40 Skeletal System

Theddy Slongo

40.1 General Considerations

Child are injuries have increased in relation to the past. New variety of sports and sporting equipment have been introduced over the past years so that even younger children are sustaining injuries and fractures that normally older children were incurring. This new equipment enables children to driving and run at higher speeds and the incurred fractures are becoming more complex. A new "code of procedure" has to be developed so that children are correctly treated in every hospital. Unfortunately, these new types of fractures are not being treated correctly. Too often, children are considered only small adults and that child's fractures always heal more easily. However, specific injuries of the growth plate, the joints as well as special fractures like the greenstick and bowing fracture are too often assessed wrongly in their healing behavior.

Factors Influencing the Treatment

- In childhood with its growing skeleton, the following parameters have to be taken into consideration:
  - Adequate, correct diagnostics
  - Type of the fracture
  - Bone and segment
  - Age according bone size and physeal growth
  - Weight
  - Option of treatment: Non-surgical or surgical
  - If surgical treatment: Kind of equipment
  - Own experience
  - Healing time according age
  - Practicability of postoperative management
  - Cost effectiveness

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- These factors are not to be regarded solely but in the sum. Thus, not only the X-ray image has to be studied, but also individual condition and surroundings. If, for example, the child already goes to school, a cast may be a handicap
- The aim of child-oriented treatment must be to achieve the greatest possible clinical efficiency, e.g., excellent results with minimal intervention
- Hence, the only treatment strategy is:

> The first treatment should be the correct and the definitive treatment

Development and Growth

- Compared to mature bone, immature bone is more capable of reaction and adaptation, but it is also more vulnerable
- A fracture in an immature bone signals either the acceleration or deceleration of growth, which has the potential to induce deformity, and adds to the complications of the fracture itself
- Age is one of the most important aspects as children's fractures heal more rapidly the younger the child. Depending on the child's age and the direction of the deformity, the bone can remodel to correct even the most angular of malunions
- The most important area of injury in the immature skeleton is the growth plate or epiphysis
- While treatment generally does not differ in adults between 20–60 years, in childhood large differences exist within the different ages (0–19 years of age). For example, the treatment of a fracture in a five-year-old child does not have to correspond and may even be inappropriate in a 12–14-year-old

Regulation of Epiphyseal Growth

- The growth plate (physeal line) is the primary center for growth in most bones and may be divided into two zones according to function:
  – The zone of growth, involved in both longitudinal and circumferential bone growth
  – The zone of matrix formation
- The growth plate is capable of responding to different stimuli (e.g., fracture or injury) with either compression (e.g., cessation of growth) or tension (e.g., bone resorption). This can have positive or negative influence on growing and axis

Growth and Remodeling of Metaphyseal and Diaphyseal Bone

- The metaphysis is the site of most rapid change in bone structure, as the deeper zones of the growth plate mature and the growth plate produces primarily trabeculae
- Circumferential growth of the diaphysis is a function of appositional bone formation by the periosteum, together with osteoclast resorption by the endosteum so as to enlarge the medullary cavity
- As growth continues, the bone is capable of reducing, or even correcting, angular deformity by selective resorption and apposition, possibly driven by compression and tension forces (Table 40.1)

Radiological Anatomy

- On X-ray, children's joints seem much greater than they really are (Fig. 40.1)
- The reason for this is the thick cartilage around the epiphysis

Table 40.1 Self-correction potential of the growing skeleton

Deformity	Anatomical bone part	Mechanism
Side-to-side displacement	Periosteal, end-osteal	Direct
Axial deformity (frontal/sagittal plane)	Epiphyseal	Indirect
Shortening/lengthening		
Rotation failures		

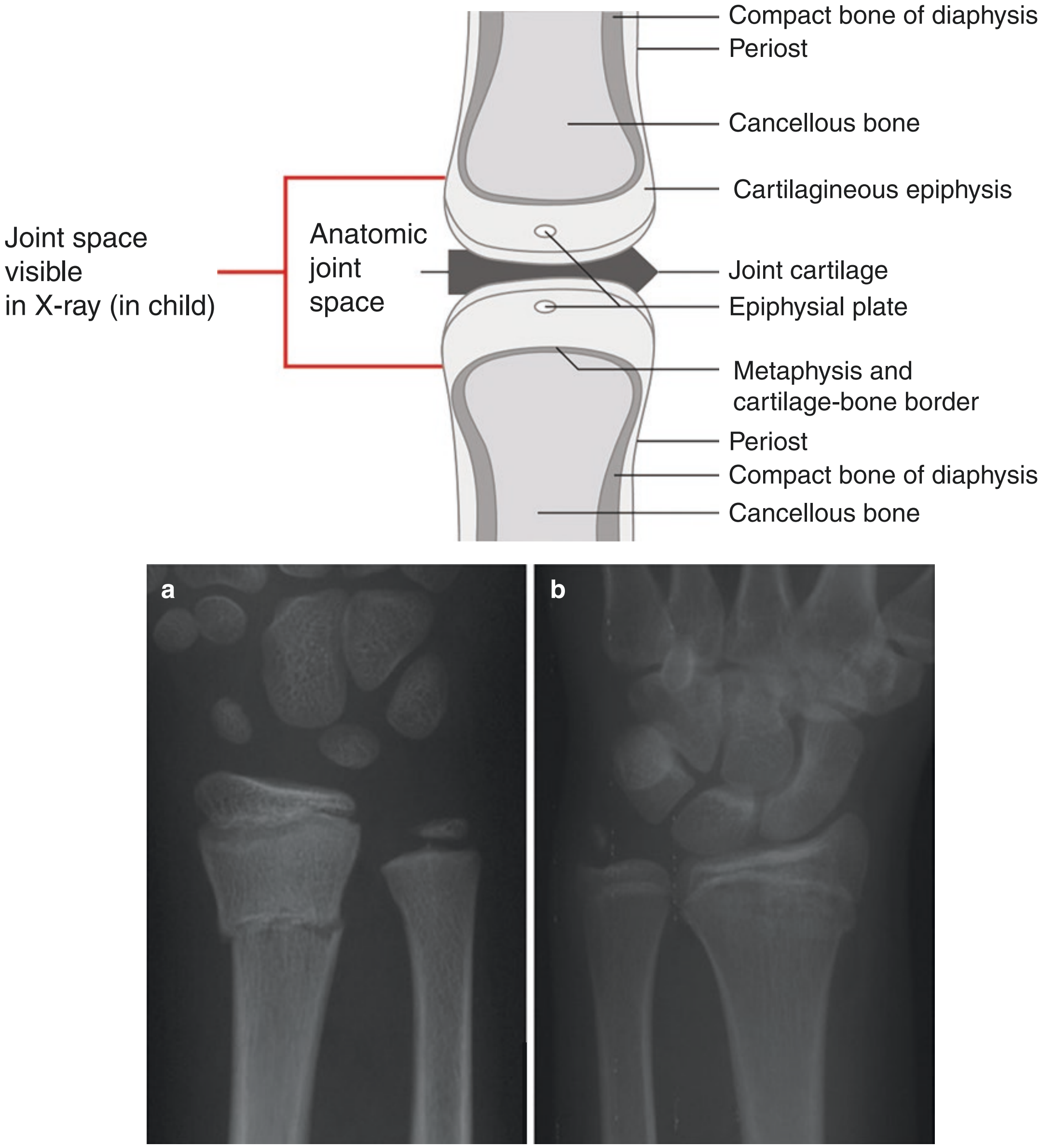


Fig. 40.1 Radiological anatomy of the joint in childhood. (**a**) 4 years old child, (**b**) 14 years old child

40.2 Classification

- There are numerous systems for classifying bone fractures:
  - According to localization, displacement and stability (Table 40.2)
  - According to localization and involvement of the growth plate (Table 40.3)
  - According to the Salter–Harris/Aitken system (Fig. 40.2, Table 40.4)
  - According to the (Table 40.5 and Table 40.6)

Table 40.2 Bone fracture classification according to location, displacement, and stability

	Localization		
Stability	Diaphyseal/metaphyseal	Articular	Therapy
Sufficiently stable for initial retention	Transverse fractures, with tolerance limits depending on age Or Oblique/spiral fractures of one bone of the lower leg or forearm	Non-displaced or minimally (<2 mm) displaced articular fractures	Immobilization with plaster in combination with cast wedging if necessary
Unstable fractures	All fully displaced fractures	Articular fractures with a gap >2 mm!	Reduction under anesthesia with either conservative (plaster) or operative stabilization

Table 40.3 Classification according to location and growth plate involvement

Shaft fracture	Diaphyseal	Stable	Non displaced fractures without shortening
		Unstable	Displaced fractures with shortening or having the tendency for shortening
		Greenstick	Bowing fractures with complete fracture of one cortex and incomplete facture of the cortex of the contra lateral side
	Metaphyseal	Buckle	Compression of the metaphyseal cortex of one side
		Incomplete	Greenstick fracture in the metaphysis
		Lig. avulsion	Ligament avulsion
Articular fracture	Epiphyseal	Aitken I Salter-Harris I + II	See Table 40.4
		Aitken II + III Salter-Harris III + IV	See Table 40.4
		Tillaux or bi-plane fracture	In puberty by partially closed growth plate
		Flake fracture	“Normally” in combination with joint dislocation
		Lig. avulsion	Bony or cartilage avulsion

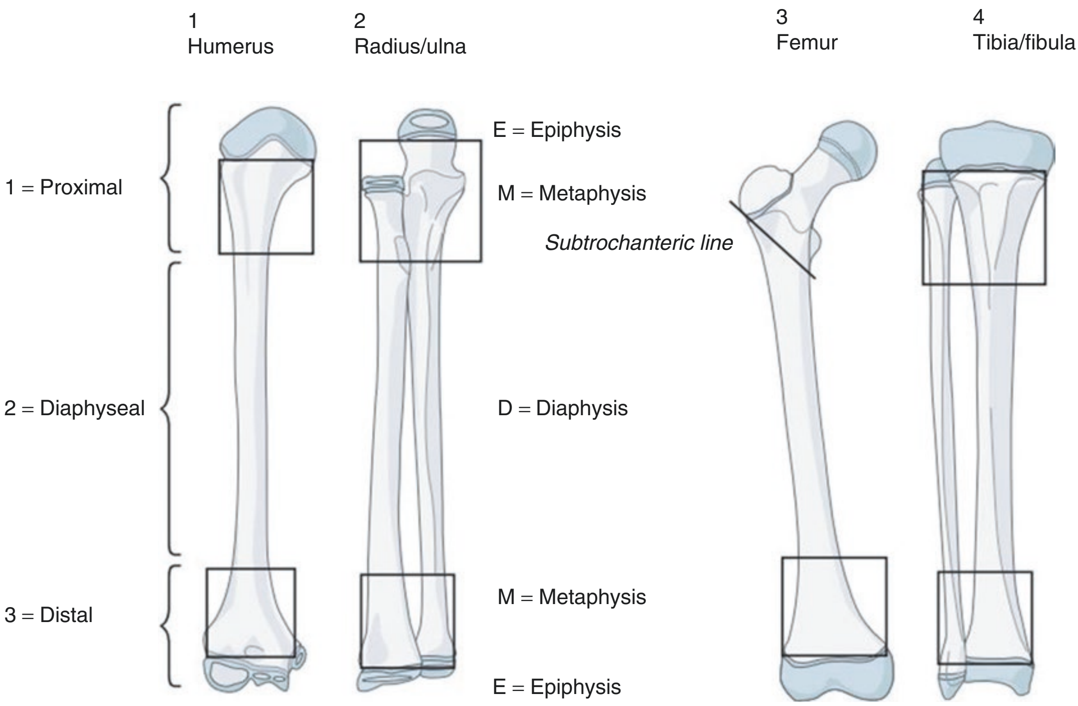


Fig. 40.2 Fracture location related to bone segments and sub-segments. For children the defined square must be placed over the larger parts of the growth plate

Table 40.4 Salter–Harris/Aitken classification

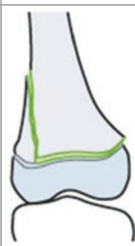
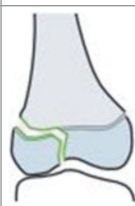
Salter– Harris			Aitken
I	Epiphyseal separation		
II	Epiphysiolysis with metaphyseal wedge		 I
III	Epiphyseal fracture		II

Table 40.4 (continued)

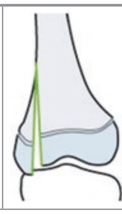
Salter– Harris			Aitken
IV	Epiphyseal fracture with metaphyseal wedge		III

Table 40.5 Overall classification system of pediatric fracture classification

Diagnosis							
Localization					Morphology		
Bone 1 2 3 4	Segment 1 2 3	–	Subsegment E M D	/	Child 1–9	Severity .1 .2	Displacement I–IV

Table 40.6 Classification of pediatric fractures

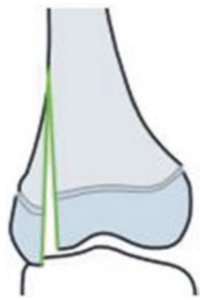
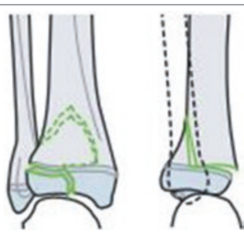
E = Epiphysis					
	E/1 S–H I		E/4 S–H IV		E/7 Ligament avulsions
	E/2 S–H II		E/5 Tillaux (two plane) fractures		E/8 Flake fractures
	E/3 S–H III		E/6 Tri-plane fractures	E/9 Other fractures	

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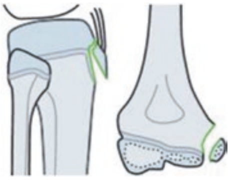
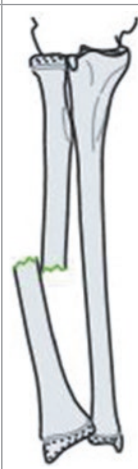
Table 40.6 (continued)

