2 Head

2.1 Introduction

Young children regularly fall, and quite often they fall on their head. It is unknown how often this results in a skull fracture, since it is rarely indicated to perform a diagnostic examination, such as a radiograph or a CT scan. When there are no neurological symptoms, a radiograph of the skull is not clinically indicated (see Sect. 2.5). However, from a forensic point of view, a radiograph of the skull is indicated – especially when the child is less than 1 year old. This also applies when there are no neurological symptoms (see Sect. 2.6), even though a normal X-ray of the skull does not exclude intracranial injury.

A skull fracture seen during an operation or autopsy is not necessarily visible on a radiograph [1]. In 16 children with an epidural haemorrhage and a skull fracture, the skull fracture was radiologically visible in 10 children, in four children it was seen during operation and in two during autopsy [2].

2.2 Signs, Symptoms and Complications

Due to the lack of clinical symptoms or complications, the majority of skull fractures have little or no clinical consequences. A skull fracture is suspected based on the anamnesis or the physical examination. Older children may complain of a localised headache. Physical examination may reveal local swelling, a haematoma, a palpable fracture or indications for a basilar skull fracture.

Skull fractures do have indicative value: their presence implies that considerable force has been exerted on the skull [3]. However, it does not always mean that underlying structures such as dura, bridging veins or brain have been damaged (see Sect. 2.5).

The injury most often seen on skull radiographs of young children after a trauma is a fracture of the calvaria [4]. The incidence of skull fractures in children that present at the emergency department for a skull trauma ranges from 2% to 20% [5]. Most frequently it concerns a fracture of the parietal bone, followed by the occipital, frontal and temporal bones. Generally, it is a linear fracture without dislocation, followed by depressed fractures and basilar skull fractures. In principle, skull fractures of the calvaria do not cause any harm, unless they are accompanied by fragmentation causing bone-splinter damage to brain tissue. A possible complication of a skull fracture is a ‘growing skull fracture’. This occurs when the dura is imbedded in the fracture and as such prevents healing (see Sect. 2.7).

2.3 Biomechanical Aspects of Fractures of the Cranium

Accidental and non-accidental craniocerebral trauma is the result of two kinds of impacting force: ‘static’ and ‘dynamic’ (or rapid) loading [6, 7]. In both types of fracture the skull changes shape, this applies to children as well as to adults. This book only discusses the effects of static and dynamic loading on the skull, and not the effects on the brain.

2.3.1 Static Loading

Static loading is a relatively slow impact of forces exerted on the skull over a protracted period of time

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(>200 ms). This occurs when the skull is squeezed and compressed, which may lead to multiple fractures. The results of static loading can be focal and diffuse. It may lead to a linear fracture restricted to one skull bone (focal), but often there are multiple fractures (diffuse). Static loading may occur during, for example, childbirth or traffic accidents, when the head is wedged for a period of time.

2.3.2 Dynamic Loading

Dynamic (or rapid) loading is the impact of forces over a shorter period (<200 ms, often even less than 50 ms). Dynamic loading can be subdivided into 'impulse' and 'impact' loading.

Impulse loading is the result of fast movements of the head, without impact (acceleration – deceleration). This does not lead to skull fractures.

When there are skull fractures in dynamic loading, they are always due to impact loading (= contact = cranial collision) [7]: blunt or penetrating trauma directly on the skull.

There are three possible situations:

- Head stationary – Object moves
- Head moves – Object stationary
- Head moves – Object moves

When head and object both move, there are again three options: both move in the same direction, they move in opposite directions, or the impact is oblique. The contact results in the head changing shape and there is (or may be) damage to the skull (including the scalp) and/or the object.

2.3.3 Possible Injuries from Dynamic Impact Loading

Dynamic impact loading may lead to the following injuries (in order of occurrence)

- Damage to the scalp
- Skull fractures
- Intracranial damage (contusions, epidural/subdural/subarachnoid haemorrhages, intracranial haemorrhages, axonal injuries).

2.3.3.1 Damage to the Scalp

In dynamic loading, damage to one or all layers of the scalp (epidermis, dermis, galea aponeurotica and periosteum of the skull) is always the result of impact loading. The skin may remain intact, in spite of damage to the deeper layers. Sometimes the deeper damage to the scalp is only found at autopsy of the deceased child [8].

Injuries that may be found are: haematomas, contusions, excoriations and lacerations of the (epi)dermis, subgaleal haemorrhages or a haematoma of the skull. Particularly in children, lacerations may be an important cause of blood loss. They are a potential point of entry for infection, especially with an associated skull fracture [9].

2.3.3.2 Skull Fractures

Compared to a child's skull, the adult skull is fairly rigid. The adult skull can cope with some deformation; however, when the deformation exceeds a certain point, no recovery is possible and a fracture will occur. Postmortem research has shown that the adult skull can be indented a few centimetres before it resumes its original shape with or without fracture [10, 11]. This may lead to considerable damage of the underlying tissue.

A child's skull is made of thin and malleable bone tissue and does not have the rigidity and strength of the adult skull. Moreover, the skull bones of a child are separated by sutures that have not been fused yet. According to Lancon et al., this makes the child's skull relatively resistant to fractures. In their opinion it takes a significant trauma [8]. However, the question is whether this position is correct. Weber maintains that a number of sites on the immature skull have increased susceptibility to fractures [12]; this applies in particular to the parietal bone in infants.

In relation to the adult skull, these specific properties of the infantile skull enable it to tolerate greater deformation before it breaks. This deformation may even lead to a depression of the cranium without incurring a fracture (the so-called ping-pong deformation of the skull = 'celluloid fracture', see Sect. 2.4.3.2).

The degree of deformation of the skull at the moment that the fracture is sustained and the nature and size of the fracture and the associated injury will depend on a number of factors (see [13]).

- Trauma-related
  - Location of contact
  - The force of the impact at the moment of contact
- Anatomy-related
  - The scalp
  - The age of the child
  - Shape, build, thickness and malleability of the skull at the point of impact and other sites

2.3.3.3 Trauma-Related Factors

The Location of the Contact Trauma

The location of the contact trauma determines only to a certain extent the location, nature and extent of the skull fracture.

Damage to the scalp is an important indicator for the primary site of impact. For this reason, a precise registration of external injuries is always required, in particular when physical violence is suspected. In 80% of children with a skull fracture external injury is found that indicates a skull trauma. In 84% of children fractures were found ipsilateral and in 16% contralateral from the point of impact [2]. However, the absence of external injuries does not exclude a skull fracture.

A study of adults that had sustained a skull fracture showed that, depending on the place of impact, different types of skull fracture can result from equal amounts of energy. It is not clear whether this can also be applied to children and, if so, whether this is the same for every age group.

A contact trauma on top of the cranium will usually lead to a cranial fracture that may carry on into the temporal region or the base of the skull. A blow to the occipital region will usually lead to a linear fracture in the posterior cranial fossa. A blow to the temporoparietal region may cause a fracture that runs through the temporal bone to the base of the skull. A blow to the forehead causes a fracture that may run into the orbit and even into the maxilla [14].

Force of Impact at the Moment of Contact

The amount of energy released at contact is determined by four elements (see also Sect. 2.6.3):

- The shape, weight and nature of the object. It may be a solid object that will not give way during contact (such as a hammer, concrete floor or stone) or a more or less soft object with a surface that gives way at contact (such as a mattress or a floor covered with thick soft carpet). In soft and yielding objects, the deformation of the surface will absorb a large part of the energy released at contact. Yet, the literature has shown that a child falling on a soft surface can also sustain a fracture [12]. In a solid non-giving surface hardly any energy is carried over to the object.
- The velocity resulting from the speed of the head and the object at the moment of impact.
- A fixed or free-moving head. When the head can move freely, it will move along in the same direction as the object. In this manner, part of the energy at impact is absorbed by the movement.
- The size of the contact surface. If contact takes place on a limited surface, all energy released at contact will be concentrated at this surface. If the site of impact is larger, the energy will spread itself over this surface.

2.3.3.4 Anatomy-Related Factors

The Scalp

The skull is covered by five layers: skin, subcutaneous fatty tissue, the epicranial muscles, subepicranial connective tissue and the pericranium. Tedeschi showed that when force is exerted on the skull, the skin will protect it against fractures. Compared to when the skin is present, the risk for a fracture increases tenfold when no skin is present [15].

The Age of the Child

In a short-distance fall, children with open sutures and a thinner albeit more malleable skull will generally sustain a fracture less often than older children with closed sutures and a more rigid skull. Yet, children up to 1 year old can sustain a skull fracture in a relatively small trauma, in spite of the substantial malleability of their skull (see Sect. 2.6.3). However, this will only rarely lead to serious intracranial injury. Life-threatening intracranial injury has even never been reported (see also Chap. 6).

