

# MODERN TREATMENT OF PAEDIATRIC LIMB FRACTURES

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## INTRODUCTION

Injuries of the skeleton are extremely frequent in childhood due to the impulsive character of children. One out of seven children visiting the emergency department has a fracture.

The knowledge of the immature skeleton is a must for every paediatric surgeon dealing with fractures in childhood. Growth itself and different physical qualities of the skeleton are the main differences between a child and an adult. The potential for adaptation is much higher in the immature bone, however, it is also more vulnerable than the mature one. Fractures of immature bones could result in growth acceleration or growth restriction inducing deformity problems. Luckily enough fractures in children heal rapidly depending on the child's age and deformity direction, remodelling with correction of nearly all angular malunions is possible. The growth plate or epiphysis of the immature skeleton is where the attention of the paediatric surgeon should be drawn. The epiphysis is the primary centre for bone growth and is divided into two functional zones: the growth zone and the matrix formation zone. The growth zone is involved in longitudinal and circumferential bone growth, whereas the epiphysis responds to compression or tension stimuli. The most rapid structural changes occur in the metaphysis where primary trabeculae are produced. The circumferential growth of the diaphysis is described as an appositional bone formation whereas the medullary cavity is enlarged.

The factor growth, a privilege of the child's bone enables a reduction or even a correction of angular deformities by selective absorption or apposition of bone mass, possibly driven by compression and tension forces. Never the less an exact evaluation of the fracture is inevitable with appropriate therapeutic

intervention, keeping in mind that the initial treatment should also be the definitive one.

## GENERAL CONSIDERATIONS

### FRACTURE TYPES

Fractures can be divided in sufficiently stable or unstable fractures. Regarding the anatomical localization they can be divided in dia- or metaphyseal and articular ones.

TABLE 1

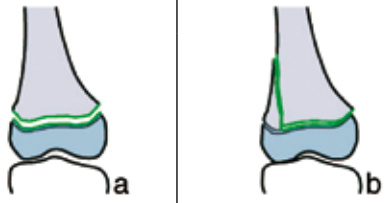
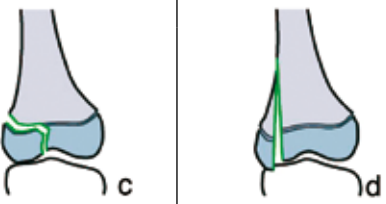
*Bone fracture classification according to location, displacement and stability.*

Sufficiently stable	Diametaphyseal	Transverse, oblique or spiral fractures without shortening and with tolerable limits according to the age or involving one of the bones of forearm or lower limb Greenstick fracture: Bowing fractures with complete fracture of one cortex and incomplete one of the contra lateral cortex Buckle fracture: Compression of the metaphyseal cortex of one side Bowing fracture: Greenstick fracture in the metaphysic Supracondylar fracture
	Articular, Epiphyseal	Dislocation < 2 mm
Unstable	Diametaphyseal	Fully dislocated with shortening or shortening tendency Supracondylar fracture
	Articular, Epiphyseal	Dislocation > 2 mm

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TABLE 2

Further classification can be applied according to the epiphysis involvement: (Salter / Aitken classification).

Salter				Aitken
I.	Epiphysiolysis (a)			I.
II.	Epiphysiolysis with metaphyseal wedge (b)			
III.	Epiphyseal fracture (c)			II.
IV.	Epiphyseal fracture with metaphyseal wedge (d)			III.

X-RAY EXAMINATIONS

The clinical picture is very important as X-ray in children does not necessarily show the fracture. An X-ray should provide the desired information and only if there is a therapeutically consequence. X-ray in two levels is mandatory, whereas the proximal and distal joints should be also visible. X-ray of the contra lateral extremity is obsolete. Keep in mind that on the X-ray of a child’s joint this shows bigger than in reality as around the epiphysis the cartilage is thick.

PRINCIPLES OF CONSERVATIVE TREATMENT

*Closed reduction*

Closed reduction is nowadays mainly used for the upper extremities and should be always carried out under anaesthesia (local or general). Whilst the child is in supine position at the side border of the table, the forearm is extended using finger traps. The elbow is in 90° flexion and a counter-weight is placed over the humerus for 20–30 min. A reduction follows by a manoeuvre repeating the fracture mechanism and trying to spread the interosseous membrane. After X-ray control, a plaster is applied.

*Extension treatment*

Extension treatment decreased significantly as surgical procedures have been adapted for children reducing the hospitalization significantly. Extensions are indicated only for femur fractures in newborns and children under the age of 3 years, mostly as overhead – extension. The children have to be given sufficient analgesia and sedation. Primarily the healthy leg is stuck with plaster on full leg length. The plaster on the affected leg is placed distal of the fracture in order to achieve traction. Both legs are fixed on the over-

head arch so that the buttocks of the child do not have contact with the mattress.

*Plaster cast wedging*

Plaster cast wedging is indicated for treatment of a remaining angulation of an un-dislocated fracture after fracture stabilisation without reduction. Wedging should be performed at least one week after the trauma as soon as swelling and pain have disappeared. The plaster is cut at the deepest point of the concavity of the deformity and the bone moved to the right position by placing the wedge in the cut.

PRINCIPLES OF SURGICAL TREATMENT

*Semi-open reduction*

Semi-open reduction is indicated for partial or total unstable dislocated fractures which can be reduced and closed definitively. A closed reduction is performed under sterile conditions as described above followed by percutaneous K-wire fixation and immobilisation with a plaster splint.

*Kirschner wires*

Kirschner wires (K-wires) osteosynthesis is indicated for retraction of reduced metaphyseal limb fractures as well as fractures of the hand and foot. They are not suitable for stabilisation of diaphyseal fractures. K-wires should be preferably inserted percutaneously in order to remove them without anaesthesia. The crossing points of the K-wires should be proximal to the fracture line and should penetrate the opposite cortex. In case the epiphysis has to be crossed, repeated attempts should be avoided and thinner K-wires should be preferred. The infection risk is reduced by daily care of the pins with antiseptic agents. K-wires can be removed after 3–4 weeks.

*External fixator osteosynthesis*

External fixator osteosynthesis (monotube / tubular system / circular frame etc.) is indicated in cases of comminuted femur, tibia, forearm fractures, in older children, polytrauma, and long spiral fractures. A closed reduction should be attempted either using an extension table or if feasible without one. An imaging intensifier is necessary in order to place the Schanz screws on both ends of the fracture, depending on the system used, i.e. in the monotube system, the entry points are predefined. When using the frame system, one entry point should be near the fracture, the other in a distance. Reduction is performed with all clamps open and then fixed. Daily care of the pins reduces the infection risk.

*Elastic Stable Intramedullary Nailing*

Elastic Stable Intramedullary Nailing (ESIN) is a minimal invasive, movement stable and partial weight bearing system that enables the retraction of transverse, oblique and short spiral, diaphyseal fractures in children (3–15 years old) using intramedullary special elastic nails. See special chapter below.