M = Metaphysis					
	M/2 Incomplete fracture (Torus / Buckle Or greenstick)		M/3 Complete fracture		M/7 Ligament avulsion
M/9 Other fractures					
D = Diaphysis					
	D/1 Bowing fractures		D/4 Complete transverse fractures <30°		D/6 Monteggia lesions
	D/2 Greenstick fractures		D/5 Complete oblique/ spiral fracture >30°		D/7 Galeazzi lesions
D/9 Other fractures					

AO Pediatric Comprehensive Classification of Long-Bone Fractures (PCCF)

- The AO Pediatric Comprehensive Classification of Long-Bone Fractures (PCCF) is available to all surgeons as a software package at www.aofoundation.org/aocoiac
- Fracture location is related to the four long bones and their three segments, as well as the specific pediatric sub-segments. The bones and segments within the bones follow a coding scheme similar to that in adults, but the identification of the segments differs. For pediatric long-bone fractures, the end segment has two subsegments:
  – Segment 1: Proximal – including epiphysis (E) and metaphysic (M) subsegments
  – Segment 2: Diaphysis (D)
- Segment 3: Distal – including metaphysic (M) and epiphysis (E) subsegments
- For the radius/ulna and tibia/fibula bone pairs, both bones must be included in the defined square (Fig. 40.2)
- As malleolar fractures are uncommon in children, they are simply coded as distal tibia fractures (e.g., the fracture of the medial malleolus is a typical Salter–Harris III or IV fracture of the distal tibia, coded as 43)
- The original severity coding of A–B–C used in adults is replaced by a classification system that is known and accepted all over the world, determined according to diaphysis (D), metaphysis (M) and epiphysis (E)
- Epiphyseal fractures (E) involve the epiphysis and its growth plates
- Metaphyseal fractures (M) are identified according to the position of the defined square (where the center of the fracture lines must be located in the defined square) with one side over the growth plate
- For easier and more accurate application of the squares, and thus more reliable classification, a series of defined squares is copied to a transparency that is overlaid on the a.p. radiographic view
- Nowadays, with the PACS system, the drawing of this square is easy and much more precise
- The defined square does not apply to the proximal femur, where metaphyseal fractures are located between the growth plate of the head and the intertrochanteric line
- The morphology of the fracture is documented by a type-specific child code and a severity code, as well as an additional code for displacement of specific fractures

Overall Structure of Pediatric Fracture Classification (Table 40.5)

- Relevant pediatric fracture patterns, transformed into a "child code," are specific and grouped according to each of the fracture location categories of E, M or D (Table 40.6, Fig. 40.2)
  – Patterns of epiphyseal fractures include the known epiphyseal injuries I–IV according to Salter–Harris using the child codes E/1 to E/4. Other child codes (E/5 to E/9) are used to identify Tillaux (two-plane) fractures (E/5), tri-plane fractures (E/6), ligament avulsions (E/7), and flake fractures (E/8)
  – Three child patterns are identified for metaphyseal fractures, e.g., the buckle/torus or greenstick fractures (M/2), complete fractures (M/3) and osteoligamentous, musculo-ligamentous avulsion or just avulsion injuries (M/7)
  – Child patterns within segment 2 (diaphyseal fractures) include bowing fractures (D/1), greenstick fractures (D/2), complete transverse fractures (angle ≤30°; D/4), complete oblique/spiral fractures (angle >30°; D/5), Monteggia (D/6), and Galeazzi lesions (D/7)
- The grade of fracture severity distinguishes between simple (noted as .1) and wedge (partially unstable fractures with three fragments including a fully separated fragment) or complex fractures, e.g., totally unstable fractures with more than three fragments (noted as .2) (Fig. 40.3)
- Severity implies anticipated difficulties and method of treatment, not the prognosis

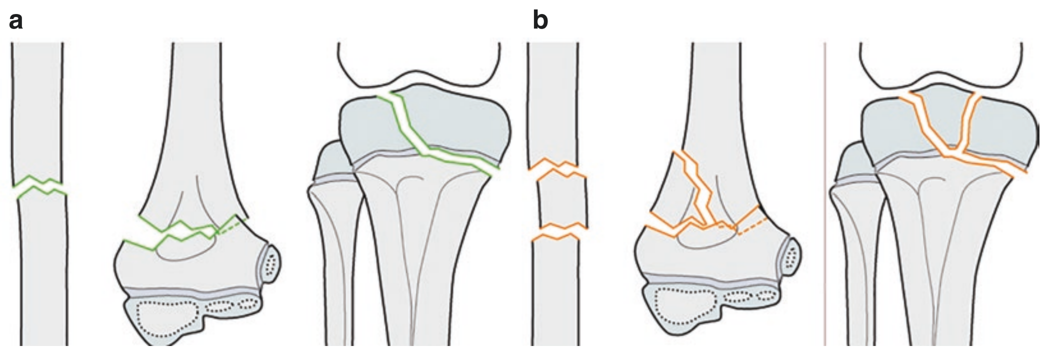


Fig. 40.3 Fracture severity: (**a**) simple (noted as .1), (**b**) partially unstable or totally unstable fractures with more than three fragments (noted as .2)

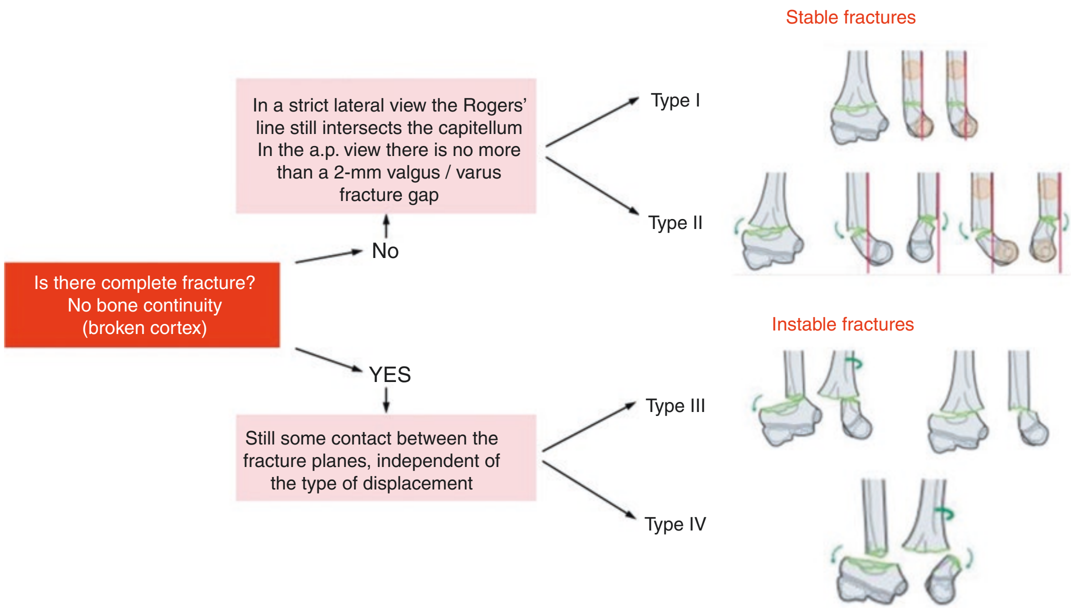


Fig. 40.4 Fracture displacement for specific fractures

- Fracture displacement for specific fractures (Fig. 40.4)
  - Supracondylar humeral fractures (code 13-M/3) are given an additional code regarding the grade of displacement at four levels (I–IV)
  - Radial head fractures (code 21-M/2 or /3, or 21-E/1 or /2) are given an additional code (I–III) regarding the axial deviation and level of displacement (I = no angulation and no displacement, II = angulation with displacement that is less than half the bone diameter, III = angulation with displacement that is more than half the bone diameter)
- Paired bones
  - Except for the known Monteggia and Galeazzi lesions, when paired bones (e.g., radius/ulna or tibia/fibula) are both fractured with the same child pattern, a single classification code should be used with the severity code used to describe the worst of the two fractures
  - When a single bone is fractured, a small letter describing that bone (e.g., "r," "u," "t" or "f") should be added after the seg-

ment code (e.g., the code "22u" identifies an isolated diaphyseal fracture of the ulna)
  - When paired bones are fractured, each with a different child pattern (e.g., complete fracture of the radius and a bowing fracture of the ulna), each bone must be coded separately including the appropriate small letter (22r-D/5.1 and 22u-D/1.1). This allows for the detailed documentation of combined fractures of the radius and ulna, or those of the tibia and fibula in clinical studies, so their relative influence on treatment outcomes can be properly evaluated

Further Rules for Correct Classification

- Fractures of the apophysis are recognized as metaphyseal injuries
- Transitional fractures with or without a metaphyseal wedge are classified as epiphyseal fractures
- Ligament avulsions
  - Intra-articular and extra-articular ligament avulsions are epiphyseal and metaphyseal injuries, respectively
  - The side of ligament-avulsion fractures of the distal humerus and of the distal femur is indicated by the small letter "u" (ulnar/medial) or "r" (radial/lateral) for the humerus and by "t" (tibial/medial) or "f" (fibula/lateral) for the femur
- Femoral neck fractures
  - Epiphysiolysis and epiphysiolysis with a metaphyseal wedge are coded as normal type-E epiphyseal Salter–Harris I and II fractures, E/1 and E/2
  - Fractures of the femoral neck are coded as normal type-M metaphyseal fractures coded from I to III
  - On the proximal femur, the intertrochanteric line limits the metaphysis

40.3 Skeleton Standard and Special X-Rays

General Considerations

- Not every fracture is visible on the X-ray in childhood
- An X-ray is only indicated if it has a therapeutic consequence
- If the decision to X-ray has been made, then it should be taken appropriately to provide the information desired
- It is obligatory to take X-rays in two planes, a.p. and lateral, even in emergency situations, including the proximal and distal joint of the broken segment
- X-ray of the opposite extremity is unnecessary, since no new knowledge or additional information can be gained
- A guide to radiological investigation of the skeleton is given in Table 40.7

Table 40.7 A guide to radiological investigation of the skeleton

Skull	
Skull a.p. and lateral	To see fractures
Skull Town's view	For occipital fractures and fractures of the foramen magnum
Spine	
Cervical, thoracic, lumbar a.p. and lateral	For a general overview
Cervical spine, oblique X-ray	Intervertebral foramina, small intervertebral joints
Cervical spine segmental functional X-ray	Intersegmental blocking, hypermobility by ligament avulsion
Ribs	
Thorax a.p. and lateral	Posterior rib segments
Thorax oblique	Anterior rib segments
Thorax tangential, special X-ray	For detail (after consultation with the radiologist)
Sternum	
Sternum lateral view	Special indications (funnel chest)
Shoulder	
Shoulder a.p. (under traction on both arms, 15 kg comparison of both sides)	Dislocation of the acromioclavicular joint
Shoulder in glenoid tangential projection	Overlapping free view of the humeral head and the glenoid joint ("true" a.p. view) Side difference indicates an injury of the acromion
Y-view (acromion, coracoid and the tangential view of the scapula together form the leg of the "Y")	Dislocation of the shoulder (needs a second view)
Shoulder transthoracal	Subcapital fractures of the humerus (second view needed)
Target X-ray	For special indications (suspicion of a Bankart lesion or hill–Sachs lesion)
Elbow joint	
Elbow a.p. and lateral	Fractures
Elbow under imaging intensifier	For special indications (radial head, processus coronoideus)

(continued)

Table 40.7 (continued)

Hand	
Hand dorso-palmar and lateral	Fractures and dislocations, swellings
Special view of the scaphoid (scaphoid quartet)	Fractures
Thorax	
Thorax a.p. and lateral	Aspiration, lung contusion, pneumothorax, heart, aortic arch silhouette
Pelvis	
Pelvis normal a.p.	Fractures
Hip joint axial	Fractures
Lauenstein X-ray of the ala of the ileum	Fractures of the ileum, the anterior wall
Obturator X-ray	Fractures of the anterior acetabular column, pubis and the posterior acetabular wall
Ankle joint	
A stress X-ray should not be taken. MRI shows ligament avulsions much better, however the diagnosis is of academic value since ligament avulsion is no longer treated surgically	
a.p. and lateral view	Fractures, joint incongruence
Foot	
Foot a.p.	Fractures
Foot in dorso-plantar oblique projection	Fractures
Foot in plantar-dorsal oblique projection (prone position of the child)	Medial tarsal bones (cuneiform medial and intermedium)
Foot lateral and axial	Calcaneus fractures

