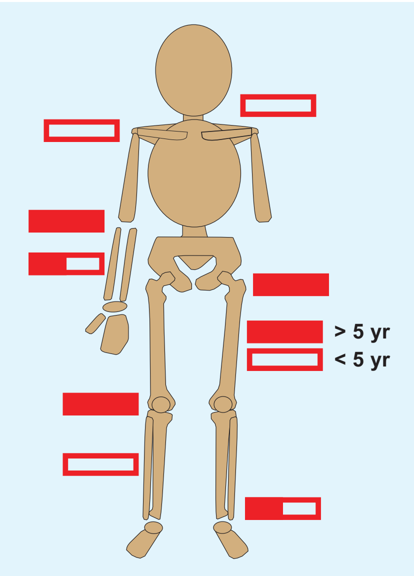


C Special views on röntgenogramme Oblique projection (*blue*) uncovers a condylar fracture invisible on standard anteroposterior projection.

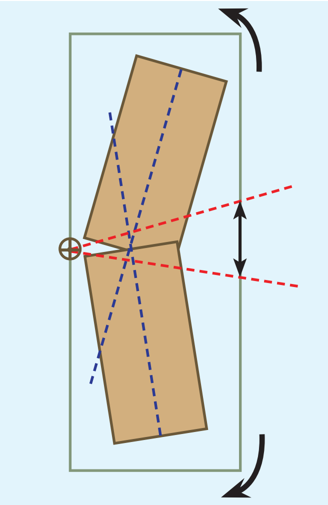


D Soft tissue on röntgenogramme Bleeding from an occult fracture elevates the joint capsule, creating a contrast in density. The sign is significant posteriorly (*red*) when the elbow is at 90 degrees of flexion because the capsule is draped tightly over the back of the joint, requiring significant fluid under pressure to elevate it. An anterior sign (*yellow*) is inconclusive as the capsule is relaxed off the distal humerus in this elbow position.

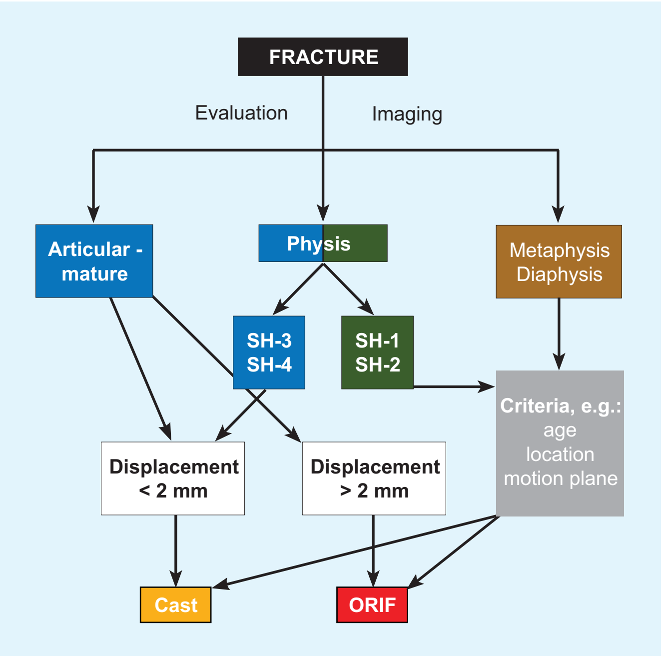
E Arthrogram for radionegative injury The distal epiphysis of humerus is unossified in the 1st year of life. Thus, an epiphysial separation (*orange*) is invisible on röntgenogramme, where the secondary signs of abnormal relationships of radius and ulna with humerus raise suspicion that is confirmed by arthrogram.



A Operative treatment In the immature child, the rate (*red*) varies by site. Overall rate is increasing, the forearm having the greatest flux.



B Cast wedging If fragments drift in a cast, cut it at the level of the fracture. The center of rotation for correction is not the apex of fracture but the edge of the cast. Draw lines perpendicular to the fragments (*red*), intersect them at the edge of the cast at the level of the fracture, and measure the distance (*black*) on the opposite side of the cast to determine the size of dowel to be inserted. Cut the dowel to have flanges that are applied to the outside surface of the cast where they prevent migration inward to pressure the skin.



C Algorithm for management of children's fractures.

Computed Tomography This is most useful to evaluate an articular fracture, to most accurately measure interruption of the surface. While outcome studies have suggested that >2 mm of articular step-off on röntgenogramme significantly increases the risk of posttraumatic arthritis in certain joints, for example, wrist and ankle, this rule has been extrapolated widely to all joints and to CT, which is a more sensitive modality. There is no consensus on diastasis without step-off. CT also aids preoperative planning, for example, to determine location of fixation in a triplane ankle fracture.

Magnetic Resonance Imaging Use judiciously, as this modality requires sedation of a first-decade child. MRI is most useful to evaluate associated soft tissue injury, such as in the setting of spine fracture in order to evaluate the neural elements, or at the knee in order to rule out meniscal tear in the setting of intercondylar eminence of tibia fracture. MRI often is utilized for complications and preparation for reconstruction, for example, mapping of a physial bridge or determination of presence and extent of osteonecrosis of the head of femur.

Ultrasonogramme This is inexpensive, nonradiating, portable, and facile in the outpatient or emergency setting where it may be performed by the surgeon; is not stressful; and asks little of the child. It is useful for diaphysial fractures, where its specificity may be relied upon in decision to image further. The imprecision of ultrasonogramme around physis and joints limits its utility and influence on management.

MANAGEMENT

Cast

This is safe and inexpensive and has long experience to support it. Not as relevant to children as they are in adults are concerns about joint stiffness and interference with activities such as mobility and work. Despite this, operative treatment for children's fractures is on the rise [A]. Fiberglass is becoming the standard because it is less messy and lighter.

A splint may be applied at the initial encounter, for example, emergency department, if operation is anticipated or if the limb must remain accessible for observation, for example, swelling.

Position the patient, and assistant, appropriately. A stockinette may be folded to soften cast edges. For width of padding, balance risk of pressure sore against loss of reduction. Focus padding over prominences, for example, malleolus; over other areas of stress concentration, for example, cast edges; and where a saw will cut the cast, for example, "racing strips" along anticipated path of saw, at time of cast removal. Extensor transitions may be angled, to limit sliding of the limb in cast, for example, right angle at posterior elbow; by contrast, flexor transitions must be smooth, for example, in the antecubital fossa, to avoid soft tissue injury.

Roll—do not stretch—cast material, in order not to compress the muscle compartments. Open casts, for example, "bivalve," if swelling is anticipated. Cut the padding as well if bleeding is anticipated, as blood will harden padding risking a circumferential constriction.

A waterproof cast is attractive to patients: it allows bathing but requires care to dry. It may give a conflicting signal to a child who has been instructed in protected weight bearing yet is allowed to swim with a cast.

Wedge a cast for fragment drift [B].

A plaster cast may be soaked off. Plaster and fiberglass casts typically are sawed off. The saw has a blunt blade that breaks a cast and as such will not cut skin it touches transiently. Gain the child (and the parent's) confidence by demonstrating on your finger and inviting the child to try. The blade heats as it works, thereby risking skin burns that may leave a permanent scar. Insert plastic strips where there is access to protect the skin. Stop periodically and cool the blade. Renew the blade regularly. Do not dwell: push in, pull out, and keep moving.

Fixation

Use enough fixation. If mobilization is not imperative, supplement with a cast, which may allow simpler and less morbid fixation, for example, inserted percutaneously and removed in the clinic. The soft tissue envelope, including periosteum, is robust, and the energy of injury is more likely low compared with adults. As a result, children's fractures have inherent stability, which, along with more rapid and reliable healing, allows for less invasive and less rigid fixation, for example, elastic nails instead of plates.

The articular surface is more important than the physis: do not sacrifice reduction and stability for concerns about growth disturbance. Osteoarthritis has no simple solution, whereas much can be done about growth disturbance. Furthermore, implants (even threaded) may be placed across a physis so long as their cross-sectional area is small, the physis is not dissected (extraperiosteal, extrachondral), and they are removed within 2 years (before the physis gives up growth).

Remove plates applied in the first decade. Periosteal appositional growth will make them intraosseous by maturity. Do not remove before 6 months, in order to minimize refracture. External fixators produce ugly scars. Their rigidity and any distraction at the fracture may delay union: do not remove them before there are at least three continuous cortices of bone. As with frames for lengthening, remove the barrel and let the child bear weight, with or without a cast, for 2 to 4 weeks. In the event of a refracture, the barrel may be applied in a reduced position.

Bend smooth wires with a long tail over the skin; otherwise, the skin will overgrow them. Save a child an anæsthetic by pulling wires in the clinic, even those placed medullary in the forearm. Deep infection is rare: irritated entry sites usually recover after wire removal.

Figure C represents an algorithm for management.

PHYSIAL BRIDGE

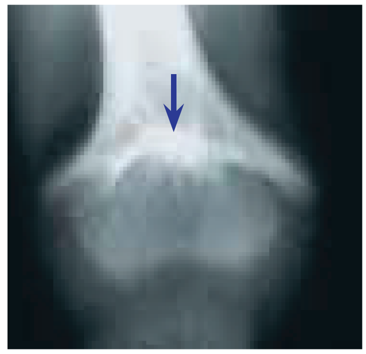
Growth disturbance after fracture may be due to chondrocyte injury in germinal or proliferative zones of the physis, or it may be due to a bridge (or bar) of bone forming across and tethering the physis. The former is remediable by secondary reconstruction, such as limb lengthening to compensate for growth arrest. The latter may be treated directly by bridge resection.

Small bridges may lyse spontaneously. Central bridges are more likely to lyse and less likely to cause deformity than peripheral ones. Central bridges may cause a fishtail deformity, which is better tolerated in the distal femur [A], where it results in a lower limb-length discrepancy, than in the distal humerus, where it is associated with elbow stiffness. Peripheral bridges produce angular deformity [B].

Time for growth is necessary for a disturbance to manifest. Educate patients about alignment of limb or joint, and follow up patients at risk through the anniversary of fracture. Röntgenographic findings include angulation after healing, asymmetric Harris growth arrest line, and limb-length discrepancy. MRI maps the physis to localize and aid determination of the extent of a bridge [C]. This modality may reduce zeal for resection, and thereby improve outcomes of resection, by giving a more accurate (and realistic) representation of the physis.

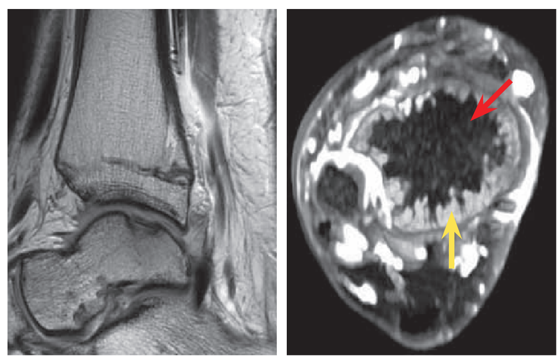
Resect bridges that occupy <25% to 50% of the physis and in a child with ≥2 years of growth remaining [D]. Outcomes are related to the size of the bridge and the health of the adjacent physis. Growth acceleration after peripheral bridge resection may correct angular deformity ≤10 degrees [E]. For greater angular deformity associated with a bridge, combine with a corrective osteotomy, which facilitates access to the bridge for resection.

If the physial bridge exceeds 50%, complete physiodesis is indicated. For angular deformity, osteotomy may be performed through the physis, where a structural graft may be placed to accomplish both goals of physiodesis and correction. Residual limb-length discrepancy is managed according to general principles (*cf*. Lower Limb chapter).

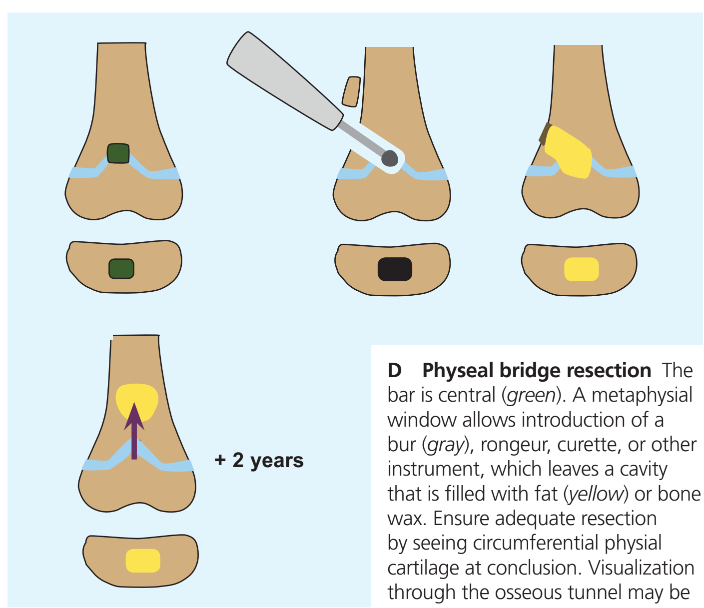


A Fishtail deformity This is produced by a central bridge, as seen on tomogram (*blue*).

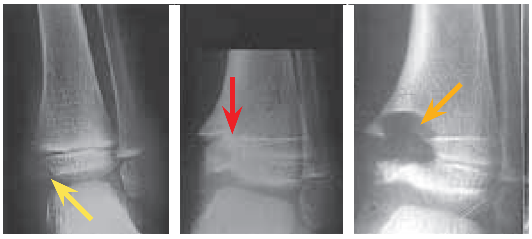
B Angular deformity This resulted from a Salter-Harris II fracture of the lateral distal femur (*red*).



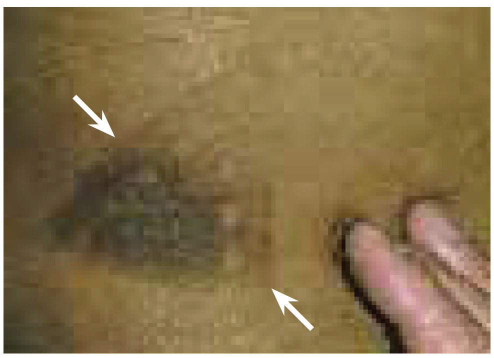
C Physeal bridge mapping MRI shows that the bridge is extensive, as evidenced by a ring of cartilage signal (*yellow*) surrounding a >50% center of bone (*red*) occupying the distal physis of tibia.



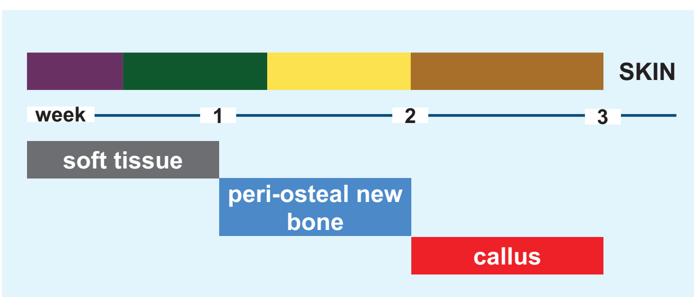
D Physeal bridge resection The bar is central (*green*). A metaphysial window allows introduction of a bur (*gray*), rongeur, curette, or other instrument, which leaves a cavity that is filled with fat (*yellow*) or bone wax. Ensure adequate resection by seeing circumferential physial cartilage at conclusion. Visualization through the osseous tunnel may be aided by a dental mirror.



E Resection of physial bridge Salter-Harris III fracture (*yellow*) resulted in peripheral bridge (*red*). The bridge was resected leaving a hole that was filled with fat (*orange*). Growth resumed and function was normal despite the osseous scar (*green*).



A Skin stigma This iron mark is most eloquent.



B Corner fracture Timeline of changes in skin and bone after injury. Evidence of remodeling continues for months.

Specificity	Fracture
High	Corner, bucket handle Femur before walking age Posterior rib Scapula Spinous process Sternum
Medium	Multiple Bilateral Different stages of healing Skull
Low	Clavicle Long bone—pattern (transverse, spiral) nonspecific

C Specificity of fractures for nonaccidental trauma. The activity level of an infant who does not walk is inconsistent with the energy necessary to break a femur. The thorax is flexible, making ribs and sternum difficult to break. Posterior rib fractures suggest a child running away. Scapula is embedded in muscle and takes considerable violence to break. Spinous processes break under vigorous traction. Multiple fractures in various stages of healing (15% of total presentations) are only medium in specificity, in part due to osteogenesis imperfecta.

NONACCIDENTAL TRAUMA

The original report emphasized skull fracture and multiple fractures in various stages of healing (Caffey). The New York Society for the Prevention of Cruelty to Children was founded in 1874 as the world's first child protective agency. The Federal Child Abuse Prevention and Treatment Act was established in 1974. One-third of abuse is neglect and 1/3 is physical injury, with the final 1/3 including sexual, emotional, and other causes.

The magnitude of the problem is arresting. Prevalence is 1%. Most abuse occurs in the first 3 years of life: 1/2 are <1 year and 1/4 are 1 to 3 years. Abuse accounts for 3/4 of fractures <2 years. After initial presentation, risk of repeat abuse (morbidity) is 1/3, while risk of death (mortality) is up to 10%.

Evaluation

Have a high index of suspicion, and be swayed only by objective findings, for example, not by socioeconomic level. Note that an abuser will seek attention at different facilities for repeat events. Infant prematurity, parental youth, and unmarried status are risks factors. The skin tells the story: cutaneous lesion is the most common finding [A], including burns and bruises. Bruises turn purple (0 to 3 days), then green-yellow (3 to 7 days), and then yellow-brown (after 1 week) [B]. Scalds spare inguinal and popliteal regions due to reflex flexion of hips and knees. One-third of children will have head injury.

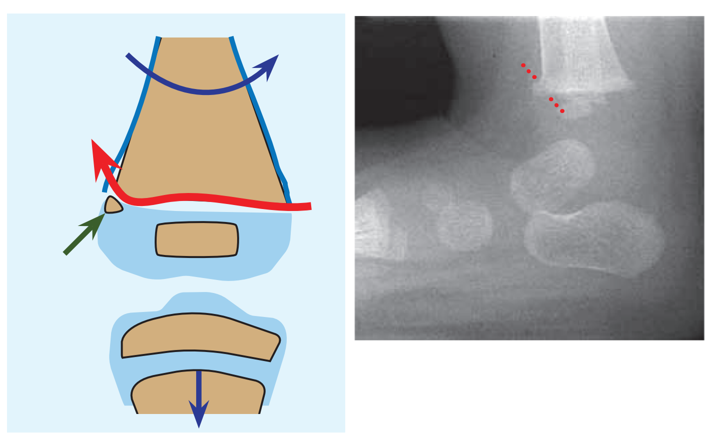
Fractures may be categorized according to specificity for nonaccidental trauma [C]. The corner fracture is nonaccidental *a priori*. The differential diagnosis list includes osteogenesis imperfecta (in particular type IV, which does not have the distinctive blue sclerae), osteomyelitis, infantile cortical hyperostosis, leukæmia, hypervitaminosis A, and rickets.

Imaging

Röntgenogrammes are the standard, ordered *per* protocol: both views of chest and skull; anteroposterior views of arms, forearms, hands, pelvis, thighs, and legs; and lateral view of spine [D]. Scintigramme surveys the skeleton and may expose fractures in difficult to image locations in a young child with incomplete ossification. False-negative rate for röntgenogramme approaches 10%, whereas for scintigramme, it is 1%.

Management

Most important is safety of the child: consult other providers, including pædiatricians, who may admit a child to complete an evaluation, and social workers, who understand how to interface with governmental agencies.



D Corner fracture This is pathognomonic of nonaccidental trauma. The perichondrium holds on to a piece of bone at the corner of the metaphysis (*green*). Mechanism of injury is torsion under traction (*blue*). If the force (*red*) travels more proximal through metaphysis and breaks out at both metaphysial corners, the curvilinear appearance has been likened to a "bucket handle."

FOOT

Foot fractures account for 5% of children's fractures, yet rarely is there an indication for operation. Half involve the metatarsal bones.

Toe

Hallux fracture may involve avulsion of the nail plate and injury to the nail matrix, which may be flipped into a physial separation as indicated by persistent displacement despite reduction. Treat this open injury with irrigation, open reduction, and smooth wire fixation. Lesser toe injuries may be displaced such that they require reduction and buddy-tape immobilization.

Metatarsal

Fall from a height, such as a bunk bed, may result in a pædiatric equivalent of Lisfranc injury. This is characterized by a flexion and axial force that drives the medial cuneiform into the first metatarsal to second metatarsal interspace, creating a lateral proximal Salter-Harris IV fracture of the first metatarsal [A]. Reduce if necessary, fix with wires, and immobilize in a cast.

Stress fractures in adolescents are diaphysial and heal uneventfully with protection and immobilization [B].

The base of the fifth metatarsal presents several patterns:

- Apophysitis or avulsion. The radiolucent apophysial cartilage is oriented longitudinally. This occurs under pull of peroneus brevis in a prepubescent child, who presents with tenderness and swelling. Protect weight bearing and immobilize in a cast.
- Accessory ossicle. Do not confuse this with fracture (*cf.* Foot chapter). This is rounded, with an orientation if determinable that is oblique.
- Metaphysial–diaphysial fracture [C]. Jones described this in himself after a night out dancing with his wife. Mechanism is inversion with abrupt traction by a peroneus brevis that attempts to rectify the foot. The fracture, which is transverse, occurs at a vascular watershed zone, hence the risk of delayed or nonunion. Most heal in a cast. Consider percutaneous screw fixation in a mature adolescent or for delayed union: use at least a 4.5-mm screw that fills the medulla to obtain internal cortical purchase.