*Screw osteosynthesis*

Screw osteosynthesis is indicated in cases of articular and periarticular fractures, Salter Harris II fractures, mainly in the distal tibia and femur and femoral neck fractures. Nowadays the screws are self drilling, self tapping and cannulated so that the implantation has become easy. The limb is positioned directly on the intensifier and then rotated so that the fracture line is

visible in the ap-view. A guide wire is placed on the fragment parallel to the intensifier, which is then drilled into the bone across the contra lateral cortex. The cannulated screw at the appropriate length is placed then over the guide wire and tightened.

*Plate osteosynthesis*

Plate osteosynthesis is indicated in cases of comminuted femur, tibia, forearm fractures and long spiral fractures with or without a wedge in older children. However, plate osteosynthesis in children should be reserved to exceptions. In such cases new types of plates like the LC-DCP and LCP plates should be used. Furthermore the so called minimal invasive plate osteosynthesis (MIPO) should be applied

*Knee / hip joints puncture*

The indications for a joint puncture are a posttraumatic hemarthros (not before 24 hrs) and suspicion for infection. The puncture should be performed under local anaesthesia or after application of anaesthetic cream. For the knee it is recommended to make the puncture in the lateral – proximal recess. For the hip the puncture could be performed either from lateral or from anterior under consideration of the artery / nerve or according to the medial (Ludloff) approach.

*Elastic Stable Intramedullary Nailing*

Elastic Stable Intramedullary Nailing (ESIN treatment) is nowadays the golden standard for nearly all shaft fractures in children and adolescents.

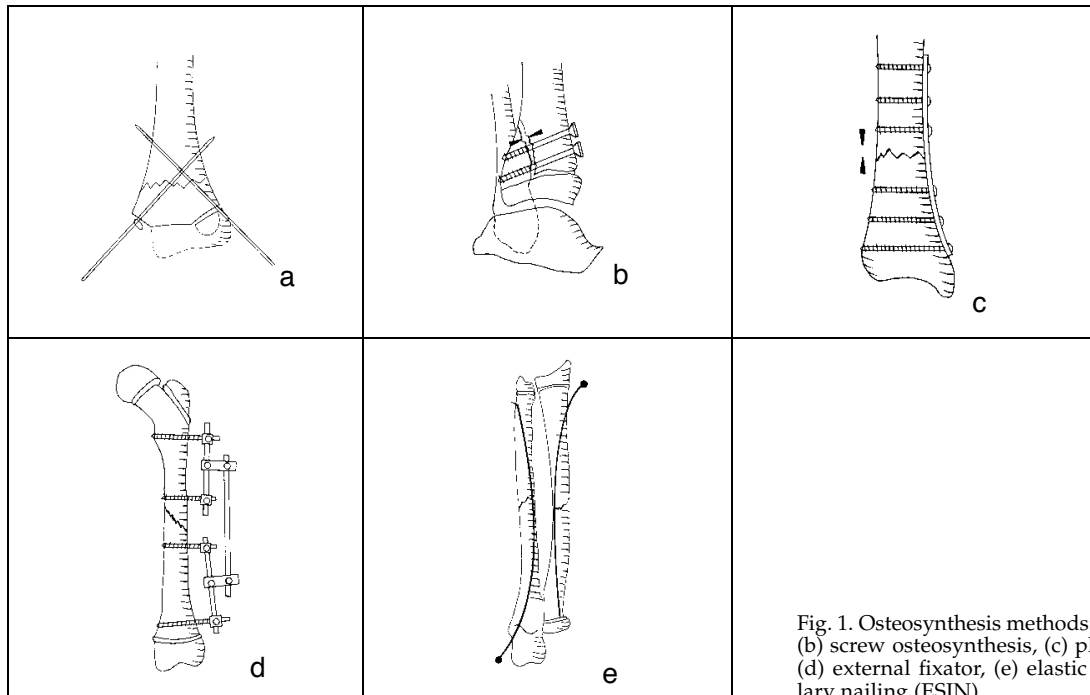


Fig. 1. Osteosynthesis methods: (a) Kirschner wire, (b) screw osteosynthesis, (c) plate osteosynthesis, (d) external fixator, (e) elastic stable intramedullary nailing (ESIN)

### Method principles

The flexible intramedullary nails provide a sufficient stability and enable the child to perform early movements with partial weight bearing. The main indications for ESIN are transverse, oblique and short diaphyseal fractures of the limbs of children. In addition the minimal invasive character of this method, with less damage of the structures at the fracture site, supports rapid healing with stimulation of periosteal and endosteal callus growth. This method enables micro motion at the fracture site, resulting in a shorter consolidation and remodelling of the bone.

### Biomechanics

The basic idea of ESIN fixation is the so called 3-point contact. This is achieved by precontouring the nails having one point at the enter site, one at the inner cortex at the fracture site and one at the tip of the nail, which is anchored in the metaphysis. In most of the cases two identical nails (diameter and precontour) are inserted opposite each other, creating an oval intramedullary construction at the fracture site. Both tips of the nail have to be sufficiently anchored in their respective proximal and distal metaphysis enabling alignment. Axial as well as translational stability is achieved when a long inner cortical contact is present. Rotational stability is assured when the tips of both nails are well anchored. See Fig. 2.

### Method (Fig. 3)

In cases of lower limb fractures, children less than 8 years of age are fixed on a standard table, children older than 8 years are fixed on a fracture table. Depending on the type of fracture a decision on the direction of nailing is taken. Either the retrograde tech-

nique is applied as in most of the cases or the antegrade technique. After a preliminary reduction using the image intensifier the nail entry point is marked about 2–3 cm proximal to the epiphysis. A skin incision is performed about 3–4 cm distal of the planed entry point on the bone. The bone is palpated and the near cortex is penetrated with an awl which is held in a vertical position to the bone, until it is anchored to the cortex. Then the awl is lowered at an angle of about 10° and pushed through the medullary channel. The nails are then selected using the rule: one third of the narrowest diameter of the medullary channel. The nails are then bent in the same way over the length of the bone whereas the maximum bending point has to correspond to the fracture level. The first nail is driven to the fracture level. In a similar way the contralateral side of the bone is dissected and the second nail is inserted up to the fracture level. The fracture is reduced under X-ray control. Accordingly, the nail, which seems to easily pass the fracture, is driven forward first, pulling most effectively the proximal fragment into alignment. This nail should be advanced into the proximal fragment only so far as to ensure reduction. The second nail follows in the same manner. Both nails are then advanced to the proximal epiphysis, avoiding its injury. The nails are cut to length, leaving enough nail out of the bone in order to retract it later considering however that long ends induce soft tissue and skin irritation.

### End caps

In cases where the axial stability is not ensured end caps should be used. Their use prevents shortening of the bone and an excellent protection of the soft tissues.