40.4 Development of Ossification Centers

- Figures 40.5, 40.6, 40.7 show the normal development of ossification centers

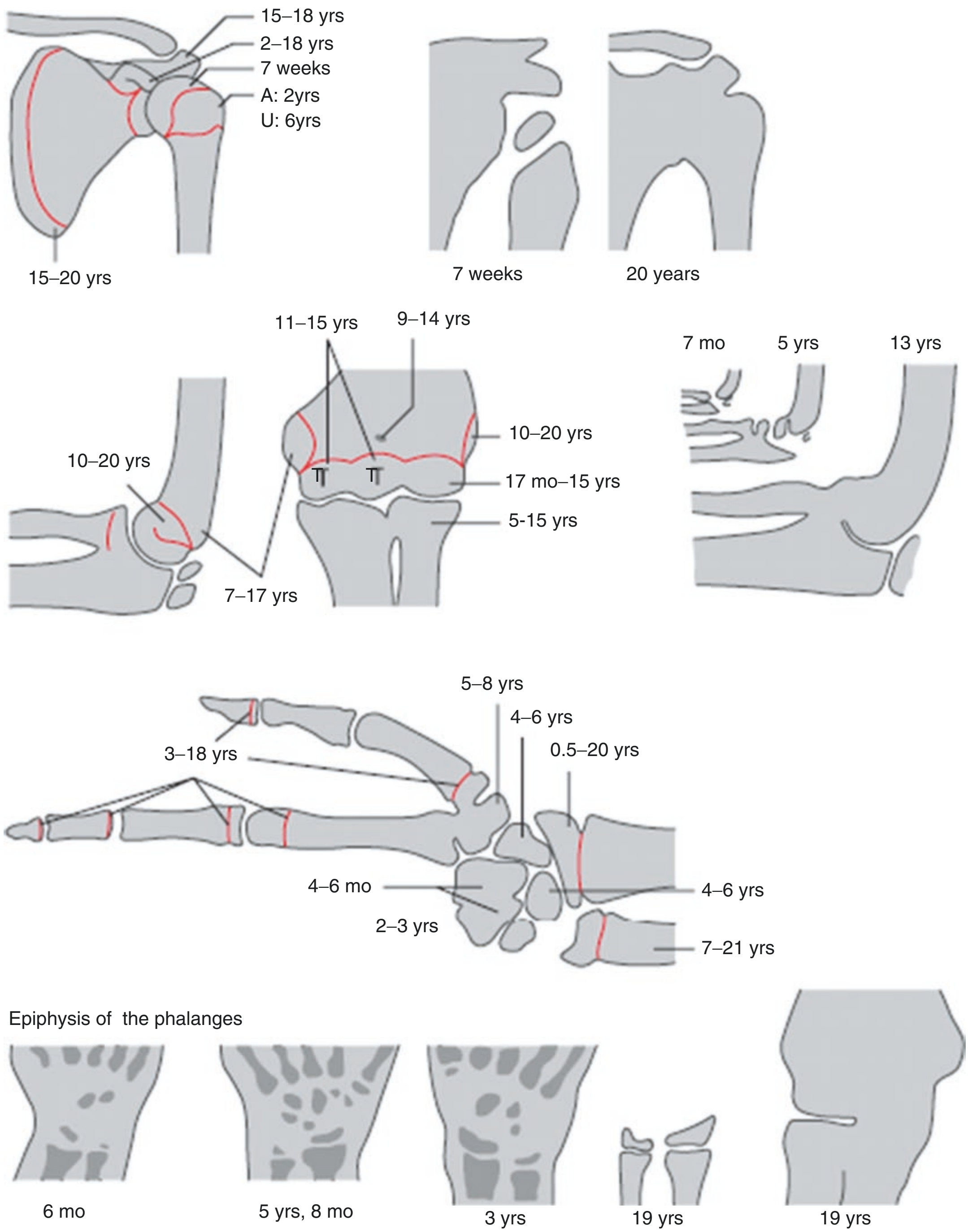


Fig. 40.5 Normal development of ossification centers upper extremities

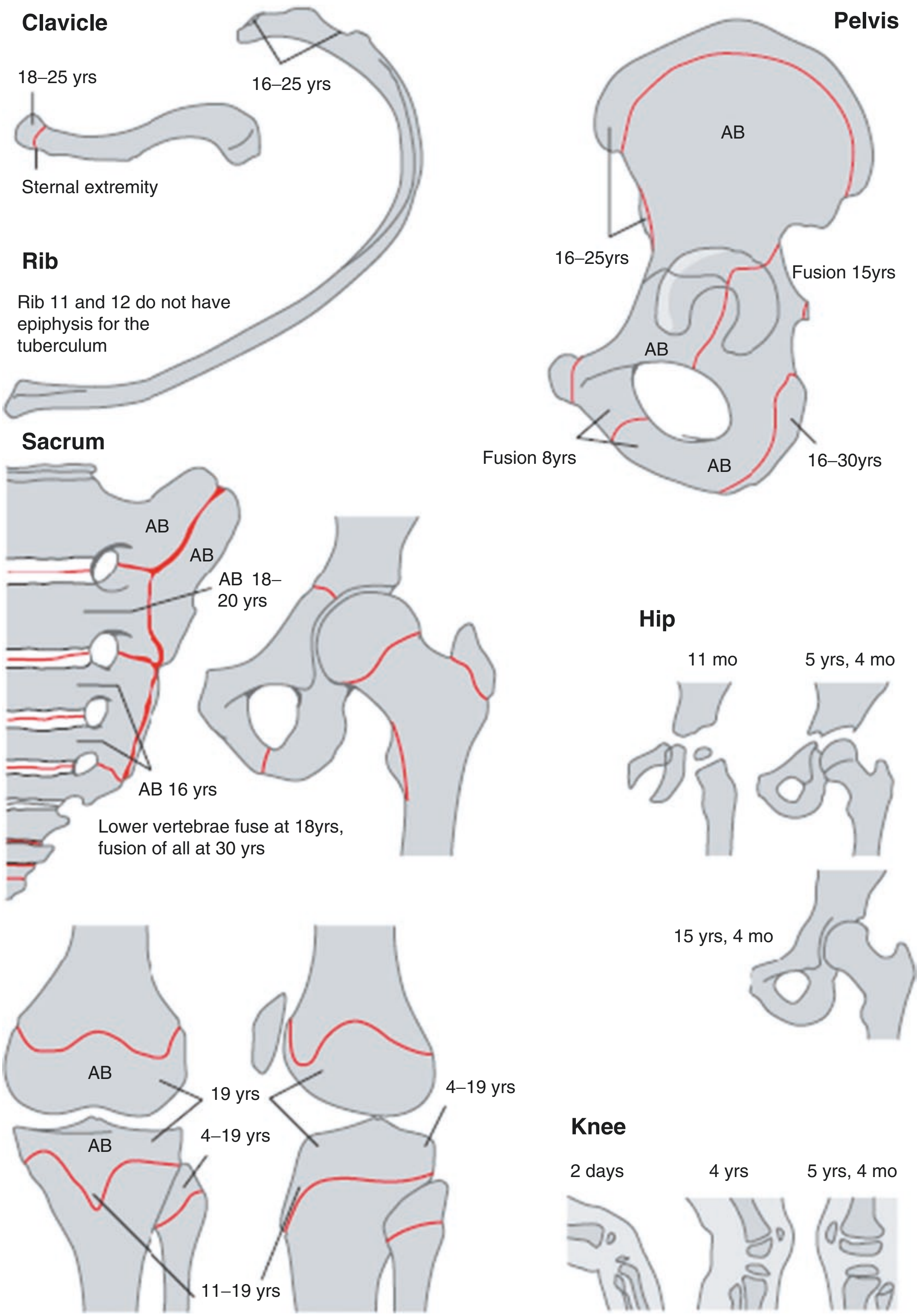


Fig. 40.6 Normal development of ossification centers pelvis, lower extremities

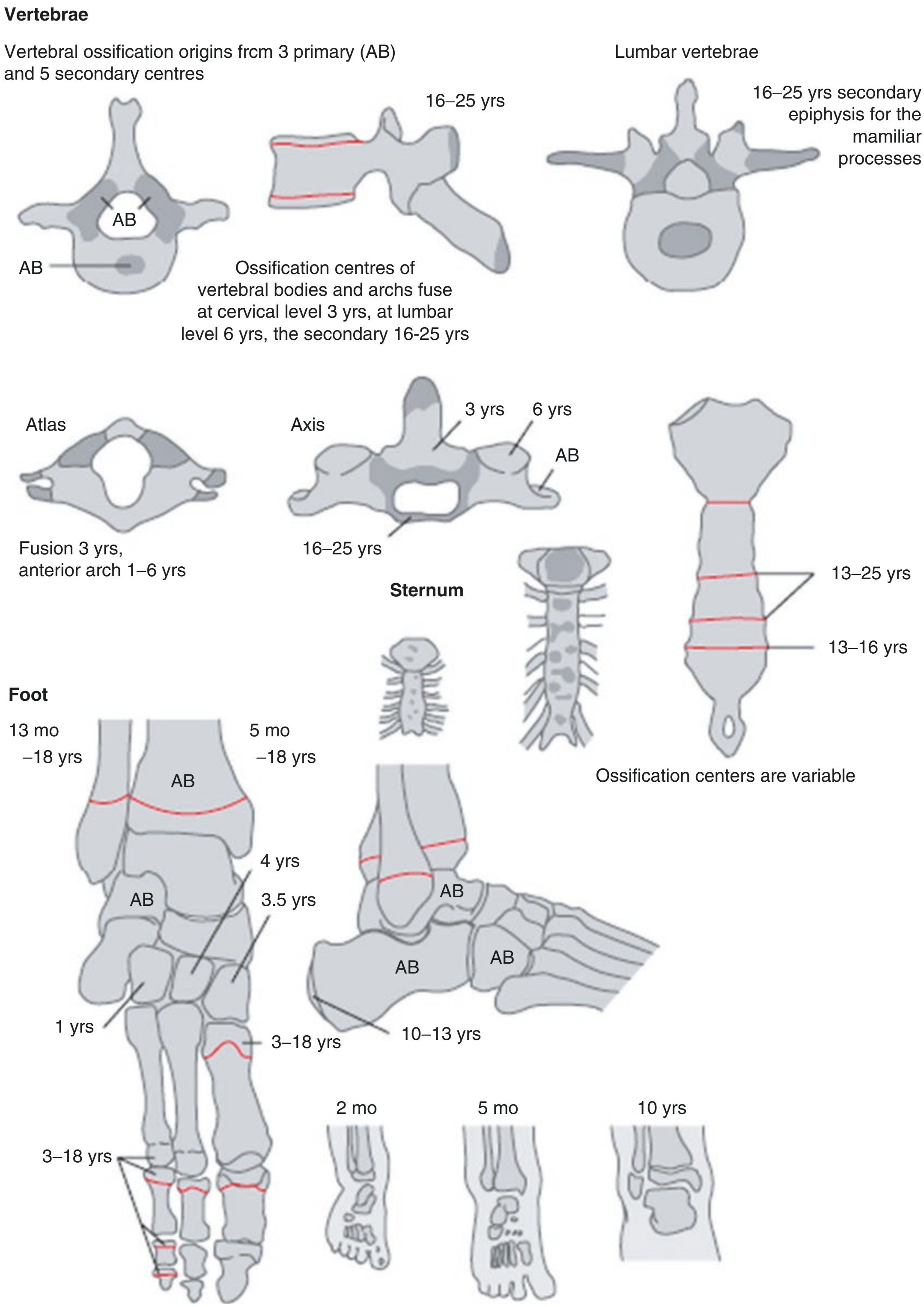


Fig. 40.7 Normal development of ossification centers spine, foot

40.5 Plaster Immobilization

- Every physician who deals with fractures must know how to apply a cast

Plaster Splint
- Indications
  - Stable fractures
  - Distortions
  - Pain after bone bruises
- The extremity must be covered with a cotton tube
- Wrapped with a thin half elastic cushion cotton
- Wrapped with a paper bandage
- Plaster gauzes are placed longitudinally along both sides of the extremity with a 3-cm plaster-free gap between them
- Today, fiberglass pre-fabricated splints are available and very user friendly
- After edema regression the cast can be closed circularly

Circular Plaster Cast
- Indications
  - Unstable fractures
  - Functional treatment
  - Secondary post-plaster splint (after edema regression)
- Same steps as above
- The extremity is enclosed in a circular plaster of paris or fiberglass cast
- Drying time for plaster: ~1.5 h; for Scotch cast ~30 min
- A primarily applied circular plaster should be opened longitudinately, especially when the tissue is swollen after fresh injuries
- When swelling subsides, the plaster can be closed again

Plaster Cast Windows
- Indications
  - Open wounds
  - Pins / K-wires
- The earliest that windows can be made in the plaster is after drying
- The window in the plaster must always be covered with the piece that was taken out in order to prevent edema in this region
- The window in the plaster must not impair the stability

Plaster Cast Wedging
- Indications
  - Remaining angulation of an undisplaced, stable fracture, after fracture stabilization without reduction
- The earliest the wedging of the plaster can be made is after 1 week. Swellings and pain must have gone completely
- The cut for the wedge must be at the deepest point of the concavity of the deformity
- The more peripheral the fracture, the more proximal should be the point for the wedge
- The child should not have any pain during this procedure

40.6 Therapy Principles

Closed Reduction (Mainly Used for the Upper Extremity)

- Every fracture reduction should be carried out under anesthesia (plexus block, general anesthesia)
- Extend the fingers (use of finger traps), hang a weight at the humerus and maintain the upper extremity with 90° flexion at the elbow for 20–30 min
- Reduce the fracture using a reduction maneuver that mimics the movement that led to the fracture in the first place
- Apply the plaster in the hanging position
- Immobilization of the fracture with a dorsovolar plaster splint

So-called Semi Open Reduction

- Indication
  - Partial or total unstable displaced fractures that can be definitively reduced
- Closed reduction under sterile conditions as described above
- Followed by percutaneous K-wire fixation
- In addition, immobilization with a plaster splint is required

Traction

- Indications
  - Limited nowadays
  - The main indication is in fractures of the femur in children between birth and 3 (4) years of age, depending on the child's weight of the child; known as overhead traction
- Sufficient analgesia and sedation of the child
- First the plaster is placed on the healthy leg over its full length
- Then the injured leg is covered with plaster, however only distal to the fracture
- Fixation of the extension on the overhead arch so that the child's buttocks are raised (there should be space for a flat hand to move freely under the buttocks without touching them)

Possibilities for Osteosynthesis

- Possibilities for osteosynthesis are illustrated in Fig. 40.8

Fig. 40.8 (**a–f**) Possibilities for osteosynthesis. (**a**) Kirschner wire, (**b**) combination Kirschner wire/external fixation, (**c**) external fixator, (**d**) elastic stable intramedullary nailing, (**e**) plate osteosynthesis, (**f**) lag screw osteosynthesis

Osteosynthesis with K-wires

- Indications
  - Closed or open reduced metaphyseal fractures
  - Fractures of the hand and foot
- Fixation with K-wires is not suitable for stabilization of diaphyseal fractures
- Whenever possible, the K-wires should be placed percutaneously so that they can be removed without anesthesia
- The crossing points of the K-wires should be proximal to the fracture line
- If the epiphysis must be crossed, repeated attempts to fix it should be avoided
- In cases such as this, thin K-wires should be used instead
- Ensure that the K-wires penetrate the opposite cortex
- Daily care of the pins reduces the risk of infection
- Normally K-wires can be removed after 3–4 weeks

Osteosynthesis with External Fixator (Ex-Fix)