Compartment Syndrome

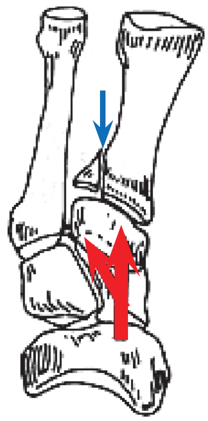
A medial incision that takes down abductor hallucis, the "door to the cage" (Henry), gives access to the deep muscles of the foot. Add two longitudinal dorsal incisions.

Tarsus

Fractures in this region represent <5% of foot fractures in children. These are treated according to general principles. Complications, for example, of head of talus after neck fracture, and comminution, for example, of calcaneus fracture, are less frequent in children. Beware of an occult injury producing limp in the young child [D]. Scintigramme may reveal a stress fracture when physical examination demonstrates foot tenderness, yet röntgenogramme is normal.

Soft Tissue

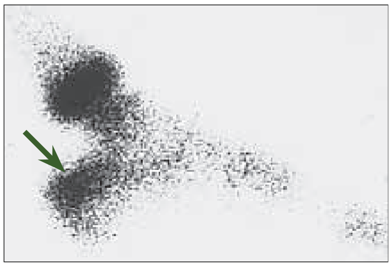
The burden of soft tissue injury for fracture in the child's foot is relatively high due to mechanism of use of the foot, for example, running and jumping, on the ground, and due to mechanisms of injury, for example, lawn mower. Such injuries require complex reconstruction [E].



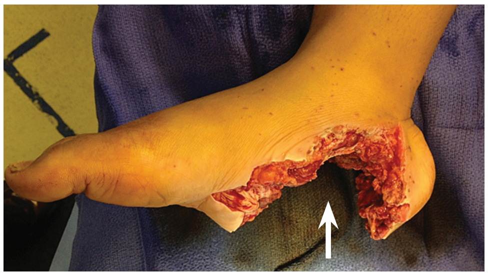
A "Bunk bed" fracture This Salter-Harris IV fracture of first metatarsal (*blue*), produced under the flexion and axial force transmitted by medial cuneiform bone, is a pædiatric equivalent of Lisfranc injury.

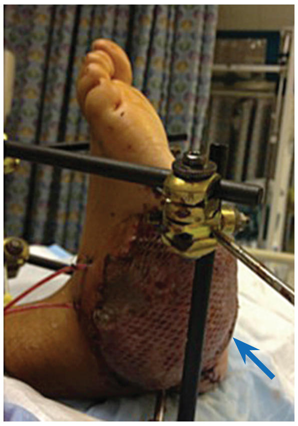
B Metatarsal stress fracture This heals with a circular radiodense blush of callus (*orange*).

C Jones fracture This fracture occurs in the metadiaphysial region, at a vascular watershed region (*red*). The transverse orientation distinguishes this from the longitudinal apophysial cartilage.

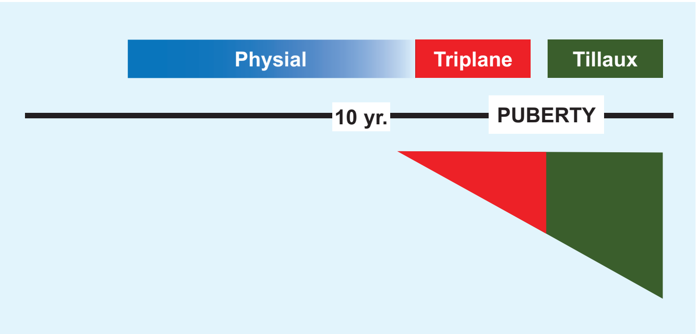


D Occult fracture of calcaneus Increased uptake (*green*) in a 5-year-old limping child with heel tenderness.

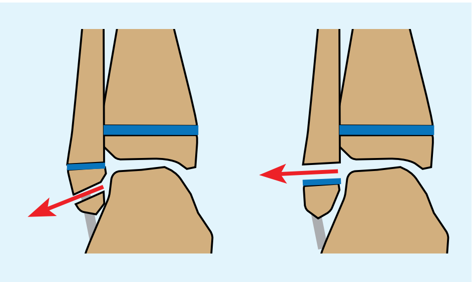




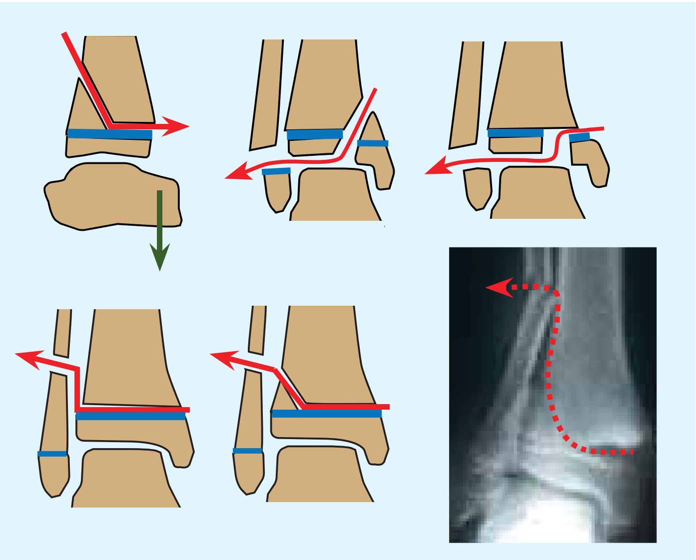
E Open fracture of calcaneus While this does not follow a physial fracture classification, it captures the motivation for adding a sixth type that includes loss of a part (*white*). A lawn mower removed the anterior part of calcaneus (*red*) along with surrounding soft tissues. Because of the lateral location of the injury, perfusion and sensation to the distal foot were preserved. Reconstruction included internal fixation of calcaneus with extensive osseous graft as well as free flap coverage.



A Categorization of ankle fractures in children Types reflect maturation of distal tibia.



B Fibula avulsion These typically are managed successfully closed.



C Salter-Harris fractures Patterns vary, as do the forces producing them, for example, ankle extension (*green*).

ANKLE

The distal physis of tibia closes by 15 years in girls and 17 years in boys. On mortise view röntgenogramme, there should be ≤8 mm clear space between tibia and fibula, and ≥1 mm overlap of tibia and fibula. Acceptable limits for talar position are <2 mm shift and <5 degrees tilt. The child is vulnerable to physial fractures at the ankle because all the ligaments that bind the joint attach to the epiphysis. Ankle fractures in children may be divided into physial and transitional [A].

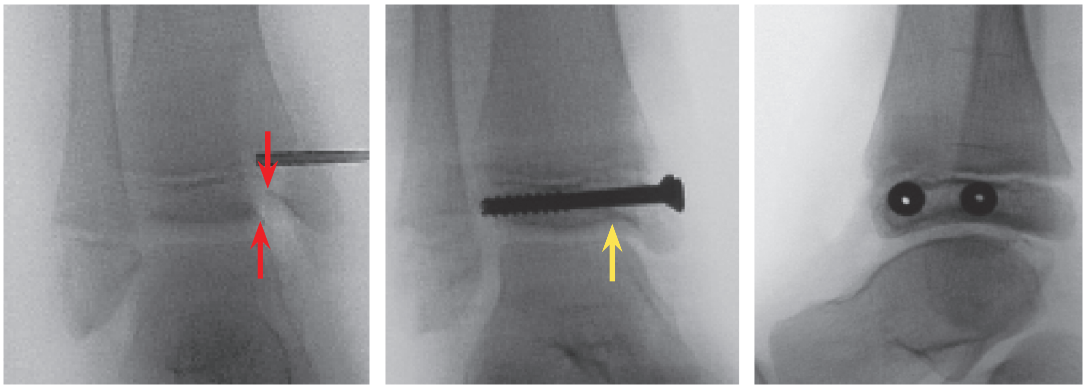
Physial Fracture

These occur before puberty, when physis are wide open. Avulsion fractures of fibula rarely require reduction and fixation [B]. Persistent fragments that do not unite may require delayed osteosynthesis if large, or excision. Do not confuse accesoria, for example, *os subtibiale* (up to 20% of children), with avulsions: the former are rounded with no matching surface on the main fibula fragment.

Salter-Harris I fractures of the distal fibula are a presumptive diagnosis based upon history of trauma, physical examination showing tenderness and swelling, and normal röntgenogrammes. They are overdiagnosed: most represent a bone contusion or ankle sprain. Immobilize without or with weight bearing until resolution of pain.

Several patterns are possible [C]. Salter-Harris II fractures may be displaced, for example, posterior with a metaphysial fragment by an ankle extension force. Intact ankle ligaments secure the distal fragment. Rest the heel on a firm platform, and apply the reduction force to bring the leg to the distal fragment: this will permit greater force than can be applied by holding the heel, in order to effect a single and as complete as possible reduction. The broad physial surface makes the reduction stable. Up to 10 degrees of residual angulation of tibia is acceptable if there is 2 years growth remaining. Associated fibula fractures may be left alone or stabilized with a percutaneously placed medullary wire, which acts as an internal splint. Residual gapping at the fracture represents soft tissue involution, in particular periosteum, which has been implicated in growth arrest. Educate the patient and family that, despite the apparent benignity of this type of fracture (including management by closed methods), growth arrest occurs in 1/4 of cases, exposing the fragility of this physis.

Salter-Harris III and IV are articular. If articular step-off is >2 mm, open reduction and internal fixation are indicated [D]. If the articular surface is not clearly delineated on röntgenogrammes (including oblique views), CT will allow accurate measurement. The surgical approach depends upon the fracture pattern. Plan incision(s) to include a direct view of the articular margin, for example, anteromedial approach to the tibial malleolar fragment. Irrigate the joint to wash out any osteochondral fragments too small to fix. Clean the fracture to remove débris that would obstruct anatomic reduction, including a periosteal flap. Palpate the articular surface with a blunt instrument to confirm that the marginal read is accurate. Fixation includes two screws in epiphysis to stably restore the joint. Excise the metaphysial fragment and overlying periosteum. The fragment is not essential for stability or union, and its removal is an anticipatory bridge excision, which will develop in up to 1/3 of cases [E].



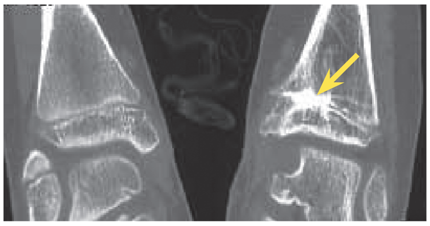
D Salter-Harris IV fracture Articular surface is displaced >2 mm (*red*). Open reduction restores congruity of articular surface (*yellow*). Two epiphysial screws, inserted percutaneously, provide stability, including against rotation, that is supplemented by a cast. After fracture healing, remove epiphysial screws, because they increase peak contact pressure across the tibiotalar joint.

Transitional Fracture

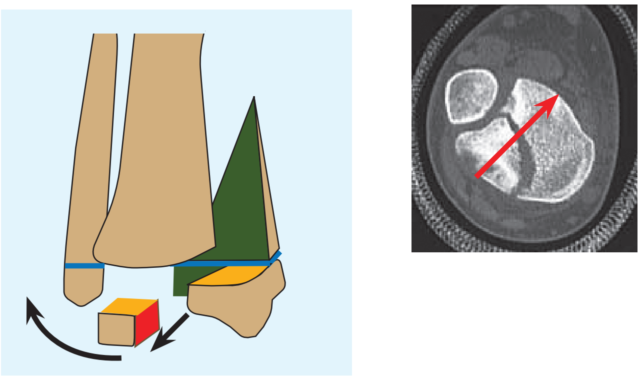
This occurs during the transition between immaturity and mature child, as the distal physis of tibia undergoes the process of closure. As a result, growth disturbance is not a concern. This represents 10% to 15% of pædiatric ankle fractures.

Triplane This fracture is so named after the three planes through which force travels: sagittal disrupts the articular surface, transverse shears the physis, and coronal produces a posterior metaphysial spike [F]. It may be medial or lateral, two-part, three-part, or four-part, presenting numerous patterns and variants that evade a useful classification. The fundamental mechanism is lateral rotation of the ankle, which may be divided into three stages: the first produces an ankle sprain or Tillaux fracture (vs.), the second produces a triplane fracture, and the third stage produces a fibula fracture in half of cases. Because of their complexity, CT is essential to plan fixation, including location of incisions and implant direction. Restore length to take advantage of desmotaxis by fixing the fibula if fractured [G]. Build the distal tibia by starting at the epiphysis. Add fixation, for example, anteroposterior screws, to capture the posterior metaphysial spike, as necessary to reduce the epiphysis to the remainder of tibia. Add a screw to fix the syndesmosis if disrupted. Beware that soft tissue swelling may influence timing of operation.

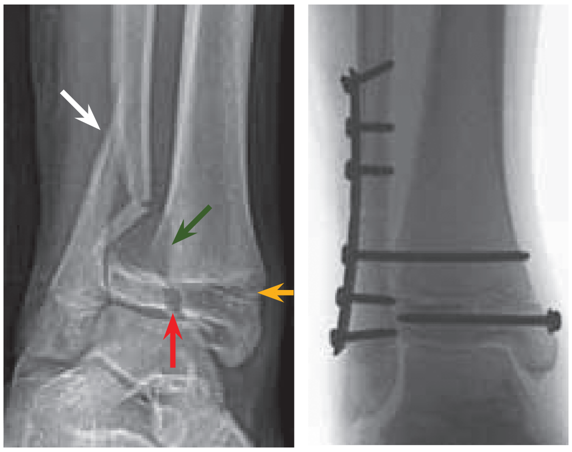
Tillaux The pathogenesis reflects direction of closure of the distal physis of tibia: this begins central, proceeds medial, turns posterior, and ends at the anterolateral corner, which will be separate and due to stress concentration prone to avulsion under pull of anterior tibiofibular ligament during lateral rotation of the ankle [H]. Unlike the triplane fracture, which is characterized by significant deformity as the distal epiphysis of tibia breaks and separates from the rest of the bone taking with it the foot, a Tillaux fracture presents with no significant deformity and minimal swelling. Tillaux patients are 1- to 2-year older than triplane patients. Because ankle alignment is normal, this fracture may not be evident on röntgenogramme, in particular on anteroposterior projection, in which fibula obscures lateral corner of distal tibial physis. Because of this, and the fact that it is articular, CT is indicated. For displacement >2 mm, perform open reduction *via* an anterolateral approach that enables inspection of the articular surface. Reduction of the fragment requires simultaneous compression with pointed tenaculum and posteromedial translation with tamp. Fix with one screw parallel to the articular surface and one oblique for rotational control. Do not worry about the physis, which by definition is mostly closed.



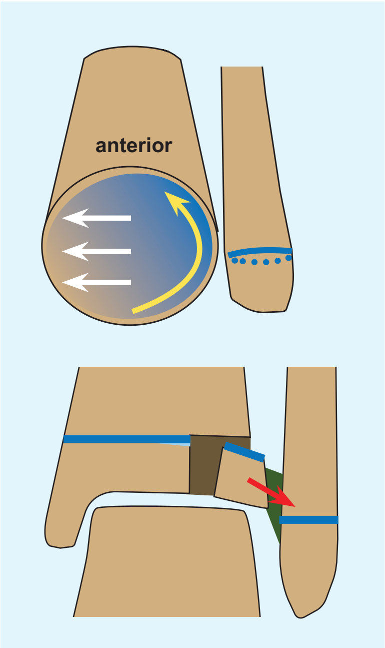
E Growth arrest after Salter-Harris II fracture Because of varus and bridge > 50% (*yellow*), complete physiodesis with corrective osteotomy was performed through the physis, where a tricortical allograft (*white*) was stabilized by an interference fit and two bioabsorbable wires.



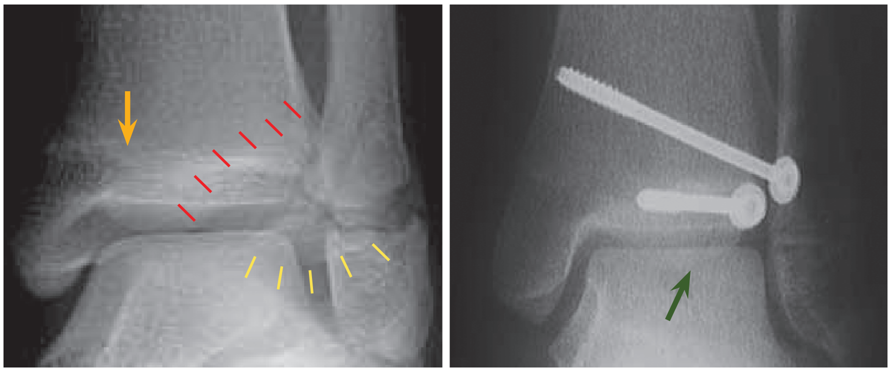
F Triplane fracture Force of fracture travels through three planes: sagittal (*red*), transverse (*orange*), and coronal (*green*). CT scan aids planning of fixation: *arrow* indicates path of anteroposterior screw (*yellow*).

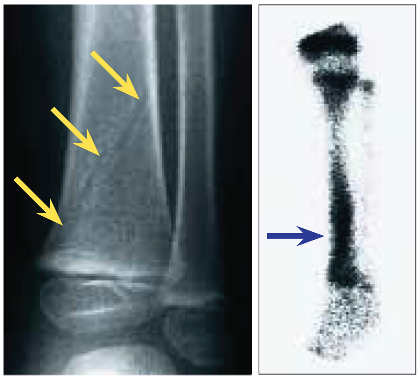


G Triplane fracture open reduction and internal fixation Plating of fibula proximal to its distal physis restored length. No anteroposterior implants were necessary to fix the posterior metaphysial fragment, which was reduced anatomically by desmotaxis. Two screws fixed the epiphysis, and a screw through the plate stabilized the syndesmosis.



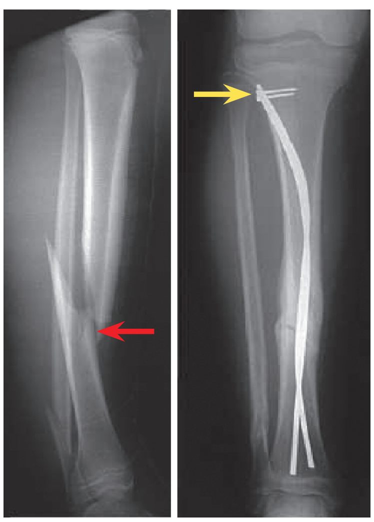
H Tillaux fracture Distal physis of tibia closes medialward (*white*) and then posterior to anterior (*yellow*). Fragment is avulsed under pull of anterior tibiofibular ligament (*green*). Fragment is difficult to see on AP röntgenogramme, which shows medial physial closure (*orange*). It is managed by open reduction (*green*) and fixed.



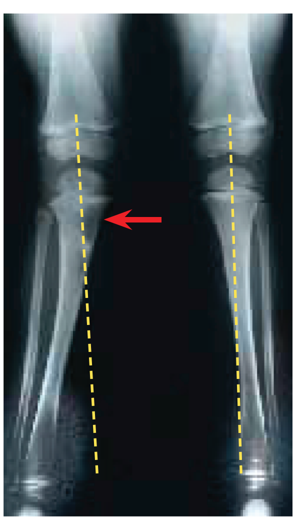


A Toddler fracture The typical pattern is distal metaphysial oblique proximal lateral to distal medial (*yellow*). Scintigramme shows increased uptake (*blue*).

B Tibia and fibula fractures These fractures may be treated effectively in cast, which was wedged for drift (*yellow*) noted at 1-week follow-up.



C Operation for tibia fracture This unstable fracture (*red*) in an adolescent is best treated operatively. Flexible medullary nails avoid the physis, in particular the tibial apophysis, which is hypersensitive to growth disturbance, and may be placed through a lateral proximal window (*yellow*) where they will not be prominent under cover of the anterior crural muscles. Ender nails are secured in place by eyelet screws, controlling migration and facilitating removal if necessary.



D Valgus following proximal metaphysis of tibia fracture 5-year-old girl sustained an undisplaced right proximal tibial fracture (*red*), which was treated in an above-knee cast. Valgus deformity is evident at 1 year after injury.

TIBIA

The subcutaneous surface of the tibia makes it slow to heal and prominent when malunited. Unlike femur, overgrowth is insignificant: mean 5 mm up to 10 mm. The tibia bears 80% of body weight through the leg. Compartment syndrome is a real risk after this fracture.

Toddler Fracture

The name describes the age of presentation. Energy is low, for example, hyperextension of the knee when landing from a jump. The child may limp or refuse to walk. Physical examination shows tenderness but little else: no swelling and no deformity. Röntgenogrammes show a faint oblique line or may be negative. Scintigramme shows increased uptake [A]. Alternatively, a presumptive diagnosis may be made based upon the typical presentation. Treat with a walking cast: apply the cast above the knee, flexed to 60 degrees, for an older child in less controllable circumstances, to automatically limit activity.