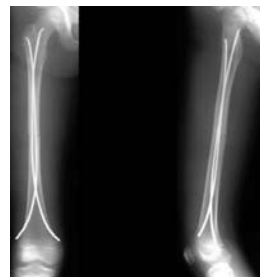
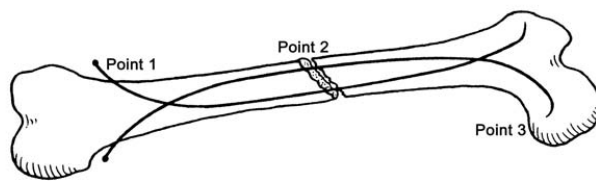


Fig. 2. Three point contact in ESIN technique. Point 1 = enter site, Point 2 = inner cortex, Point 3 = metaphysis anchorage

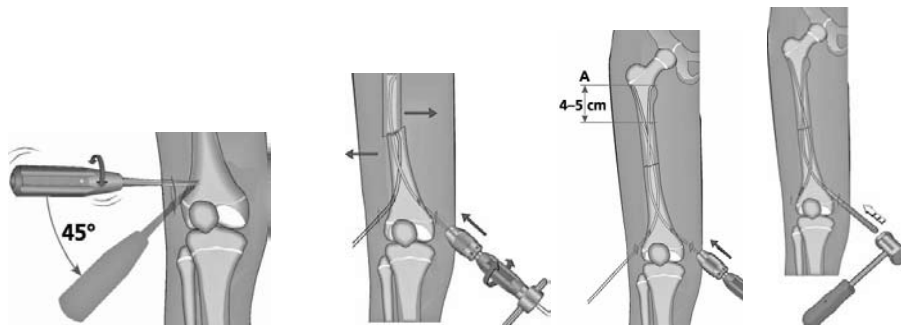


Fig. 3. ESIN, operative technique (see text for explanation)

*Joy-stick technique*

In special cases, where closed reduction is difficult the joy-stick technique can be applied. A temporary K-wire is inserted into the proximal and distal fragments. The wires can then be used as joy sticks for fracture reduction, whereas a better control of the proximal fragment can be achieved.

GUIDELINES FOR THE FRACTURE IMMOBILISATION IN CHILDHOOD

Note that time needed for healing of metaphyseal fractures is about half the time for diaphyseal fractures, whereas diaphyseal transverse fractures heal slower than diaphyseal oblique fractures.

TABLE 3

*Guidelines for the fracture immobilisation in weeks.*

Age	< 5 years	5-10 years	> 10 years
<b>Humerus:</b>			
Proximal stable	1	2-4	3-4
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 (+ elbow dislocation)	2-3	2-3	4
Forearm shaft incl. Greenstick fracture	3	4	4-6
<b>Radius:</b>			
Proximal	1-2	2-3	3-4
Distal	2-3	3-4	4-5
Salter Harris I radius distal	2	2-3	3-4
<b>Ulna:</b>			
Distal	2-3	3-4	4-5
Olecranon	2	2-3	3-4
Carpus		4-6	5-8
Metacarpal proximal and distal		2-3	3-4
Metacarpal shaft		3-4	4-6
Fingers proximal and distal	1-2	2-3	3-4
Fingers shaft	2-3	3-4	4-6
<b>Femur:</b>			
Neck of the femur		4-6	6-8
Subtrochanteric fractures	2-4	4-5	5-6
Shaft	2-3	4-5	4-6
Distal	2-3	3-4	4-5
<b>Tibia and lower leg:</b>			
Tibial spine fracture		3-4	4-6
Proximal metaphysis	2-3	3-4	4-5
Shaft	2-3	3-5	4-6
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
Fibulo - talar ligaments / osseous avulsion		3-4	4-6

L. von Laer (2007)

FRACTURES OF THE UPPER LIMBS

GLENOHUMERAL JOINT DISLOCATION

This is a rare situation in infants and young children, although dislocations have been described as a birth injury. The shoulder joint capsule possesses a certain degree of intrinsic laxity allowing displacement during stress. In most of the cases the humerus is most likely fractured through the epiphysis.

TABLE 4

*Glenohumeral joint dislocation.*

Morphology	Mostly adolescent injury with head dislocation after closing of the proximal epiphysis
Symptoms	Joint deformity, empty glenoid
Diagnosis	Clinical examination and X-ray
Correction potential	None
Complications	Lesions of the axillary nerve
Non-surgical treatment	Reduction and Gilchrist dressing
Surgical treatment	There are no good surgical methods in childhood
Immobilisation	Three weeks
X-ray control	None
Follow up	Not necessary
Prognosis	Generally good

## HUMERUS FRACTURES

This fracture is seldom in childhood and occurs mostly after direct trauma or trauma during birth. Mostly they present as transverse or oblique fractures.

TABLE 5

*Proximal humerus fractures.*

Morphology	Approximately 60% are sub-capital and 40% Salter Harris II fractures
Symptoms	Deformity, pain
Diagnosis	X-ray, whereas interpretation is often difficult especially in un-dislocated fractures. The epiphysis is misinterpreted as a fracture as well as the three ossification centres
Correction potential	Great potential Angulation in the sagittal and frontal plane is well tolerated up to 60° in children < 12 years old, up to 30° > 12 years old
Complications	Practically unknown in neonates, possible premature epiphysis closure
Non-surgical treatment	Desault or Gilchrist dressing Stable un-dislocated fracture at any age Stable fracture with angulation less than 60° in children < 12 years and less than 30° > 12 years old If anaesthesia is needed for reduction, a definitive and stable treatment should be provided
Surgical treatment	Children over 10–12 years old with unstable fracture. Monolateral / radial ESIN in an ascending technique. Open reduction is a rare exception Additional immobilisation is not necessary and the nails are removed after 3–4 months
Immobilisation	Three – four weeks
X-ray control	For non-surgical treatment at day 3–4 and week 3–4. In case of major displacement secondary surgical treatment is necessary For surgically treated postoperatively and at week 4
Follow up	Radiological and clinical at week 3
Prognosis	Generally good

TABLE 6

*Humerus shaft (diaphyseal) fractures.*

Morphology	Rare fractures
Symptoms	Deformity, pain
Diagnosis	X-ray in two planes
Correction potential	Great in all planes
Complications	Radial nerve injury especially in long spiral fractures of the distal humerus third
Non-surgical treatment	Desault or Gilchrist dressing for: Stable un-dislocated fracture or with tolerable displacement at any age Stable fracture with angulation < 30° In case anaesthesia is needed for reduction, a definitive and stable treatment should be provided
Surgical treatment	Children over 10–12 years old with unstable fracture. The preferred method is the ESIN technique without additional immobilisation and the nails are removed after 3–4 months Radial nerve irritation is not an indication for surgical intervention
Immobilisation	Three – four weeks
X-ray control	For non-surgical treatment at day 3–4 and week 3–4. In case of major displacement secondary surgical treatment is necessary For surgically treated postoperatively and at week 4
Follow up	Radiological and clinical at week 3 or 4
Prognosis	Generally good

ELBOW JOINT FRACTURES

Mostly, children of 3 to 10 years of age have elbow fractures. X-ray is often difficult to interpret and good anatomical knowledge of the elbow is necessary. Special care should be given to the diagnosis of un-dislocated lateral condyle fractures, isolated fractures of the radial neck and Monteggia fractures.