Shape, Build and Thickness of the Skull

The cranium is constructed of two layers of bone with a sponge-like structure in between (diploid). The inner layer of compact bone is the most vulnerable. On impact this layer may be damaged, whereas the outer layer does not suffer any damage. When the impact generates enough energy, the outer layer will fracture too and this may result in loose bone fragments (Fig. 2.1). Young children do not have a diploid structure of the parietal bone, leading to an increased risk for sustaining a fracture in this bone in a short-distance fall [12].

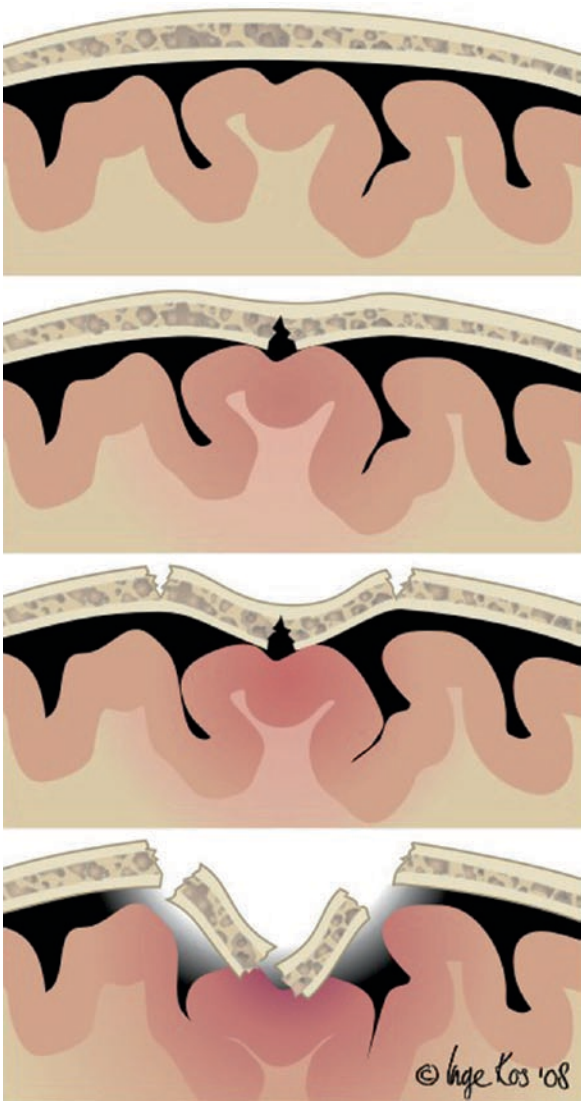

Fig. 2.1 Schematic representation of the various stages of skull fractures in contact injuries

2.4 Types of Skull Fracture

The type of fracture that the skull sustains depends mainly on the same trauma and anatomy-related factors that determine whether dynamic impact loading will result in a fracture [16]. Skull fractures can be categorised into: linear, complex and depression fractures.

The most prevalent type of fracture of the cranium is the linear fracture (Sect. 2.4.1). Here a single linear pattern can be seen. This type of fracture is usually restricted to one skull bone. Linear fractures may be present bilaterally and symmetrically.

Complex fractures show multiple fracture lines and inter-connecting fractures (Sect. 2.4.2).

In depression fractures, parts of the outer surface of the skull bone are displaced inwards over at least the thickness of the sponge-like bone layer (Sect. 2.4.3). A different kind of depression fracture is the ping-pong skull deformation in young children.

In all types, a comminuted skull fracture can be sustained when there is an associated laceration of the skin. In penetrating injuries there is not only a skull fracture, but also a laceration of the skin and injury to the dura. This results in a skull fracture that has an open connection between external and intracranial environment, presenting a considerable risk for infection.

Also, every type of fracture may potentially develop into a 'growing fracture' (see Sect. 2.7).

2.4.1 Linear Fractures

2.4.1.1 Simple Linear Fractures

Of all skull fractures in children, 74–90% are simple linear fractures (Fig. 2.2a and b) [17]. Such a fracture results from contact with a large flat object, in which the impact of a blunt trauma spreads over a large area. For example, the fall from the arm of a parent/carer that results in the head of the child banging into the floor [18]. This is a typical example of 'low velocity' impact [13].

When the head connects with an object with a large flat surface, the skull curvature flattens under the influence of the contact. The skull surface bows inwards, whereas the surrounding area bows outwards in a wave-like manner (Fig. 2.3) [14, 18]. The outward

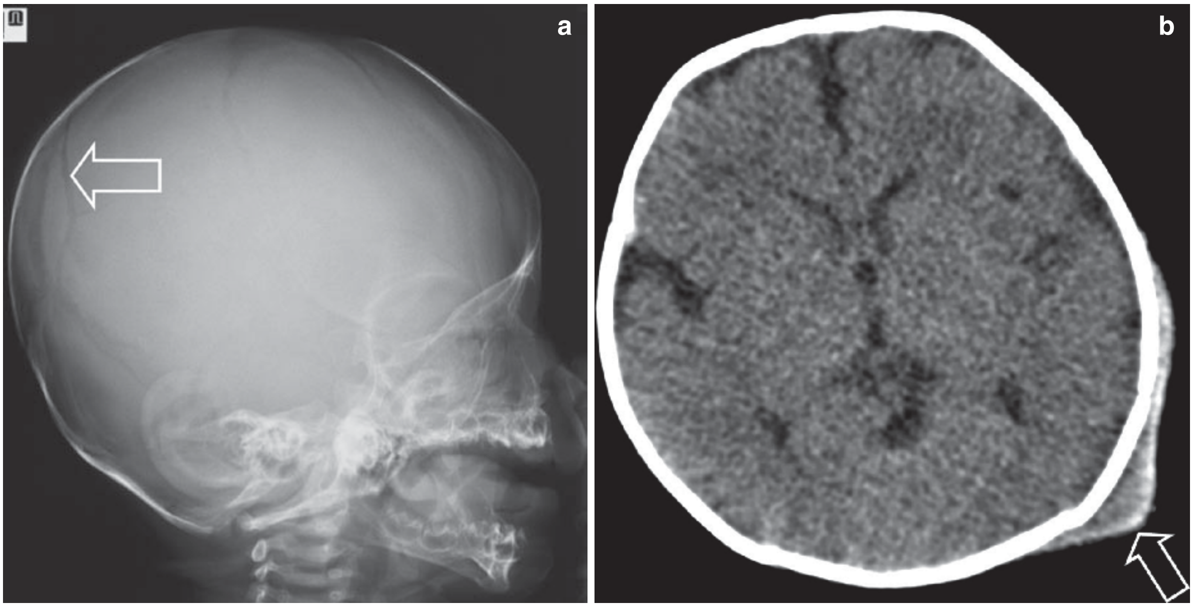

Fig. 2.2 (**a**) Two-month-old baby who, according to the anamnesis, had fallen from the arms of his 7-year-old sister. The fall had not been witnessed. The lateral view of the skull shows a parietal linear fracture (*open arrows*). (**b**) Additional CT in this patient shows post-traumatic soft-tissue swelling (*open arrow*) but no intracranial pathology

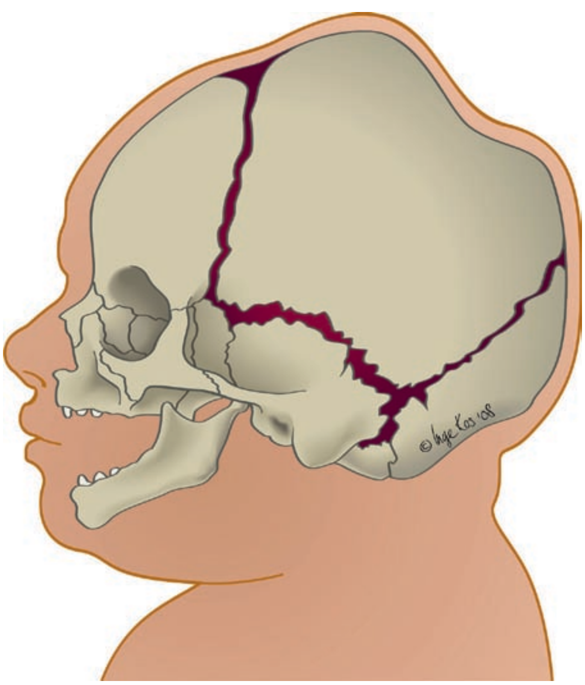

Fig. 2.3 Schematic representation of the wave pattern of skull deformation after contact with a relatively large surface. At the impact site there is inward deformation whereas peripherally the skull bows outwards

bowing of the skull may occur at a relatively large distance of the primary site of contact. Hence, the location of a linear fracture does not have to correspond with the place of contact [19]. After the skull has been deformed by the impact, it will try to resume its normal shape. At the moment that the inwardly bowed part resumes its normal shape, the fracture will spread from its original location into the direction of the place of impact as well as into the opposite direction. This may result in a fracture line that reaches the original place of contact or extents even further [13].