Diaphysial Fracture

In the first decade, most tibial diaphysial fractures may be managed by reduction and above-knee cast. Flex the knee to at least 45 degrees to ease clearance of the floor with crutches. Include a valgus mold for an intact fibula, which pushes a broken tibia into varus. Follow with weekly röntgenogrammes until stable [B]. Modify ankle position to take advantage of tension produced through the posterior compartment muscles that may be harnessed to support a reduction in the sagittal plane, for example, extend the ankle and relax these muscles in an apex anterior fracture. Up to 10 degrees of residual valgus angulation and 5 degrees of varus are acceptable. Step-off is a concern at the subcutaneous border of the mid-diaphysis, though this will remodel in the first decade. Transverse plane deformity does not remodel significantly: be cognizant of transmalleolar axis relative to flexed knee during reduction and application of cast.

In the adolescent, surgical management reduces risk of malunion, lessens the burden of follow-up, and obviates the need for casting. Open diaphysial fractures also are treated operatively for wound care and healing and because, often, soft tissue interposition prevents acceptable reduction. Flexible medullary nails [C] are benign, load sharing, and stable enough to effect and maintain reduction and to stand alone for most fractures. Exceptions include significant comminution and bone loss, where external fixation is indicated.

Stress Fracture

Ten percent of all stress fractures affect immature children, while 30% occur in the mature adolescent. The tibia is most affected, comprising 45% of all stress fractures. Sports are the most common cause. Girls are affected more than boys, in part due to a hypoœstrogenic state induced by activity. Röntgenogrammes may be negative: confirm diagnosis with scintigramme. Manage by immobilization, protected weight bearing, or activity modification. Monitor healing by symptoms and until scintigramme normalizes.

Proximal Metaphysial Fracture

Greenstick fractures of the proximal metaphysis of tibia in the 3- to 7-year-old child (Cozen) may be followed by the development of valgus deformity [D]. Mechanism is valgus force. Medial overgrowth exacerbates normal development from varus to valgus in this age group. Röntgenogrammes show deviation of tibia away from mechanical axis and asymmetry of growth arrest line.

The natural history is spontaneous correction over a 2-year window. Educate family so that they may be patient during this period of observation. For persistent deformity, modulate growth by temporarily arresting the medial proximal physis with an implant that may be removed at correction.

Intercondylar Eminence Fracture

The intercondylar eminence also is referred to as the spine of the tibia. This fracture occurs around the turn from first to second decades. Mechanism is knee hyperextension and axial loading, as in sudden braking while riding a bicycle. The anterior cruciate ligament may stretch but does not fail, a fate that befalls the intercondylar eminence where the cruciates attach. While it is named after the nonarticular part of the knee, the fracture may extend to the articular surfaces of both condyles and may be associated with meniscal tear.

Evaluation The patient presents with knee pain that prevents weight bearing and effusion due to hæmarthrosis in fracture. Pain will not allow Lachman or pivot shift testing.

Imaging The fracture may be classified on lateral view röntgenogramme [E]. CT allows accurate measurement of fragment displacement. Displacement >2 mm is unacceptable even though this is a nonarticular fracture, not because of concern for union or posttraumatic arthritis, but because this will introduce laxity in the anterior cruciate ligament that may destabilize the knee. MRI will show associated articular and ligamentous injury. Half of cases will show medial more than lateral meniscal or intermeniscal ligament entrapment, in type 3 more than type 2. Meniscal tear is rare (<5%).

Management In the emergency setting, aspirate the knee, inject a local anæsthetic, and apply a cast in full knee extension. In this position, the femoral condyles may compress any articular extension of the fracture to reduce the fragment. If there is meniscal entrapment, the reduction will be incomplete. If the fragment is solely nonarticular, it may be displaced by the extension manœeuver because the anterior cruciate ligament is taught. Confirm acceptable reduction with röntgenogrammes or CT.

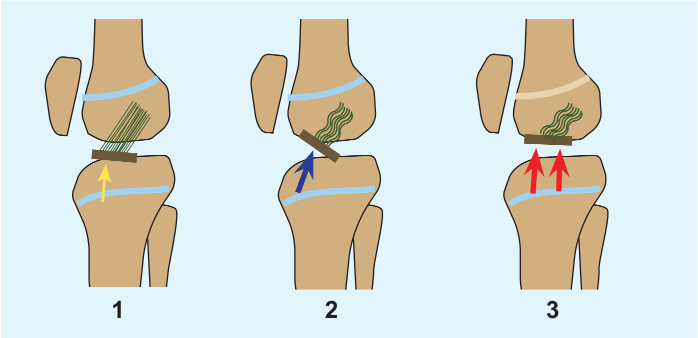
Type I fractures are treated in an above-knee cast at 30 degrees flexion (relaxed anterior cruciate ligament).

Operative reduction and internal fixation is indicated for displaced fractures [F]. Articular structures may be explored and repaired by arthroscopy, by which the fracture also may be reduced and fixed. If MRI shows an isolated fracture, it may be treated *via* a linear incision parallel to the ligamentum patellæ starting at the apex of patella and continuing to the anterior articular margin. Because the anterior cruciate ligament is presumably stretched before the fracture occurs, débride the bed of the fracture in order to countersink the fragment and thereby tension the ligament. Fixation may be by suture passed through drill holes in the apophysis, for example, if fragment is small or comminuted, or a screw, which may be placed epiphysial or transphysial and which may be metallic or bioabsorbable. Postoperative immobilization and weight bearing are tailored to union of fracture, meniscal repair if performed, and associated collateral ligament injury if present. Plan removal of transphysial, to avoid growth disturbance, or metallic screws, which will overgrow.

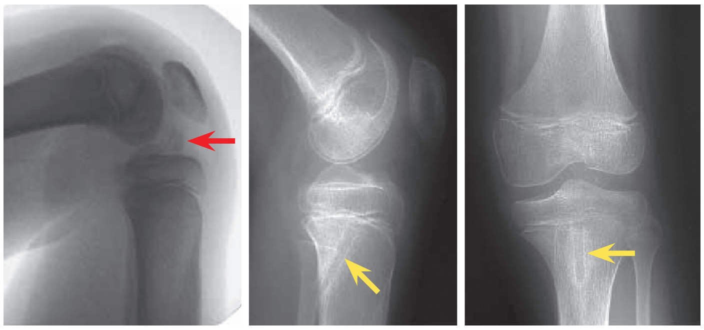
Outcomes are obscure. Children may demonstrate persistent anterior cruciate ligamentous laxity on testing despite operative treatment yet have normal function, as determined by outcome instruments, for example, Lysholm knee score >90/100, and by return to preinjury level of activity. Educate patients and families that not uncommon after this injury are stiffness and prolonged knee pain, which will resolve with dedicated rehabilitation.

Proximal Physial Fracture

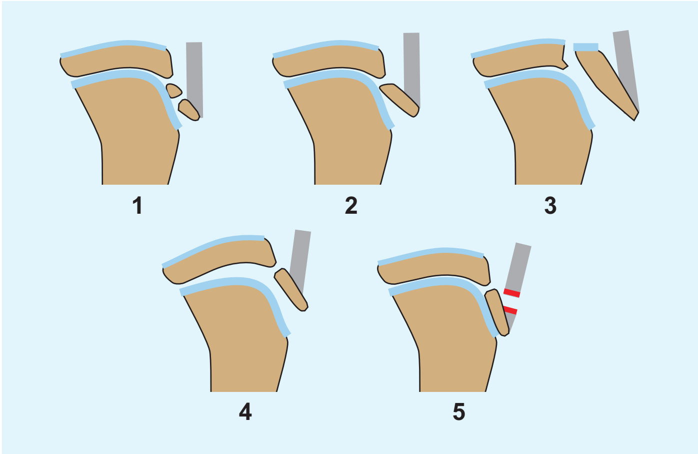
The greatest importance of these fractures is potential for popliteal artery injury by posterior displacement of the proximal metaphysis, as the proximal fragment is retained by the ligaments of the knee. Knee hyperextension drives the distal fragment into the vessel, which may be occluded or torn as it is tethered at the soleus fascia and interosseous membrane. The fractures are treated according to general principles of Salter-Harris types.



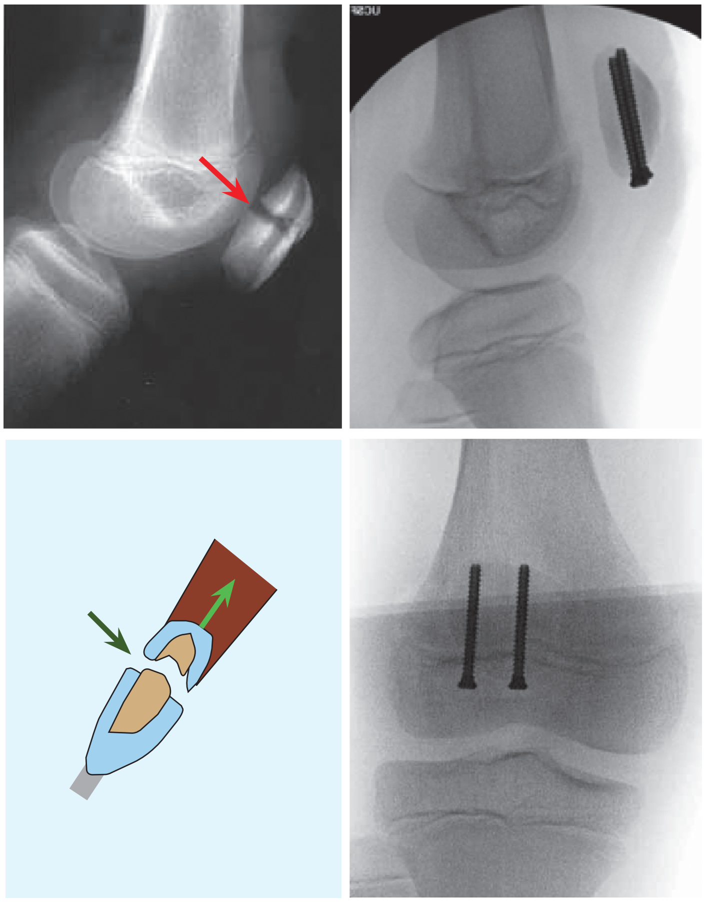
E Classification of intercondylar eminence of tibia fractures Type 1 is acceptably displaced and may be treated with cast: it will heal without anterior cruciate ligament (*green*) laxity. Type 2 may be reducible and, if so, may be treated closed in cast. Type 3 is surgical and may be whole or comminuted.



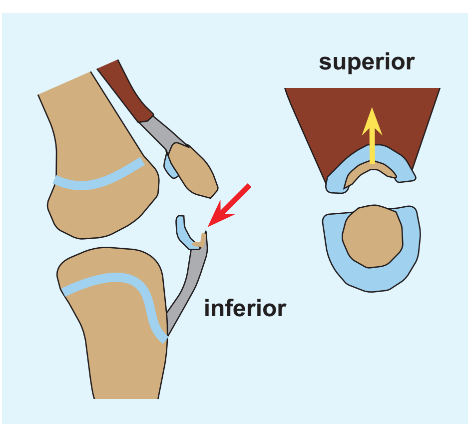
F Operative treatment of intercondylar eminence of tibia fractures This type 2 fracture (*red*) was irreducible. It was fixed with a bioabsorbable transphysial screw (*yellow*), which loses purchase after union but before physial arrest.



G Classification of tibial tubercle fractures Type 1 is a fracture within the tubercle. It may be minimally displaced, designated A, which is difficult to differentiate from chronic Osgood-Schlatter condition, or displaced, designated B. Types 2 and 3 may be subdivided into A without or B with fragmentation of the displaced fragment. In type 4, force lifts tibial tubercle then continues along the proximal physis of tibia. More than one variant are included in type 5, including avulsion of the ligamentum patellæ (*gray*) and a triplane pattern.



H Transverse patella fracture This may result from a direct blow as well as from sudden pull of quadriceps femoris (*green*). The fracture was fixed with cannulated screws augmented with heavy nonabsorbable suture. Screws were countersunk below the cartilage rim so that the suture creates a tension band construct.



I Marginal patella fractures A sleeve of cartilage may tear off along with a sliver of bone from the apex (*red*), or a rim may fracture off the base (*yellow*).

Tubercle Fractures

This fracture occurs during the pubertal growth acceleration. Mechanism is eccentric contraction of quadriceps femoris against flexion and axial loading of the knee, as in jumping during basketball.

Evaluation The patient presents with knee pain that prevents weight bearing and anterior knee swelling or articular effusion due to hæmarthrosis if the fracture extends through the epiphysis. Pain and avulsion of the tibial tubercle produce a knee extension lag. There may be a history of Osgood-Schlatter condition. Avulsion of the anterior tibial recurrent artery has been implicated in associated compartment syndrome.

Imaging The fracture may be classified on lateral view röntgenogrammes [G].

Management Minimally displaced fractures are casted in knee extension, to relax quadriceps femoris. Displacement weakens quadriceps femoris, which is an indication for operative treatment. Articular extension risks posttraumatic arthritis and may include injury to intra-articular structures. Approach displaced fractures *via* a midline incision. Explore and irrigate the joint open through the type 3 fracture or by arthroscopy. Fix fragments by screws parallel to the joint contour placed in apophysis and epiphysis. Repair a torn patellar retinaculum to support internal fixation. Repair a torn ligamentum patellæ in type V by suture through drill holes or anchors. Add an anterior crural fasciotomy performed along tibial crest through same incision by long scissors, as prophylaxis against compartment syndrome.

Genu recurvatum does not complicate such fractures or their treatment because the fractures occur when the proximal tibial physis is closing. Screw prominence may be addressed by implant removal after union.

PATELLA

There are two principal types of patella fractures, which occur with similar frequency.

Transverse Fracture

These fractures resemble those in adults [H]. Mechanism includes a direct blow.

Marginal Fracture

These may be superior, involving the base of patella, or inferior, involving the apex [I]. They are named “sleeve” fractures after the long soft tissue covering of cartilage and periosteum that accompanies a relatively smaller fragment of bone. Mechanism is avulsion due to sudden eccentric contraction of quadriceps femoris.

Evaluation The patient presents with knee pain that prevents weight bearing, articular effusion due to hæmarthrosis from fracture, and loss of knee extension.

Imaging Röntgenogrammes underestimate the injury: they may show only a fleck of bone, or they may be limited to soft tissue findings of swelling and hæmarthrosis outlining the ligamentum patellæ. Diagnostic aspiration will show blood and fat. MRI reveals the extent of cartilage and retinacular damage. Distinguish bipartite patella (*cf.* Lower Limb chapter).

Management Untreated, the periosteum heals to form an elongated patella. Long term, articular discontinuity and irregularity predispose to posttraumatic arthritis. Because these include a large articular component, open reduction and internal fixation are indicated. If the osseous margin in a sleeve fracture is too small to receive a screw, a tension band construct with wires and a heavy nonabsorbable suture, supplemented by a cast, will effectively stabilize the fragment.

FEMUR

Distal Physial Fracture

These are classified by the Salter-Harris system.

Evaluation Consider nonaccidental trauma in an infant. The more typical presentation is an early second-decade child with pain and swelling, without or with knee deformity. There is tenderness at the distal femoral physis but not along the substance or distal attachments of the collateral ligaments. A knee effusion also differentiates physial injury from collateral ligamentous injury.

Imaging Röntgenogrammes may be negative in a nondisplaced type I fracture or show only subtle widening. Stress röntgenogrammes, which require sedation, may expose loss of physial integrity [A]. However, this manœuver also further injures a physis prone to growth disturbance. Consider scintigramme or MRI, both of which will show altered signal at the distal physis, if history and physical examination do not provide a diagnosis with confidence. Articular extension is an indication for CT to determine surface step-off. While the knee is more forgiving of articular irregularity than are the wrist and ankle, most follow the 2-mm rule.

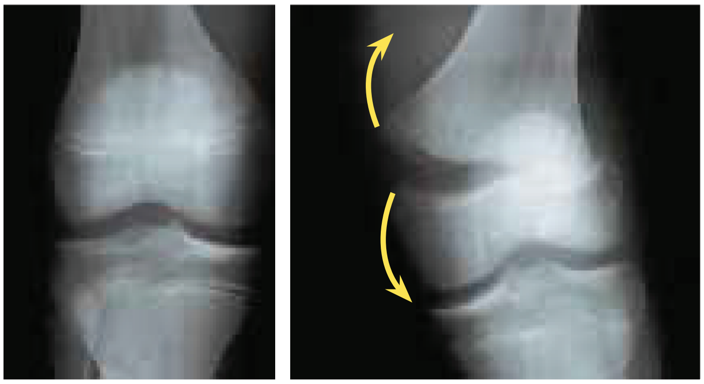
Management Apply an above-knee cast with protected weight bearing for nondisplaced fractures. For displaced Salter-Harris I fractures, close reduction and percutaneous crossed wire fixation, supplemented with a cast, are effective [B]. This also may be performed for Salter-Harris II types; alternatively, if the metaphysial fragment is large, closed or open reduction and screw fixation may be more stable and avoid physis and articular surface. Salter-Harris III and IV require open reduction under direct visualization of the articular surface, to which access is obtained by a midaxial medial or lateral incision that is curved toward tibial tubercle to permit an arthrotomy. Fixation is by screws placed in epiphysis and in metaphysis, which are supplemented by a cast [C]. In the event that screws alone are not stable, for example, when there is extensive comminution, apply an extraperiosteal and extraperichondrial plate that will be removed after union. Do not sacrifice restoration and stability of the joint for fear of growth disturbance.

Outcome Half of these physial fractures will arrest, partially causing deformity and/or completely causing shortening. The undulating shape has been implicated in shearing of the columnar architecture of the physis during displacement. Educate the family of this risk at first encounter. Monitor actively: because of the rapid growth of the distal femoral physis, signs of growth disturbance will be evident by the anniversary of fracture. Consider resection of small, discrete bridges, or complete physiodesis for those that are unresectable, without or with corrective osteotomy as indicated.

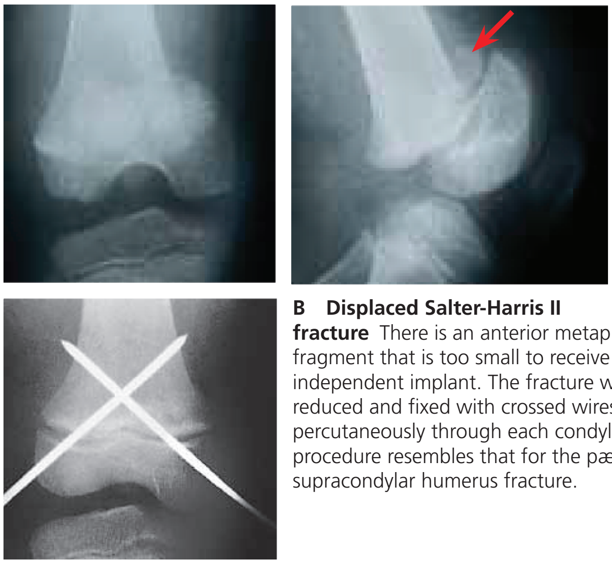
Distal Metaphysial Fracture

This is a site of torus fracture in a young child, which is managed by an above-knee cast [D]. In neuromuscular patients, osteopenia and a long lever arm in the setting of stiffness conspire to fracture this region. Limit casting in such a setting in order not to exacerbate osteopenia. The distal metaphysis of femur is a common location for benign tumors of bone, for example, nonosteogenic fibroma, which may lead to morbid fracture.

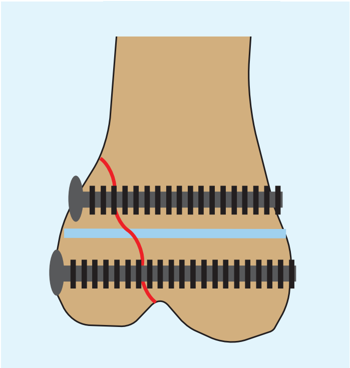
In the adolescent, sport is the most frequent culprit. The distal fragment tends to be pulled apex posterior by gastrocnemius and into varus by adductor magnus. Displaced fractures are treated by open reduction and internal fixation. A locking plate, as a fixed angle device, stabilizes distal fractures without the need to span the physis to anchor in the epiphysis. An external fixator is an alternate for distal fractures, as well as for open injuries and a floating knee.



A Salter-Harris I fracture The presenting röntgenogramme showed no abnormality. Because of clinical suspicion, stress manœuver was performed, revealing an unstable fracture of the physis (*yellow*).



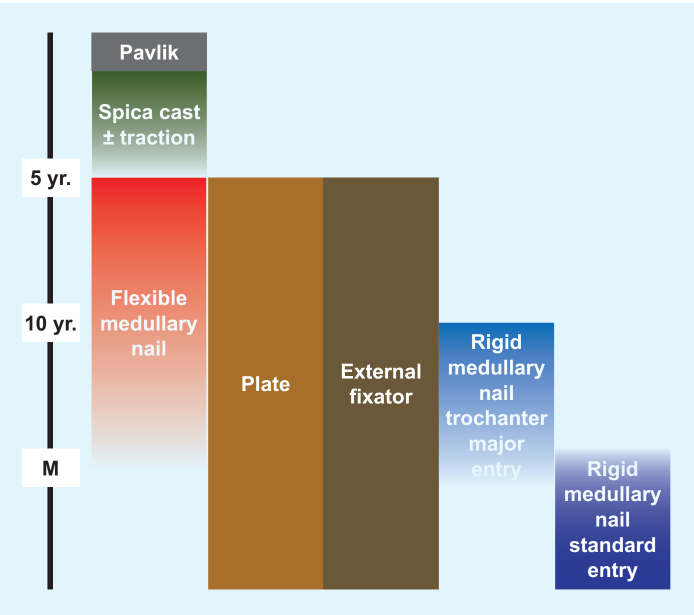
B Displaced Salter-Harris II fracture There is an anterior metaphysial fragment that is too small to receive an independent implant. The fracture was reduced and fixed with crossed wires passed percutaneously through each condyle. The procedure resembles that for the pædiatric supracondylar humerus fracture.