Classification becomes more complicated when the joint and the displacement of the distal fragment is considered.

TABLE 7  
*Elbow joint fractures.*

In relation to the joint	Articular fractures	Lateral condyle Transcondylar
	Extra – articular fractures	Supracondylar Epicondylar
In relation to the displacement of the distal fragment	Fractures in extension	Dorsal displacement in 95%
	Fractures in flexion	Ventral displacement in 5%

TABLE 8  
*Localisation of elbow fractures.*

Supracondylar fractures (a)			
Transcondylar fractures: lateral condyle (b1,2) medial condyle (very rare)			
Proximal radius fractures (e)			
Elbow joint dislocation			
Ligament avulsions: lateral epicondyle (c) medial epicondyle (d)			
Olecranon fractures (f)			
Monteggia fractures (isolated fracture of the ulna and dislocation of the radial head)			

TABLE 9  
*Supracondylar humerus fractures.*

Morphology	See above mentioned classification
Symptoms	Deformity, pain, joint swelling
Diagnosis	No displacement Displacement in one plane Displacement in two planes No bone contact
Correction potential	None
Complications	Radial nerve (deep branch) injury Premature closure of the epiphysis especially after repeated attempts for K-wire osteosynthesis Varus deformity as a result of rotation failures
Non-surgical treatment	Type I (no dislocation) and II (dislocation in one plane) Blount loop or dorso-volar plaster splint in 90° elbow angulation
Surgical treatment	Type III (dislocation in 2 planes) and IV (dislocation in 3 planes) Closed reduction (possible in 90%–95%) followed by percutaneous K-wires in either of the following techniques: ascending crossed bilateral ascending parallel radial ascending / descending monolateral radial The K-wires are removed after 3–4 weeks Small external radial fixator ESIN
Immobilisation	Plaster fixation for 3–4 weeks for all treatments
X-ray control	For the non-surgical treatment after a few days and at week 3–4 For the surgically treated at 3–4 weeks
Follow up	Functional and clinical examination at month 2–3 Physiotherapy is not necessary
Prognosis	Generally good

TABLE 10  
*Distal humerus epiphysiolysis.*

Morphology	Very rare fracture
Symptoms	Deformity, pain
Diagnosis	X-ray
Correction potential	None
Complications	See above, supracondylar fractures
Non-surgical treatment	Dorso-volar plaster splints
Surgical treatment	Crossed K-wires fixation when a reduction is necessary
Immobilisation	Three weeks
X-ray control	For the non-surgical treatment at day 7 and at week 3–4
Follow up	Functional and clinical examination at month 2
Prognosis	Generally good

TABLE 11

*Trans- or intercondylar fractures.*

Morphology	The distal epiphysis is dislocated to posterior, lateral, or forward, depending on the mechanism of injury
Symptoms	Deformity, pain, joint swelling
Diagnosis	X-ray in two planes is in most cases sufficient, an oblique view can be helpful in addition to reveal displacement
Correction potential	None
Complications	Varus deformity, late ulnar nerve irritation, avascular capitulum necrosis
Non-surgical treatment	Long arm cast immobilisation for un-dislocated fractures, followed by a cast-free X-ray control on day 4. Re-evaluation for surgical intervention in cases of secondary displacement > 2 mm
Surgical treatment	Open reduction and K-wire or screw retraction in cases with displacement > 2 mm The implants are removed after 8–12 weeks
Immobilisation	Four weeks
X-ray control	Un-dislocated fractures at day 4 and week 4–5
Follow up	Functional and clinical examination at month 6 and after 1 year
Prognosis	Generally good

TABLE 12

*Proximal radial fractures.*

Morphology	Approximately 65% are sub-capital (metaphyseal fractures of the radial neck) and 35% Salter Harris II fractures
Symptoms	Deformity, pain, blockage of pro- and supination
Diagnosis	X-ray in two planes
Correction potential	None in lateral displacement Good in the sagittal and frontal plane up to 60°
Complications	Mal- or non-union, avascular necrosis, ectopic calcification resulting in limited pro- and supination
Non-surgical treatment	Long arm cast for children younger than 10 years old and < 60° dislocation
Surgical treatment	Closed reduction and fixation with ESIN "Joy stick" technique: manipulation of the fully dislocated radial head with percutaneous K-wire
Immobilization	For the non-surgical treatment 2–3 weeks followed by functional physiotherapy For the surgically treated no immobilisation is required
X-ray control	For the non-surgical treatment at day 4, 8 and week 3 For the surgically treated at week 4
Follow up	Functional and clinical examination for 2 years
Prognosis	Generally good

TABLE 13  
*Elbow joint dislocation.*

Morphology	Mostly in children older than 8 years. Displacement dependent on the direction of the deforming force
Symptoms	Deformity, pain, joint swelling, nerve irritation
Diagnosis	X-ray. It is important not to miss a supracondylar or a lateral condylar, or a transcondylar fracture
Correction potential	None
Complications	Vascular and nerve involvements Medial ligament avulsion, overseen medial epicondyle fracture
Non-surgical treatment	Reduction and long arm cast
Surgical treatment	Medial epicondyle refixation with K-wire or screw and if the elbow is unstable a reconstruction of the medial and lateral ligaments is indicated
Immobilisation	Three weeks, then functional treatment
X-ray control	Only directly after surgery and in week 4
Follow up	Functional and clinical examination at week 6 and month 2-3
Prognosis	Generally good

TABLE 14  
*Medial or lateral epicondyle fracture.*

Morphology	These fractures are almost always present as a result of an elbow dislocation
Symptoms	Joint swelling, pain on the affected side
Diagnosis	X-ray in two planes
Correction potential	None
Complications	Mal- or non union
Non-surgical treatment	Only in initially un-dislocated fractures, however a cast free X-ray on day 3 is necessary in order to detect secondary displacements which need surgical intervention
Surgical treatment	Open reduction and retraction with K-wires or screw in dislocated fractures > 2 mm
Immobilisation	Long arm cast for 3-4 weeks
X-ray control	See above for un-dislocated fractures For the surgically treated at week 4
Follow up	Functional and clinical examination at month 2-3
Prognosis	Generally good

TABLE 15  
*Olecranon fractures.*

Morphology	The fractures, especially in younger children, are un-dislocated and incomplete
Symptoms	Deformity, pain, elbow in flexion
Diagnosis	X-ray in two planes whereas the diagnosis is very difficult, especially in young children who have non-visible ossification centres
Correction potential	None
Complications	Loss of elbow movement
Non-surgical treatment	Long arm cast for un-dislocated fractures
Surgical treatment	Open surgery with longitudinal pinning and cerclage wire fixation for dislocated fractures
Immobilisation	Long arm cast for 4 weeks
X-ray control	For non-surgical treatment at day 5–6 and at week 4 For surgically treated at week 4
Follow up	Functional and clinical examination at week 8
Prognosis	Generally good