Although linear fractures are usually confined to one skull bone, it is possible that the fracture extents into the adjacent skull bone (Figs. 2.4 and 2.5a–d). In most linear fractures, external injuries are found, such as swelling of the overlying tissues or a haematoma. Sometimes a subgaleal haematoma is seen. The extent of the subgaleal haematoma may be such that it leads to anaemia [20].

In approximately 15–30% of linear fractures intracranial injury is found [5] (see Sect. 2.5). Linear fractures tend to show diastasis (see Sect. 2.7). However, in most patients linear fractures heal without any problems (also see Sect. 2.7).

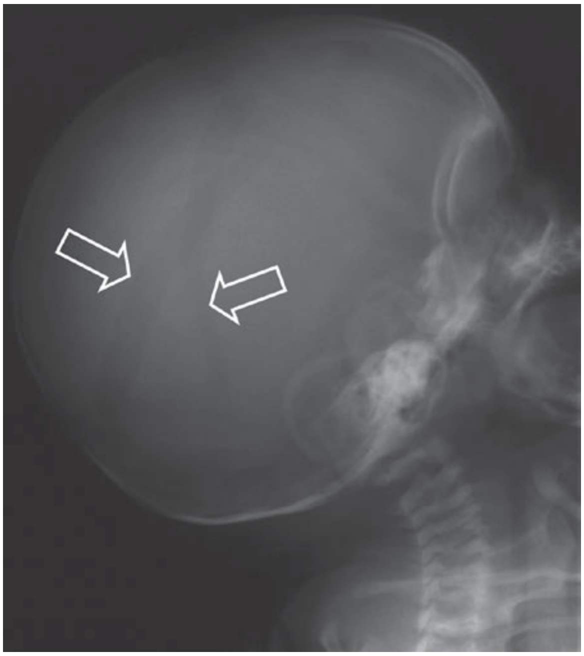

Fig. 2.4 Six-week-old neonate who presented at the emergency department for haematemesis. Since the laboratory values were not deviant, the patient was sent home. Four days later the infant was back at the emergency department, this time with multiple bruises. Radiological examination revealed a linear diastatic fracture that transgressed several sutures (*open arrows*)

2.4.1.2 Symmetrical Linear Fractures

In children, sometimes nearly symmetrical linear fractures are found resulting from bilateral compression of the skull between two surfaces [21]. This symmetry may also occur when the child hits the ground with the top of his/her head first [22] or is hit against the wall with great force and the energy released at contact spreads symmetrically over, for example, the parietal skull bones.

2.4.2 Complex Fractures

2.4.2.1 Circular (Concentric) Fractures

When the skull has a high velocity impact with a solid object, as happens in a high-energy trauma (concentric) complete or incomplete circular fractures may occur around the point of impact.

Concentric fractures are typical bowing fractures: the circles are formed in the outer surface of the skull at the junction of the inward and outward bowing part of the skull, as the result of the extreme bowing at the point of impact [13, 23].

2.4.2.2 Star-Shaped Fractures

Star-shaped fractures are formed when a flat object comes into contact with a bowed bone at (very) high velocity. At the point of impact the bone suffers an impression that results into a number of fractures that all originate from the inward-bowing point of impact [18]. Star-shaped and circular fractures may both be present (Fig. 2.6).

2.4.2.3 Complex Fractures with Signs of Shattering

Complex fractures occur when there is a great deal of violence (Fig. 2.7). This type of fracture may also result from multiple blunt trauma to the head; for example, when the skull is hit repeatedly with a hammer. In this type of fracture the skin may or may not be intact.

2.4.3 Depression Fractures and Ping-Pong Deformation

2.4.3.1 Depression Fractures

Depression fractures of the skull can occur in two ways:

- When an object with a small surface and relatively high kinetic energy hits the skull, for example a hammer or the heel of a shoe.
- When an object (irrespective of the size of the object) hits only a small part of the skull with a large amount of kinetic energy (see also Sect. 2.4.2.2), such as a gun-shot wound.

In an depression fracture, there is besides the primary point of impact hardly any deformation of the skull (Fig. 2.8) [14, 18]. At the point of impact a fracture is sustained, possibly with fragmentation. The impression results from the inability of the inner layer of the skull bone to absorb the inward bowing adequately.

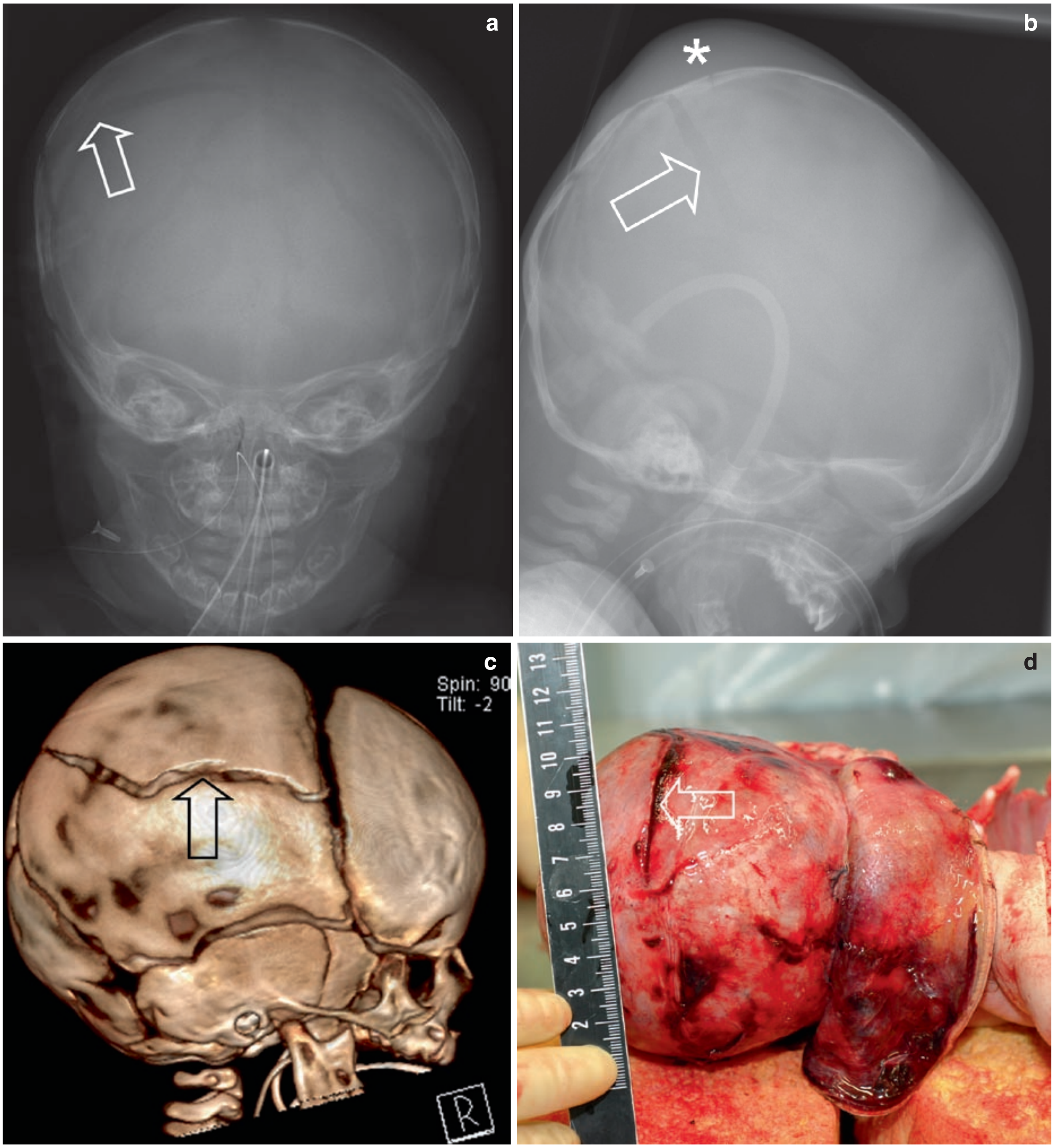

Fig. 2.5 (**a**) Two-month-old girl who, according to the anamnesis, had fallen from the changing table (85 cm high). When presented at the emergency department she was in deep coma. Five days later she died from the neurological trauma. The anterior-posterior skull view shows a bilateral linear fracture that transgressed multiple sutures (*open arrows*). (**b**) Lateral skull view shows besides the fracture in the parietal bone (*open arrow*) a clearly visible soft-tissue swelling corresponding to a post-traumatic haematoma (asterisk). (**c**) The fracture is visible on the three-dimensional CT reconstruction (*open arrow*); furthermore, conform the child's age, the sutures are still visible). (**d**) At autopsy the fracture in the parietal bone is clearly visible (*open arrow*)