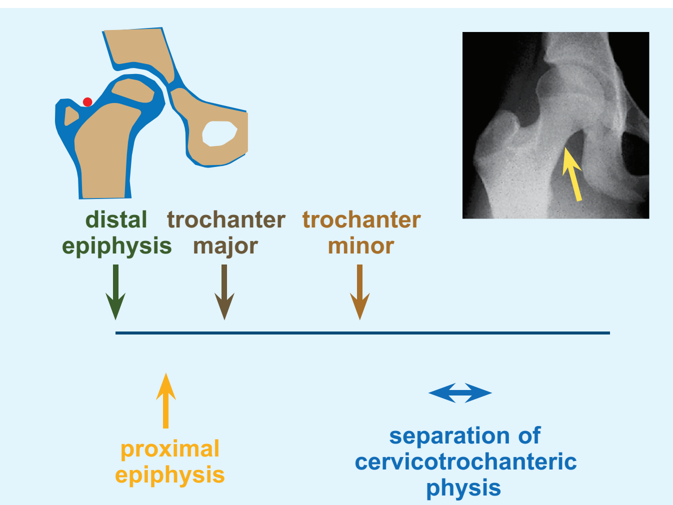
C Salter-Harris III and IV fractures These are treated with open reduction and internal fixation with large screws placed extraphysial and parallel to joint surface. Full thread facilitate extraction if necessary, for example, before corrective osteotomy for growth

D Distal metaphysis torus fracture This is a low-energy fracture managed in a cast.

A Healing of femur fracture Relationship between time of immobilization in weeks until stable callus and age in years is linear, reflecting rapidity of healing.



B Management of femur fractures according to age Operative treatment begins with school. The cervicotrochanteric physis and the trochanter major apophysis influence choice of implant.



C Ossification of proximal femur The cervicotrochanteric physis is continuous from trochanter major to neck of femur until early in the second decade, after which the two centers become independent. Injury to this physis may lead to a thin valgus neck (*yellow*), which may fracture more readily, and a small trochanter major, which may weaken the hip abductors. A trochanteric fossa starting point for antegrade nailing may injure the medial femoral circumflex artery entry (*red*) in an immature child with a small femur. The trochanter major apophysis grows longitudinally until the end of the first decade, after which appositional growth takes over.

Diaphysial Fracture

Presentation is bimodal: 2 to 4 years, which tend to be low energy such as play, and adolescence, which include motor vehicle crash and other high-energy mechanisms. Due to its thick muscle envelope, the femur has an exceptional capacity to heal, to heal rapidly and to remodel [A]. Overgrowth is greatest for femoral diaphysial fractures in the first decade: mean 1 cm up to 1″. As a result, shortening up to 1″ is acceptable and 1 cm is desirable. Unlike adults, hæmorrhage does not require replacement after this fracture in children.

Evaluation Investigate for nonaccidental trauma in an infant with a femur fracture before walking. The patient complains of pain immediately after a traumatic event and is unable to bear weight. The thigh is swollen and deformed, held in hip flexion and lateral rotation with knee flexion, a position aimed at relaxing deforming forces on the fracture to reduce pain.

Imaging Röntgenogrammes show fracture, pattern, alignment, and shortening.

Management This follows age [B].

Birth to school age Immobilize without and with reduction. A Pavlik harness suffices in the 1st year. Caution parents that, while time to stable callus is rapid, this time will be punctuated by pain as the child instinctively kicks with the lower limbs. For the older infant, apply a spica (Latin *spica*: "ear of grain," after the pattern of applying the strips of plaster or fiberglass) cast in the "human position" (Salter). This brings the distal fragment to the proximal fragment, in response to deforming muscular forces:

- Hip flexion to 90 degrees, because the proximal fragment is flexed by iliopsoa. This allows sitting, including transportation by car.
- Hip abduction 45 degrees, to counteract hip abductors. This gives access to the perineum for care.
- Gentle lateral hip rotation, for the lateral hip rotators.
- Apply a valgus mold against the varus force of adductor magnus on the distal fragment.
- Knee flexion >60 degrees, to reduce shortening by injured muscles in spasm. Compression of the popliteal fossa during application of traction in knee flexion risks compartment syndrome.

Even though the cast may be applied in an emergency setting, in the operating room, the child is reliably relaxed and imaging is optimal. Obtain röntgenogrammes at 1 week for alignment and shortening, and to make sure family is coping, because a spica cast is a heavy burden of care. Acceptable alignment is ≤30 degrees in sagittal plane, the plane of motion of the knee, and ≤10 degrees in the coronal plane. Even though little remodeling occurs in the transverse plane, the patient can compensate by hip rotation ≤30 degrees. Such numbers are guidelines, influenced by several factors and prone to measurement error. Factors include age–for example, more is accepted at a younger age due to greater remodeling potential–and location–for example, more may be acceptable closer to an enarthrodial joint that can compensate for residual deformity. Error may be intra- or inter-observer, as well as the result of parallax related to positioning.

Coming out of a spica cast is stressful for a child: prepare the family and offer a hip abduction brace as a weaning device. A limp will persist for weeks, reflecting in part the accompanying psychic injury. Obtain röntgenogrammes at anniversary of fracture to measure for overgrowth.

Traction Consider this for shortening >1″. Use a distal femoral pin, because the tibial apophysis is prone to growth disturbance. Apply weight until shortening becomes <1″, and continue until callus is stable enough to cast, which is confirmed by reduced pain on physical examination and radiographic appearance. As the age of operation declines, the indication for traction fades. Traction counteracts shortening, which correlates with energy of injury, which correlates with the age of the child, which correlates with operative treatment. Cost is equivalent to operative treatment, which allows a child to get out of bed and get back to a normal environment.

5 YEARS TO MATURITY Starting at school age, operative treatment is indicated. The standard treatment in adults is antegrade medullary nailing. The principal determinant of technique in a child is physis [C].

Flexible medullary nailing avoids the physis [D]. It may be antegrade, starting at lateral cortex distal to trochanter major, or retrograde, starting at lateral and medial cortices proximal to distal femoral physis. The technique has several advantages:

- It is safe, avoiding physis.
- It is load sharing, encouraging callus formation and union.
- It allows for controlled shortening, which counteracts the overgrowth phenomenon.
- Its lack of rigidity is an advantage when the soft tissue envelope has not been extensively disrupted. As the fracture heals, normalization and symmetry of muscle contraction allow spontaneous correction of rotational malalignment, which does not otherwise remodel significantly.
- It may be performed through discrete incisions.

Use same diameter nails, to avoid differential stress that risks fracture displacement. Select a nail that is 40% of isthmus diameter, so that 2 fill ≥ 80% of the canal. Nails may be C-shaped or S-shaped.

There are three types of flexible nails [E]. The original report by Rush described fixation of a proximal ulna fracture in an adult. Ender introduced his nails for periprosthetic fractures, after the concept of filling a vase with stems until they all stand straight, as proposed earlier by Rush. The original report from Nancy described fixation of both bone forearm fractures. Image intensification aids selection of extraphysial entry site. There is no consensus on routine implant removal, although it may be necessary for tip prominence.

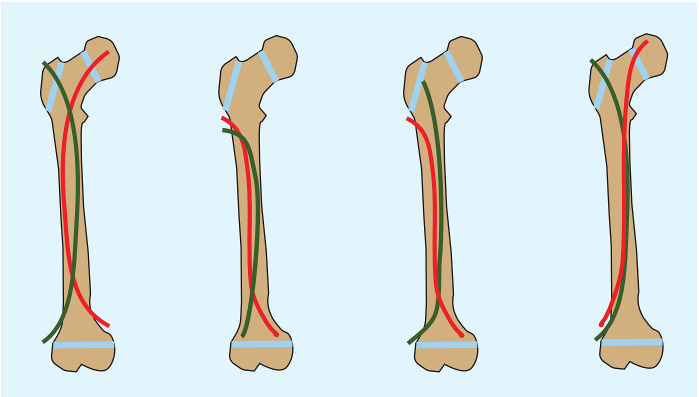
Contraindications for flexible medullary nailing are comminution and adult weight.

Bridge plating acts as an internal extramedullary splint, fixed proximal and distal to the fracture. It avoids physis and is rigid; as such, it may be used for all ages. It can span a region of comminution for length-unstable fractures. It may be performed by a less invasive submuscular technique. Locking screws add stability to very proximal or distal fractures. A plate fixes rotation (no spontaneous correction), is load bearing, does not allow "physiologic" shortening, and may be overgrown by a bone increasing in diameter *via* periosteal apposition, thereby necessitating removal.

External fixation has the same advantages as bridge plating. It has the additional advantage of allowing access to soft tissues in open fractures while staying remote from the zone of injury. Conical pins may be removed in clinic: they loosen after the first revolution. Because of the rigidity of the implant, and morbidity of pin sites, premature removal has resulted in refracture. Wait until there are at least three continuous cortices of callus, and dynamize the construct first by removing the barrel but leaving the pins in place for 2 to 4 weeks.

Beginning in the second decade, antegrade rigid nailing through trochanter major is safe and effective. It has the benefits that have made antegrade rigid nailing the standard for adult femur fractures. Because of appositional growth after 8 years, the trochanter major is durable, and it is remote from the lateral epiphysial vessels in the retinacula of Weitbrecht. Küntscher's original report of medullary nailing of femur fractures through a trochanter major starting site included a 10-year-old boy.

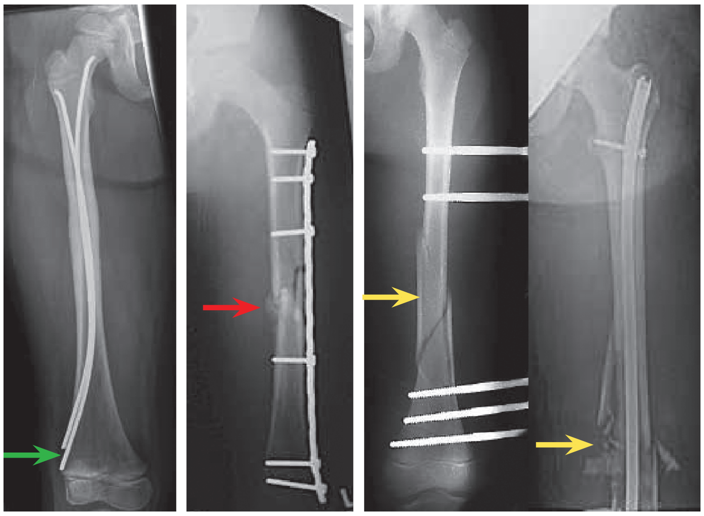
Implant choice [F] is secondary to the principal innovation in treatment of femur fractures, namely, the decision to operate in the skeletally immature.



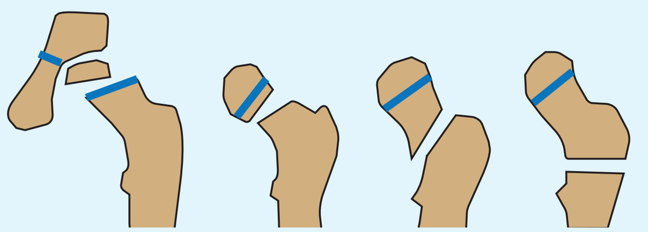
D Flexible nailing of femoral diaphysial fracture Nails may be antegrade or retrograde, inserted lateral and medial. Retrograde allows more proximal fixation for more proximal fractures. Nails may be passed across physis, which will not be disturbed because nail is smooth and diameter is small compared with total cross-sectional area, and into epiphysis, which is hard and mechanically stable. Two lateral entry points are simpler and use a single incision.

Nail	Features
Rush	Steel Most rigid Sharp beveled tip to allow penetration of bone and deflection off cortical surface. Hooked end for steering and extraction Predetermined lengths
Ender	Steel Blunt beveled tip to allow deflection off cortex Prebent to ease passage through medulla Eyelets at end may receive cortical screws that allow nails to be inserted flush with cortex, prevent migration, and facilitate steering and extraction Predetermined lengths
Nancy (France)	Titanium or steel Most flexible makes them easiest to insert Bent keel tip facilitates passage through medulla and across fracture for reduction Memory metal results in three point contact in medulla Cut to length, which along with widest range of diameters makes this most versatile

E Flexible nails.

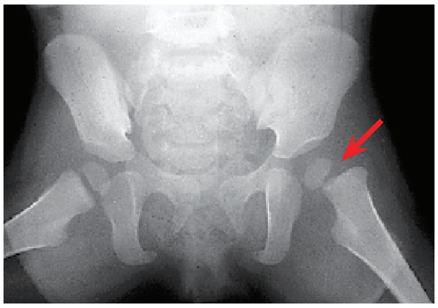


F Implant choices for femoral diaphysial fractures Nancy nails were inserted through a single lateral incision (*green*), which is easier and saves the child a scar. Plate bridges the fracture as an internal fixator (*red*). Indication for external fixator was comminution (*yellow*), which also may be treated effectively with a trochanter major nail in an adolescent.

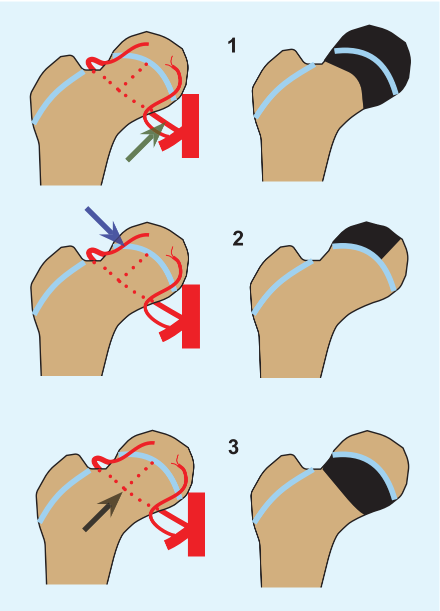


Type	1	2	3	4
Frequency	10%	50%	25%	15%
AVN	75%	50%	25%	10%

G Delbet-Colonna classification of proximal femoral fractures AVN: avascular necrosis. AVN in intertrochanteric fractures is explained by injury to the retinacular vessels at the intertrochanteric notch, arising from the anastomotic ring between medial and lateral femoral circumflex arteries.



H Transcervical femoral fracture Beware of nonaccidental trauma.



I Patterns of avascular necrosis (Ratliff) Injury to medial femoral circumflex (*green*) results in head and neck necrosis. Injury to the lateral epiphyseal artery (*blue*) kills the head. Injury to the ascending superior metaphysial vessels (*gray*) leads to cervical necrosis with preservation of the epiphysis.

Proximal Fracture

These are so rare that no surgeon has substantial experience (Blount). They are classified by the Delbet-Colonna system [G].

Physial

This Salter-Harris I type is most common in infancy and early childhood [H]. It has an association with nonaccidental trauma. The fracture is subtyped as A without or B with dislocation of the epiphysis, for example, hip dislocation followed by fracture during reduction leaving the epiphysis behind. Avascular necrosis is universal in B. Displaced fractures require open reduction *via* an anterior approach. Fix with smooth wires bent over lateral proximal metaphysial cortex, and supplement with a hip spica cast in the "human position" (*v.s.*). Follow closely with röntgenogrammes for wire migration and avascular necrosis.

Cervical

This occurs in older children. MRI delineates minimally displaced fractures. Displaced fractures require open reduction *via* an anterior approach. Fix with screws: there is enough proximal fragment to benefit from the stability of this implant, which may be removed once healed if placed across the physis to avoid growth disturbance or in the event of osteonecrosis. Given the grave consequences of such fractures, reduction and stability are more important than the physis.

Cervicotrochanteric

This is managed like cervical fracture.

Intertrochanteric

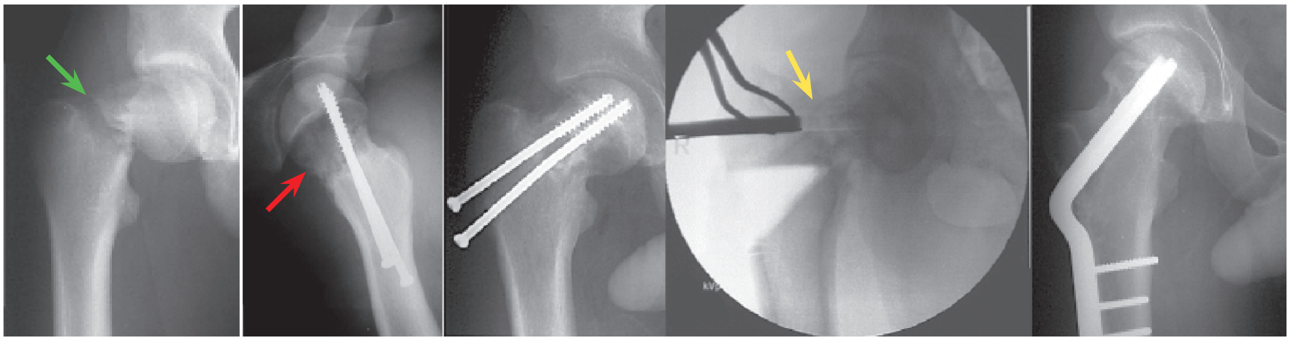
This is managed by a fixed angle device, including blade plate and cephalomedullary nail.

Complications

Complications distinguish this fracture due to tenuity of the blood supply to the proximal femur. Patterns of avascular necrosis have been classified geographically [I], mapping according to location of vessel injury. While trauma is the principal agent, the effect may be mitigated by accurate reduction for vessels that are occluded by displacement but not torn. This necessitates open treatment with direct visualization, which also decompresses intracapsular hæmatoma. The window for presentation of avascular necrosis is up to 2 years after injury.

Vascular insufficiency and instability, even with fixation, account for delayed or nonunion [J]. Malunion, typically coxa vara, has been associated with spica casting with incomplete reduction and with late displacement. Physial arrest may lead to abnormal growth of the proximal femur or limb-length discrepancy, which increases in significance with decreasing age. Late displacement may occur for fractures treated in a hip spica cast: follow closely with serial röntgenogrammes.

J Cervical nonunion Cervical fracture (*green*) was managed by closed reduction and two screw fixation. Cervical avascular necrosis (*red*) with preservation of the epiphysis resulted in nonunion (*yellow*), progressive collapse into coxa vara, and backing out of implants. This was treated by valgus osteotomy fixed with a blade plate. The neck was grafted through the osteotomy with autogenous bone graft obtained from the wedge exsected to put the proximal femur into valgus and thereby move the fracture from shear to compression.



CLAVICLE

Clavicle fractures may occur through bone or through proximal or distal physis [A].

Physial Fracture

This presents in the first decade; the second decade ushers in clavicular dislocation, which may be differentiated by ultrasonogramme or MRI. Physial fractures remodel well due to the intact periosteal sleeve that is in continuity between bone and physis. Coracoclavicular and acromioclavicular ligaments remain intact. Manage with a shoulder sling until nontender and the patient is able to raise the upper limb above the horizon.

Diaphysial Fracture

These may be divided into birth or other trauma. The neonate may present with pseudoparalysis. This may be distinguished from brachial plexopathy by presence of a Moro reflex, which the child will manifest despite pain of fracture. Most common mechanism is a direct blow during a fall. The patient presents with tenderness, inability to lift the upper limb, swelling, and often visible deformity of this subcutaneous bone.

Röntgenogrammes are sufficient to show the fracture. Thirty- to 40-degree cephalic tilt of the X-ray beam isolates the clavicle from the thorax. Distinguish pseudarthrosis of the clavicle (*cf.* Upper Limb chapter). Consider MRI if there is neurovascular compromise.

Closed management consists of a shoulder sling: the bone heals and remodels well. The absolute indication for operative treatment is injury to the surrounding soft tissues, which may be real in an open fracture or impending, as evidenced by blanching of the skin. Make a direct approach *via* an inferior incision along the long axis of clavicle, protecting rami of the supraclavicular nerve. A plate is the implant of choice, which may require removal for prominence if applied dorsal.

A relative indication extrapolated from the adult experience is shortening >2 cm, which is associated with muscle weakness. This may serve as a guideline for the adolescent. The benefit of operative treatment in adults rests in the prevention of nonunion, which is the dominant predictor of functional outcome. The number needed to treat to avoid nonunion is high (>5). Nonunion and malunion are not significant concerns in a child. These, along with earlier return to activity but no long-term difference in activity level, must be balanced by implant removal and postoperative infection.