- Indications
  - Comminuted fractures mainly in older children (femur, tibia, forearm)
  - Polytrauma
  - Long spiral fractures, e.g., spiral wedge of the femur in older children
- Normally closed reduction with or without traction table
- Type: Monotube®, tubular system, circular frame
- Place the Schanz screws under imaging intensifier
- In Monotube® systems, the distances between the entry points are predefined
- In “frame systems” one entry point should be near the fracture, the other further away from it
- All clamps must be open for reduction
- After sufficient reduction all clamps have to be closed and secured
- Daily care of the pins reduces the infection risk
- Elastic stable intramedullary nailing (ESIN)
- Indications
  - Transverse, oblique and short spiral, diaphyseal fractures in childhood (3–15 years)
- ESIN is minimally invasive, minimally traumatic, and sufficiently stable for movement and partial weight bearing; it is biologically and child friendly way, using special elastic nails, of enabling osteosynthesis
  - Operation technique: see Sect. 40.15

Lag Screw Osteosynthesis

- Indication
  - Articular and peri-articular fractures, Salter–Harris II fractures, mainly in the distal tibi and femur, femoral neck fractures
- Self-drilling and taping cannulated screws (dimensions 4/4.5/6.5 mm) are mainly used
- Directly position the extremity on the intensifier
- Rotate the extremity so that the fracture line is visible in a proper a.p. view
- Put the guide wire on the fragment parallel to the table of the intensifier
- Drill the guide wire into the bone to the contralateral cortex
- Measure the length
- Put the correct-sized cannulated screw over the guide wire
- Tighten the screws until the fracture is closed

Plate Osteosynthesis

- Indications
  - Comminuted fractures, mainly in older children (femur, tibia, forearm), long spiral fractures with/without spiral wedge of the femur in older children
  - Today, ESIN and EndCaps can be used for such fractures as well
- Usage of plates is reserved to exceptions and in special cases
- When an osteosynthesis with a plate is indicated, we recommend the application of new types of plates such as LC-DCP and LCP plates. If possible, these types of plates can be applied using a minimally invasive technique (MIPO)

Knee Joint Puncture (Fig. 40.9)

- Indications
  - Posttraumatic hemarthros (not before 24 h!)
  - Signs or suspicion of infection

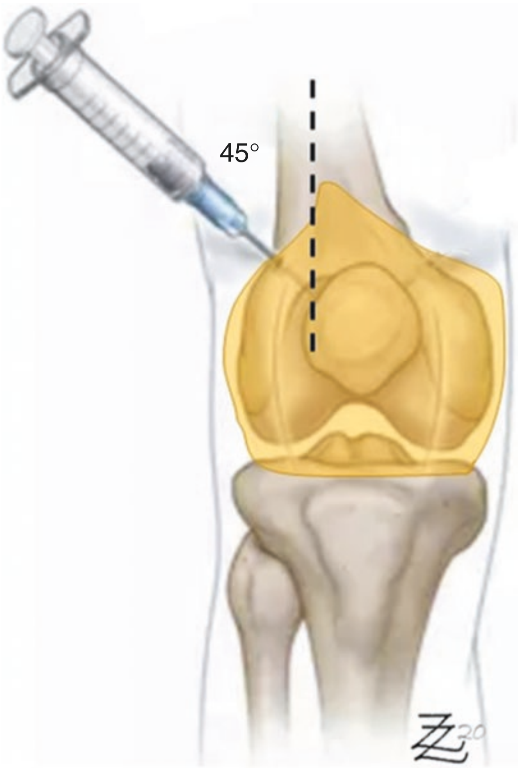


Fig. 40.9 Knee joint puncture

- Procedure
  - Apply local anesthesia or anesthetic cream well before the puncture
  - Puncture in the lateral proximal recess

Hip Joint Puncture (Fig. 40.10)
- Indications
  - Posttraumatic hemarthros (not before 24 h!)
  - Sings or suspicion of infection

Fig. 40.10 Hip joint puncture

- Procedure (three different approaches)
  - From lateral approach
  - From anterior approach (take care to avoid the artery and nerve!)
  - Ludloff approach (preferred by author)

Period of Healing
- Guidelines for fracture immobilization in childhood are given in Table 40.8
- Metaphyseal fractures heal in half the time of the diaphyseal fractures
- Diaphyseal transverse fractures heal more slowly than diaphyseal oblique fractures

Table 40.8 Guidelines for fracture immobilization in childhood

Fracture	Immobilization in weeks (age dependent)		
	<5 years	5–10 years	> 10 years
Clavicle	1	2	2–3
Humerus proximal stable	1	2–4	3–4
Humerus proximal unstable	1	2–4	3–4
Humerus shaft	2–3	3–4	4–6
Supracondylar	2–3	3–4	4–5
Radial condyle	3	3–4	4
Ulnar condyle/Y–fracture	2–3	3–4	3–4
Ulnar epicondyle (+dislocation of the elbow)	2–3	2–3	4
Radius proximal	1–2	2–3	3–4
Olecranon	2	2–3	3–4
Forearm shaft including greenstick fracture	3	4	4–6
Radius (+ radius + ulna) distal	2–3	3–4	4–5
Salter–Harris I radius distal	2	2–3	3–4
Carpal		4–6	5–8
Metacarpal proximal and distal		2–3	3–4
Metacarpal shaft		3–4	4–6
Finger proximal and distal	1–2	2–3	3–4
Finger shaft	2–3	3–4	4–6
Femur neck of the femur		4–6	6–8
Femur subtrochanteric fractures	2–4	4–5	5–6
Femur shaft	2–3	4–5	4–6
Femur distal	2–3	3–4	4–5
Tibial spine fracture		3–4	4–6
Tibia proximal metaphysis	2–3	3–4	4–5
Tibia shaft	2–3	3–5	4–6
Tibia distal and malleolar	2–3	3–4	4–5
Hind foot and calcaneus		4–6	5–10
Mid-foot and toes distal	2–3	3–4	4
Toes	1–2	2–3	3–4
Fibulotalar ligaments/ osseous avulsion		3–4	4–6

Source: von Laer L (1991) Fractures and dislocation during growth. *Injury* **36**(2):356

40.7 Spinal Injuries

General Considerations

- Spinal injuries in childhood are not as rare as one assumes
- The most common injuries are simple fractures after anterior crush injuries or compression fractures of the vertebral body
- In injuries involving the atlas and axis, rotatory subluxation or dislocation is one of the most common lesions in children, rather than fractures of the atlanto-axial articulation
- Injuries of the thoracic and lumbar spine are more common in childhood than in adulthood. The majority of these fractures result from traffic accidents. Child abuse should also be considered
- Obstetric fractures involve mostly the cervical spine (with high mortality)
- End-plate fractures in younger children are followed by scoliosis
- Fractures of vertebral bodies have good remodeling capacity, depending of the child's age
- Diagnosis can be difficult due to congenital malformations (congenital non-union, hemivertebra, congenital vertebral fusions) or following diseases (post-traumatic malformations or Scheuermann's disease)
- The normal spine in children differs considerably from that in adults, especially in the cervical region

Classification

- Stable spine fractures with compression of the vertebral body or "end-plate" injuries
- Unstable fractures with involvement of the vertebral arch and the pedicles
- Ligament avulsion

  Or
- Fractures involving end-plates with growth disturbance
- Fractures not involving end-plates

Diagnostic Work-Up

- Diagnosis includes accurate evaluation of the level and extent of injuries to both chondro-osseous and nervous system tissues
- Radiographic evaluation must be carried out paying due attention to potentially severe unstable injuries and must include prior adequate immobilization of the spine
- Osseous injuries can be seen on an adequate a.p. and lateral view

- Oblique views may be necessary
- CT scan or MRI may be indicated

Treatment

- A number of unique problems can be encountered in the treatment of infants, children, and adolescents with spine injuries
- In any closed, non-surgical treatment regime, the spinal deformity must be reduced and adequately stabilized, and protected from re-displacement during the healing process
- Treatment guidelines are given in Table 40.9

Prognosis

- The prognosis of undisplaced stable fractures is good, depending on the type of injury (growth plate/end-plates, wedge compression)

Table 40.9 Treatment guidelines for spinal injuries in infants, children, and adolescents

Fracture	Therapy
Stable/non-displaced	Simple bed rest is indicated, since most children with stable (compression) fractures are asymptomatic within a few days or weeks. External support may be necessary
Stable displaced	Surgical stabilization with dorsal fusion
Unstable	Surgical stabilization with dorsal fusion

- The prognosis of displaced fractures depends on the accompanying neurological problems

40.8 Sling-Shot Injury of the Cervical Spine

General Considerations

- Sling-shot injury of the cervical spine happens more frequently than fractures in childhood

Diagnostic Work-Up

- Normal X-ray indicating a straightened position of the cervical spine

Treatment

- Pain management
- Immobilization with a soft ruff
- Physiotherapy

Prognosis

- Good

40.9 Pectoral Girdle and Clavicle

General Considerations

- Fractures of the clavicle (Table 40.10) occur most frequently in children during the first 10 years
- Fractures of the scapula, which is highly mobile and well protected by muscles, are rare
- Fractures of the scapula result from direct violence, such as crushing injury, and traffic accidents

Gleno-Humeral Joint Dislocation

- Subluxation and dislocation of the shoulder (Table 40.11) are rare in infants or young children
- The capsule of the shoulder joint has some intrinsic laxity that allows some displacement during stress
- "Dislocation" of the shoulder has also been described as a birth injury. However, great care should be taken before making such a diagnosis, as the proximal humerus is most likely to be fractured through the epiphysis

Table 40.10 Fractures of the clavicle

Morphology	Fractures of the mid-shaft are most common and range from greenstick to complete fractures
Signs	Pain, swelling, painful movement of the arm
Diagnosis	Clinically and radiologically
Correction potential	Good
Complications	Nerve problems, non-union, cosmetics
Non-surgical therapy	In principle non-surgical → sternal brace or "figure-of-eight" orthesis pulling the shoulder backwards
Surgical procedure	Only fully displaced, comminuted fractures in adults (author's preferred method is ESIN)
Immobilization	2–3 weeks
X-ray control	After 3 weeks
Follow-up	Only clinically

Table 40.11 Gleno-humeral joint dislocation

Morphology	Injury of the adolescent, appearing, in contrast to epiphysiolysis, in the form of a head dislocation after closure of the proximal epiphysis
Signs	Visible deformity, empty glenoid
Diagnosis	Clinical and radiography
Correction potential	None
Complications	Lesions of the axillary nerve
Non-surgical therapy	Immediate reduction and Gilchrist dressing
Surgical procedure	There are no good operative methods in childhood
Immobilization	3 weeks
X-ray control	None
Follow-up	No control necessary

Prognosis

- For clavicle fractures, very good
- Prognosis of dislocation of the gleno-humeral joint depends on the time lapsed since the incident and the type of injury

40.10 Humeral Fractures

General Considerations

- Rare in childhood, following direct trauma or obstetric injury
- Mostly transverse or oblique fractures

Fractures of the Proximal Humerus

- Proximal humeral fractures and their management are detailed in Table 40.12

Table 40.12 Proximal humeral fractures and their management

Morphology	About 60% are subcapital fractures; 38% are Salter–Harris II fractures; pure epiphysiolysis are rare
Signs	Deformation, pain
Diagnosis	X-ray; interpretation is often difficult in undisplaced fractures, displacement of the epiphyseal line is interpreted as a fracture Note the three ossification centers
Correction potential	Great potential, angulation in the sagittal and frontal plane is tolerated up to 60° in children <12 years old and up to 30° >12 years
Complications	Practically unknown; in neonates premature close of the growth plate is possible
Non-surgical therapy	• Stable, undisplaced fracture, any age • Stable fracture with angulation < 60°: < 10 years < 30°: > 10 years Or Stable fracture with tolerable displacement, any age immobilization for 3–4 weeks in a Desault or Gilchrist dressing Or If anesthesia is needed for reduction, definitive treatment with stable fixation is recommended
Surgical procedure	• Children >10–12 years of age • Unstable fracture if a reduction under anesthesia is necessary • Major displacement after non-surgical treatment • Author's preferred method: ESIN from a monolateral, radial approach in an ascending technique • No additional immobilization is needed • Nail removal after 3–4 months Or Percutaneous (2.5-mm threaded) K-wire fixation • Open reduction is a rare exception
Immobilization	3–4 weeks
X-ray control	Non-surgical therapy: Days 3–4 and weeks 3–4 Surgical procedure: Postoperatively and week 4
Follow-up	Week 3 or 4 radiological and clinical

Fractures of the Distal Humerus

- Distal humeral fractures and their management are detailed in Table 40.13

Table 40.13 Supracondylar humerus fracture

Morphology	See Table 40.5
Signs	Swelling, pain, visible deformation
Diagnosis	X-ray in two planes Classification: • No displacement • Displacement in one plane • Displacement in two planes • No bone contact
Correction potential	Practically non-existent
Complications	• Radial (medial) nerve injury (deep branch) • Premature closure of the growth plate after repeated drilling • Varus deformity as a consequence of a rotational failure
Non-surgical therapy	Classification: Type I and II • Blount loop • Dorso-volar plaster splint in 90° position
Surgical procedure	• Classification: Type III and IV • Closed reduction (in 90%–95% is possible) • Percutaneous K-wire fixation (ascending crossed bilateral, parallel radial, ascending or descending monolateral radial) • Small external radial fixator (method preferred by author) • ESIN
Immobilization	Operative and non-surgical treatment; 3–4 weeks of plaster fixation Removal of the percutaneous K-wires at this time
X-ray control	Non-surgical treatment: After a few days and at week 3–4, depending of the child's age Surgical procedure: After 3–4 weeks
Follow-up	2–3 months after injury functional, clinical examination no physiotherapy

Fracture of the Humerus shaft (Diaphyseal Fractures)

- Fractures of the humeral shaft and their management are detailed in Table 40.14

Table 40.14 Fracture of the humerus shaft (diaphyseal fractures) and their management