The impression may reflect the shape of the object. Sometimes there is only an impression in the outer layer, whereas the inner layer remains intact [13]. Sometimes the skull is perforated. A number of these fractures have no complications. In one-third the dura is damaged, and in one in four children damage to the

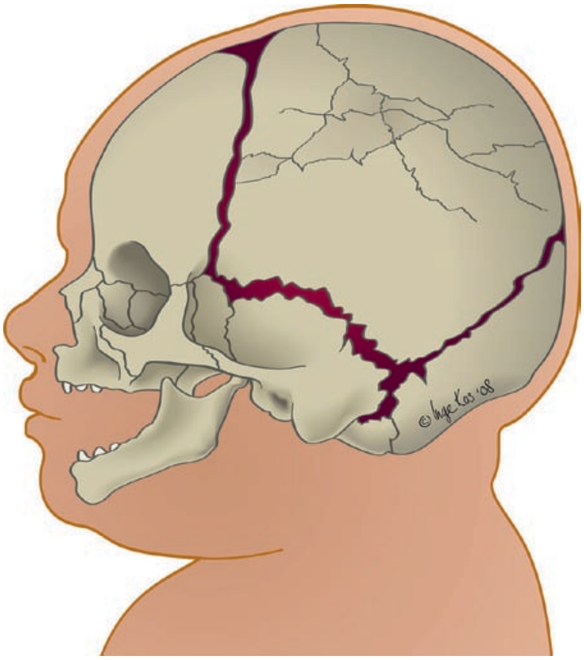

Fig. 2.6 Schematic representation of a burst fracture

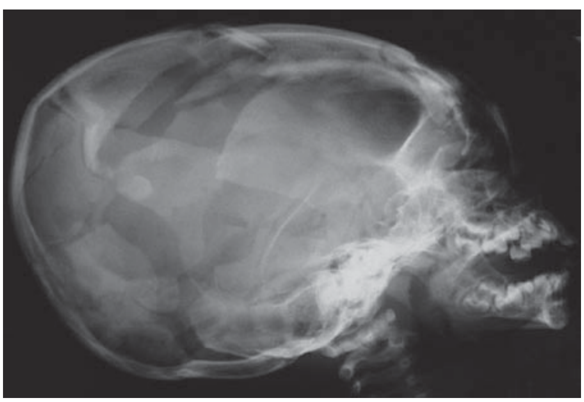

Fig. 2.7 The skull radiograph of a 1-year-old girl who was thrown from the fifth floor of an apartment building by her carer shows a crushed skull

cerebral cortex is found [17]. A depression fracture increases the risk for posttraumatic seizures.

In approximately 30% of children with an depression fracture, intracranial injury is found [5, 24]. The deeper the fracture, the higher the chance that dura and brain tissue have been damaged. Besides intracranial haemorrhages, compression of the underlying brain tissue, laceration of the brain parenchyma and intraparenchymal bone fragments may occur [24, 25].

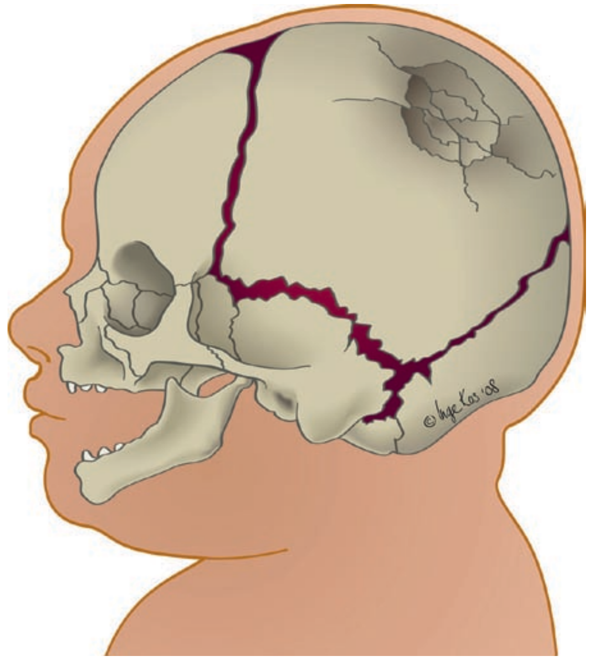

Fig. 2.8 Schematic representation of a depression fracture

2.4.3.2 Ping-Pong Deformation

In infants (generally <6 months old), when the impact site is small, instead of a depression fracture a ping-pong deformation of the skull may occur ('celluloid fracture') (Fig. 2.9a and b) [19]. This is due to the larger malleability and elasticity of the immature skull. In the differential diagnosis, one should be aware of congenital impressions of the skull (Figs. 2.10 and 2.11a and b).

2.5 Skull Fractures and Intracranial Injury

Skull fractures and intracranial injury are only correlated to a limited degree. Skull fractures may be present without intracranial injury. Dunning et al. mention that a skull fracture has a relative risk of 6.13 (95% CI 3.35–11.2) for intracranial haemorrhage [26]. On the other hand, there may be intracranial injury without a skull fracture. This applies to accidental as well as to non-accidental causes [13, 27].

According to Harwood-Nash, skull fractures are more often seen with associated subdural haemorrhages in older

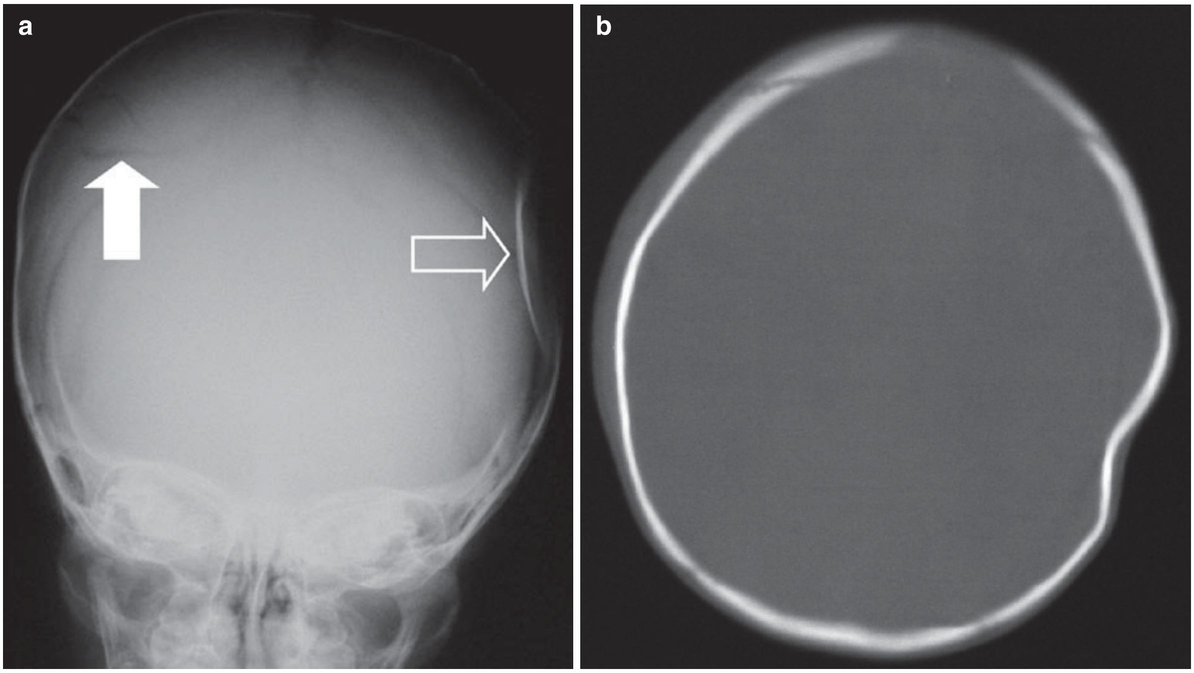

Fig. 2.9 (**a**) Eight-month-old infant, who had an obscure clinical history had allegedly fallen from a single bed on top of a drying rack (that lay on the floor). The skull view shows a ping-pong deformation (*open arrow*) and a linear fracture of the parietal bone (*arrow*). B Skull CT did not show any intracranial pathology. On the left-hand side, a cortical deformation without fracture can be seen

Fig. 2.10 Schematic representation of the origin of congenital impressions

children than in infants [2]. However, the location of the skull fracture is not a good indicator for the location of the subdural haemorrhage. The series of Harwood-Nash showed that subdural haemorrhages were predominantly found contralateral to the fracture [2].