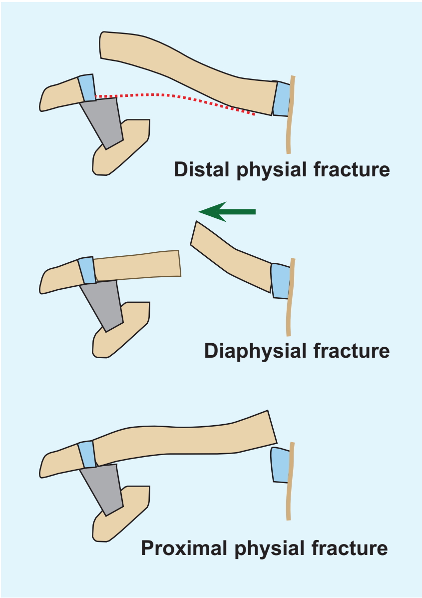
HUMERUS

Proximal Fracture

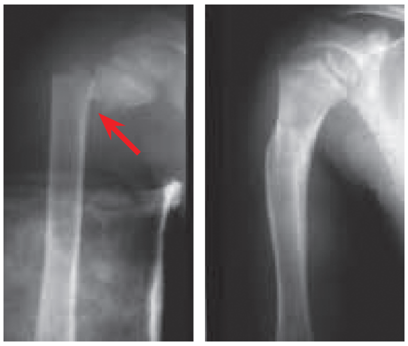
Like clavicle fracture, proximal humerus fractures may be divided into birth or other trauma. Remodeling is excellent due to the highest differential in growth of the proximal physis (80%) and accommodation of the enarthrodial adjacent joint [A]. Even though the head is supplied primarily by the anterolateral ascending branch of the anterior circumflex artery, avascular necrosis is not the concern for the proximal femur.

Evaluation The neonate may present with pseudoparalysis. The older child presents with tenderness, without or with a palpable anterior apex, and with the arm rotated medialward to relax tension in the pectoralis major against the distal fragment.

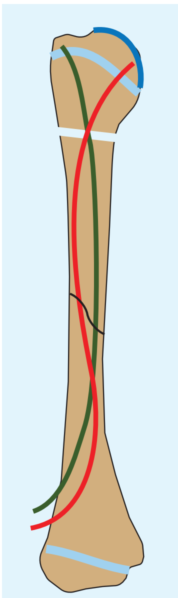
Imaging Röntgenogrammes should include an axillary view. Most fractures are Salter-Harris I (neonate), Salter-Harris II (older child), or transmetaphysial at the surgical neck.



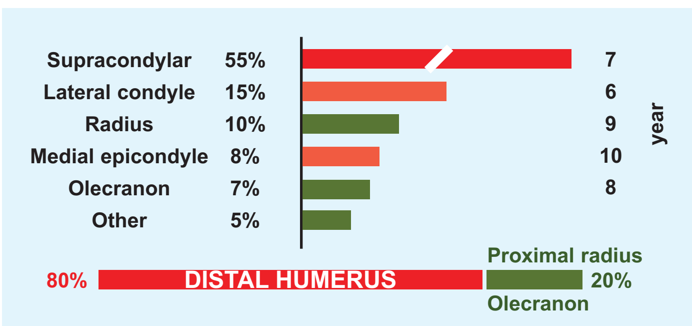
A Clavicle fracture types These may be physial: the bone escapes through the periosteum, which remains in continuity (*red*) to aid remodeling and healing. A diaphysial fracture may jeopardize the overlying skin (*green*).



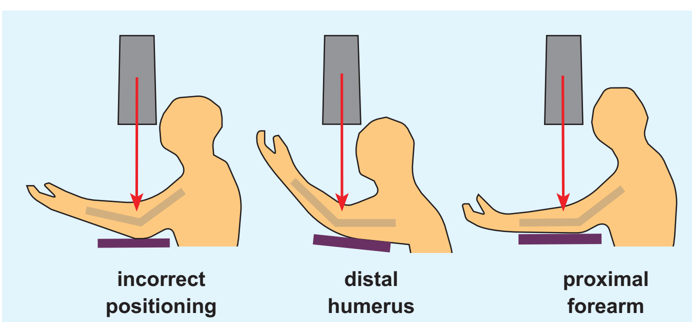
A Proximal humeral fracture The remodeling potential of the proximal humerus is excellent. This fracture was completely displaced and shortened in an 8-year-old girl. It had remodeled completely 2 years later.



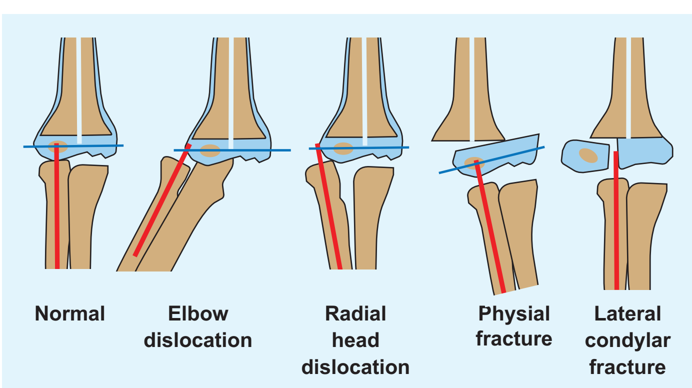
B Operative treatment of humerus diaphysis fracture Ender flexible medullary nailing may be performed retrograde through a small incision.



A Elbow fractures in children Frequency and mean age of presentation.



B Positioning for radiographs of the elbow Even though the elbow hurts, take time in positioning the upper limb to obtain orthogonal, focused, and specific views to best see a fracture.



Management The proximal humerus can be expected to remodel ≤90 degrees in the first decade. As a result, most fractures are managed by a shoulder sling**.** In the second decade, acceptable angulation declines to 45 degrees at 2 years of growth remaining. Reduction is best in the operating room, where the patient is most effectively relaxed, imaging is best, and stability may be determined. Reduction may be hindered by buttonholing of the metaphysis into the deltoid or interposition of the biceps tendon between fracture fragments.

Indications for operative fixation include open fracture, neurovascular compromise, and unacceptable or unstable reduction. For unstable reduction, percutaneous wires may be placed retrograde without or with antegrade fixation through the greater tubercle. For the other indications, use a deltopectoral approach for complete access, followed by wire or screw fixation. Forgo anatomic reduction—this will heal and remodel well—for less dissection.

Diaphysial Fracture

These may be associated with injury to the radial nerve (Holstein-Lewis), which is tethered as it pierces the lateral intermuscular septum traveling anterior to gain access to the surface of brachialis muscle.

Most fractures may be managed closed with a hanging arm cast or a functional brace. Acceptable displacement is ≤30 degrees angulation and bayonet apposition ≤ 2 cm. For fractures with neurovascular compromise, or unacceptable or unstable reduction, operative treatment is indicated. If the radial nerve is explored, the fracture may be plated. Alternatively, flexible medullary nails may be placed retrograde through a lateral approach, using an entry site posterior to the ridge where the implants may lie under cover of triceps with less prominence [B].

ELBOW

Pædiatric elbow fractures are common, complex, and often complicated [A]. Eighty percent occur at the distal humerus, 20% affecting the proximal radius and olecranon.

Evaluation

Fall from a play structure is the most common mechanism. The patient complains of elbow pain. Swelling may be diffuse, for example, supracondylar fracture, or unilateral, for example, lateral condyle fracture. The elbow may be well aligned or deformed. The skin may be unaffected, ecchymotic, puckered, or breached. Compartments may be soft, firm, or tense. Pulses may be normal, reduced, or absent. The hand may be warm and pink with brisk capillary refill or cool and blanched or blue. Neural function may be normal or compromised: because this requires cooperation of a child in pain and who is frightened, the examination may be inconclusive. There may be concomitant injuries, such as of wrist in addition to elbow.

Imaging

Order specific tests and specific views for specific problems.

Röntgenogramme This is the mainstay for imaging elbow fractures [B]. Obtain anteroposterior and lateral views of the distal humerus (not elbow) for supracondylar fracture. A radiocapitular view isolates head and neck of radius relative to capitulum, for fracture and dislocation. Medial oblique view may reveal a fracture of the lateral condyle of humerus invisible on anteroposterior and lateral projections.

In addition to the bone, look at the soft tissues, for example, sail sign of occult fracture. In addition to individual bones, look at the relationships between them [C].

Röntgenogramme assesses ossification of the distal humerus, which follows a predictable sequence [D]. Variant ossification may simulate fracture. Absent ossification may conceal fracture.

C Radiographic alignment of elbow In the normal state, radius points to capitulum in every position and view, ulna is centered under humerus, and radius and ulna move together.

Arthrogramme This outlines the unossified cartilaginous distal humerus that surrounds the ossification centers. It distinguishes a physial fracture from elbow dislocation. It shows the articular surface for fractures that extend into the joint, for example, lateral condyle fracture. It permits a dynamic examination of the elbow, for example, for radial head instability.

Ultrasonogramme This noninvasive, rapid, nonradiating, and nonstressful modality can detect an elbow effusion, including a lipohæmarthrosis elevating the posterior fat pad; soft tissue injury, for example, collateral ligament tear; and abnormal relationship of osseous landmarks, for example, increased radiocapitular distance in nursemaid's elbow.

Other MRI, CT, and scintigramme have indications that follow general principles, for example, MRI for soft tissue injury such as ligament tear or osteochondritis dissecans lesion.

Anatomy

A condyle is a rounded paired end of a long bone that is articular. In the distal humerus, the lateral condyle is called "capitulum," the medial "trochlea." Nonarticular apophysis positioned "on top of" (Greek επι−) each condyle are the medial and lateral epicondyles, which serve as sites of attachment for the flexor pronator mass and the mobile wad, respectively, as well as the collateral ligaments.

The vascular supply to the distal humerus is tenuous [E]. Lack of distal anastomoses and dependence of capitulum on one terminal branch and trochlea on two terminal branches of the brachial artery makes these osseous structures vulnerable to delayed union or nonunion or avascular necrosis after fracture.

The capitulum is flexed 40 degrees relative to the shaft of the humerus. A line drawn along the anterior surface of humerus bisects the capitulum. The physis of capitulum subtends a mean angle of 72 degrees (range 64 to 81 degrees) relative to the longitudinal axis of humerus (Baumann angle). The distal humerus is thinned in the sagittal plane to receive the olecranon into a fossa. This forms on lateral projection röntgenogramme an "hourglass," of which the humeral diaphysis forms the upper chamber and the trochlea forms the lower chamber. The tenuity of the olecranon fossa makes reduction and its maintenance difficult, akin to balancing two playing cards on edge.

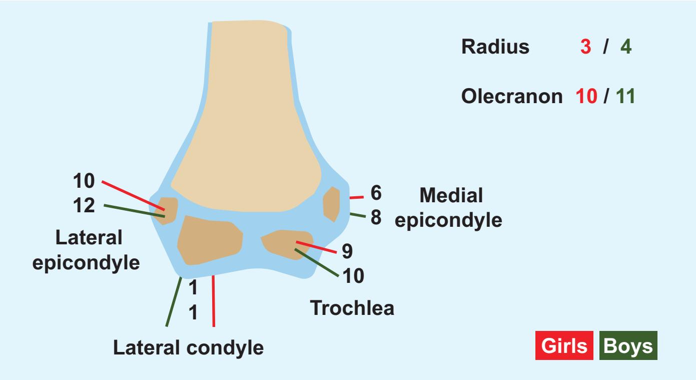
The carrying angle (10 to 15 degrees, greater in girls than boys) is made up of the brachial angle, between long axis of humerus and transverse elbow axis, and the antebrachial angle, between long axis of ulna and transverse elbow axis.

Pulled Elbow

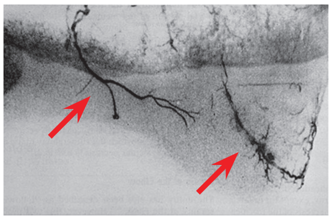
This may be produced when a nursemaid suddenly pulls a child by the arm away from danger [G]. Presentation is 1 to 5 years.

Evaluation Despite the name, half of cases have no history of a pull. Subluxation of radial head with interposition of annular ligament is sensed by the child as instability. The elbow is slightly flexed and the forearm is stuck in pronation. The child will not move the upper limb, even though play continues suggesting no pain at rest. There is no swelling or deformity. Röntgenogrammes screen for a fracture, and ultrasonogramme may show displacement of the radial head. Recurrence may occur in 15%: it correlates inversely with age but does not persist beyond the first decade.

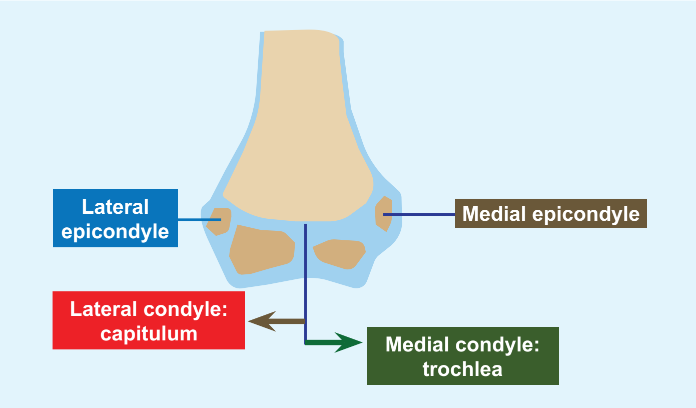
Management The presentation tends to be characteristic, such that a reduction manœuver may be attempted without imaging. The palpable click when the head of radius centers unencumbered against the capitulum is both therapeutic and confirmatory of the diagnosis. Reduce by forceful forearm supination, in which position the annular ligament is taut, thumb pressure on the anterior head of the radius, and elbow flexion, followed by repeated pronation and supination. Alternatively, start with hyperpronation to reproduce the mechanism of injury. In the absence of a click, observation for half an hour will show the child beginning to use the upper limb again. Teach a parent the manœuver for



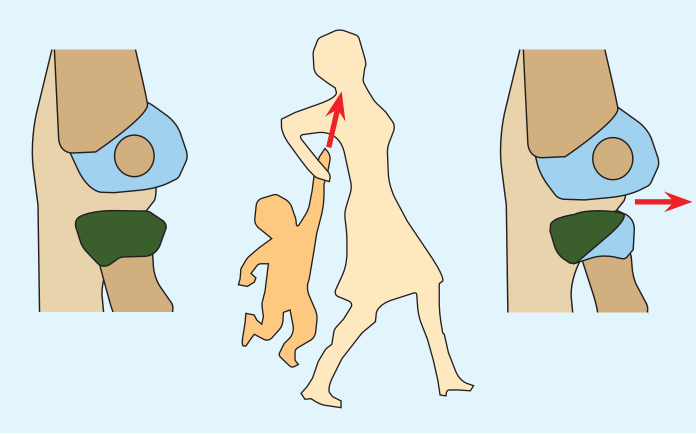
D Ossification of distal humerus Mean age (years) for girls and boys.



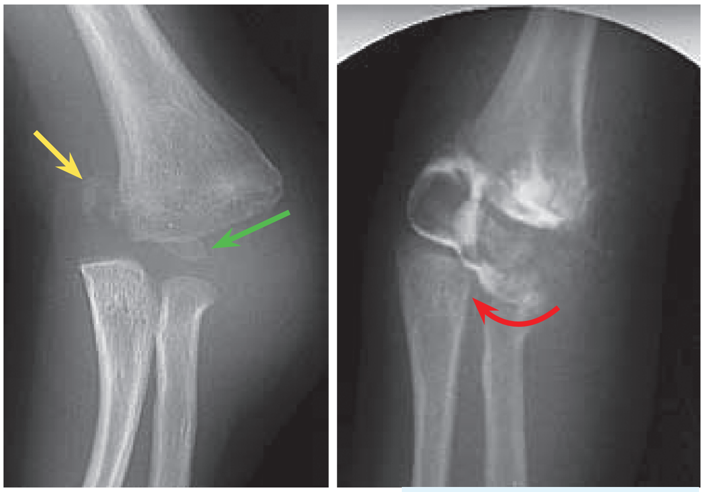
E Vascularity of distal humerus The trochlea is perfused by nonanastomotic end arterioles (*red*).

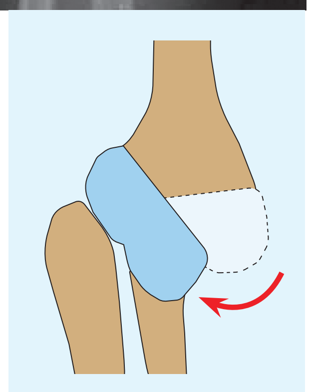


F Anatomic landmarks of the distal humerus The distal physis of humerus (*blue*) contributes to longitudinal growth and differs from the physis for the epicondylar apophysis.

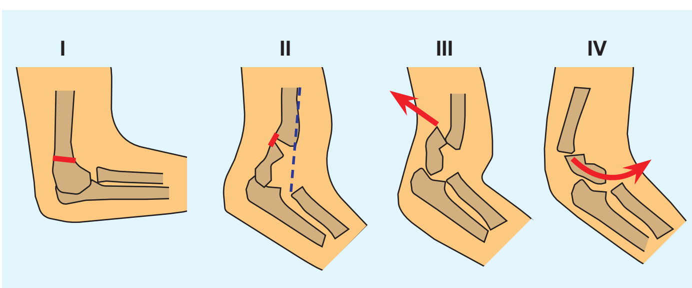


G Nursemaid's elbow Because of the eccentric shape of the radial head, the broadest part contacts the incisure on the ulna in supination, making this the most stable position for the proximal radioulnar articulation. In pronation, the annular ligament (*green*) is relaxed. With a pull on the elbow (*red*) with the forearm in pronation, the annular ligament slips in between capitulum and radial head, which subluxates to become partially uncovered.





H Distal physial separation Röntgenogrammes show malalignment of ulna–radius relative to humerus. Proximal radius is aligned with capitulum, which has moved from its normal location (*green*). Ulna is aligned with bone that represents healing around the trochlea (*yellow*). That radius and ulna are aligned with the bone of the distal humerus demonstrates that the elbow joint is not dislocated. Arthrogram (*red*) outlines the distal epiphysis of humerus, revealing the fracture.



I Classification of supracondylar humerus fractures (Gartland) I is non- or minimally displaced. II is displaced posterior to a line drawn along the anterior cortex of the distal humerus (*blue*), with intact posterior cortex. In III, the posterior cortex is disrupted as the distal fragment is displaced posterior to the humerus. Flexion of the distal fragment has been designated type IV. A designation of A indicates medial displacement, and B lateral.

J Cutaneous injury associated with supracondylar humerus fracture The proximal spike (*red*) tents and bruises and may perforate the antecubital skin. If closed reduction does not produce acceptable alignment, open reduction may be performed *via* an incision over the site of injury (*white*).

recurrent episodes. In uncertain cases, for example, after prior reduction attempts, place the patient in a sling and re-evaluate the next day. Consider MRI for persistent pain or lack of use.

Distal Humerus Physial Separation

This fracture occurs in children <7 years, after which it cedes to supracondylar fracture as the physis stabilizes by the formation of a V-shaped cleft between the condyles.

Evaluation It is associated with birth trauma and nonaccidental trauma. The child presents with pain, swelling, and pseudoparalysis. The wide physial surfaces limit deformity, in particular tilt, as compared with supracondylar fracture. Physical examination may reveal "muffled crepitus," as cartilage moves against cartilage. Röntgenogrammes show that the radius and capitulum (which appears at 1 year) are in line with each other, demonstrating that the elbow joint is not dislocated, but out of line from the remainder of the humerus, demonstrating that the elbow joint has shifted off the distal humerus. If röntgenogrammes are unclear, ultrasonogramme will show enough to decide management, without the need for sedation as would be required for MRI.

Management Cubitus varus is the most common complication of closed reduction and casting. Treat this like a supracondylar humerus fracture (*q.v.*). Perform an arthrogramme to ensure accurate visualization of the distal humerus, which will aid reduction and percutaneous wire fixation [H].

Supracondylar Humerus Fracture

This represents more than half of pædiatric elbow fractures. It is the most operated pædiatric fracture. Stress concentration as the distal metaphysis of humerus thins abruptly to the fossa of olecranon, which provides a fulcrum in the extended elbow of an outstretched upper limb planted to stop a fall, makes this site vulnerable to fracture.

Classification The fracture has been classified according to the direction and extent of sagittal displacement [I]. Extension types represent >95%. They are produced by a fall onto the outstretched upper limb, with the hand as the point of contact. Flexion type is produced by a fall onto the flexed elbow, with the olecranon as the point of contact. This is more unstable because the posterior soft tissue envelope, which acts as an internal tether for closed reduction, is disrupted to allow the distal fragment to flex and translate anteriorward. Of extension types, 2/3 are I, with equal distribution of the remainder among II and III.

Evaluation The elbow hurts, is swollen, and assumes a sinuous shape. In extension type, the antecubital skin may be bruised by the proximal spike, puckered when the proximal spike perforates the brachialis (indicating potential for difficult reduction), or breached [J]. The forearm compartments may be tense: pain with passive stretch may be difficult to assess in a child who is scared. Similarly, the child may not cooperate with motor and sensory testing of the hand: be patient and persist. It is essential to know the injury function, to ensure that no significant change occurred by operation. Are pulses palpable and comparable to the other side? Is the hand warm or cool, pink or dusky? Is capillary refill brisk, <2 seconds?

Imaging Röntgenogrammes classify the fracture. They also assess reduction and fixation. Measure Baumann angle, an indirect measure of carrying angle. Pay attention to the medial cortex: do not accept shortening or overlap, because this risks cubitus varus. Restoration of the hourglass indicates correction of rotation. A lateral of the distal fragment and an oblique of the proximal fragment, which present a widening fracture surface, represent malrotation. In fact, this is the intended appearance of osteotomy to correct cubitus varus (*v.i.*). Make sure every implant captures enough of both fragments.