Morphology	Rare fractures
Signs	Deformity, pain
Diagnosis	X-ray (two images taken at 90° to one another)
Correction potential	There is a great potential in all planes
Complications	Damage to the radial nerve (long spiral fractures of the distal third)
Non-surgical therapy	• Stable undisplaced fracture, any age • Stable fracture with angulation <30° Or Stable fracture with tolerable displacement, any age Immobilization for 3–4 weeks in a Desault or Gilchrist dressing Or If anesthesia is needed for reduction, definitive treatment with stable fixation is recommended
Surgical procedure	• Children >10–12 years of age • Radial nerve irritation is not an indication for surgical intervention • Unstable fracture if a reduction under anesthesia is necessary • Major displacement after non-surgical treatment • Author's preferred method: ESIN • No additional immobilization is needed • Nail removal after 3–4 months
Immobilization	3–4 weeks
X-ray control	Non-surgical therapy: Days 3–4 and weeks 3–4 Surgical procedure: Postoperatively and week 4
Follow-up	Week 3 or 4 radiologically and clinically

Prognosis
- Very good

40.11 Elbow Joint Region Fractures

General Considerations
- Mostly children between 3 and 10 years old sustain these fractures
- Good knowledge of the child's anatomy of the distal humerus and the proximal forearm is imperative
- The X-ray is often difficult to interpret, nevertheless an X-ray of contralateral, uninjured site is unnecessary and no longer required
- Correct diagnosis should always be achieved before starting treatment
- Special fractures
  - Non-displaced fractures of the lateral condyle
  - Isolated fractures of the radial neck
  - Monteggia fractures
  - Rotation failures in supracondylar humerus fractures due to varus or valgus deformity resulting from the fracture

Classification
- Fractures in the region of the elbow joint are discussed in Tables 40.13, 40.14, 40.15, 40.16, 40.17, 40.18, 40.19, 40.20, 40.21, 40.22, 40.23, 40.24, 40.25, and 40.26

Table 40.15 Regarding the joint

Articular	Fractures of the lateral condyle Transcondylar fractures of the humerus
Extra-articular	Supracondylar fracture of the humerus Epicondylar fractures

Table 40.16 Regarding the direction of displacement of the distal fragment

Fractures in extension	In 95% of all cases, the distal fragment is displaced dorsally
Fractures in flexion	The distal fragment is displaced ventrally only in 5%

Table 40.17 Localization of elbow fractures according to frequency

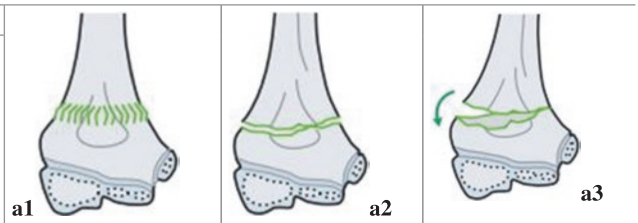
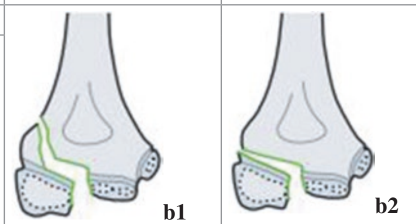
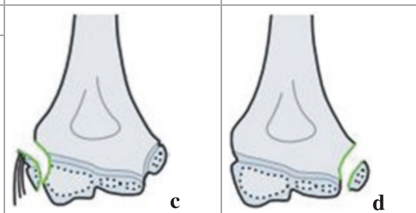
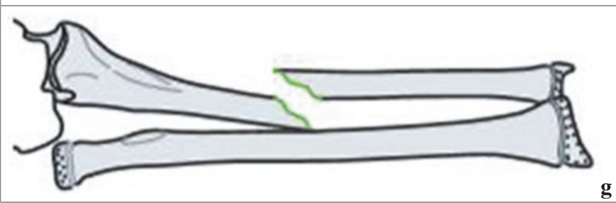
Supracondylar fractures • Torus / buckle fracture (a1) • Complete non-displaced (a2) • Complete displaced (a3)	
Transcondylar fractures • Lateral condyle (b1,2) • Medial condyle (very seldom in childhood)	
Ligament avulsions • Lateral epicondyle (c) • Medial epicondyle (d)	
Fractures of the proximal radius • Torus / buckle fracture (e1) • Complete non-displaced, non-angulated (e2) • Complete displaced, angulated (e3)	
Olecranon fractures • Complete displaced (*f*)	
Monteggia fractures Isolated fracture of the ulna and dislocation of the radial head (g)	
Dislocation of the elbow joint	

Table 40.18 Epiphysiolysis of the distal humerus

Morphology	Very rare fracture
Signs	Pain, deformity
Diagnosis	X-ray
Correction potential	None
Complications	Same as for supracondylar fractures (see Table 40.13)
Non-surgical therapy	Dorso-volar plaster splints
Surgical procedure	If a reduction is indicated: Fixation with crossed K-wires
Immobilization	3 weeks
X-ray control	Day 7 (non-surgical) 3–4 weeks end control
Follow-up	2 months

Table 40.19 Transcondylar, intercondylar fractures

Morphology	The entire distal epiphysis of the humerus is displaced posteriorly, laterally or forwards, depending on the injury mechanism. The most frequent fracture is that of the lateral condyle
Signs	Pain, swelling
Diagnosis	X-ray in two planes. Sometimes only the oblique view will disclose either displacement or evidence of the undisplaced fracture line
Correction potential	None
Complications	Delayed healing and blocked union with varus deformity, late ulnar nerve irritation, avascular necrosis of the capitulum
Non-surgical therapy	• Initial undisplaced fractures (long arm cast) followed by a cast-free X-ray control on day 4–5 • Secondary displacement over 2 mm needs surgical intervention
Surgical procedure	Initial displacement over 2 mm (open reduction and K-wire or screw fixation) Implant removal after 8–12 weeks
Immobilization	4 weeks
X-ray control	Undisplaced fractures day 4–5, cast free!! Consolidation is visible after 4–5 weeks
Follow-up	6 months and 1 year

Table 40.20 Proximal radial fractures

Morphology	65% subcapital = metaphyseal fractures of the radial neck 35% Salter–Harris II fractures
Signs	Pain, blockage of pronation and supination
Diagnosis	X-ray in two planes, sonography
Correction potential	None in lateral displacement Good in the sagittal and frontal plane up to 60°
Complications	Avascular necrosis, malunion or non-union, premature fusion of the growth plate, ectopic calcification, limited pronation and supination
Non-surgical therapy	<10 years of life up to 60° (long arm cast)
Surgical procedure	If anesthesia is needed for reduction closed reduction by indirect manipulation fixation with ESIN Trick: The fully displaced radial head can be manipulated by fixing the fragment with a percutaneous K-wire, and thereby moved to the right location (joy-stick technique)
Immobilization	Non-surgical therapy: 2–3 weeks, then functional therapy Surgical procedure: No immobilization is required
X-ray control	Non-surgical therapy: Day 4 and 8 and after 3 weeks Surgical procedure: Only after 4 weeks
Follow-up	Clinical controls for 2 years after accident

Table 40.21 Dislocation of the elbow

Morphology	Mostly in children over 8 year of age displacement direction correlates with deforming force direction
Signs	Deformity, pain, swelling, nerve irritation
Diagnosis	Clinically and X-ray The differential diagnosis of an elbow dislocation basically consists of distinguishing a dislocation from a supracondylar fracture, a lateral condylar fracture, or a transcondylar fracture

Table 40.21 (contiued)

Correction potential	None
Complications	Medial ligament avulsion, fracture of the medial epicondyle vascular and nerve complications
Non-surgical therapy	Immediate reduction of an acute posterior dislocation may often be accomplished without general anesthesia Dislocation of the radial head during this maneuver Long arm cast for 3 weeks, then functional therapy
Surgical procedure	Re-fixation of the medial epicondyle with K-wire or screw reconstruction of the medial and lateral ligaments if the elbow is unstable
Immobilization	3 weeks
X-ray control	Only after surgery in week 4
Follow-up	6 weeks and 6 months

Table 40.22 Fracture of the medial or lateral epicondyle

Morphology	Fracture of the medial or lateral epicondyle (nearly always as a result of an elbow dislocation)
Signs	Swelling, local pain (lateral or medial)
Diagnosis	X-ray in two planes
Correction potential	None
Complications	Non-union
Non-surgical therapy	Only undisplaced fractures Look for secondary displacement on day 3–4
Surgical procedure	Displaced (> 2 mm) fractures: Open reduction and K-wires or screw fixation Secondary displaced fractures after non-surgical therapy in the control
Immobilization	3–4 weeks, long arm cast
X-ray control	Undisplaced, cast free on day 3–4 Operated fractures in week 4
Follow-up	2–3 months after injury

Table 40.23 Olecranon fractures

Morphology	Olecranon fractures are usually undisplaced and incomplete, particularly in younger children Often seen in combination with other injuries
Signs	Swelling and pain, elbow in flexion
Diagnosis	X-ray in two planes, sometimes very difficult, especially in young children (absence of ossification centers)
Correction potential	None
Complications	Restricted movement
Non-surgical therapy	Long arm cast for undisplaced fractures
Surgical procedure	Longitudinal pinning and cerclage wire fixation in dislocated fractures
Immobilization	Long arm cast for 4 weeks
X-ray control	Non-surgical therapy: Days 5–6 and at week 4 Surgical procedure: At week 4
Follow-up	Clinical control at week 8

Table 40.24 Subluxation of the radial head (Chassaignac)

Morphology	Mostly due to traction on the forearm in 1- to 3-year-old children Subluxation of the radial head
Signs	Painful pronation, elbow in extension
Diagnosis	Clinically, history
Correction potential	Good
Complications	Neglected fracture of the radial neck, persistent dislocation
Non-surgical therapy	Elbow in flexion → fast supination and extension → the click is noticeable
Surgical procedure	Indicated only in neglected cases
Immobilization	None
X-ray control	None
Follow-up	None

Table 40.25 Radial neck fractures

Morphology	Mostly in combination of elbow dislocation, axial trauma on the elbow; the annular ligament can be interposed, more real metaphyseal (neck) fractures than SH I & II
Signs	Restriction of elbow function and pain and swelling
Diagnosis	Clinically & radiologically
Correction potential	Less than 30° of angulation acceptable
Complications	Neglected fracture of the radial neck, persistent dislocation
Non-surgical therapy	Elbow in flexion • fast supination and extension • "Israeli moneuvre"
Surgical procedure	Dislocation more than 50% of the shaft and/or angulated more than 30° Autorth's recommended technique ESIN
Immobilization	None
X-ray control	Postoperative and 4 weeks
Follow-up	3 months

Table 40.26 Monteggia lesions

Morphology	Fracture of the proximal third of the ulna in association with dislocation of the radial head This injury has to be suspected whenever a fracture anywhere along the ulna (bowing, greenstick injury) is visible without an obvious associated fracture of the radius 
Signs	Swelling and pain, elbow in flexion
Diagnosis	X-ray in two planes including both wrist and elbow joints

Table 40.26 (contiued)

Correction potential	None
Complications	Restricted movement, persistence of radial head dislocation
Non-surgical therapy	Long arm cast in undisplaced fractures with correctly centered radial head, towards the center of the humerus in lateral and a.p. X-ray view
Surgical procedure	Displaced fractures with dislocated radial head • Closed reduction of the fracture and radial head dislocation • Fixation of the ulna with ESIN (method preferred by author) Secondary dislocation after non-surgical therapy
Immobilization	4 weeks
X-ray control	Non-surgical therapy: Days 5–6 and at week 4 Surgical procedure: At week 4
Follow-up	Clinical control at week 8

40.12 Forearm Fractures

General Considerations

- Diaphyseal injuries are common in children
- The severity may vary from pure bowing (Table 40.27) to greenstick (Table 40.28) or even to a complete fracture (Table 40.29) with or without displacement
- The level of the fracture varies
- In children, the tendency for the radius and ulna fractures to be aligned is greater than in adults
- Great fracture variability
  - Same fracture type in both bones, but not aligned
  - Isolated fracture of the radius
  - Bowing of radius and ulna (Table 40.27)
  - Fracture of the ulna and bowing of the radius or reversed
- A Galeazzi fracture is the name given to fracture of the distal radius with dislocation of the distal radio-ulnar joint (Table 40.30)

Table 40.27 Bowing fracture of the forearm

Morphology	Plastic deformity of the shaft without fracture of the cortex → microfractures 
Signs	Pain, deformity, restricted movement
Diagnosis	X-ray, two planes
Correction potential	None
Complications	Restricted movement (pronation and supination), re-fracture
Non-surgical therapy	<20° bending → long arm cast, cast wedging (only if necessary), no anesthesia
Surgical procedure	>20° bending → closed indirect reduction and stabilization with ESIN technique
Immobilization	Non-surgical therapy → 4 weeks Surgical procedure → immobilization is not required
X-ray control	At weeks 4
Follow-up	Over 1 year

Table 40.28 Greenstick fracture of the forearm shaft

Morphology	Plastic deformity of the shaft with one-sided cortex fracture 
Signs	Pain, deformity, restricted movement
Diagnosis	X-ray, two planes

Table 40.28 (contiued)

Correction potential	None
Complications	Restricted movement (pronation and supination), re-fracture
Non-surgical therapy	<20° bending → long arm cast, eventually cast wedging, no anesthesia
Surgical procedure	>20° bending → closed indirect reduction and completion of the fracture → stabilization with ESIN technique
Immobilization	Non-surgical therapy → 4 weeks Immobilization is not required after surgical procedure
X-ray control	At week 4
Follow-up	Over 1 year

Table 40.29 Complete diaphyseal forearm fracture

Morphology	Both cortexes are fractured, with or without displacement
Signs	Pain, swelling, deformity
Diagnosis	X-ray in two planes
Correction potential	Partial, 10°–15°
Complications	Mal-union with restricted movement, re-fracture
Non-surgical therapy	Only non-displaced, stable fractures, using a well-molded cast with three-point fixation Angulation <15° can be treated by cast wedging
Surgical procedure	All displaced unstable fractures at any age Failure of retention in non-surgical therapy (ESIN with the possibility of reducing the fracture by making a small incision at the level of the fracture in about 10% of cases)
Immobilization	5–6 weeks for non-surgical therapy No immobilization when ESIN is used
X-ray control	Non-surgical therapy: Days 6–7 and weeks 5–6 ESIN: Weeks 5–6 and before nail removal
Follow-up	6 months