It may happen that there is an epidural haematoma that results directly from the fracture. In a fracture of the temporal bone, the medial meningeal artery may be damaged, which can lead to an epidural haemorrhage in the temporoparietal area. Epidural haemorrhages are nearly always of arterial origin. In a fracture of the occipital bone, the venous sinus may be damaged, leading to a venous epidural haemorrhage in the posterior cranial fossa [20].

Mogby et al. carried out a retrospective study into the relation between skull fractures, visible on radiographs, and intracranial injury in 87 children under the age of 2 years old with a skull fracture [28]. In 67 children no neurological pathology was found. In 32 of those children, the researchers performed a CT scan to exclude intracranial injury. In six children (19%) small focal haemorrhages were found around the fracture. This did not result in an intervention or change in policy. Of the 32 children in the CT group, 29 were admitted as opposed to ten children

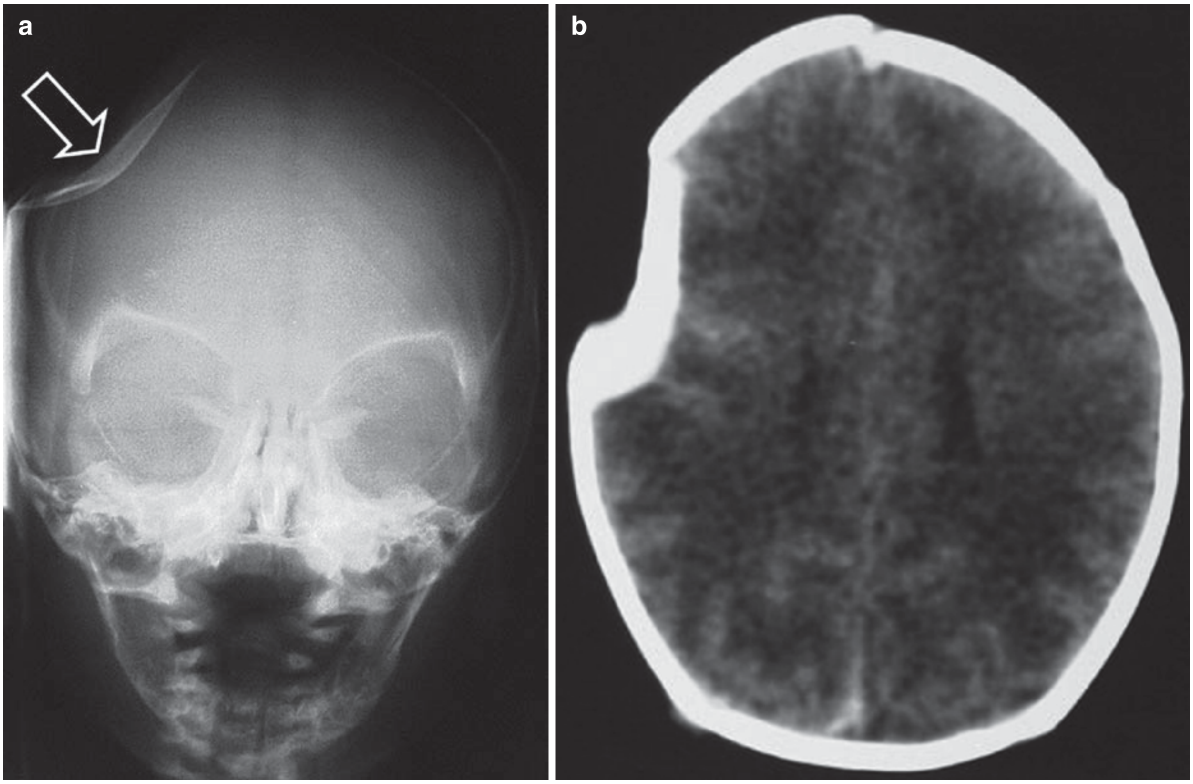

Fig. 2.11 (**a**) Three-day-old infant boy. Protracted breech presentation, no traumatic delivery. At physical examination a clearly visible impression of the skull was seen. Skull view shows an impression of the right parietal bone (*open arrow*). (**b**) Follow-up CT did not show any signs of trauma. In view of the anamnesis and the clinical findings, this image is due to a congenital impression

who did not have a CT. The children in the CT group were hospitalised longer. None of the children without neurological symptoms developed neurological complication at a later stage. In 20 of 87 children, acute neurological pathology was found. They all had a CT scan, and in 16 of 20 children pathology was found. Three children had minor pathology, 13 children showed serious pathology. In 15 children with acute neurological pathology further examination was performed within the scope of possible care proceedings. Based on these findings, 13 of them where placed into care. Mogby et al. concluded that detection of a skull fracture is more reliable using conventional radiology. Furthermore, no direct correlation was found between skull fractures and intracranial injury. According to Mogby et al., there is no indication for a CT scan based solely on the presence of a skull fracture. A CT scan is indicated when there are neurological symptoms. Finally, they concluded that a CT scan has added value when child abuse is seriously suspected, even when there are no neurological symptoms and conventional radiology shows no fractures.

Demaerel et al. found that 45% of infants under the age of 2 years with intracranial injury did not have a skull fracture. It was also found that 56% of children with a skull fracture did not have any intracranial injuries. Finally, Demaerel et al. concluded that it is impossible to differentiate between accidental and non-accidental causes based on radiological examination [29].

Gruskin and Schutzman performed a retrospect study into the predictors of complications in skull-/brain trauma in 278 infants under the age of 2 years, presenting at the emergency department of an academic hospital [30]. They concluded that clinical signs and symptoms were not suitable as predictors for skull fractures and/or intracranial injury. Also, they found three characteristics to identify children that are at low risk for complications:

- A fall of less than 1 m
- No neurological symptoms in the anamnesis
- No abnormalities of the scalp at physical examination

2.6 Skull Fractures: Differential Diagnosis

In children, skull fractures due to dynamic impact loading are regularly seen. There are three types of cause: accidental (accident of fall, in traffic, playing sports, around the home, etc.), non-accidental (physical violence) or medical (birth, bone diseases, etc.). Per age group, differences are seen when categorising for cause.

Children of less than 1 year old are six times more likely to sustain a skull fracture than older children [31–33]. In children of this age the skull fracture is often the result of child abuse, although one should not dismiss accidental falls or birth trauma out of hand (see Sects. 2.6.1. and 2.6.3). In children from approximately 1 year (if sufficiently mobile) to the age of 4, accidental falls during play seem to be the most prevalent cause. In children between 4 and 14 years of age, it is mostly traffic accidents and violence [34, 35].

2.6.1 Skull Fractures and Child Abuse

In physical violence, the fracture is the result of the direct impact of considerable external force, such as contact with a flat surface or a punch with a fist. Physical violence seems to be involved in only a relatively small part of skull fractures in childhood. Johnstone et al. evaluated 409 children under the age of 13 years; only 3% of skull fractures were due to child abuse [36]. However, this percentage increases dramatically as the studied population gets younger. Hobbs came to the conclusion that 33% (29 of 89 children) of skull fractures in children of less than 2 years of age result from child abuse [37]. Leventhal et al. studied 93 children under the age of 3 years with skull fractures; 80% was less than 1 year old. In the group of infants of less than 1 year old, 27% of fractures resulted from child abuse [38]. Meservy et al. evaluated 134 children of less than 2 years old; in 39 infants (29%) child abuse was the cause of the skull fracture [39].

According to Kleinman et al., 10–13% of all cases of physical violence concern skull fractures [27]. Merten et al. found a comparable percentage, slightly less than 10% (67 children with a skull fracture in a total of 712 abused children) [40]. Neither Kleinman nor Merten differentiated for age.

Loder and Bookout carried out research in abused children of less than 16 months of age that had sustained fractures as a consequence. In 35% of children a skull fracture was found [41].

Reece maintains that 80% of skull fractures sustained through child abuse occur in infants of less than 1 year old [42].

Of all fractures sustained by children as the result of child abuse 7–30% are skull fractures [27]. According to some authors, skull fractures are even the one but most frequently occurring fracture in child abuse [31, 43, 44].

In 41% of children that die as a result of physical violence, skull fractures are found [33].

2.6.2 Type of Skull Fracture and Child Abuse

The most prevalent skull fracture in physical violence is the unilaterally localised, simple linear fracture of the parietal bone without depression. However, this is also happens to be the most prevalent skull fracture in accidents [19].