Management Type I is treated with above-elbow cast. Types II and III are treated by closed reduction and wire fixation, within 24 hours of injury. The technique originated in adults (Swenson). Reduction consists of several components.

- "Milk" the limb. This may be accomplished manually or by a von Esmarch rubber bandage. It reduces swelling, which facilitates manipulation of the fracture. Be gentle over the proximal spike, where the brachial artery is draped and where this manœuver may add injury.
- Traction. Take time to overcome muscles in spasm. Include varus and valgus, to disengage any cortical overlap, and medial and lateral rotation of the distal fragment.
- Anterior and distalward force on olecranon. This is akin to reduction of a distal radius fracture.
- Flex the elbow to lock the reduction against the intact soft tissue envelope. This may blanch the hand. Pronate and supinate the forearm to fine-tune the final position. Do not be so zealous with this step that the posterior soft tissues are torn and now the fracture is a less stable type IV.

If reduction is unacceptable closed, open the fracture. Make an incision over the proximal spike, long enough to bluntly dissect free entrapped brachialis and other soft tissues [J]. Insert into the fracture an elevator that may be used as a shoehorn to translate the distal fragment anteriorward. At this point, the reduction may be completed closed. Medial and lateral incisions are indirect and may destabilize the fracture. A formal exploratory anterior incision carries risk in a traumatized and distorted elbow.

Fixation is percutaneous with smooth Kirschner wires of diameter appropriate for age [K]. These may be inserted lateral, through capitulum, or medial, through medial epicondyle. Iatrogenic injury to the ulnar nerve by medial wire may be mitigated by inserting this after lateral fixation in elbow extension to relax the ulnar nerve posteriorward and by making a small incision to reflect the ulnar nerve. Medial and lateral wires are biomechanically most stable. Lateral wires are stable enough, if the count equals the type, for example, three wires for a type III.

Flexion type fractures are treated by closed reduction and wire fixation. Reduction is gentle and variable according to instability of distal fragment.

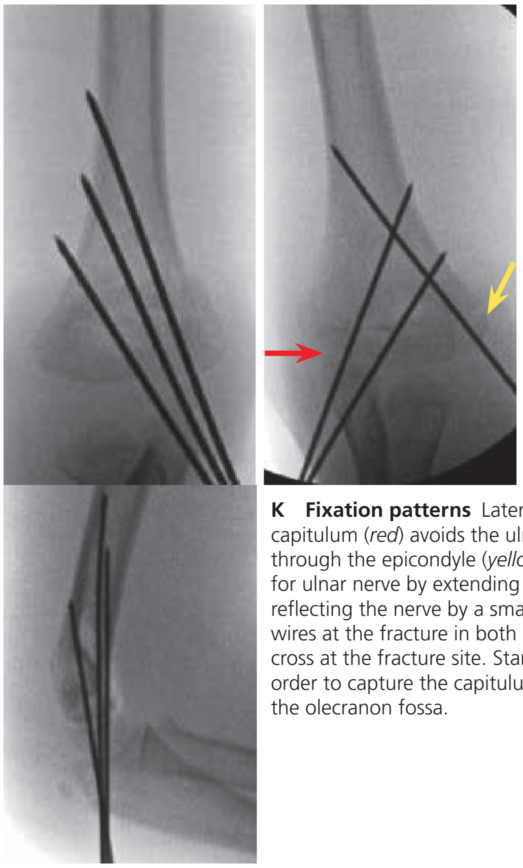
After operation, apply an above-elbow cast in 80 degrees of flexion. Increasing flexion increases risk of compartment syndrome. Bivalve the cast to allow for early swelling. Follow the patient within a week for röntgenogrammes and to overwrap the cast. Displacement is unlikely after 1 week, because this fracture heals rapidly. Remove wires and cast in the clinic at 3 to 4 weeks after operation.

Complications

NEURAPRAXIA This occurs in 10% to 15% of cases [L]. Nerves traversing the elbow are stretched and not cut by the fracture. When the distal fragment is displaced lateralward, the anterior interosseous nerve is tethered by the proximal spike. When displaced medialward, the radial nerve is draped over the spike. In flexion type, the ulnar nerve is injured as it travels posterior to the elbow.

Iatrogenic neurapraxia with medial wiring is 4%, > 90% ulnar. Iatrogenic neurapraxia of lateral-only wiring is 3%, half of the median nerve. Iatrogenic injury is understood by a medial wire to the ulnar nerve. Not clear are the contributions of reduction, including multiple attempts, and wire insertion, including multiple attempts and passage beyond the opposite cortex, all of which contribute regardless of insertion side.

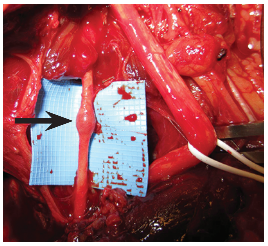
The majority of nerve injuries are apraxias. Recovery may be long and follows a pattern expected of wallerian degeneration: ulnar nerve is last to recover, with a window up to 8 months. Educate the patient and family, who may witness a claw hand before function returns. Consider electromyography and nerve conduction studies at 6 months: if there is no evidence of significant recovery, neurolysis is indicated. Act upon a change in nerve function after operation. Exploration is immediate and direct. Consider removal of a medial wire for ulnar deficit. Check röntgenogrammes for a fracture gap suggesting nerve entrapment. An early MRI neurogram may be performed after wire removal.



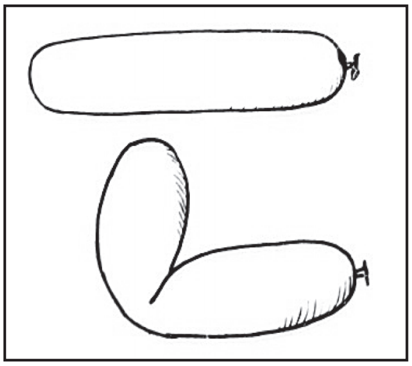
K Fixation patterns Lateral through capitulum (*red*) avoids the ulnar nerve. Medial through the epicondyle (*yellow*) is made safer for ulnar nerve by extending the elbow and reflecting the nerve by a small incision. Diverge wires at the fracture in both planes. Do not cross at the fracture site. Start wires anterior in order to capture the capitulum and the bone of the olecranon fossa.

AIN	Radial	Median	Ulnar	PIN	Multiple	Total
5.5	4.5	3.5	2	1	1.5	12.5

L Nerve injury % for extension type. AIN: anterior interosseous nerve. PIN: posterior interosseous nerve.

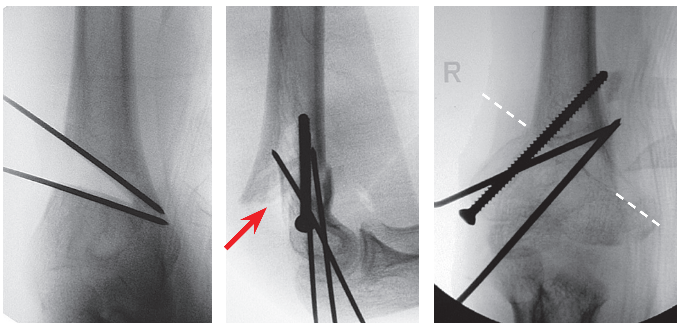


M Vascular injury The brachial artery was explored for a dysvascular hand after fixation. The median nerve is retracted. The artery, thinned by spasm, was occluded by a thrombus (black). The artery was grafted due to an associated intimal tear.

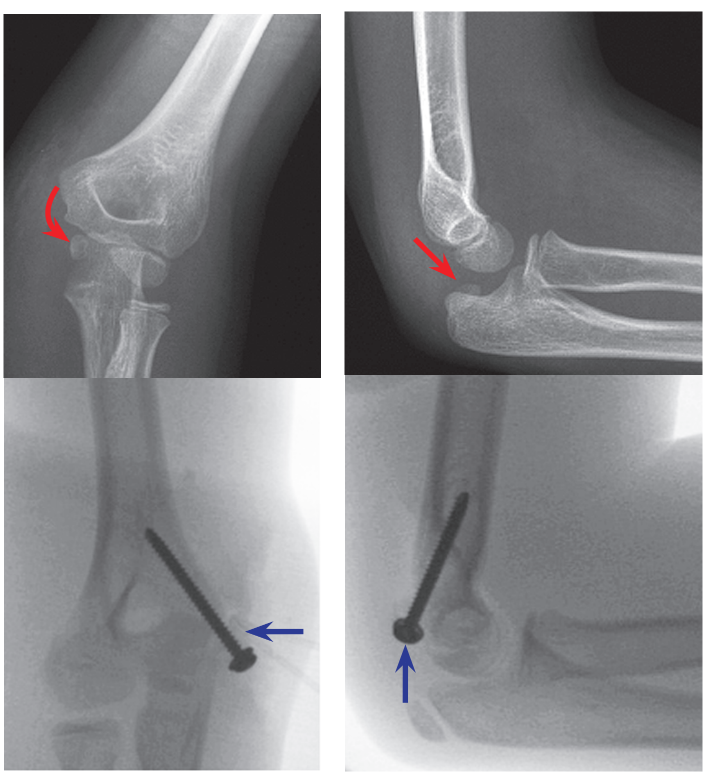


N Swollen limb Bleeding into the limb has been likened to a balloon (Charnley). It will be constricted at the elbow with flexion, which is associated with compartment syndrome if > 90 degrees.

O Remodeling in sagittal plane Remodeling is possible in the plane of elbow motion. The capitulum moves anteriorward to be crossed by the anterior humeral line over 3 years.



P Osteotomy for cubitus varus There are many techniques. By a lateral approach, a wedge is resected. Osteotomy is closed and the distal fragment is rotated lateralward (mismatch between proximal and distal fragments on lateral) to correct varus and medial rotation. Osteotomy is fixed with a screw, which is retained, supplemented with percutaneous wires. The most common complication is displacement, hence the screw or alternately use of a plate or external fixator.



Q ORIF of medial epicondyle fracture The epicondyle is incarcerated in a valgus elbow (*red*), leaving the donor site empty. It is reduced to its posterior location and fixed with a screw (*blue*).

Vasculopathy A change in circulation is noted in 5% of cases, most in type III, including reduction in temperature, reduced or absent pulse, change in cutaneous color, and slowed capillary refill. While bone and joint outcomes are unaffected by when the fracture is surgically treated within the first 24 hours, a dysvascular distal limb, characterized as cold, blanched, or dusky, with absent pulses and sluggish capillary refill, is an emergency.

Reduce and fix the fracture. If vascular status is normal, characterized by present pulses, observe. If the distal limb is dysvascular, explore the brachial artery and repair as indicated. There is no consensus on the pulseless limb (by Doppler), but well-perfused hand. Pulselessness may be regarded as an indication for vascular imaging or exploration of the brachial artery [M], which will show injury in more than half of cases. A well-perfused hand may be regarded as a sign of collateral flow that is sufficient until a brachial artery in spasm recovers or a thrombus recannulates, or even if the brachial artery remains occluded. The latter scenario cannot predict future vascular demand.

Less than 1% of cases are complicated by compartment syndrome. This has been related historically to closed reduction and casting in elbow flexion > 90 degrees [N]. This led to splinting in extension until swelling dissipated, followed by flexion for reduction while the fracture remains malleable (Egyptian method).

Malunion This may be hyperextension or cubitus varus. A goal of reduction is to position the distal fragment so that the capitulum is crossed but not necessarily bisected by the anterior humeral line. The strict criteria for reduction of this fracture, which is nonarticular, are related to the small differential of growth at the distal humerus (20%) and the ginglymoid nature of the elbow joint. If the distal fragment is posterior to the anterior humeral line, remodeling may improve alignment in the plane of joint motion. This is variable, increasing with decreasing age [O].

Lack of coronal plane remodeling results in cubitus varus, as the distal fragment tends to displace to shorten the medial column. Despite the name, which emphasizes the coronal deformity, varus is accompanied by medial rotation, such that the clinical deformity is striking, as both the elbow (varus) and the forearm (medial rotation) are affected. Indication for operative treatment is unacceptable appearance [P]. Evidence of dysfunction, including ulnar neuritis, is limited. Wire fixation alone is associated with osteotomy displacement.

Stiffness Loss of >5 degrees occurs in <5% of cases. One factor is heterotopic ossification, as an aberrant response to muscle injury, in particular brachialis. Heterotopic ossification may be excised once motion has plateaued.

Medial Epicondyle Fracture

This is an avulsion, under pull of medial collateral ligament following a valgus stress sustained by a fall onto the outstretched upper limb. Half are associated with elbow dislocation.

Evaluation Dislocation results in an elbow that is diffusely swollen with medial ecchymosis, a presentation that is out of proportion with avulsion of a small osseous fragment. There may be a history of chronic elbow pain due to overuse. There may be ulnar neurapraxia, from stretch, entanglement around the epicondyle, or entrapment in the joint.

Imaging When incarcerated, the fragment may be obscured on röntgenogrammes by overlap with the olecranon. In such a case, its absence from the normal site is a key sign.

Management Because the epicondyle is not articular and does not contribute to longitudinal growth of the humerus, significant displacement has been accepted historically. Apply an above-elbow cast with the forearm in pronation to relax the flexor–pronator mass. Mobilize the elbow early (3 weeks) because the global soft tissue injury to the joint will stiffen the elbow. Educate patient and family that recovery will be protracted, and consult a physiotherapist.

Absolute indication for intervention is incarceration in the joint of the epicondyle, which does not escape during spontaneous reduction [Q]. If the fragment cannot be extracted by a closed manœuver consisting of elbow valgus, forearm supination, and wrist and finger extension (Roberts), which reproduces the mechanism and tensions the flexor–pronator mass, open reduction is indicated.

Operation for displacement, and how much, is debatable. Controversy swirls around elbow instability rather than mal- or nonunion. This is akin to fracture of the intercondylar eminence of tibia, where associated laxity of the anterior cruciate ligament may have the greater impact on functional outcome. As a result of this recognition, in particular for the throwing athlete who will apply extreme valgus stress during cocking and swing (e.g., baseball pitcher), millimeter displacement beyond single digits is an indication for reduction and fixation. First find and decompress the ulnar nerve. Fix the fragment with a screw and washer, or with two wires and a nonabsorbable suture in a tension band construct. Mobilize early to avoid elbow stiffness. Because of the subcutaneous nature of the epicondyle, implant removal is not uncommon.

Lateral Condyle Fracture

This is a challenging fracture because it is articular, it is bathed in synovial fluid, and it depends upon a posterior terminal nonanastomosing branch of the brachial artery. These factors conspire to delay or prevent union and to create growth disturbance.

The fracture originally was classified according to exit at the articular surface (Milch). In type I, the fracture travels through the capitulum. In type II, the fracture emerges between capitulum and trochlea, thereby separating radiocapitular from ulnohumeral joints to produce an unstable elbow. This recognition is the principal contribution of this system. Alternatively, the fracture may be classified according to articular breach and displacement [R, S], which guide treatment. The mechanism of injury combines avulsion under varus stress with axial loading through radius.

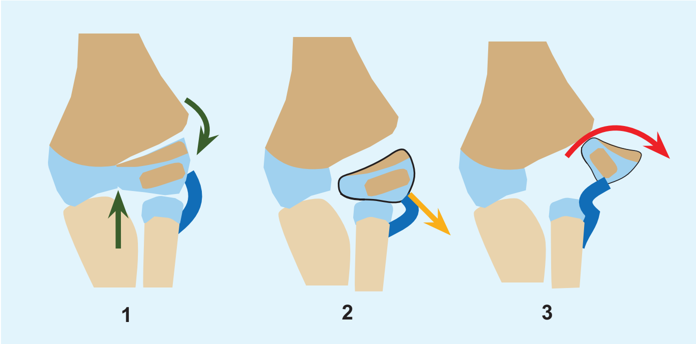
Evaluation The patient presents with pain, lateral swelling, ecchymosis, and crepitus without gross elbow deformity.

Imaging Röntgenogrammes are the standard. Oblique views, in particular medially directed, may expose a fracture invisible on standard anteroposterior projection. Operative arthrogram aids assessment of fracture type and reduction of articular surface.

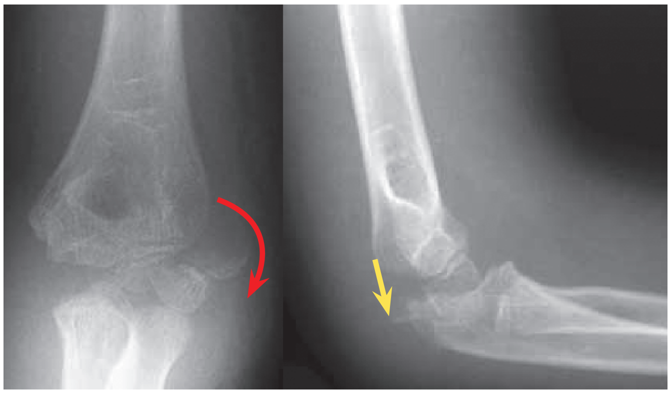
Management Less than 2 mm of diastasis of the metaphysis suggests an intact articular surface. This may be managed by above-elbow cast. Follow weekly with röntgenogrammes for late displacement.

For displacement > 2 mm, outline the articular surface with an arthrogram: if intact, fix with divergent percutaneous wires. If the articular surface is disrupted, and for widely displaced fractures, open reduction and internal fixation are indicated:

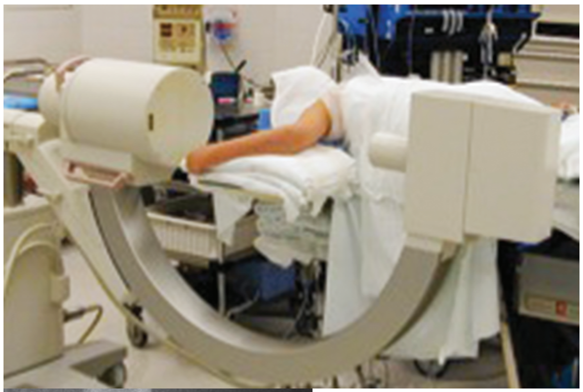
- Consider performing this in the prone position [T].
- Do not dissect the distal fragment, in particular posterior, where its tenuous blood supply enters. Excessive dissection for complete visualization risks osteonecrosis.
- Expose the anterior cortex of the proximal fragment and the anterior fracture edges.
- Clean the fracture to the trochlea.
- Reduce the distal fragment with a pointed tenaculum, applying medialward translation, flexion (the capitulum is flexed 40 degrees), and compression. Read the reduction anterior and lateral.
- Fix with divergent steel wires inserted percutaneously remote from incision. Bioabsorbable pins have been used for longer fixation without cutaneous exposure given that these fractures heal relatively slowly. A screw may be used if there is a large metaphysial fragment.
- Excise the lateral periosteum at the fracture to reduce lateral overgrowth and spur formation.

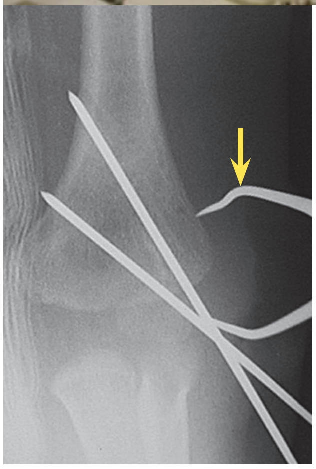


R Classification of lateral condylar fractures In type 1, the lateral condyle fragment hinges at an intact articular surface, opening at the metaphysis. This may be treated closed. In type 2, the fragment is completely separated and translated but not rotated (*orange*). In type 3, the fragment is widely rotated (*red*).



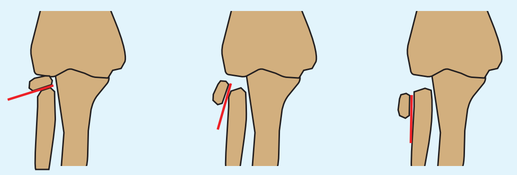
S Lateral condyle of humerus fracture The fracture passes through the capitulum (Milch I). The fragment is widely rotated (*red*) and displaced (*yellow*), making this a type III.





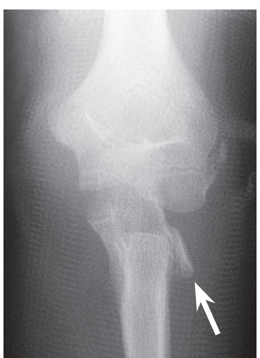
T Operative treatment of lateral condyle of humerus fracture The patient is prone. The limb does not move, and the elbow has a constant valgus force that supports reduction. The image intensifier may be rotated (*red*) to obtain anteroposterior and lateral images without disturbing limb or reduction. The fracture was reduced by a pointed tenaculum (*yellow*), which holds the fracture while two divergent wires are inserted percutaneously remote from the surgical incision.

U Growth disturbance Fishtail deformity (*red*) represents focal osteonecrosis from injury to the lateral trochlear vessel. Distortion of the distal articular surface of humerus limits motion.