TABLE 16  
*Radial head subluxation (Chassaignac).*

Morphology	Typical injury in children 1–3 years old with subluxation of the radial head after traction on the forearm
Symptoms	Elbow in extension with painful pronation
Diagnosis	Clinical signs and history
Correction potential	Good
Complications	Neglected fracture of the radial neck, persistent dislocation
Non-surgical treatment	The elbow is kept in flexion whilst a fast supination and extension is performed. A click is felt
Surgical treatment	Only in neglected and overseen cases
Immobilisation	Not necessary
X-ray control	Not necessary
Follow up	Not necessary
Prognosis	Generally very good

TABLE 17  
*Monteggia lesions.*

Morphology	Fracture of the proximal ulna third combined with radial head dislocation Take care to examine the radial head whenever there is a visible ulna fracture without a fracture of the radius
Symptoms	Deformity, pain, swelling, elbow in flexed position
Diagnosis	X-ray including both the wrist and the elbow joints in two planes
Correction potential	None
Complications	Elbow movement loss
Non-surgical treatment	Long arm cast in un-dislocated fractures with centred radial head in both planes
Surgical treatment	Closed fracture reduction and radial head dislocation followed by ulna fixation with ESIN
Immobilisation	Long arm cast for 4 weeks
X-ray control	For non-surgical treatment at day 5–6 and at week 4. Dislocated fractures are then treated surgically For surgically treated at week 4
Follow up	Functional and clinical examination at week 8
Prognosis	Generally good

#### FOREARM FRACTURES

Diaphyseal forearm fractures are common in children at all ages. They may vary from pure bowing to greenstick or even to a complete fracture with or without dislocation, including fractures of both bones at the same or different levels, isolated radius frac-

ture, radius and/or ulna bowing and ulna fracture combined with radius bowing or vice versa. The Galeazzi fracture represents a special form whereas a distal radius fracture is combined with a distal radio-ulnar joint dislocation.

TABLE 18  
*Forearm "bowing" fracture.*

Morphology	Shaft deformity without cortex fracture
Symptoms	Deformity, pain
Diagnosis	X-ray in two planes
Correction potential	None
Complications	Pro- and supination loss
Non-surgical treatment	Bending < 20°: long arm cast with cast wedging if necessary
Surgical treatment	Bending > 20°: closed reduction and ESIN stabilization
Immobilisation	For non-surgical treatment 4 weeks For surgical treatment no immobilisation is required
X-ray control	At week 4
Follow up	For more than one year
Prognosis	Generally good

TABLE 19

*Forearm shaft "Greenstick" fracture.*

Morphology	Plastic deformity of the shaft with fracture of the cortex on one side
Symptoms	Deformity, pain
Diagnosis	X-ray in two planes
Correction potential	None
Complications	Pro- and supination loss
Non-surgical treatment	Long arm cast in cases of bending $< 20^\circ$ with cast wedging if necessary
Surgical treatment	Closed reduction in cases of bending $> 20^\circ$ followed by ESIN
Immobilisation	For non-surgical treatment 4 weeks For surgically treated no immobilisation is required
X-ray control	At week 4
Follow up	For more than one year
Prognosis	Generally good

TABLE 20

*Forearm complete diaphyseal fracture.*

Morphology	Complete fracture of both cortex with or without dislocation
Symptoms	Deformity, pain, swelling
Diagnosis	X-ray in two planes
Correction potential	Partially, if dislocation is $< 10^\circ$ – $15^\circ$
Complications	Movement loss after malunion
Non-surgical treatment	Well moulded cast with 3-point fixation in non dislocated stable fractures. A secondary angulation $< 15^\circ$ is treated by cast wedging
Surgical treatment	All dislocated unstable fractures at any age. Closed reduction followed by ESIN. If necessary an open reduction with a small incision at the fracture level is indicated
Immobilisation	Non-surgical treatment 5–6 weeks For surgically treated no immobilisation is required
X-ray control	For non-surgical treatment at day 6 and week 5 For surgically treated 5–6 weeks and before implant removal
Follow up	6 months
Prognosis	Generally good

TABLE 21

*Forearm distal third (metaphyseal fractures) fractures.*

Morphology	Metaphyseal torus or buckle, bowing and greenstick fractures Complete metaphyseal fractures with or without displacement Salter Harris I and II fractures
Symptoms	Deformity, pain, swelling, median nerve irritation
Diagnosis	X-ray in two planes
Correction potential	Extremely good, children younger than 10 years old up to 20°
Complications	With correct treatment practically none. Sometimes an overgrowth of the radius is possible as well as a premature closure of the epiphysis
Non-surgical treatment	Torus / greenstick and bowing fractures need a long arm cast without reduction. Dislocated, complete fractures should be reduced under general anaesthesia, since relaxation is an essential part of the reduction. 95% of all fractures can be reduced and stabilise non-surgically
Surgical treatment	Only complete unstable fractures of the distal radius in older children or adolescence need surgical stabilisation by K-wires or external fixator, exceptional an open reduction and a plate fixation.
Immobilisation	Three – four weeks No additional immobilisation is necessary for external fixator or plate osteosynthesis
X-ray control	Day 6–7 and week 3–4
Follow up	If there is a malunion at consolidation
Prognosis	Generally good

## WRIST AND HAND FRACTURES

Metacarpal unstable fractures are rare in children, however finger fractures are common, especially phalangeal fractures and interphalangeal dislocations. Scaphoid fractures are rare in children under 12 years old and the treatment in non dislocated fractures is conservative with a scaphoid cast for 6 weeks. Dislo-

cated fractures are treated surgically. Metacarpal fractures are the most frequent fractures of the hand whereas proximal fractures can be found at the MC I, where the single epiphysis is proximal and distal fractures can be found at the MC II–V, where the single epiphysis is distal.

TABLE 22

*Metacarpal I fracture.*

Morphology	Metaphyseal torus or Slater Harris I and II fractures Shaft fractures are rare
Symptoms	Deformity, pain
Diagnosis	X-ray in two planes
Correction potential	In all except the frontal plane
Complications	Premature epiphyseal closure
Non-surgical treatment	Forearm cast for un-dislocated metaphyseal or diaphyseal fractures without reduction
Surgical treatment	Closed reduction followed by K-wires in dislocated metaphyseal fractures Closed reduction followed by mini-ESIN osteosynthesis in dislocated diaphyseal fractures
Immobilisation	Forearm cast 2–3 weeks for proximal fractures and 3–4 weeks for shaft fractures, independent of osteosynthesis
X-ray control	For non-surgical treatment at day 4 and week 3 For surgically treated at week 4
Follow up	Not necessary
Prognosis	Generally good

TABLE 23  
Metacarpal II – V fractures.