When the fracture is bilaterally present or when there are multiple fractures with depression and diastasis >3 mm, one should consider child abuse as the main cause, especially with a ambiguous patient history. Also, in depression fractures, fractures with diastasis of the fracture lines and occipital fractures, one should consider physical violence as a possible cause [8, 39, 40, 45–47].

Kleinman even considers depression fractures of the occipital bone as very suspect for child abuse [48]. However, the presence of the earlier-mentioned fractures, taken out of context, is never evidence of physical violence [49, 50].

Finally, the literature reports regularly that fractures that transgress the sutures (carry from one skull bone into the other) are highly suspect for child abuse (see, e.g. Fig. 8.46). However, this appears to be incorrect: fractures that continue into the adjacent bone are also found in accidental causes [51, 52].

2.6.3 Differential Diagnosis Between Non-accidental and Accidental Fractures

In the differential diagnosis of non-accidental skull fractures, one should be aware of accidental fractures that result from either static or dynamic impact loading.

2.6.3.1 Static Loading: Birth Trauma

In uncomplicated deliveries, skull fractures are rare. Rubin did a prospective study in 15,435 births and only found one skull fracture [53]. Two other studies showed in a total of more than 51,000 births, 11 skull fractures (see Chap. 6) [54, 55]. In an article (letter), Groenendaal and Hukkelhoven report in 158,035 births 1,174 fractures that were due to birth trauma [56]; this study did not report any skull fractures.

Most skull fractures that result from birth are uncomplicated linear fractures in the parietal bone. This kind of fracture almost always concurs with a difficult delivery or externally applied mechanical force. For example, skull fractures are found in 5% of children that had had vacuum extraction [57]. The risk for sustaining a skull fracture when vacuum extraction is used increases considerably when the cup releases unexpectedly and has to be re-applied, and when there is a haematoma. The risk also increases in mature maternal age, primigravid and macrosomia. Yet, a simple linear fracture may also occur in a normal spontaneous vaginal birth without specific complications or the use of forceps or vacuum extraction [58].

Sometimes a depression fracture is the result of a delivery [59]. Complicated skull fractures occur mainly with forceps deliveries, but depression fractures have also been reported with excessive manipulation during a Caesarean section or vacuum extraction [59, 60]. A growing skull fracture has been reported twice as resulting from vacuum extraction [61, 62]. Rupp et al. describe as complications of a vacuum extraction, circular fractures and/or elevation of the outer layer of the skull, subperiosteal and intra-osseous haemorrhages, and epidural and subdural haemorrhages [63].

A Caesarean section seldom leads to skull fractures. Alexander et al. found 418 children with injuries in a total of 37,110 Caesarean sections [64]. Six of them sustained a skull fracture due to complicating factors prior to the Caesarean section, such as complications resulting from an earlier effort at a vaginal delivery.

There is a considerable chance that a linear fracture is not detected directly after birth. Complex skull fractures are usually visible immediately after birth and are often accompanied by marked and acute intracranial injuries [59].

During the first months it is based only on the radiological evidence of the fracture, according to Kleinman and Barnes, generally impossible to differentiate whether the skull fracture resulted from birth trauma or child abuse [27]. Skull fractures in children of less than 1 year of age tend to heal without notable sclerosis. In time, the fracture lines fade.

The chance that the fracture results from the delivery is negligible after an uncomplicated non-traumatic delivery, and when directly after the delivery the child did not show any visible swelling on the head or symptoms pointing to intracranial injury. Of the children with a skull haematoma, 10–25% may have a skull fracture [65, 66].

On the whole one may assume that a complicated linear fracture that was sustained during delivery will not be all that well visible after 2 months, and will have disappeared after 6 months [27].

For the incidence of skull fractures as birth trauma in children with congenital defects, such as osteogenesis imperfecta or Menkes disease, we refer to Chap. 7.

2.6.3.2 Static Loading: Crush Injuries of the Head

Crush injuries of the head are usually the result of static loading, although in some accidents, such as traffic accidents, there is a combination of dynamic (e.g. head against car while being hit by a car) and static loading (e.g. when the wheel runs over the head; hereby the head lies more or less stationary and is pressed against a rigid structure). As a result of static loading, the skull is deformed relatively slowly and there may be damage to the intracranial structures, such as the brain [67].

Duhaime et al. report on 7 children between the age of 15 months and 6 years that had sustained crush injuries [67]. They all suffered basilar fractures, 6 had multiple and often extensive fractures of the cranium. The researchers did not report whether the 7th child, who died soon after arriving at the hospital (transection of the cervicomedullary myelum), had sustained any other fractures besides the earlier-mentioned basilar fracture. Four children were victims of traffic accidents, and had been run over by a reversing car. In the three other children there was static loading when the child climbed on a heavy object or pulled at a heavy object that consequently dropped on the skull of the child (solid stone front of a fireplace, 27-inch television, 45 kg clock). However, the question is whether in the case of these three children one can speak of static loading. It could also be dynamic impact loading, in which the child falls on the floor with its head more or less stationary on the underlying surface and the object drops on the child (see Sect. 2.6.3 on dynamic impact loading: crush injuries). This can be compared to the effects of a fall from great height, which may also lead to multiple and extensive fractures of the cranium.

According to Takeshi et al., serious crush injuries of the head are usually fatal. They also pose that the prognosis of this type of injury, either lethal or excellent, depends on the extent in which the skull and brain have been able to withstand the force [68]. Six of the seven children (average age: 5.9 years) they described had sustained skull fractures. In six children the head had been run over by the wheel of a car. In four children multiple linear fractures of the cranium were found and in six children a basilar fracture.

2.6.3.3 Dynamic Impact Loading: Accidental Falls

As mentioned earlier, uncomplicated fractures hardly ever cause clinical symptoms. Hence, there usually is no additional examination. On the whole, no medical help will even be sought. Consequently, accidental falls may result in a larger number of skull fractures than one would deduce from data in the literature. This can also mean, that more young children will sustain a skull fractures after a short-distance fall than one would be able to determine from data in the literature.

Accidental skull fractures will rarely lead to serious or life-threatening intracranial injury. Severe trauma, such as a car accident, may cause intracranial injuries. However, in those cases, the patient's history corresponds with the injuries found, and cannot be confused with child abuse. For a comprehensive overview regarding the origin of skull fractures accompanied by intracranial injury and other fractures and possible death based on accidental causes, we refer to Chap. 6.

When a skull fracture is the result of a fall from a bed or a changing table, it is unlikely that there will also be other fractures, such as rib fractures or a midshaft fracture of one of the extremities. In a non-accidental skull fracture, for example when a parent hits the child's head against the wall, or at the end of his/her wits throws the child to the floor, it will nearly always lead to a different kind of injury, either intracranial or in other locations of the body. The overall picture will look more like a serious accident; however, the anamnesis will not be able to explain the injury and its location. In other words: an accidental skull fracture can nearly always be explained based on the anamnesis.

In addition to the anamnesis, the fracture characteristics will provide limited opportunities to further differentiate between accidental and non-accidental fractures. Hobbs evaluated 89 children of less than 2 years old with skull fractures [37]. Sixty of them had sustained fractures due to accidental causes. The remaining 29 were victims of child abuse. Table 2.1 gives an overview of the differences between both groups.

2.6.3.4 Skull Fractures in Relation to the Distance and Context of the Fall

In the medical literature there is no consensus on the minimal distance a child must fall to sustain a skull

Table 2.1 Characteristics of accidental and non-accidental skull fractures in children of <2 years old [37]

	Accidental	Non-accidental
Type of fracture	Generally simple and linear, uncomplicated	Multiple or complex Depression fracture 'Growing fracture' (see Sect. 2.7)
Fracture width	<3 mm (never >5 mm)	>3 mm
Location	Generally, fracture in one skull bone Mainly parietal Rarely other locations	More than one skull bone Mainly parietal and occipital Sometimes frontal or temporal or in the anterior cranial fossa or the medical cranial fossa
Intracranial injury	Rare	Frequently, combined with other fractures

fracture. Some mention a distance of less than 1 m, and emphasise at the same time that it is very rare [69]. Also, one often refers to complicating factors that are associated with the fall at the moment the skull fractures occur, such as a fall from the arms of a parent or carer [69].