Table 40.30 Forearm fractures – distal third (metaphyseal fractures)

Morphology	• Metaphyseal torus or buckle fractures • Metaphyseal bowing and greenstick fractures • Complete metaphyseal fractures with or without displacement • Salter–Harris I and II fractures
Signs	Pain, swelling, deformity (medial nerve irritation)
Diagnosis	X-ray in two planes
Correction potential	Extremely good, children in <10 years, up to 50°
Complications	Correctly treated, practically none Sometimes an overgrowth of the radius is possible as well as premature closure of the growth plate
Non-surgical therapy	Long arm cast immobilization for torus, greenstick and bowing fractures without reduction Complete fractures should be reduced under general anesthesia since muscle relaxation is an essential part of the reduction in the hands of an experienced surgeon 95% of all fractures can be reduced and stabilized non-surgically
Surgical procedure	Only complete unstable fractures of the distal radius in older or adolescent children need surgical stabilization (K-wires or external fixator) Plate fixation is an exception
Immobilization	3–4 weeks for the majority No immobilization for external fixator or plating
X-ray control	Days 6–7 and weeks 3–4
Follow-up	If there is a malunion at consolidation

Treatment of Forearm Fractures without Anesthesia

- Place child in supine position (Fig. 40.11)
- Place upper extremity in 90° abduction on the edge of the table with their elbow in 90° flexion
- Cover the whole arm with a stocking
- Elevate the forearm using finger traps
- A counterweight is attached across the upper arm with the elbow at 90° flexion, to an extent that the child can still tolerate
- This position is maintained for 15–20 min
- Reduce the fracture by pressing both hands together to stretch the interosseous membrane
- X-ray control
- Apply a well padded dressing
- Apply a well molded long arm cast (must be opened after drying) or dorso-volar long arm splint (author's preferred method)

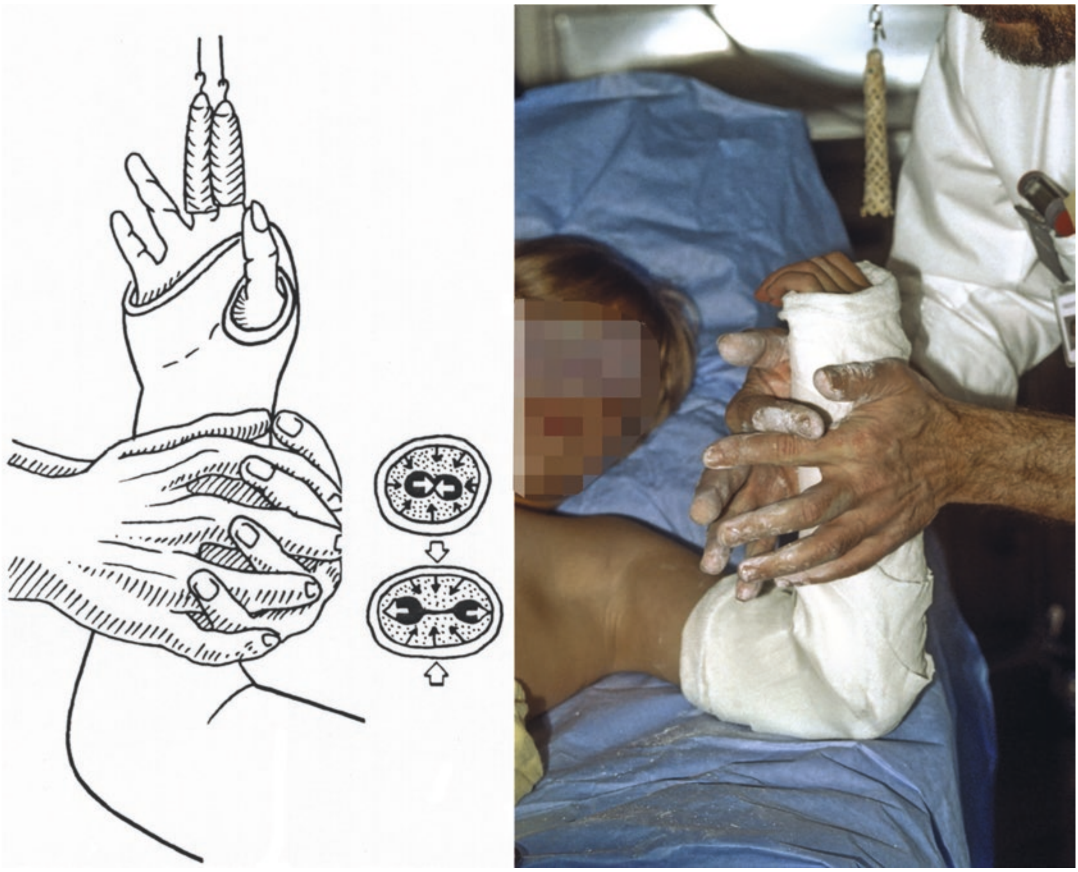


Fig. 40.11 Treatment of forearm fractures without anesthesia

40.13 Wrist and Hand Fractures

General Considerations

- Whereas carpal injuries and multiple unstable fractures of the metacarpals are rare in children, other hand and finger fractures are frequent in children, especially phalangeal fractures and interphalangeal dislocations
- Fractures of the scaphoid are rare in children under 12 years of age. The treatment is Non-surgical with a scaphoid cast for 6 weeks
- Displaced fractures are treated operatively, similar to fractures in adults
- Diagnosis can be difficult and often requires special X-ray techniques
- Fractures of the metacarpals are the most frequent hand fractures
- Each metacarpal has only one epiphysis; for MC I it is proximal (Table 40.31), for MC II–V, distal (Table 40.32)
- Hence, more proximal fractures can be found on the MC I and more distal fractures on the MC II-V

Table 40.31 Fracture of the first metacarpal

Morphology	Mostly metaphyseal torus fractures or Salter–Harris I and II fractures; shaft fractures are rare
Signs	Pain, deformity
Diagnosis	X-ray in two planes
Correction potential	Possible in all planes, exception the frontal plane
Complications	Premature closure of the growth plate
Non-surgical therapy	Undisplaced metaphyseal and diaphyseal fractures treated with a forearm cast without reduction
Surgical procedure	Displaced metaphyseal fractures, closed reduction and ± K-wire fixation Displaced diaphyseal fractures, closed reduction ± osteosynthesis (mini-ESIN, author's preferred method)
Immobilization	Proximal fractures: 2–3 weeks Shaft fractures: 3–4 weeks, independent of the fixation
X-ray control	Non-surgical therapy: Day 4 and week 3 Surgical procedure: Week 4
Follow-up	End of treatment

Table 40.32 Fracture of metacarpals II–V

Morphology	Proximal fractures are rare and mostly undisplaced Subcapital fractures are more frequent, especially metacarpal V
Signs	Pain, deformity When the metacarpal or phalanx bones are involved, the uniform plane of the fingernails is disrupted, and the finger affected overlaps the others
Diagnosis	X-ray in two planes
Correction potential	Very good Remodeling is never capable of correcting a rotational deformity of the fingers
Complications	Axial deviations
Non-surgical therapy	Undisplaced basal fractures and fractures of the shaft Well-fitting plaster cast or splint or "Iselin splint" without reduction
Surgical procedure	Displaced proximal fractures: Closed reduction ± K-wire fixation and plaster cast Displaced shaft fractures: Closed reduction ± plaster cast or mini-ESIN
Immobilization	Proximal fractures: 2–3 weeks Shaft fractures 3–4 weeks, independent of the fixation
X-ray control	Non-surgical: Day 3 or 4 and weeks 3–4 Operative: Weeks 3–4
Follow-up	End of treatment

40.14 Pelvic Ring Fractures

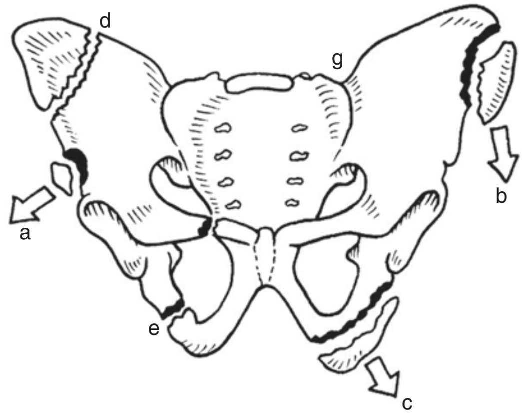
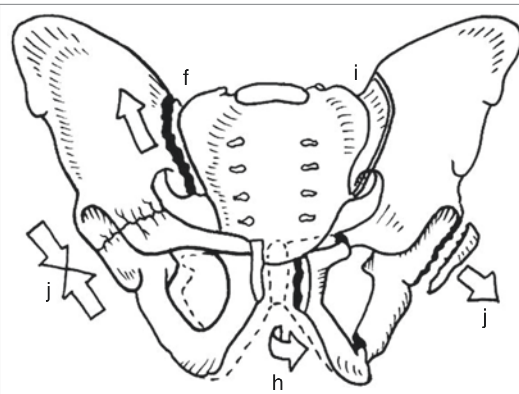
General Considerations

- Pelvic fractures are rarely isolated; most appear as accompanying injuries after heavy direct or multiple trauma
- The degree of severity ranges from a simple fracture of the pubic bone to a complete pelvic ring disruption

Classification

- The classification of pelvic ring fractures is given in Table 40.33

Table 40.33 Classification of pelvic ring fractures

<table>
<tr><th colspan="2">Fractures of the pelvic ring without delayed deformities (stable fractures)</th></tr>
<tr><td>Avulsion of the apophysis of:
• The inferior iliac spine (a)
• The superior iliac spine (b)
• The ischial tuberosity (c)</td><td rowspan="5"></td></tr>
<tr><td>Ilium ala fractures (d)</td></tr>
<tr><td>Pubic arch fractures
(pubis and ischium) (e)</td></tr>
<tr><td>Fractures of the ilium (f)</td></tr>
<tr><td>Iliosacral joint loosening (g)</td></tr>
<tr><th colspan="2">Fractures with severe delayed deformities (unstable fractures)</th></tr>
<tr><td>Symphysis separation (h)</td><td rowspan="3"></td></tr>
<tr><td>Sacroiliac joint disruption (i)</td></tr>
<tr><td>Acetabular fractures (j)</td></tr>
</table>

Treatment

- Treatment of pelvic ring fractures is given in Table 40.34

Table 40.34 Treatment of pelvic ring fractures

	Undisplaced/stable	Displaced/stable
Avulsion of apophysis	Crutches/analgesia <10 days	Same
Ilium ala fracture	Crutches until pain free	Open reduction with screw or K-wire fixation
Pubic arch fracture (pubis and ischium)	Crutches until pain free	Same
Fracture of the ilium	Crutches until pain free	Same
Symphysis loosening	Crutches until pain free	Same
Complete unstable symphysis separation	Crutches for 3–4 weeks	External fixator or Recco-plate fixation in older children
Sacro-iliac joint disruption	External fixator	Reduction, external fixator ±transarticular screw or 4-hole plate
Acetabular fractures	Spica cast 5–6 weeks	Open reduction and screw/plate fixation

Hip Dislocation

- Hip dislocation and its management is discussed in Table 40.35

Table 40.35 Hip dislocation and its management

Morphology	Different types: Superior-iliac, posterior-iliac, anterior-pubic, fracture dislocation Very rare in childhood
Signs	Pain, the involved limb is shorter and is held in flexion, adduction, and internal rotation
Diagnosis	Clinical, X-ray, CT
Correction potential	None
Complications	Femoral head necrosis, re-dislocation, secondary hip dysplasia
Non-surgical therapy	Within the first 8 h, aspiration of the joint; if there is any sign of incongruence, open reduction is indicated
Surgical procedure	Incongruence after reduction Combined with fracture of the acetabular rim
Immobilization	Depending on the injury and treatment: 1–6 weeks
X-ray control	In weeks 4–6 Scintigraphy or MRI if indicated additionally
Follow-up	When necrosis is suspected: Every 6 months

40.15 Lower Limb Fractures

Femoral Neck Fractures

- Femoral neck fractures and their management are discussed in Table 40.36
- The capital femoral and trochanteric epiphyses have cartilaginous continuity along the posterior superior femoral neck due to embryonal development
- Damage to this cartilaginous continuity, as in a femoral neck fracture, may seriously impair normal development of the neck
- Femoral head necrosis results from vessel damage in this region!