Morphology	The subcapital fractures are more frequent than the proximal ones. They are mostly un-dislocated and frequently at the metacarpal V
Symptoms	Deformity, pain. In case of malrotation the fingernails are not positioned in a plane and the involved digit overlaps the others
Diagnosis	X-ray in two planes
Correction potential	Very good, however be ware that rotational deformities cannot be corrected by remodelling
Complications	Axial deviations
Non-surgical treatment	Well formed cast, splint or "Iselin" splint for un-dislocated fractures without reduction
Surgical treatment	Closed reduction followed by K-wires for dislocated proximal fractures Closed reduction and mini ESIN for dislocated shaft fractures
Immobilisation	Proximal fractures 2–3 weeks Shaft fractures 3–4 weeks; independent of the fixation
X-ray control	For non-surgical treatment at day 3 and week 4 For surgically treated at week 3–4
Follow up	Not necessary
Prognosis	Very good

FRACTURES OF THE LOWER LIMBS

PELVIC RING FRACTURES

Pelvic fractures appear rarely isolated, most of them are accompanying injuries after heavy direct trauma. The degree of severity ranges from simple isolated fracture of the pubis to a complete disruption of the pelvic ring.

TABLE 24A  
Pelvic ring fractures.

Stable fractures of the pelvic ring	
Apophysis avulsion of the – inferior iliac spine (a) – iliac spine (b) – ischial tuberosity (c)	
Ilium ala fractures (d)	
Pubic arch fractures (e)	
Ilium fractures (f)	
Ileosacral joint loosening (g)	
Unstable fractures of the pelvic ring	
Symphysis, pubic separation (h)	
Sacroiliac joints disruption (i)	
Acetabular fractures (j)	

TABLE 24B

*Therapy.*

Fracture	Un-dislocated / stable	Dislocated / stable
Apophysis avulsions	Crutches and analgetics ca. 10 days	
Ilium fractures	Crutches until pain-free	Open reduction and screw or K-wires
Pubic fractures	Crutches until pain-free	
Ischium fractures	Crutches until pain-free	
Stable symphysis separation	Crutches until pain-free	
Unstable symphysis separation	Crutches for 3–4 weeks	External fixator or plate in older children
Sacroiliac joints disruption	External fixator	Reduction, external fixator, transarticular screw or plate
Acetabular fractures	Spica cast 5–6 weeks	Open reduction and screw or plate

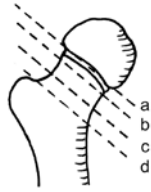
TABLE 25

*Hip dislocation.*

Morphology	Very rare condition in children Superior or posterior iliac Anterior pubic Fracture with dislocation
Symptoms	Pain, the limb is flexed, adducted and inwards rotated, appearing shorter
Diagnosis	Clinical, X-ray, CT
Correction potential	None
Complications	Femoral head necrosis, re-dislocation, hip dysplasia
Non-surgical treatment	Reduction and joint puncture within the first 8 hrs. In case of incongruence open reduction is necessary
Surgical treatment	Reduction and in case of incongruence open surgery combined with fixation of acetabular rim fracture
Immobilisation	One week to six weeks, depending on injury pattern and treatment
X-ray control	Directly after reduction and at week 4–6 Scintigraphy or MRI if necessary to evaluate head necrosis
Follow up	In six months interval on suspicion of head necrosis
Prognosis	Difficult to predict

TABLE 26

*Femoral neck fractures.*

Morphology	Very rare injury (4 types): transphyseal injury (a) transcervical injury (b) cervicotrochanteric injury (c) pertrochanteric injury (d)	
Symptoms	Pain, the involved limb is held in flexion, adduction, and internal rotation. The limb is shorter on the affected side.	
Diagnosis	Clinically, X-ray in two planes, CT	
Correction potential	Limited	
Complications	Femoral head necrosis, mal- or non-union, varus – deformity	
Non-surgical treatment	Only un-dislocated fractures joint puncture with fluid aspiration	
Surgical treatment	Open reduction, threaded K- wire fixation in small children, screw or angular plate fixation in older children	
Immobilisation	Depending of the injury and treatment 4–8 weeks	
X-ray control	After reduction, at week 4–6, scintigraphy or MRI when indicated	
Follow up	At suspicion of necrosis every 6 months	
Prognosis	Very good	

The capital femoral and trochanteric epiphyses are connected with cartilage, running along the poster superior femoral neck. The development of the femo-

ral neck may be seriously impaired after femoral neck fracture, especially if the vessels are damaged, resulting in femoral head necrosis.

TABLE 27

*Femoral shaft fractures.*

Morphology	Most frequent injury of the lower leg Transverse, oblique and spiral fractures of the proximal and middle third Subtrochanteric fractures
Symptoms	Deformity, pain, excessive blood loss, shock
Diagnosis	X-ray in two planes, including the hip and knee joint
Correction potential	Very good, depending of the age of the child
Complications	Leg length discrepancy, rotation failure, deviation of the axis
Non-surgical treatment	Children under 3–4 years old: overhead extension or for stable fractures initial spica cast
Surgical treatment	Children 3–4 until to 13–14 years old, depending of the weight: closed reduction and ESIN Absolutely unstable, complex fractures: external fixator or minimal invasive plating
Immobilisation	Overhead extension: 3–4 weeks Spica cast: 3–4 weeks No immobilisation in ESIN or external fixator
X-ray control	Overhead extension, spica cast: after application and at week 3–4 Surgical treatment: postoperative and at week 5–6, before implant removal
Follow up	Children > 10 years old: end of growth
Prognosis	Very good

## DISTAL FEMUR AND PROXIMAL TIBIA FRACTURES

These are very rare fractures in children and occur mostly after height energy trauma with hemarthros as an indirect sign. The X-ray is difficult to interpret and osteochondral fragments, "flake fractures", should be looked for.

TABLE 28

*Distal femur 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)						
Fractures of the proximal tibia: Tibia plateau (e) Tibia spine injuries (f1) Salter Harris I + II fractures (f2) Salter Harris III + IV fracture (h)						
Fractures of the proximal tibia metaphysis						

TABLE 29

*Supracondylar and condylar femur fractures.*

Morphology	Supracondylar buckle fractures Complete transverse or oblique fractures metaphyseal or epiphyseal (Salter – Harris I + II) Uni – or bicondylar (Salter Harris III + IV) fractures; very rare in childhood
Symptoms	Pain, knee stiffness, swelling, pulseless lower leg
Diagnosis	X-ray in two planes
Correction potential	Depending on the age of the child relatively good
Complications	Supracondylar fractures should have no complications Varus or valgus angulation following premature partial closure of the epiphysis, limitation of knee motion, leg length discrepancy
Non-surgical treatment	All un-dislocated fractures independent of the age: long leg plaster cast in 10° flexion When anaesthesia is needed for a fracture reduction, a stable and definite fixation is obligatory
Surgical treatment	All dislocated fractures needing reduction – Extra-articular fractures: closed reduction and K-wires – Articular fractures: open reduction and K-wires or screw fixation
Immobilisation	4–6 weeks
X-ray control	For non-surgical treatment at day 4, 10 and week 4 For surgically treated at week 4–6
Follow up	Depending on the fracture type up to two years
Prognosis	Very good

TABLE 30  
*Fractures of the proximal tibial epiphysis.*

Morphology	Fracture types: – Complete – Greenstick – Bowing and torus or buckle
Symptoms	Pain, swelling
Diagnosis	X-ray in two planes
Correction potential	No correction of valgus deformity
Complications	Progressive valgus angulation
Non-surgical treatment	Stable, un-dislocated fractures with valgus angulation < 10°: long leg cast, cast wedging after 8 days
Surgical treatment	Dislocated fractures and fractures with valgus angulation > 10°: closed or open reduction and K-wire fixation or external fixator
Immobilisation	5 weeks
X-ray control	For non-surgical treatment at day 4, 8 and week 5 For surgically treated postoperative at week 5
Follow up	In 6 month intervals up to two years
Prognosis	Very good

#### PATELLA FRACTURES AND DISLOCATIONS

Patellar dislocations are the most common, considering all subluxations and dislocations. In many children especially young girls, a chronic subluxation mimics a dislocation. Genua valga, overweight and patella alta are prerequisites.