Johnson et al. carried out a study in 72 consecutive children of <5 years old (4 months to 4 years and 9 months), who presented at the emergency department due to skull injuries after a fall [70]. They collected data on distance of fall in a free fall or falling down the stairs, the surface area of the landing and the length of the child. Distance of fall ranged from 50 cm to 3 m. Most children fell less than 1 m. Of the 72 children, 49 fell on a hard surface and 23 on a soft surface (covered in carpet). In 52 children the fall resulted in a visible injury to the head (35 on hard surface, 17 on soft surface – there was no significant difference). There were visible skull injuries in all children that had fallen over >1.5 m, and in 95% of children that had fallen over a distance of >1 m. In 32 children (44%), a skull radiograph was made. In four cases a skull fracture was visible, of which three were linear. Two of the children with a linear fracture had fallen >1 m. One child sustained the fracture in a fall of 80–90 cm against the stone edge around a fireplace. The 4th child sustained a basilar fracture in a fall of over 3 m from a window on the first floor. Johnson et al. concluded that children seldom sustain serious injuries in accidents in and around the home. They maintain that skull fractures are rare and occur only in <5% of all accidents. In their opinion, it takes a fall of at least 1 m or, in lesser distances, on a limited surface area to cause a skull fracture.

Thomas et al. carried out a study in 112 children of <1 year old that had experienced a skull trauma [71]. In 96 children a skull radiograph was made. According to the parents, 32 children fell over a distance of >1 m. Thomas et al. found six children with a skull fracture that belonged to the group of 80 children that had fallen over a distance of <1 m. According to the parents, two children with a skull fracture had fallen from a height of <30 cm. In four of the six children that had sustained a fracture the physicians were sufficiently concerned to report the incident to the child protection service. When additional examinations were performed, two of the children were found to have further fractures. Based on the statements of the parents, it appeared to be impossible to predict which children had skull fractures. The presence of external injuries or neurological symptoms appeared to be an unreliable indicator for skull fractures. The reported distance of the fall was also not indicative. Hence, Thomas et al. are of the opinion that in children of <1 year of age that present with head trauma, a skull radiograph should routinely be made. In their study it led to the identification of four children with a skull fracture as the result of child abuse.

2.6.3.5 Skull Fractures in an Uncomplicated Fall

An uncomplicated fall is a short-distance free fall on a flat surface. The fall originates from a position in which the child stands still or lies still and is the result of the child's own movement patron, in accordance with its level of development. Hereby one may think of a situation in which the child falls from a changing table because it turns over, or when a child falls over while standing because it loses balance.

Data on how a child sustains a skull fracture after an uncomplicated fall have been derived from fall studies as performed by Weber [12, 51, 72]. They can also be derived from data of accidental falls in children as observed by independent bystanders.

Fall Studies in Deceased Children

Nearly every young child has fallen on his/her head from a standing position or from limited height; for example, from a changing table or from a stroller. Since there is a difference of opinion between several physicians and researchers on whether children that fall from such a height can sustain a skull fracture, Weber did experimental research with deceased children of <8.2 months old. In his first article he describes three test series each with five children who he dropped in free fall from a height of 0.82 m on several surfaces (stone-tile surface, carpeted floor, foam-supported linoleum floor) [51]. Hereby, the horizontally positioned body and the parieto-occipital part of the skull hit the surface simultaneously. In all cases autopsy showed linear skull fractures of the parietal bone. One child sustained bilateral fractures. In three children the fractures run across the sutures. Based on this study, Weber concluded that skull fractures can be sustained in a fall from a changing table. He also concluded that when child abuse is suspected, differentiation with an accidental fall is only possible when the whole picture is taken into consideration. In a second article Weber describes a follow-up study in another 35 children who he dropped on a soft surface [72]. In 10 children a 2 cm thick foam rubber mat was used and for the other 25 a once folded, 8 cm-thick blanket. Weber found a skull fracture in one child in the rubber-mat group (two linear fractures in the left parietal bone). In the other group, he found bowing fractures in four children (linear fractures or ping-pong fractures).

In interpreting Weber's data, one must be aware of the fact that a living child will fall differently to a deceased child, due to active muscle tension and, when old enough, a fall reflex. Yet, Weber's studies show that it is possible to sustain a skull fracture in an uncomplicated fall from a height of <1 m.

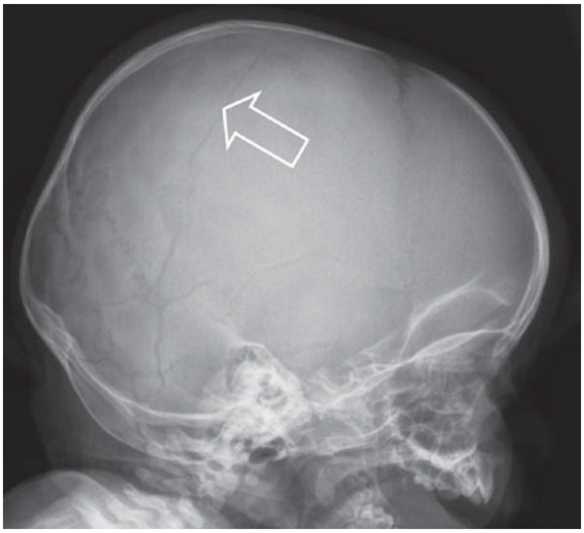

Fig. 2.12 Eight-month-old boy infant with cutaneous swelling after a fall from a bed. Radiological examination shows a linear fracture of the skull (*open arrow*)

Uncomplicated Fall over a Short Distance (Maximal 1–1.5 m)

The medical literature contains many articles and case notes on the nature of skull fractures after a short-distance fall (<1–1.5 m). Based on the earlier-mentioned data one may conclude that skull fractures resulting from such a fall can occur in living children. In the literature one sometimes comes across case notes on severe to life-threatening injuries sustained in a short-distance fall. In such cases, there are often complicating factors associated with the fall (see below and Chap. 6).

Helfer et al. described injuries in 246 children of <5 years of age [73]. The group consisted of 161 children whose parents filled out a questionnaire when they saw a physician for a fall over a distance of <90 cm (bed or settee) and 85 children who had fallen from their crib/cot or from the examination table during their stay in hospital. Two children in the group that had fallen outside the hospital had sustained a skull fracture (age < 6 months). In the children who had fallen while hospitalised, one skull fracture was found. The majority of children did not have any externally visible injuries.

Nimityongskul and Anderson did research into the origin of injuries in 76 children (age ranged from neonate to 16 years), who had fallen out of bed, crib/cot or chair while hospitalised [74]; 57 children were <5 years of age and 23 children <1 year of age. Fall distance was between 30 and 100 cm. Most children had superficial injuries (haematomas of the scalp and lacerations of the face). One 12-month-old child had an uncomplicated occipital skull fracture.

Lyons and Oates described 207 children of <6 years of age who had fallen from their crib/cot ($n=124$) or bed ($n=83$) [75]. The distance of the fall ranged from 65 cm (lowered side rail) to 110 cm (side rail up) in a fall from a crib or cot, and from 50 to 85 cm (including side rails) in a fall from a bed. In 31 children there were visible injuries, in 26 to the skull. In one child (age 10 months), an uncomplicated linear skull fracture was found after a fall from a cot (Fig. 2.12).

Tarantino et al. studied 167 children of <10 months old (average age 5.2 months, 56% male), who fell over a distance of less than 1.25 m and for that reason presented at the emergency department [76]. They excluded all falls from baby walkers and car seats, falls down the stairs and all accidents resulting from walking, running or climbing. They also excluded children that had fallen on objects or on whom a carer had fallen. Fifty-fife percent of children fell out of bed, 20% fell from the arms of a parent/carer (being dropped), 16% fell from a settee and 10% fell in a different manner. Eighty-five percent of children had no or minimal injuries. The remaining children ($n=25$) had severe skull trauma: 16 a closed-head injury, of whom 12 had sustained a skull fracture, two had intracranial haemorrhaging and seven had fracture of one of the long bones. Additional examination revealed that the children who had sustained intracranial haemorrhages were victims of child abuse. After these two children had been excluded, it appeared that the only risk to sustain a severe injury in a fall was from the arms of a carer.

Tarantino et al. concluded that the biomechanics of a fall from the arms of a carer may be different from other kinds of short-distance fall, such as a fall from a bed, settee or changing table.

The research of Warrington and Wright also confirmed the findings in studies from before 1995, which are largely based on the data of fall incidents while hospitalised. Warrington and Wright studied accidents in non-mobile children in the home setting [69]. By using questionnaires that had to be filled out they requested parents of 6-month-old children to describe every accident since birth. They asked the parents to describe the type of fall, the distance of the fall, the injury and the medical help given (in case this was sought). The number of forms returned was 11,466. In 2,554 children, 3,357 fall incidents were reported. Fifty-three percent of children fell out of bed or from the settee, and 12% fell from an arm while being carried or when the person who carried the child fell down while holding the child. In the remaining children a large diversity of falls was seen: from a table, chair or changing table, from a baby bouncer, etc. In <1% cause of the fall was not reported. Seventy-six percent of children fell only once, and in 5% it was thrice or more. The number of falls increased with the age of the child. Less than 25% occurred before the age of 4 months. Only 14% of children sustained visible injuries, of which 56% were haematomas. In 97% the injury was visible on the head. Less than 1% (21 children) sustained a concussion or fracture. One-hundred and sixty-two children were taken to hospital after their fall, and 18 children were hospitalised. In the hospital, a skull fracture was diagnosed in three children; however, this was no reason for hospitalisation. Skull fractures were never seen after a fall from a bed or settee. None of the children suffered intracranial injuries such as subdural or epidural haemorrhages.