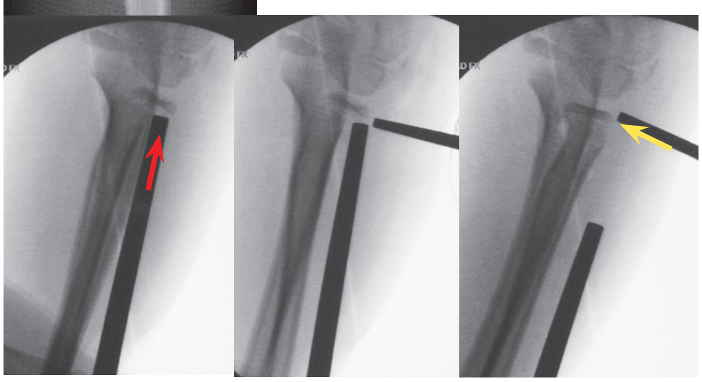


1	2	3
Translation (%)		
<50	50–100	>100
Angulation (degrees)		
0–30	31–60	61–90

V Classification of proximal radius fractures The two components of displacement are translation and angulation.



W Indirect reduction of type III fracture Pronate the forearm. Make a small incision distally at middorsum. Bluntly dissect along the fractured radial shaft. Use a long thin tamp with a mallet to elevate the fragment out of angulation (*red*). For correction of translation, make a small incision at the level of fracture and spread bluntly under the supinator with the forearm pronated to avoid injury to the posterior interosseous nerve. Tamp the fragment medialward to center it under the capitulum (*yellow*).



Medial Condyle Fracture

This represents <1% of elbow fractures in children. The approach to this resembles lateral condyle fracture. The following are distinctive features:

- The medial condyle fracture may be missed on röntgenogramme, due to the relatively late appearance of its ossification center, hence its inclusion in TRASH: The Radiological Appearance Seemed Harmless. Normal appearance of medial epicondyle when a medial fracture is suspected clinically is an indication for MRI of the elbow.
- Two independent branches of brachial artery supply the trochlea. Injury to the lateral ramus may lead to osteonecrosis of the lateral aspect of the trochlea, producing a fishtail deformity of the distal humerus [U].

Proximal Radius Fracture

More than 90% of proximal radius fractures are transmetaphysial (neck) or involve the proximal physis (Salter-Harris II, or I). Radial head fracture is rare in a child. The radiocapitular joint stabilizes the elbow against valgus stress and provides longitudinal stability of the forearm and wrist during grip. Like condylar fractures, articular location slows union. Like medial epicondyle fractures, proximal radius fractures stiffen the elbow. Delay of open treatment > 48 hours increases the likelihood of stiffness.

Evaluation Pain is localized at the proximal radius and exacerbated by supination. There is associated swelling but no gross deformity of the elbow. The patient may complain of referred wrist pain.

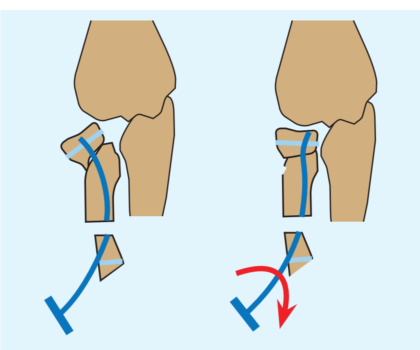
Imaging Radiocapitular view (45 degrees oblique with elbow flexed at 90 degrees) röntgenogramme isolates capitulum and proximal radius away from overlap by trochlea and ulna, respectively. Angulation may be easier to measure, but translation may be more important due to the cam effect of the proximal radius on ulna [V].

Management Apply an above-elbow cast for type 1 for 3 weeks.

Type 2 and 3 fractures are indications for operative treatment. Start with manipulation under anæsthesia, where the child is fully relaxed and imaging is good. Apply thumb pressure on the radial head with the elbow flexed at 90 degrees, with a varus force to open the radiocapitular joint and while repeatedly pronating and supinating the forearm. With pronation, advance the thumb, so that it blocks the radial head during supination.

Open treatment may be indirect or direct. Indirect approach *via* a small incision may reduce stiffness [W]. A flexible medullary nail inserted retrograde may hook the proximal fragment, reducing it by rotation of the nail [X]. A wire may be inserted into and in the plane of the fracture, after which it may be levered to elevate the proximal fragment and correct angulation, akin to the Sauve-Kapandji technique for the distal radius. For fractures irreducible by indirect methods, open reduction is performed *via* a Kocher approach.

This is an example where open reduction of a fracture need not be followed automatically by internal fixation. The fovea of radius stabilizes the fragment against the capitulum. Move the elbow and forearm to make sure the reduction is stable: if not, then fix it with 1 to 2 wires.



X Indirect reduction of type III fracture A flexible medullary nail (*blue*) is introduced retrograde across fracture into proximal fragment, which is reduced by rotation of the nail (*red*).

Olecranon Fracture

A unique feature of olecranon fracture in a child is apophysial avulsion in type I osteogenesis imperfecta. This occurs at a younger age and may be bilateral. Because of reduced bone quality, treat with a tension band construct that uses long medullary wires, which are more stable due to bending and internal cortical contact.

Evaluation Pain is localized over the olecranon. Make sure that there is no pain over radial head and that forearm supination is supple, to rule out a Monteggia fracture (*v.i.*). There is associated swelling but no gross deformity of the elbow.

Imaging Röntgenogrammes demonstrate articular extension, displacement, and comminution. CT is indicated to evaluate a fractured articular surface.

Management Displacement <2 mm may be managed in an above-elbow cast in 30 degrees of flexion, to relax the triceps brachii.

Surgical treatment is indicated for articular displacement >2 mm. Most pædiatric olecranon fractures are uncomminuted and can be effectively fixed with a tension band construct, using a nonabsorbable suture rather than wire.

FOREARM

Monteggia Fracture

Force applied to the forearm results in osseous failure of the ulna with ligamentous failure of the radius, including annular and quadrate ligaments. This may be missed in a young child before ossification of the proximal epiphysis of radius or when focus on an ulna fracture distracts from injury at the elbow.

Evaluation There is pain over ulna fracture and radiocapitular articulation, where head of radius may produce a fullness or may be palpable. There may be a posterior interosseous nerve deficit due to traction by the displaced radial head in the supinator.

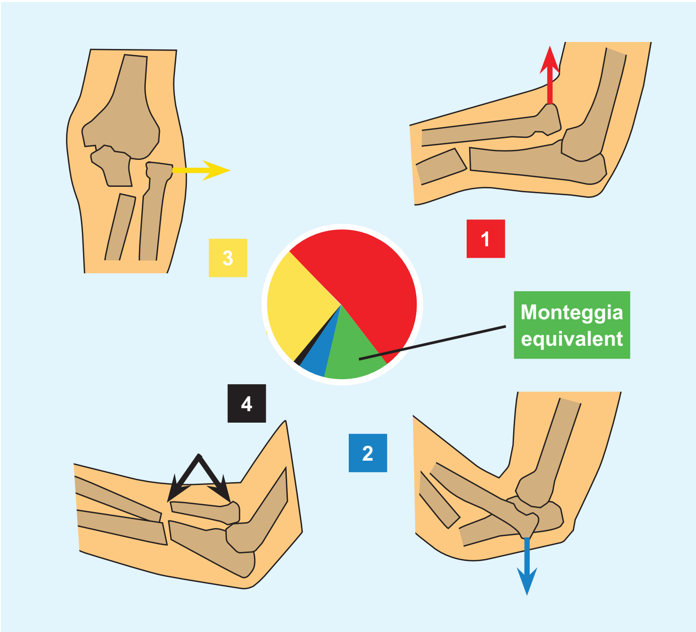
The fracture has been classified by Bado [A, B].

Imaging Röntgenogrammes may show fracture or plastic deformation of the ulna, with the apex into the interosseous space toward the radius. On lateral projection, ulnar border is normally straight: beware of an anterior convexity. Obtain dedicated elbow images, including radiocapitular view. CT and MRI may be necessary to confirm complete reduction of head of radius because its ossification center is small.

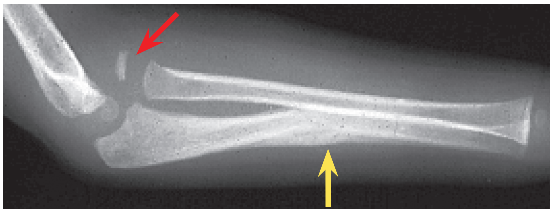
Management Even though the fracture is classified according to direction of radial head dislocation, and disability is related to radial head dislocation, the ulna fracture guides treatment.

- Plastic deformation or greenstick fracture of ulna. Perform a closed reduction, which both straightens ulna and reduces radial head. Follow with weekly röntgenogrammes to rule out late displacement.
- If closed reduction does not stabilize the radial head, and for complete fracture of ulna, which may drift despite reduction and result in late dislocation of radial head, place a percutaneous medullary wire into the ulna, which as it straightens and lengthens allows closed reduction of radial head. Use the largest diameter to engage isthmus because length is as important as alignment. Perform an arthrogram and put the elbow and forearm through full range of motion to make sure head of radius is anatomically located and stable.
- Comminuted or otherwise length-unstable ulna fracture. Open reduction and plate fixation of the ulna to restore length are necessary for a stable reduction of radial head.

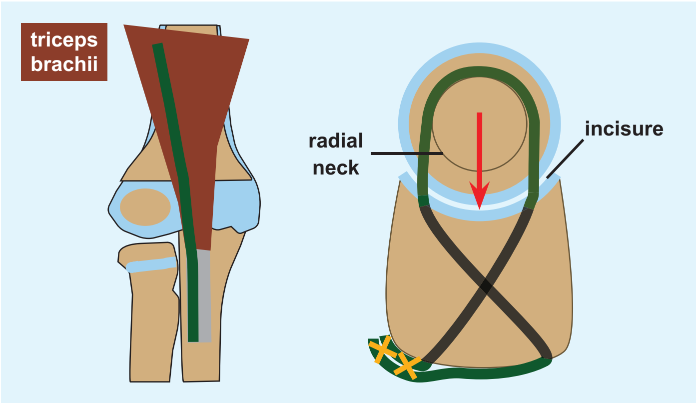
For chronic presentation, defined as >3 months, consider reconstruction [C]. Anterior dislocation of radial head may hurt and limit motion of the elbow. Despite this, children are undeterred, which, together with variable results after late reconstruction, argue for observation. Balance this with deformation of proximal radius, elbow instability, and degenerative arthritis in the adult, which may be more persuasive.



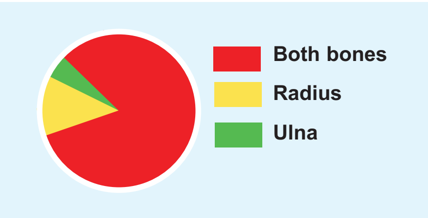
A Classification and distribution of Monteggia fracture The first three types are distinguished by direction of radial head dislocation. Type 4 includes fracture of both bones, in addition to radial head dislocation.



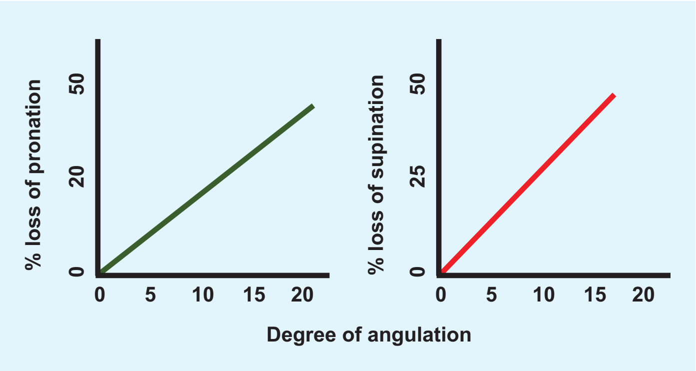
B Monteggia equivalent Bado recognized a further category of equivalent lesions. There is a fracture through the proximal physis of radius. The anterior apex of ulna fracture dislocated the head of radius at time of injury.



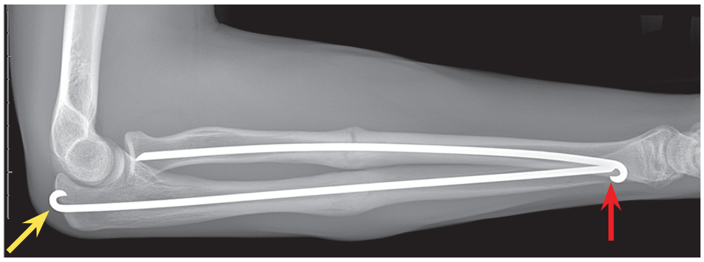
C Reconstruction of chronic Monteggia fracture Prerequisite is no dysplasia of the radial head. An extended Kocher incision allows access to triceps aponeurosis and proximal ulna for osteotomy. Position the patient prone with forearm supinated, and stay under supinator, in order to avoid posterior interosseous nerve. Open the radiocapitular joint and remove obstacles to reduction, including the torn and degenerated annular ligament. Cut the ulna and allow it to lengthen and realign with an apex dorsal bow. Drill two tunnels (*gray*) through the ulna to emerge on either side of radial incisure. Weave a slip of triceps aponeurosis (*green*), left attached at its distal insertion, through the tunnels around the neck of radius. Tension the reconstructed ligament while pronating and supinating the forearm, sewing free end of aponeurosis to insertion (*orange*). Fix the ulna with a plate in the position that achieves a radial head relocation without pressure. Tunnel architecture results in a net force (*red*) that is centered in incisure.



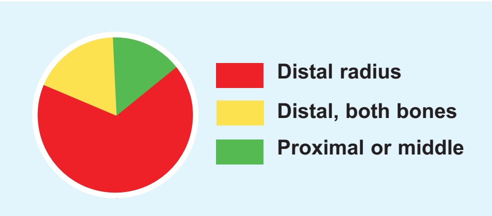
D Distribution of diaphysial fractures Most involve both bones.



E Loss of motion with angulation of both bones of forearm 10 degrees of residual angulation in the midforearm produces a loss of rotation that approaches 20% of pronation (*green*) and 25% of supination (*red*). Due to its steeper curve, 40% of supination is lost by 15 degrees.



F Medullary nailing of both bone forearm fractures Rush rods are the original and continue to be effective. Their hooked ends may be sunk into olecranon (*yellow*) in a mature adolescent and lay flush at the radial entry site (*red*) to reduce prominence. The beveled end allows nails to glance off the opposite cortex. Retract the dorsal tendons of the distal forearm to protect them from the sharp edge at the tip of the nails. Steinmann pins are versatile, in particular for younger children. Bend their tip slightly to create a bevel and to aid traversal of the fracture. Bend the other end into a hook, which can engage the entry sites less prominently and which facilitates extraction if necessary.



G Distribution of forearm fractures Distal radius predominates.

Type	Displacement	Comment
Epiphysial	<50% translation	
Metaphysial	≤ 30 degrees in 1st decade ≤ 20 degrees in 2nd decade Bayonet apposition in 1st decade	0.9 degrees/ month sagittal 0.8 degrees / month coronal

H Acceptable displacement in distal radius fractures Remodeling of distal radius is excellent given 75% growth at this end of the bone. Up to 10 degrees of angulation produces no dysfunction in the adult. For metaphysial fractures, remodeling approaches 1 degree/month and is reliable up to 20 degrees, variable between 20 and 30 degrees.

Both Bone Fracture

Forearm fractures behave like intra-articular fractures: malunion restricts movement in the transverse plane. Most involve both bones [D]. The mechanism of injury is a fall onto an outstretched upper limb, planting of the hand, and supination of the distal forearm to produce an apex volar deformity or pronation of the distal forearm to produce an apex dorsal deformity.

Evaluation The forearm is deformed and swollen. Check the skin for breach. Rule out compartment syndrome. Examine the entire upper limb for another fracture, for example, supracondylar humerus fracture producing a "floating elbow."

Imaging Röntgenogrammes show the following:

- Which bone is fractured
- Apex and degree of deformity
- Level of fracture—proximal, middle, and distal
- Fracture pattern—plastic deformation, greenstick, complete, and comminuted
- The bicipital tuberosity, which is the landmark for determining rotation. It is seen *en profil* medial at 90 degrees of supination and lateral at 90 degrees of pronation. In neutral, it is overlapped by the radius.

Management For uncomplicated fractures, including no significant cutaneous breach and no compartment syndrome, closed reduction is the initial approach. The manœuver that distinguishes both bone forearm fracture reduction is rotation: two bones are being reduced simultaneously, and the mechanism of injury includes rotation. The direction of rotation of the distal forearm may be determined by the adage, "Turn the thumb toward the apex." Position the forearm in cast to counteract deforming forces on the distal elements. Supinate for proximal fractures in response to the action of supinator on the proximal fragment and pronator on the distal fragments. Harness the interosseous membrane when molding the cast to have the shortest anteroposterior diameter.

Acceptable residual angulation is determined by age, level of fracture, and anticipated loss of forearm rotation [E]. Residual angulation of 15 degrees leads to 25% loss of pronation. Supination is more sensitive, with 25% loss occurring at 10 degrees. As a result, a guideline is ≤20 degrees in the first decade, relying on remodeling for partial correction, which declines to 10 degrees in the adolescent. Bayonet apposition is acceptable in the first decade.

Operation is indicated for complicated fractures, unacceptable or unstable reduction, concomitant fractures, and refracture, which occur in 5% of cases. Flexible medullary nailing may be performed closed *via* entry points proximal to Lister tubercle after retraction of extensor pollicis longus and under anconeus to avoid proximal physis of ulna [F]. If closed reduction is difficult, open the fracture sites (dissected by the trauma) enough to admit tenacula safely. In the first-decade child, nailing of a single bone, often the ulna because it is easier, may be sufficient if the other bone is reduced thereby to an acceptable angle. In such a case, the nail acts as an internal splint for the uninstrumented bone. Plate fixation is indicated for comminuted fractures. Plates are more stable but require formal, more extensive dissection. In the first-decade child, potential for bone overgrowth is an indication for plate removal, which is not uncomplicated.

Distal Radius Fracture

This is the most common fracture in children [G]. Mechanism is a fall onto the outstretched upper limb. Greater than 95% are apex volar, as the child lands on the palm of the hand. This fracture may be transmetaphysial, torus or complete, or a Salter-Harris type. The type II metaphysial fragment is the original "Holland" fragment, after the first published röntgenogramme by the English radiologist Charles Thurston Holland (1863–1941).

Evaluation There is sinusoid deformation of the wrist associated with swelling. Examine the volar wrist, for example, for tense ecchymosis, and rule out carpal tunnel syndrome.

Imaging Röntgenogrammes show the following:

- Fracture type
- Apex and amount of deformity

Management Because outcomes for torus fracture are predictably good, apply a below-elbow cast or splint and modify activity. In the distal radius, displacement may be divided into epiphysial and metaphysial [H]. For Salter-Harris III or IV fractures, >2-mm displacement is unacceptable at the articular surface.

For uncomplicated fractures, including no carpal tunnel syndrome, that are displaced significantly, closed reduction is the initial approach:

- Apply traction. This may be prolonged before reduction to take advantage of viscoelasticity by hanging the limb by finger traps.
- Reproduce the mechanism of injury to aid unlocking fragments.
- Translation. This is distal followed by anterior. Do not flex the wrist to achieve the latter, because this will reduce the volume and compress the contents of the carpal tunnel.
- Apply an ulnar force to counteract with supination to relax the brachioradialis, which is a major deformer and which accounts for late displacement in cast [I].

Abide by the adage, "One reduction by one surgeon" (Blount), for physial fractures, in order not to add to the risk of growth disturbance. Follow with röntgenogrammes because displacement occurs during the first 2 weeks in 5% of cases.

Indications for operation are as follows:

- Complicated fractures, for example, requiring carpal tunnel release, in order to avoid late displacement requiring repeat intervention
- Multiple fractures, for example, ipsilateral supracondylar humerus fracture
- Unacceptable or unstable reduction, for example, drift in cast

Fix with 1 to 2 percutaneous transphysial wires passed retrograde through the styloid process of radius [J]. Bluntly dissect the soft tissues in this region, where rami of the superficial radial nerve course on their way to the dorsal hand.

Galeazzi Fracture

This represents fracture of the radius with disruption of the radioulnar joint. In children, soft tissue integrity leads to physial variants [K]. Unlike Monteggia fracture, this is rare in children compared with adults, peaking during adolescence. The radius fracture may be apex volar with volar displacement of the ulna, which is produced by a supination force on the forearm. Alternatively, a pronation force results in an apex dorsal radius fracture with dorsal displacement of the ulna.

These are managed closed in most children. Indications for operation are unstable or irreducible distal ulna and unacceptable angulation of the radius. Plate the radius and cross pin the ulna.

WRIST AND HAND

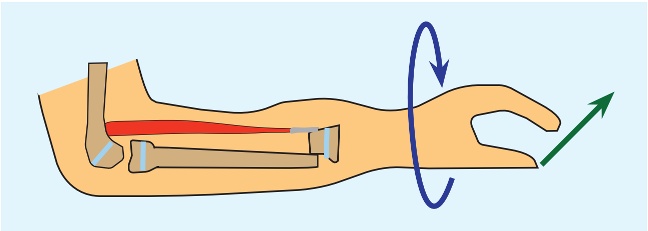
Half of hand injuries have an osseous component. Incidence is bimodal: a peak occurs at preschool, consisting of a crush mechanism where soft tissue injury predominates, for example, a closing door, while a larger peak is seen in the second decade, when sports lead to fractures [L].

Scaphoid Fracture

While carpal fractures are rare in children, the scaphoid is most frequently broken. Peak incidence is in the teenage years. Because they are rare, scaphoid fractures may be missed in children.