TABLE 31  
*Patellar dislocation.*

Morphology	Almost always complete or incomplete lateral dislocations
Symptoms	Pain, swelling, knee blocking, hemarthros
Diagnosis	Clinical examination, X-ray in two planes
Correction potential	None
Complications	Overlooked “flake fracture”
Non-surgical treatment	Reduction with extended knee and hip in flexion Puncture of the hemarthros
Surgical treatment	Arthroscopy is indicated in cases of osteochondral fractures which are either re-fixed or removed
Immobilisation	Cylinder cast for 4 weeks
X-ray control	After reduction
Follow up	Physiotherapy in cases of habitual dislocation
Prognosis	Very good

TABLE 32  
*Patellar fractures.*

Morphology	Incomplete and complete fractures Inferior and superior fractures Longitudinal and transverse fractures Sleeve fractures Norm variations i.e. bipartite patella
Symptoms	Pain, swelling, knee blocking hemarthros
Diagnosis	Clinical examination, X-ray in two planes
Correction potential	Partial, gaps are always filled with fibrous cartilage
Complications	Non-union and pre-arthrosis
Non-surgical treatment	Cylinder cast for fissures, un-dislocated and stable fractures
Surgical treatment	All dislocated fractures with circumferential patella wiring Implant removal after 4–5 months
Immobilization	4–5 weeks
X-ray control	For non-surgical treatment at day 6 and week 5 For surgically treated postoperative at week 5
Follow up	6 months after implant removal

#### TIBIAL SHAFT FRACTURES

They are one of the most common fractures of the lower limb in children. However, the fractures vary considerably according to the child's age and the injury mechanism. Spiral tibial fractures with an intact fibula are typical for infants and young children.

Complete fractures of the tibia and fibula are unstable and have rotational failures. Toddler fractures with bowing of the fibula or (more rare) of the tibia are special types.

TABLE 33  
*Isolated tibial shaft fractures.*

Morphology	Fractures of the middle and distal third Spiral fractures are more frequent than transverse fractures
Symptoms	Pain, swelling, deformation
Diagnosis	X-ray in two planes including the knee and ankle joint
Correction potential	Depending on the age of the child, good. No correction of rotation
Complications	Cosmetic, different feet rotation, remaining angulation
Non-surgical treatment	Un-dislocated and stable fractures with angulation $< 10^\circ$ : long leg cast with cast wedging at day 4–5 if necessary
Surgical treatment	The indication for surgical treatment is rare, however given in cases of tibia shortening with fibula bowing
Immobilisation	For non-surgical treatment at week 4–5 For surgically treated no immobilisation is necessary
X-ray control	For non-surgical treatment at day 4, 10 and week 4–5 For surgically treated postoperative at week 5
Follow up	In 6 month interval up to two years
Prognosis	Very good

TABLE 34  
Complete tibia and fibula fractures.

Morphology	Fractures of the middle and distal third Spiral fractures are more frequent than transverse fractures
Symptoms	Pain, swelling, deformation
Diagnosis	X-ray in two planes including the knee and ankle joint
Correction potential	Depending on the age of the child, good. No correction of rotation
Complications	Cosmetic, different feet rotation, remaining angulation
Non-surgical treatment	Un-dislocated and stable fractures with angulation < 10°: long leg cast with cast wedging at day 4–5 if necessary
Surgical treatment	The indication for the surgical treatment is rare Dislocated and unstable fractures (oblique, spiral): ESIN or external fixator
Immobilisation	For non-surgical treatment at week 4–5 For surgically no immobilisation is necessary
X-ray control	For non-surgical treatment at day 4, 10 and week 4–5 For surgically treated postoperative and at week 5
Follow up	In 6 month intervals, up to two years
Prognosis	Good

DISTAL TIBIA AND THE ANKLE JOINT FRACTURES

TABLE 35  
Classification reflecting the type of fractures.

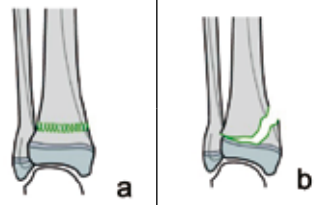

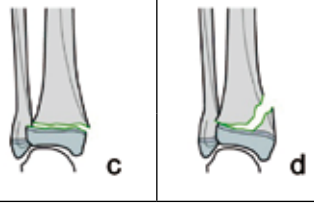



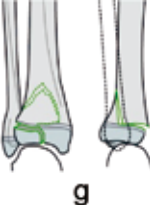
Extra-articular			
Metaphyseal torus / green stick fracture (a)			
Complete metaphyseal fracture (b)			
Epiphysiolysis (Salter Harris I) (c)			
Epiphysiolysis + metaphyseal wedge (d)			
Articular fractures			
Tillaux (two plane) fracture (Salter Harris III) (e)			
Epiphyseal fracture with metaphyseal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

TABLE 36  
*Extra-articular fractures.*

Morphology	Metaphyseal torus fracture Metaphyseal bowing fracture Complete metaphyseal fracture Epiphysiolysis ( Salter Harris I ) Epiphysiolysis with metaphyseal wedge
Symptoms	Pain, deformation
Diagnosis	X-ray in two planes
Correction potential	Very good
Complications	Leg length difference, valgus deformity, premature closure of the epiphysis, fibulo-tibial synostosis
Non-surgical treatment	Metaphyseal torus and bowing fractures: plaster cast and cast wedging if necessary Metaphyseal complete fracture, stable: reduction, plaster cast Stable, Salter Harris I + II fractures: reduction, plaster cast
Surgical treatment	Complete dislocated, unstable metaphyseal fractures: closed reduction and external fixator or K-wires or ESIN dislocated, unstable Salter Harris I + II fractures: closed reduction and minimal invasive screw fixation or K-wire fixation
Immobilisation	4–6 weeks
X-ray control	For non-surgical treatment at day 6 and week 4–5 For surgically treated postoperative and at week 5
Follow up	In 6 month interval up to two years
Prognosis	Good

TABLE 37  
*Articular fractures (Salter Harris III and IV).*

Morphology	Epiphyseal fractures (Salter Harris III) Epiphyseal fractures with metaphyseal wedge (Salter Harris IV) “tow- or tri- plane fractures”
Symptoms	Pain, deformation
Diagnosis	X-ray in two planes
Correction potential	Moderate
Complications	Leg length difference valgus deformity, premature closure of the epiphysis
Non-surgical treatment	Un-dislocated fractures with a articular gap < 2 mm: leg cast or splint
Surgical treatment	Dislocated, unstable Salter Harris III + IV fractures: closed reduction and minimal invasive screw fixation or K-wire fixation
Immobilisation	4–6 weeks
X-ray control	For non-surgical treatment at day 6 and week 4–5 For surgically treated, postoperative and at week 5
Follow up	In 6 month intervals up to two years
Prognosis	Good

TABLE 38

Two – plane fractures “Fractures of Tillaux”.