Femoral Shaft Fractures

- Femoral shaft fractures and their management are discussed in Table 40.37

Table 40.36 Femoral neck fractures and their management

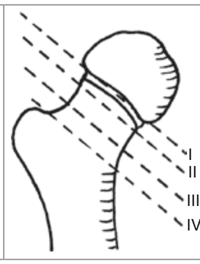
Morphology	Very rare injury in childhood: I Transphyseal injury II Transcervical injury III Cervico-trochanteric injury IV Pertrochanteric injury	
Signs	Pain, the involved limb is shorter and is held in flexion, adduction, and internal rotation	
Diagnosis	Clinical, X-ray in two planes, CT	
Correction potential	Limited	
Complications	Femoral head necrosis, malunion, non-union varus deformity	
Non-surgical therapy	Only undisplaced and stable fractures Joint aspiration	
Surgical procedure	Displaced fractures Open reduction (recommended) Threaded K-wire fixation in small children Screw or angular plate fixation in older children	
Immobilization	Depending on the injury and treatment: 4–8 weeks	
X-ray control	In weeks 4–6 Scintigraphy recommended MRI (using titanium implants if possible) when indicated	
Follow-up	If necrosis is suspected every 6 months	

Table 40.37 Femoral shaft fractures and their management

Morphology	Most frequent injury of the lower leg • Subtrochanteric fractures • Fractures (transverse or oblique) of the proximal and middle third
Signs	Pain, deformity, restricted movement, blood loss, shock
Diagnosis	X-ray in two planes, including both hip and knee joint
Correction potential	Very good, depending of the child's age
Complications	Leg length discrepancy, rotation failure, deviation of the axis
Non-surgical therapy	Children <3–4 years • outpatient overhead extension or for stable fractures initial spica cast (not for children with multiple injuries)
Surgical procedure	Children 4–13/14 years, depending on their weight • closed reduction and ESIN as the first method of choice Unstable, complex fractures • external fixation or minimal invasive plating (MIPO)
Immobilization	3–4 weeks No immobilization after ESIN, MIPO, ex-fix treatment
X-ray control	Overhead extension or spica cast: Weeks 3–4 Surgical procedure: weeks 5–6, before implant removal
Follow-up	Children >10 years until growth stops

Operative Technique with Elastic Stable Intramedullary Nailing (ESIN)

- Child in supine position
- For children <8 years: free position, fixed on the standard table
- For children >8 years: fracture table is recommended (especially for transverse fractures)
- Decide on the direction of the nailing:
  - Rretrograde (normally)
  - Antegrade (special situations)
- A preliminary reduction with the aid of an image intensifier on the fracture table is performed
- The nail entry point is normally one finger's breadth about the proximal tip of the patella, which corresponds to 2–3 cm proximal the epiphyseal line
- Aa skin incision about 3–4 cm in the distal direction from the planned entry point in the bone is performed
- The nail entry point is created by penetrating the near cortex with the awl or drill bit
- The awl is inserted vertically down to the bone, then lowered about 45° to the cortical surface whilst rotating it so that the bone cortex is perforated in an upwards showing angle. With a rotating motion, continue to penetrate the cortical bone at an upward angle
- The nail diameter should be one-third of the narrowest diameter of the medullary canal and as long as the bone when bent. Both nails must be bent in the same way
- The greatest curvature of the nails must be at the level of the fracture
- The first nail is driven to the level of the fracture
- In a similar manner to that previously described, the femur is opened on the opposite side
- The second nail is driven up to the level of the fracture
- The fracture is visualized with fluoroscopy and a decision is taken, which nail will be easier to pass across the fracture and will most effectively pull the proximal fragment into alignment
- This nail is driven across the fracture, monitoring its position with fluoroscopy
- This nail is advanced into the proximal fragment only so far as to ensure that the reduction is maintained
- The second nail is positioned in the same manner
- Both nails can now be advanced to the proximal epiphysis

- Both nails are cut to the right length outside of the skin
- The rotation of the leg is controled
- The final position of the nails is achieved when the end points are placed in the proximal fragment
- The proximal ends of the nails should poke out at least 8 mm from the cortex in order to facilitate easy removal, whilst the low profile minimizes soft-tissue irritation
- If the fracture is distracted, traction is released and the patient's heel is impacted
- In case of axial instability (long oblique or spiral or comminuted fractures, today EndCaps can be used to increase axial stability
- Skin closure
- The nails are not removed before complete consolidation, at least 4–5 months
- Figure 40.12 shows the operative steps

40.16 Distal Femur and Proximal Tibia Fractures

General Considerations

- Very rare fractures in childhood, following high-energy trauma or traffic accidents
- The radiological diagnosis is not easy, however it is not as difficult as for the elbow
- Hemarthros indicates a severe trauma
- Osteochondral fragments, "flake fractures," must be looked for

Classification

- Distal femur and proximal tibia fractures are described in Table 40.38
- Supracondylar and condylar fractures of the femur and their management are described in Table 40.39

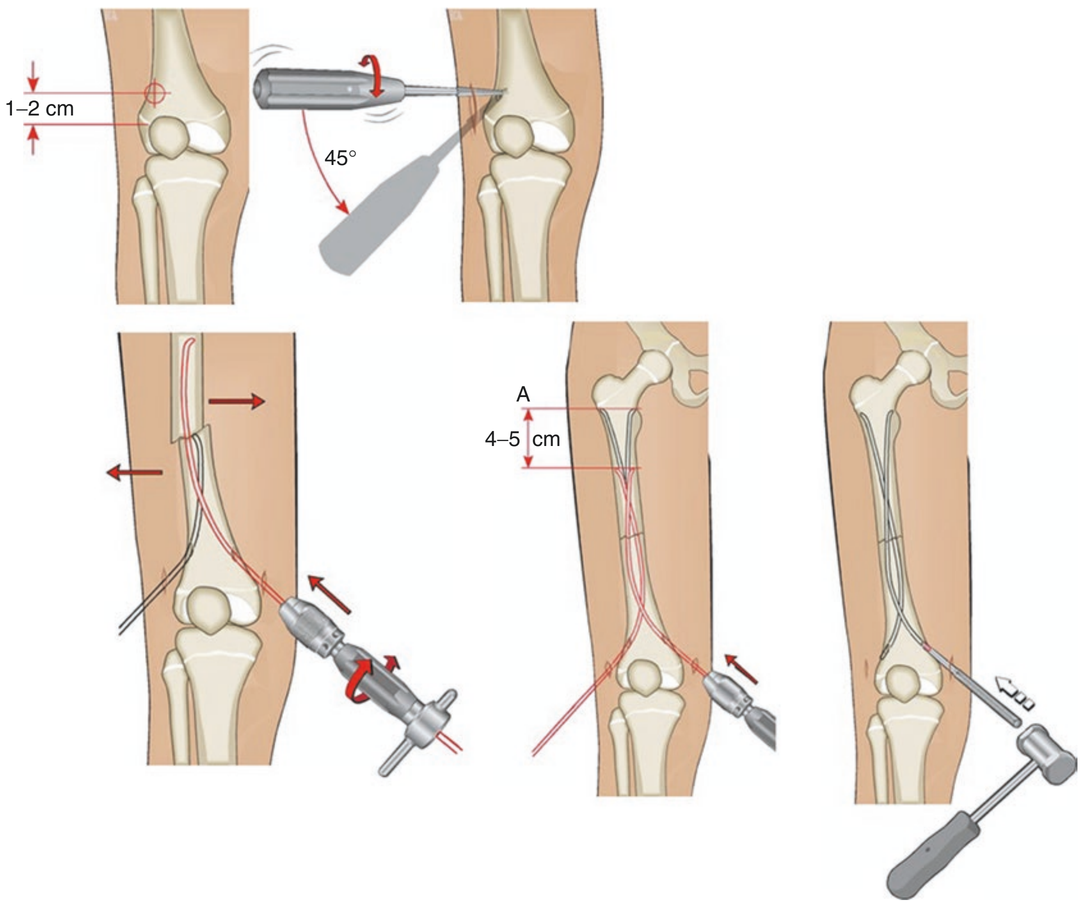


Fig. 40.12 Operative technique with Elastic-Stable-Intramedullary-Nailing (ESIN)

Table 40.38 Distal and proximal tibia fractures

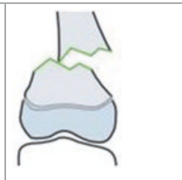
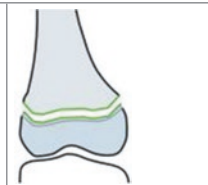
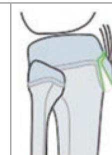
Supracondylar and condylar region						
• Supracondylar fractures (*a*) • Salter–Harris I + II fractures (*b1,2*) • Unicondylar Salter–Harris III + IV fractures (*c1,2*) • Bicondylar Salter–Harris III + IV fractures (*d*)	 **a**	 **b1**	 **b2**	 **c1**	 **c2**	 **d**
Fractures of the proximal tibia "Tibiaplateau"						
• Tibia spine injuries (e) • Salter–Harris I + II fractures (f1,2) • Salter–Harris III + IV fractures (g) • Tibial tuberosity fracture (h)	 **e**	 **f1**	 **f2**	 **g**	 **h**	
Fractures of the proximal tibia metaphysis						
• Simple metaphyseal fracture (i) • Complex metaphyseal fracture (j)	 **i**		 **j**			

Table 40.39 Supracondylar and condylar fractures of the femur

Morphology	• Supracondylar buckle fractures • Complete transverse or oblique fractures, metaphyseal or physeal (Salter–Harris I + II) • Uni- or bicondylar (Salter–Harris III + IV) fractures (very rare in childhood)
Signs	Pain, knee stiffness, swelling, pulseless lower leg
Diagnosis	X-ray in two planes
Correction potential	Good, depending on the child's age
Complications	None for supracondylar fractures Varus or valgus angulation following premature partial closure of the growth plate, limitation of knee motion, leg length discrepancy
Non-surgical therapy	All undisplaced fractures independent of the age Long leg cast immobilization in 10° flexed
Surgical procedure	All displaced fractures, which need reduction • Closed (extra-articular fractures) reduction and K-wires or ex-fix stabilization • Open (articular fractures) reduction and K-wires or screw fixation • Any fracture that needs a reduction under anesthesia should be treated with a stable, definitive fixation
Immobilization	4–6 weeks
X-ray control	Non-surgical: Days 4, 10 and week 4 Operative: Postoperative and weeks 4–6
Follow-up	Up to 2 years, depending on the fracture type

- Fractures of the proximal tibial epiphysis and their management are detailed in Table 40.40

Table 40.40 Fractures of the proximal tibial epiphysis and their management

Morphology	Fracture types: • Complete • Type "greenstick" • "Judge fracture" • Type bowing and torus or buckle
Signs	Pain, swelling
Diagnosis	X-ray in two planes • medial open wedge fracture
Correction potential	No correction of valgus deformity
Complications	Consolidation problems with progressive valgus angulation
Non-surgical therapy	Stable, undisplaced fractures with valgus angulation <10° • long leg cast, cast wedging after 8 days to compress the medial cortex
Surgical procedure	Displaced fractures and fractures with valgus angulation >10° • closed or open reduction K-wires or medial ex-fix stabilization (compression on the medial cortex)
Immobilization	~ 5 weeks
X-ray control	Non-surgical therapy: Days 4, 8 and week 5 Surgical procedure: Postoperative and week 5
Follow-up	Every 6 months for 2 years

40.17 Patella Fractures and Dislocations

General Considerations

- Patellar dislocations (Table 40.41) are common when considering the entire spectrum of acute and chronic subluxation and dislocation injuries
- More frequently, chronic subluxation mimics actual dislocation

- Dislocation of the patella is frequent in young girls
- Prerequisites are "genua valga," being overweight, and "patella alta"
- Fractures of the patella (Table 40.42) result from direct trauma and high-energy extension trauma (such as high jumping)

40.18 Tibial Shaft Fractures

General Considerations

- Fracture of the tibial shaft (Table 40.43) is one of the most frequent fractures of the lower leg in childhood

Table 40.41 Patellar dislocation and its management

Morphology	Nearly always dislocations in the lateral direction The dislocation may be complete or incomplete
Signs	Pain, swelling, blocking of the knee, hemorrhage in the joint
Diagnosis	Clinic signs, X-ray in two planes
Correction potential	None
Complications	Overlooked "flake fracture" Repeated dislocations
Non-surgical therapy	Reduction and extension of the knee while the hip is flexed ± aspiration of the hemarthros if the knee is painful
Surgical procedure	If there are any signs of osteochondral fractures arthroscopy is indicated Re-fixation or removal of the fragment
Immobilization	The limb should be immobilized in a cylindrical cast
X-ray control	After reduction
Follow-up	Physiotherapy if habitual dislocation is suspected

Table 40.42 Patellar fractures and their management

Morphology	• Incomplete and complete fractures • Inferior and superior fractures • Longitudinal and transverse fractures • "Sleeve" fracture • Variations of the norm • bipartite patella
Signs	Pain, swelling, blocking of the knee, hemorrhage in the joint
Diagnosis	Clinic, X-ray in two planes
Correction potential	Partial, a cartilaginous gap is always filled out with fibrous cartilage
Complications	Non-union, pre-arthrosis
Non-surgical therapy	Fissures, undisplaced, stable fractures • cylindrical cast
Surgical procedure	All displaced fractures • circumferential wiring of the patella Implant removal after 4–5 months
Immobilization	4–5 weeks
X-ray control	Non-surgical therapy: Day 6 and week 5 Surgical procedure: Postoperative and week 5
Follow-up	6 months after implant removal

Table 40.43 Tibial shaft fractures

Morphology	Fractures of the middle and distal third Spiral fractures are more frequent than transverse fractures
Signs	Pain, swelling, angulation
Diagnosis	X-ray in two planes including the knee and ankle joint
Correction potential	Good, depending on the age No correction for rotation deformities
Complications	Different rotation of the feet, remaining angulation
Non-surgical therapy	Undisplaced and stable fractures with angulation <10° (open long leg cast and if necessary cast wedging on days 4–5)
Surgical procedure	The indication for operative therapy is rare Shortening of the tibia with bowing of the fibula (ex-fix or MIPO) ESIN can produce non-union because of the blocking fibula
Immobilization	4–5 weeks No immobilization is required after surgical procedure
X-ray control	Non-surgical therapy: Days 4 and 10 and weeks 4–5 Surgical procedure: Postoperative, week 5
Follow-up	Every 6 months, up to 2 years after the procedure

- Injuries of this region vary considerably with both age and mechanism of injury
- In infants and children, the typical injury is a spiral tibial fracture with an intact fibula
- This circumstance influences the kind of treatment and the outcome
- Complete fractures of the tibia and fibula (Table 40.44) are unstable, and often shortened with rotational failures
- Special types: toddler fractures or bowing of the fibula or (rarely) of the tibia
- Fractures of the tibial shaft (isolated tibial fractures)