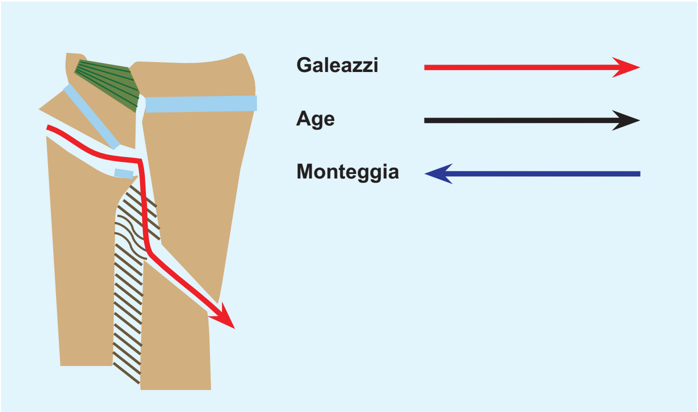
Evaluation There is guarded wrist motion. Tenderness at the volar distal pole is more reliable than in the anatomic snuffbox, which may be uncomfortable in the normal state.

Imaging Include an oblique scaphoid view röntgenogramme [M]. If röntgenogrammes are negative, consider scintigramme for detection



I Deforming force of brachioradialis To counteract brachioradialis (*red*) during reduction, apply an ulnar force to (*green*) and supinate (*blue*) the distal fragment.

J Fixation of distal radius fracture A wire is passed percutaneously retrograde through styloid process of radius.

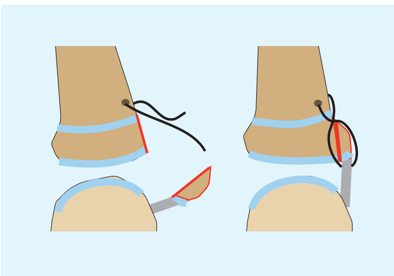


K Galeazzi equivalent Salter-Harris II of distal ulna with metaphysis of radius (*red*) The distal radioulnar joint and triangular fibrocartilaginous complex (*green*) that stabilizes it remain intact. The force parallels the direction of the fibers of the interosseous membrane (*brown*). Galeazzi fracture has been described as a reverse Monteggia fracture, based upon both the characteristics of the injury and the age of presentation.

Part	Most injured
Rays	Border
Digit	Smallest finger
Thumb	In adolescents
Phalanx	Proximal
	Base
Metacarpal	5th
	Shaft

L Distribution of hand fractures The smallest finger is most exposed and most injured.

M Scaphoid fracture This is treated according to general principles.



N Fixation of hand fractures Most are pinned. Large fragments may be fixed with screws. For small but critical fragments, tension band construct takes advantage of stout surrounding soft tissues, which are restored in the process.

O Bouquet pinning As the vase is filled, the flowers rectify.

and CT or MRI for characterization. MRI also reveals associated triangular fibrocartilage complex tears.

Management Distal pole fractures heal in a thumb spica cast, as do nondisplaced waist fractures. Displaced waist fractures are at risk of osteonecrosis and are treated with open reduction and internal fixation. Open reduction and internal fixation, with autogenous bone grafting, are indicated for established nonunions. Wrist pain after successful treatment of scaphoid fractures may represent persistent triangular fibrocartilage complex tears, which may be addressed arthroscopically.

Metacarpal Fracture

Physial Nonarticular types are managed by closed reduction and casting. Articular types require open reduction and wire internal fixation if displaced, to reduce risk of posttraumatic arthritis.

Bennett fracture Fractures of the base of first metacarpal include Salter-Harris III and IV types [N]. They often require operation for displacement, due to intrinsic mobility of the thumb and deforming forces of its muscular attachments, opponens pollicis for a radial epiphysial fragment and abductor pollicis longus for an ulnar fragment.

Neck

Brawler's fracture The most common metacarpal fracture in children is of the neck of fifth metacarpal. It is more fittingly called "brawler's fracture" because a boxer is trained to punch not swing, to not make contact with the most mobile metacarpal. This presents a flexion deformity, which should be reduced if the metacarpal head is prominent in the palm. Reduction also is indicated for associated rotational deformity of the smallest finger. Flex the metacarpophalangeal joint to 90 degrees and drive the proximal phalanx of the smallest finger dorsal to extend the distal metacarpal fragment (Jahss manœuver).

Shaft These fractures are treated according to general principles. Acceptable alignment, from second to fifth metacarpals, is 20, 30, 40, and 50 degrees, respectively. Rotational deformity such that the finger crosses others during flexion is unacceptable. Unacceptable loss of length is >3 mm, which is associated with a decrease in extrinsic flexion and extension ratios as well as reduction in interosseous power for grip > 10%.

Operative treatment consists of closed or open reduction with transverse or medullary wire fixation or a combination of the two techniques. Medullary nailing has been described as bouquet pinning, after the universal concept (*cf.* flexible nailing of femur fractures) that filling the canal will simultaneously correct angulation and restore length [O]. The starting points for retrograde nailing are the radial and ulnar collateral recesses. Antegrade nailing, starting at the base of metacarpal and prebending the wire tips, may reduce neck fractures in the same manner as for proximal radius fractures (*q.v.*).

Phalangeal Fracture

Educate the patient and family that juxta- and intra-articular digital fractures are at risk for prolonged stiffness or permanent loss of motion and that associated swelling may persist for months.

Physial The metacarpophalangeal collateral ligaments originate from the metacarpal epiphysis and insert onto the epiphysis of the proximal phalanx, which accounts for the high frequency of physial fractures in this region.

Skier's, gamekeeper's thumb Salter-Harris III fracture at the base of first metacarpal, including skier's (acute) or gamekeeper's (chronic) thumb, often requires surgical intervention due to intrinsic mobility of the thumb.

Middle phalanx Fractures of this epiphysis may result from hyperextension, during which the volar plate holds onto a fragment, or under eccentric load of the central slip, which avulses a dorsal fragment. Treat volar plate avulsions with a short period of immobilization and early motion, to avoid stiffness: a fibrous union is stable and does not interfere with function. Immobilize (in full extension) avulsions of the central slip longer to allow it to heal without a lag.

P "Extraoctave" fracture Despite displacement at presentation, this was readily reduced closed. The fracture of the fourth phalanx requires no reduction.

"Extraoctave" fracture Salter-Harris I or II fracture of the proximal phalanx of the smallest finger with abduction of the distal fragment may extend the reach of a pianist's hand [P]. Lever the smallest finger.

radiad over a pencil or other similarly shaped object placed deep into the fourth web space., This requires fortitude of both patient and surgeon. After reduction, buddy taping is as effective as a splint or cast.

JERSEY FRACTURE Eccentric load on flexor digitorum profundus, as when a finger is caught in a jersey during sports, may avulse a volar fragment off the distal phalangeal epiphysis. Since superficialis is intact, the child will be able to flex the proximal interphalangeal joint, leading to missed or delayed diagnosis if the distal joint is not isolated and tested. The fracture may be widely displaced proximalward in the tendon sheath. This is treated by open reduction, often over a dorsal button.

MALLET FRACTURE In mallet fracture, a fragment of dorsal epiphysis of the distal phalanx is pulled off during eccentric loading of the extensor tendon. Splint this in extension. Counsel patient and parents that an extensor lag (<10 degrees) or a dorsal prominence may persist after healing, which does not impact function. Subluxation of the distal phalanx is an indication of extensive injury and an indication for operative treatment.

SEYMOUR FRACTURE This is an open Salter-Harris I or II physial fracture of the terminal phalanx associated with avulsion of the base of the nail. Flexed posture of the finger may lead to confusion with a mallet injury. The infolded germinal matrix obstructs reduction and may lead to a pseudomallet deformity if not lifted out of the physial region. Because of this, and because this is open with a risk of infection, open reduction and internal fixation are indicated. Repair the nail bed after careful extraction from the fracture. Fix the phalanx with a percutaneous wire passed retrograde and longitudinally across the interphalangeal joint, as much to protect the nail bed repair as to stabilize the fracture.

Shaft For nonarticular types, buddy taping suffices. Follow long oblique or spiral fractures closely for late displacement.

TUFT FRACTURE The mechanism is a crush of the finger tip. Most significant is evaluation of the nail. For a subungual hæmatoma > 50%, remove the plate and explore and repair the nail bed as indicated. Place a spacer between bed and eponychium to facilitate regrowth of the plate.

Condyles The mechanism of condylar fracture is axial load with shear or impaction (akin to a pilon fracture). Pattern of fracture may be unicondylar, bicondylar, or comminuted. Röntgenogrammes may show a double shadow on lateral projection, reflecting displacement of one of the condyles relative to the other. CT may be necessary to measure accurately articular displacement. The level of fracture is at the opposite end of the physis, limiting remodeling. Because of this, along with the fact that it is an articular fracture of a small joint, little displacement is acceptable. Manage by closed reduction with a percutaneous wire used as a joystick. If open reduction is necessary, preserve the soft tissue envelope in order not to add to the risk of avascular necrosis. The long fracture surface may receive screws for fixation.

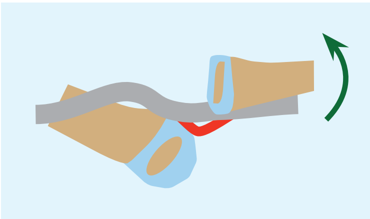
Dislocation

Most dislocations are uncomplicated and stable once reduced. Apply traction for reduction, which is followed by buddy tapping for 1 to 2 weeks with early mobilization to avoid stiffness.

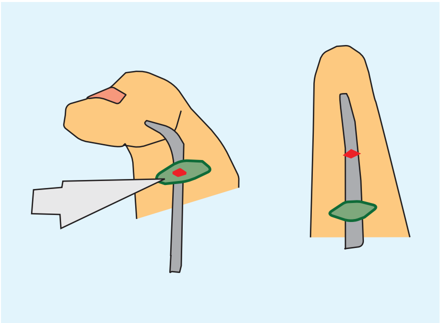
Irreducible dislocations, more likely at the metacarpophalangeal joint, typically are due to volar plate entrapment [Q]. These are termed complex because an open reduction is necessary: a dorsal approach, while indirect from the volar plate, avoids the digital neurovascular bundle that is displaced into the dislocation.

Tendon Laceration

This is evaluated and managed according to general principles. A child with a deep wound will be more difficult to examine in an emergency setting than an adult: consider the operating room, including extension of the laceration [R]. Partial tendon laceration is more difficult to diagnose than complete laceration, which alters the resting position of the hand [S]. After tendon repair, cast immobilization (4 weeks) yields better results than protected mobilization, in part due to less tendency to stiffness and less cooperation in the child.

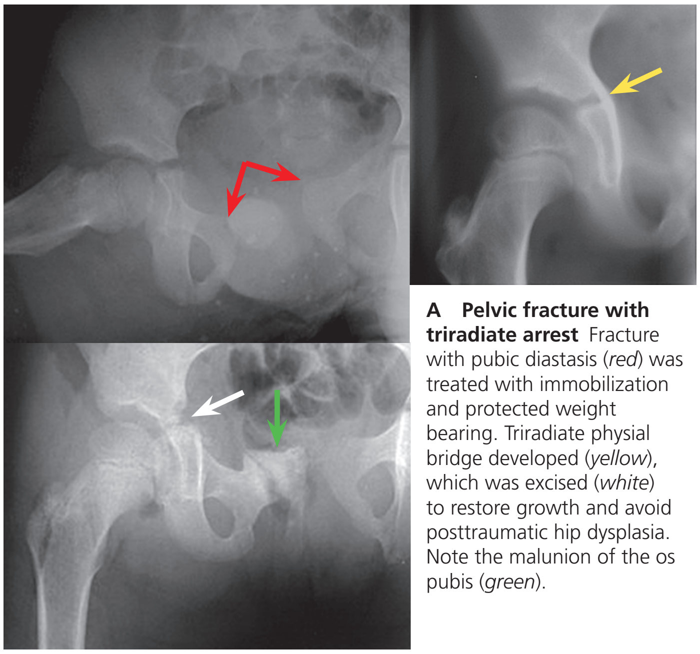


Q Complex dislocation Dorsal displacement (*green*) of proximal phalanx brings with it the volar plate (*red*), which becomes interposed to obstruct reduction.

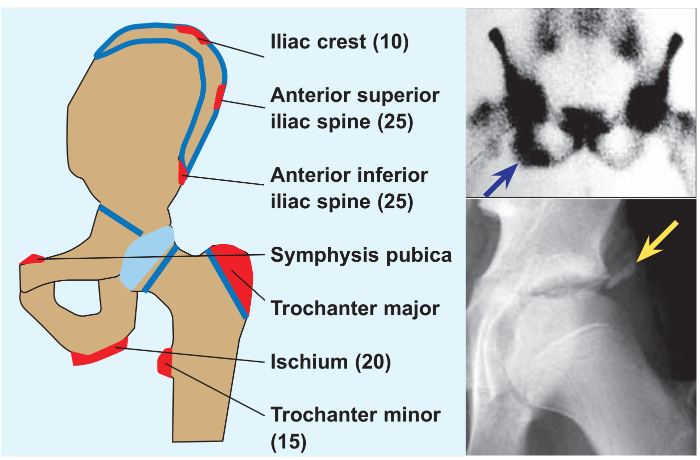


R Site of laceration A tendon laceration sustained in a flexed position may present a cutaneous wound (*green*) that is proximal to a partial injury (*red*) or that is distal to a complete injury.

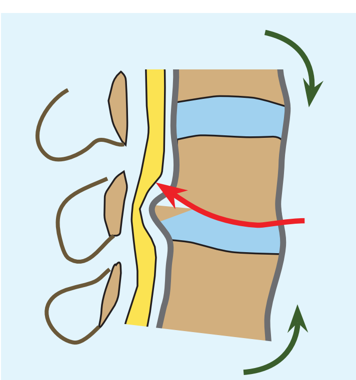
S Complete laceration There is no resting flexor tone.



A Pelvic fracture with triradiate arrest Fracture with pubic diastasis (*red*) was treated with immobilization and protected weight bearing. Triradiate physial bridge developed (*yellow*), which was excised (*white*) to restore growth and avoid posttraumatic hip dysplasia. Note the malunion of the os pubis (*green*).



B Avulsion fractures of the pelvis Numbers represent percentage incidence. Scintigramme shows increased uptake at ischial apophysial avulsion (*blue*) in a gymnast. Röntgenogramme shows avulsion of the anterior inferior iliac spine (*yellow*) in a soccer player.



C Slipped vertebral epiphysis The lesion represents a Salter-Harris I or II fracture of the vertebral epiphysis. Under axial loading and flexion (*green*), the intervening physis gives way before the stronger fibers of the anulus. Rotation accounts for laterality. The epiphysis slips posteriorward into the vertebral canal, where it may encroach upon the theca and cauda equina. The lesion has been typed as cartilaginous or osteochondral, small or large, and central or lateral. Most frequent location is low lumbar.

PELVIS

Fractures of the pelvis are managed according to general principles, for example, identify associated visceral injury such as bladder disruption. Several factors distinguish the child from the adult:

- Incidence of pelvic fractures in children is <0.2% of all fractures, compared with 2% for adults.
- Energy for fracture is higher in children, while energy of hip dislocation is lower. In syndromes such as trisomy 21, hip dislocation does not have the same grave consequences of avascular necrosis and osteochondral fracture as in adults.
- The triradiate cartilage is at risk for growth disturbance [A].
- Apophysial avulsion fractures are managed mostly by protected weight bearing [B]. These typically are acute, occurring during sports characterized by sudden acceleration, for example, running for a soccer ball. Tenderness localizes the injury and röntgenogrammes confirm the diagnosis. MRI allows accurate measurement of displacement. There is no consensus on unacceptable displacement: >2 cm may result in weakness of attached muscle, for example, of hamstrings in ischial avulsion, to which gymnasts are particularly vulnerable. Most heal with rest over a 3-month period. Use a screw if there is a sufficiently large osseous fragment. Union takes longer than closed primary healing. Otherwise, excise the fragment and repair the tendon to donor site *via* drill holes or anchors.

SPINE

Prevalence of spine fractures in children is 1% of adults. There are two injuries that are unique to children.

SCIWORA

The acronym stands for *S*pinal *C*ord *I*njury *W*ithout *R*adiographic *A*bnormality. This is seen principally in the first decade. There is a mismatch in elasticity between the pædiatric spine and spinal cord. The former stretches up to 5 cm but returns to the original position without residual displacement to appear radiographically normal. The latter does not tolerate stretch beyond 5 mm, resulting in traumatic myelopathy. Myelopathy may be acute or delayed (≤48 h) and transient or complete. Its severity correlates inversely with age: the younger the patient, the greater the mismatch in elasticity. While röntgenogrammes are negative, MRI will show the spinal cord injury.

Management is focused on the neural injury. Immobilize the spine and protect activity for 3 months. Reassess spinal stability with dynamic imaging. The spinal column heals but the spinal cord may not.

Slipped Vertebral Epiphysis

Each vertebral body is rimmed by an *epi*physis, which is articular at the intervertebral disc. The epiphysis is thickened along its circumference like a "ring" into which insert the fibers of the anulus similar to an "apophysis" [C].

Evaluation The patient presents with back pain, without or with radiculopathy, and a flexed posture with tilting opposite to any laterality of displacement in order to increase the capacity of canal and intervertebral foramen. The principal differential is herniated intervertebral disc. This, along with the circumpubertal age of presentation, accounts for the typical delay in diagnosis.

IMAGING Röntgenogrammes may show an osseous fragment off the posterior corner of the vertebral body, although CT is definitive. Myelography shows a sharp thecal indentation. MRI, which may miss the osseous fragment, delineates the associated protrusion of the intervertebral disc.

Management This is symptomatic unless pain is unacceptable in intensity or duration, there is neural compromise, or the osseous fragment encroaches upon >50% of the vertebral canal. Excision of the fragment may be more successful than discectomy for back pain because the intervertebral disc is relatively spared.

TRAUMATIC DISLOCATION

Traumatic joint dislocations in children are treated with a controlled reduction. Reduction may be closed with sedation in an emergency setting or in the operating room adding chemical paralysis as indicated. Operative reduction allows conversion to open reduction if closed method is unsuccessful, and fixation of associated fractures.

Elbow Dislocation

This may be associated with fracture of the medial epicondyle (*q.v.*). The dislocation may spontaneously reduce, giving a normal appearance on röntgenogramme, including no significant displacement of the medial epicondyle. Significant and diffuse elbow swelling with tenderness and variable ecchymosis over the medial epicondyle betray the gravity of the injury. Beware that the medial epicondyle may become incarcerated in the joint, which is an indication for open reduction.

Elbow instability occurs when fracture of the lateral condyle (*q.v.*) extends into the intercondylar groove (Milch type II), necessitating reduction of the elbow at the time of open reduction and internal fixation of the fracture.

Dislocation of the head of radius may be congenital or traumatic. Traumatic may be isolated or in conjunction with fracture, for example, of Monteggia (*q.v.*). Confirm anatomic reduction of the head of radius by demonstrating that it points at the capitulum in every radiographic view, including at all angles of elbow flexion in the lateral projection and on a radiocapitular view. Add an arthrogram or MRI when in doubt.

Ankle Dislocation

Physial fractures, such as a triplane of the distal tibia (*q.v.*), may present as an ankle dislocation [A]. At the time of operation, raise an anterior flap over the fibula to evaluate the syndesmosis: if this is disrupted, reduce the fibula into the incisura of the tibia under direct vision before fixation. This manœeuver avoids posterior displacement under indirect clamp reduction with image intensification, which may narrow the mortise and restrict talar movement.

Knee Dislocation

This may be atraumatic. Atraumatic knee dislocation may be isolated, referred to as congenital (*cf.* Lower Limb chapter), or associated with another condition, for example, in Larsen syndrome (*cf.* Syndromes chapter). The majority of traumatic knee dislocations in children are patellar (*q.v.*), which may or may not spontaneously reduce. Traumatic tibiofemoral knee dislocations in adolescents are managed according to adult principles.

Hip Dislocation

Most hip dislocations in children are posterior, presenting as an adducted, flexed, and medially rotated thigh [B]. As a general rule, hip dislocation requires less energy in children compared with adults, whereas it takes more energy to fracture the proximal femur of a child. The teenager represents a transitional stage. Reduce a hip dislocation within 6 hours, in case the retinacular vessels are stretched or kinked rather than torn. In the setting of an open proximal femoral physis, perform the manœuver in the operating room, where chemical paralysis will reduce the risk of physial fracture [C]. The physis is the weakest site and will yield at the rim of the acetabulum if the pericoxal muscles are not relaxed. The resulting epiphysial separation may tear the retinacular vessels, resulting in osteonecrosis of the proximal epiphysis of femur. Opening the hip to clear an obstacle to reduction, such as entrapped labrum, is preferable to a forcible closed reduction.

An eccentric reduction, or a joint width relatively greater than the contralateral side or absolutely >3 mm, is an indication for imaging such as a CT or MRI to evaluate the hip for an intra-articular fragment. Such imaging also examines the pelvis for associated injury. In the operating room, an arthrogram may be performed to confirm concentric reduction. Scintigraphy to evaluate blood flow to the head of femur has been unreliable in predicting osteonecrosis. An intra-articular fragment may be extracted by arthroscopic or an open approach.

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