Morphology	Special types of injuries affecting part of the anterolateral tibial epiphysis occurring mostly in adolescent children The presence of a posterior metaphyseal fragment makes this injury into a “tri-plane” fracture
Symptoms	Pain, deformation
Diagnosis	X-ray in two planes may not reveal the complete fracture. Clarification can be achieved by an examination under image intensifier, however, CT exhibits greater accuracy
Correction potential	Good
Complications	Leg length difference, valgus deformity, premature closure of the epiphysis, fibulo-tibial synostosis
Non-surgical treatment	Un-dislocated (<2mm gap) two-plane fractures and tri-plane fractures: well padded compression dressing and posterior splint. After swelling disappears a Sarmiento-type cast
Surgical treatment	Dislocated two- and tri-plane fractures: reduction and retraction with cannulated, self drilling, self tapping screws
Immobilisation	4–6 weeks
X-ray control	For non-surgical treatment at day 6 and week 4–5 For surgically treated postoperative and at week 5
Follow up	In 6 month interval up to two years
Prognosis	Good

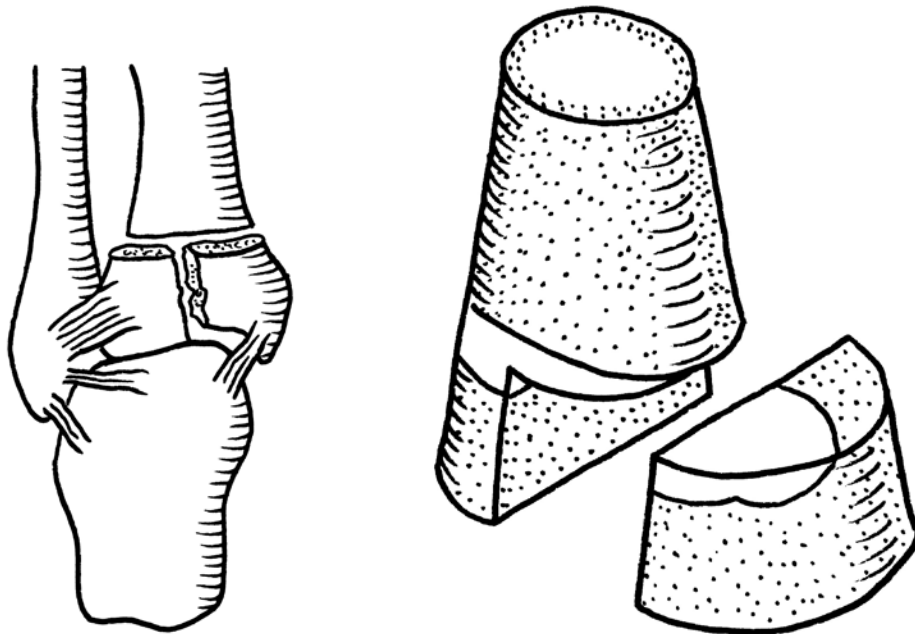


Fig. 4 Schematic illustration of a bi-plane fracture

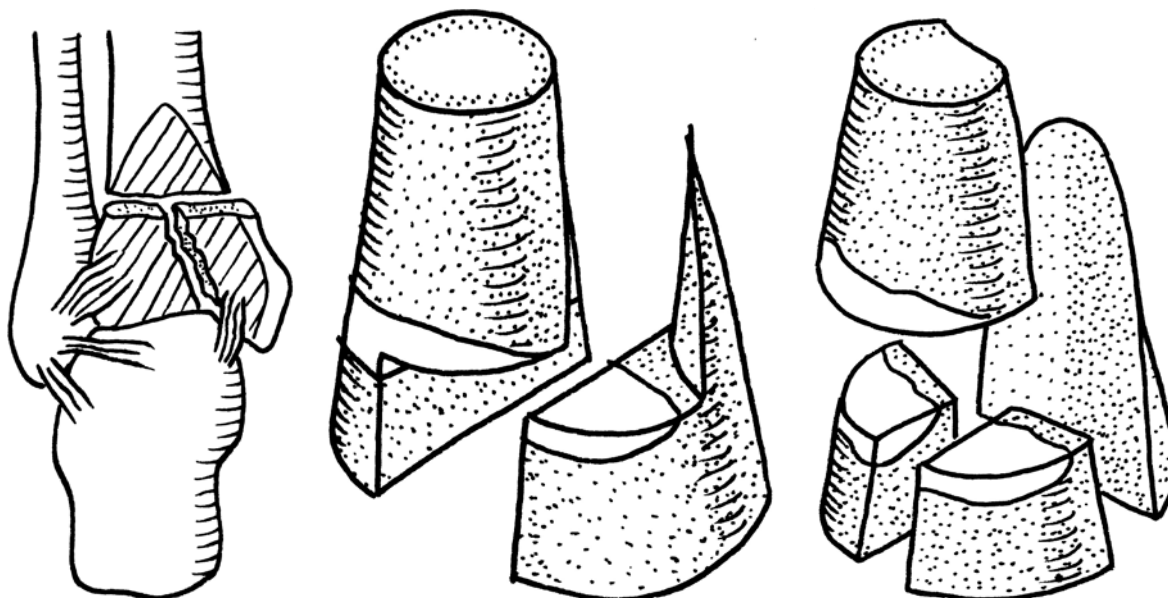


Fig. 5. Schematic illustration of a tri-plane fracture

#### FRACTURES OF THE FOOT

Fractures of the talus and the calcaneus are rare in childhood, whereas fractures of the metatarsals, especially the first or fifth are more frequent. Symptomatic accessory bones make diagnosis difficult.

TABLE 39  
*Fractures of the foot.*

Fracture	Therapy	Immobilisation
Calcaneus	Un-dislocated: non-weight-bearing cast	6–8 weeks
	Dislocated: open reduction and screw or plate stabilisation with a non-weight-bearing cast	
Talus	Un-dislocated: non-weight-bearing cast	6–8 weeks
	Dislocated: open reduction and screw or K-wire fixation with a non-weight-bearing cast	
Metatarsal	Un-dislocated: non-weight-bearing cast	3–4 weeks
	Dislocated: open reduction and screw or K-wire fixation with a non-weight-bearing cast	

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