Table 40.44 Complete fracture of the tibia and fibula

Morphology	Fractures of the middle and distal third Spiral fractures are more frequent than transverse fractures Very often fully displaced as the stabilizing effect of the fibula is missing
Signs	Pain, swelling, angulation
Diagnosis	X-ray in two planes including the knee and ankle joint
Correction potential	Good, depending on the child's age No correction for rotation deformity
Complications	Different rotation of the feet, remaining angulation, leg length discrepancy
Non-surgical therapy	Undisplaced and stable fractures with angulation <10° (open long leg cast and if necessary cast wedging on days 4–5)
Surgical procedure	The indication for surgery is rare Displaced/unstable fractures (oblique and spiral) Method of choice • ESIN or ex-fix (MIPO in older children)
Immobilization	4–5 weeks No immobilization required after surgical procedure
X-ray control	Non-surgical therapy: Days 4 and 10 and weeks 4–5 Surgical procedure: Postoperative, week 5
Follow-up	Every 6 months, for up to 2 years after the procedure

40.19 Distal Tibia and Ankle Joint Fractures

General Considerations

- Like the proximal region, the distal metaphysis may sustain injury in patterns of varying severity
- Due to the microstructural differences between the thick diaphysis and the thinner metaphysis, greenstick and torus fractures are common

- Fractures of the ankle joint are classified according to the maturation of the epiphysis and the child's age (Table 40.45)
- The epiphysis begins to close from the age of 12 in girls, 14 in boys
- Fracture types vary depending on epiphyseal maturation
- Extra-articular (Table 40.46) and intra-articular (Table 40.47) fractures and their management are discussed below

Table 40.45 Classification of isolated distal tibia and ankle joint fractures

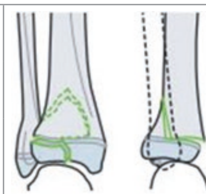
Extra-articular			
Metaphyseal torus or greenstick fracture (*a*) Complete metaphyseal fracture (*b*) Epiphysiolysis (Salter–Harris I) (*c*)	 a	 b	 c
Epiphysiolysis with metaphyseal wedge (*d*)	 d		
Articular fractures			
Epiphyseal fracture (Salter–Harris III) (*e*) or Tillaux (two-plane) fracture Epiphyseal fracture with metaphyseal wedge (Salter–Harris IV) (*f*) Tri-plane fracture (Salter–Harris IV) (*g*)	 e	 f	 g

Table 40.46 Distal tibia extra-articular fractures and their management

Morphology	Metaphyseal torus fracture Metaphyseal bowing fracture Complete metaphyseal fracture Epiphysiolysis (Salter–Harris I) Epiphysiolysis with metaphyseal wedge
Signs	Pain, deformation, restricted movement
Diagnosis	X-rays in two planes Look for accessory ossification Documentation under image intensifier may be necessary
Correction potential	Very good
Complications	Alteration of leg length, valgus deformity, premature closure of the growth plate, fibulo-tibial synostosis
Non-surgical therapy	Metaphyseal torus and bowing fracture (plaster cast immobilization and cast wedging if necessary) Metaphyseal complete fracture (stable reduction, plaster cast) Stable, Salter–Harris I + II fractures and reduction, plaster cast)
Surgical procedure	Complete displaced, unstable metaphyseal fractures • Closed or open reduction and ex-fix or K-wires or ESIN fixation when distal fragment >4 cm Displaced, unstable Salter–Harris I + II fractures • Closed or open reduction and minimal invasive screw fixation under image intensifier with cannulated self-drilling, self-tapping screws or K-wire fixation
Immobilization	4–6 weeks
X-ray control	Non-surgical therapy: Day 6, weeks 4–5 Surgical procedure: Postoperative, week 5
Follow-up	Every 6 months, for up to 2 years after the procedure

40.19.1 Bi- and Tri-plane Fractures: "Fractures of Tillaux"

General Considerations

- This particular type of injury affects a part of the anterolateral tibial epiphysis

Table 40.47 Distal tibia intra-articular fractures (Salter–Harris III and IV) and their management

Morphology	Epiphyseal fractures (Salter–Harris III) Epiphyseal fractures with metaphyseal wedge (Salter–Harris IV) "two-plane" or "tri-plane" fractures
Signs	Pain, deformation, restricted movement
Diagnosis	X-ray in two planes Look for accessory ossification Documentation under image intensifier may be necessary
Correction potential	Moderate
Complications	Alteration of leg length, valgus deformity, premature closure of the epiphysis, non-union
Nonoperative therapy	Cast or splint for undisplaced fractures with an articular gap <2 mm
Operative treatment	Displaced unstable Salter–Harris III + IV fractures (closed or open reduction and minimally invasive screw fixation under image intensifier with cannulated self-drilling, self-tapping screws or K-wire fixation)
Immobilization	4–6 weeks
X-ray control	Nonoperative therapy: Day 6, weeks 4–5 Operative treatment: Postoperative, week 5
Follow-up	Every 6 months for up to 2 years after the procedure

- The segment may extrude anteriorly and laterally
- Ankle congruity is of concern because juvenile two-plane fractures involve the weight-bearing articular surface
- The fracture may be accompanied by a posterior metaphyseal fragment and in this case the fracture is called a "tri-plane fracture"
- The exact diagnosis can often be difficult when only based on standard a.p. X-ray projection of the distal tibia and fibula
- Exact examination under the image intensifier can clarify the diagnosis
- However, CT may exhibit far greater accuracy than plain radiographs in delineating the degree of joint displacement and fragment separation

- This fracture type occurs especially in adolescents
- A schematic and model illustration of a bi-plane fracture at the ankle joint is shown in Fig. 40.13
- A schematic and model illustration of a tri-plane fracture at the ankle joint is shown in Fig. 40.14

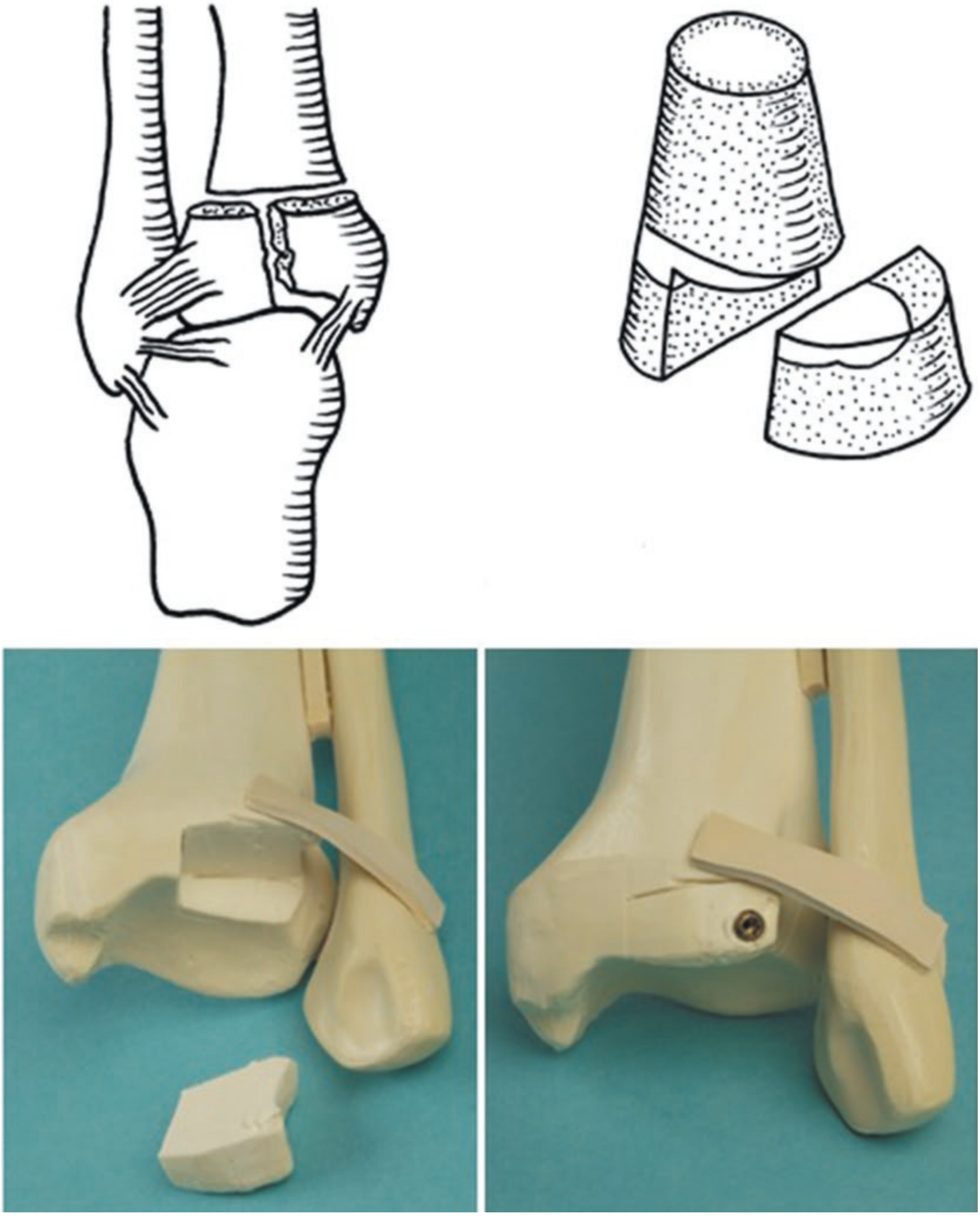


Fig. 40.13 Schematic and model illustration of a bi-better we say two-plane as this is the international term plane fracture at the ankle joint

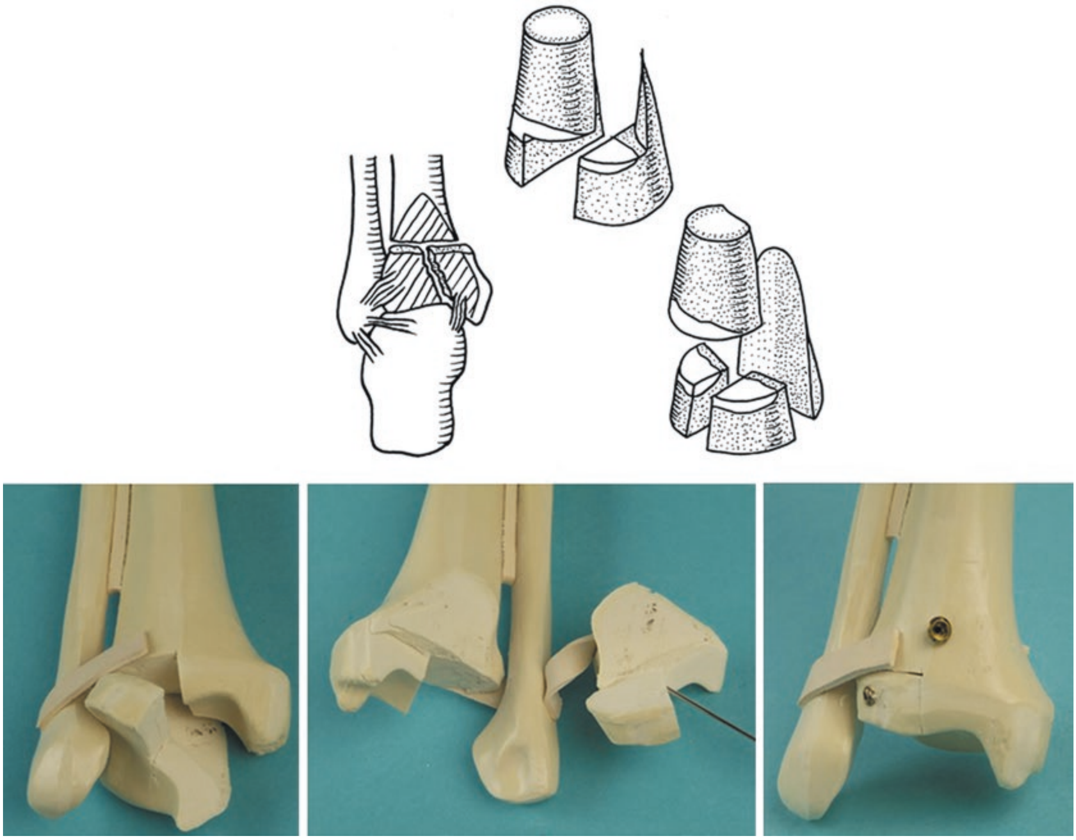


Fig. 40.14 Schematic and model illustration of a tri-plane fracture at the ankle joint

Treatment

- The aim of therapy is exact reconstruction of the joint surface
- Undisplaced (<2-mm gap) bi-plane and tri-plane fractures are treated non-surgically by a well-padded compression dressing and posterior splint. After the swelling has disappeared the fixation is changed to a Sarmiento type cast
- Displaced bi- and tri-plane fractures are treated surgically
- Reduction of the fracture and retention are achieved using a minimally invasive technique such as that using cannulated, self-drilling, self-tapping screws
- The extremity is placed directly on the image intensifier
- The leg must be turned so that the fracture can be seen exactly in an a.p. view
- The screws must be placed exactly perpendicular to this plane. The adaptation of the fracture can easily be observed with the intensifier

40.20 Foot Fractures

General Considerations

- Fractures of the talus and the calcaneus are rare in childhood
- Fractures of the metatarsals are frequent, the first and fifth rays in particular are involved
- The first metatarsal may be injured proximally, either in the metaphysis or the proximal growth plate
- Solitary fractures of the metatarsal diaphysis are usually undisplaced
- Symptomatic accessory bones make diagnosis difficult

Treatment

- The treatment of foot fractures is detailed in Table 40.48 and complications arising are listed in Table 40.49

Table 40.48 The treatment of foot fractures

Fracture type	Therapy	Immobilization
Calcaneus	Undisplaced→non-weight-bearing cast	6–8 weeks
	Displaced→open reduction and screw or plate stabilization, non-weight-bearing cast	
Talus	Undisplaced→non-weight-bearing cast	6–8 weeks
	Displaced→open reduction and screw or K-wire fixation, non-weight-bearing cast	
Metatarsal	Undisplaced→non-weight-bearing cast	3–4 weeks
	Displaced→open reduction and screw or K-wire fixation, non-weight-bearing cast	

Table 40.49 Complications of foot fractures

Fracture type	Complication
Calcaneus	Arthrosis, stiffness in the subtalar joint, pain
Talus	Necrosis, arthrosis of the ankle joint, stiffness in the ankle joints
Metatarsals	Non-union, pain