2.6.3.6 Skull Fractures in a Complicated Fall

In a complicated fall, the child does not have a short-distance free fall, landing on a flat surface. There may be complications during:

- The initial moments of a fall: for example, the arms of a carer, a fall from a swinging swing or a fall with a baby walker.
- The fall itself: for example, a fall of the carer who holds the child on his/her arm, and in which the carer falls fully or partly on the child; a fall from a bunk bed in which the child comes into contact with parts of the bed while falling; or a fall with a baby walker from the stairs.
- The landing: for example, a fall on a non-flat surface or a fall on objects.

One also speaks of a complicated fall when the child falls from great height and the complications, such as sustaining a complex skull fracture and intracranial injury, are mainly the result of the higher velocity at landing.

Fall from the Arms of Parent/Carer

Warrington and Wright studied the incidence of falling in non-mobile children in a home setting (see paragraph 2.6.3.5) [69]. The study of Tarantino et al. also looked into the consequences of a fall from the arms of a parent/carer (see paragraph 2.6.3.5) [76].

Minns reports the possibility that infants, as early as 5 weeks old and when held with one hand against the shoulder of the carer, are able to lean back in such a manner that they fall. This usually involves a fall of approximately 1.5 m [77]. As a result of such a fall, they may sustain a focal haematoma and even extensive skull fractures and focal contusion of the brain (Fig. 2.13). Minns maintains that in these children there will be no other signs of encephalopathy or any delay in seeking medical help. A good anamnesis and careful scrutiny of the circumstances will provide ample information to differentiate between accidental and non-accidental skull/brain trauma.

In 2004, Pediatrics published an article of Bechtel et al. called ‘Characteristics that distinguish accidental from abusive injury in hospitalised young children with head trauma’ [78]. In 2005, a letter of Lueder was published in response, regarding retinal haemorrhages in a number of accidental falls [79]. In their answer to Lueder’s letter, Bechtel et al. described a number of situations in which children had fallen, for example, from the hands of parents/carers and consequently sustained skull fractures and other injuries (see Table 2.2) [80].

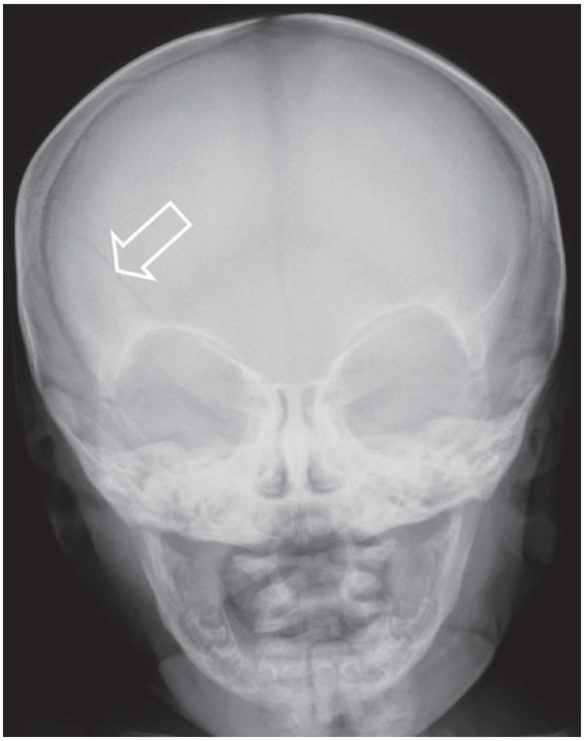

Fig. 2.13 Six-week-old infant girl who had fallen from the arms of her mother on a tile floor. Radiological examination shows a linear fracture of the skull (*open arrow*)

Fall on an Object

Wheeler and Shope described a 7-month-old infant who fell out of bed and sustained a ping-pong fracture of the skull (2 × 4 × 0.5 cm in the right parietal bone) [81]. The child appeared to have fallen over a distance of approximately 60 cm on top of a metal toy car. Nobody saw the fall. There were no signs of underlying brain damage, retinal haemorrhages or other fractures.

Fall from a Perambulator or Stroller

A fall from a perambulator, in particular in children of <1 year old, is not rare. Injuries are mainly found in the head/neck area (including intracranial injuries and skull fractures) [82, 83]. According to Watson and Ozanne, the risk for serious injuries is considerable, since by far the majority of children (96% of children in their study) that had fallen from a perambulator fell on their head [84].

Serious cranial injury has only been described in case reports. It concerns typical injuries that originate from contact; for example, epidural haemorrhages [85]. This does not have to lead to a skull fracture [85]. Permanent injuries as well as death are extremely rare [82–85]. In their review of the literature, Lee and Fong found three children that died after their parents reported a fall from a perambulator. In the end, two of the children appeared to be victims of child abuse [85].

Arnholz et al. describe the origin of bilateral skull fractures in a 6-week-old baby who had fallen from a perambulator from a height of approximately 90 cm on top of his/her head on concrete steps [22]. As associated injuries 'two separate and symmetrical areas of scalp haemorrhage' were found. Arnholz et al. point out that bilateral fractures are rarely the result of an accident and for that reason should be seen as extremely suspect for child abuse. Their findings correspond with Weber's experiments with deceased children (see Sect. 2.6.3.5).

Table 2.2 Injuries in children who fell from the arms of a carer [78–80]

Age	Distance	Context	Witnesses?	Findings at examination
1 month	1 meter	Fell from the father's arms, who was lying on the bed	+	Skull fracture right side of the skull Epidural haemorrhage Retina bleed (one eye) in right eye
4 month	1 meter	Fell from the arms of an older child	?	Skull fracture on the lift side Intraretinal bleeds at the back of the left eye
4 month	1.25 meter	Fell from mother's arms and hit its head against the edge of the table	+	Skull fracture on the right side Intracranial haemorrhage Intraretinal bleeds around the optical disc and arcs
8 month	60 cm	Fell from mother's arms, who was lying on the settee	?	Skull fracture on the left side Epidural haemorrhage One intraretinal bleed in the left eye

Fall from Shopping Trolley

Smith et al. evaluated retrospectively the emergency department data of over 75,000 shopping trolley-related injuries in children <15 years of age [86]. Eighty-four percent of children was <5 years. The most prevalent injuries were head and neck injuries (74%).

In a prospective study, Smith et al. evaluated 62 children ranging in age from 4 months to 10 years (average 2.8 years) that had presented at the emergency department for shopping-trolley-related injuries over a period of 15 months [87]. The majority of children had sustained the injury by falling out of the trolley (58%), followed by toppling over of the trolley (26%). Injury resulting from falling out of the trolley occurred at all ages, whereas toppling over of the trolley was mainly responsible for injuries in children <1 year old. Forty-nine children (79%) appeared to have sustained head injuries, of which five had skull fractures. Smith et al. concluded that accidents with shopping trolleys can lead to serious and potentially life-threatening injuries, although there were no cases of (intra)cranial injury – in spite of falling on a solid (often concrete) surface. No intracranial haemorrhages were found.

Fall from Bouncy Chairs, Baby Bouncers and Car Seats

Wickham and Abrahamson studied the risk of the use bouncy chairs (Fig. 2.14) and car seats [88]. Seventeen of the 131 children (average age: 6.9 months) with head injury they examined appeared to have fallen from bouncy chairs or car seats. All falls with bouncy chairs took place while the child was seated in his/her chair which was placed on a high surface (such as a table). This also seemed to be the case in two of the six children in the car-seat group. Fourteen of 17 children fell on a solid surface. One child had sustained a skull fracture as a result of the fall. There were no serious or life-threatening injuries.

A baby bouncer is a playing device (Fig. 2.15) made for children that are well able to keep their head upright, but are yet unable to walk (see Chap. 6). The literature only has few case reports that point at the risks of the use of baby bouncers [89–91]. Unfortunately, the literature is not quite clear on the definition of a baby bouncer, which makes it difficult to compare the results.

Clayton describes a case of a fatal fall from a baby bouncer [89]. A 5-month-old child had fallen after two other children had rocked the child in the bouncer. At the time of the fall, the head was no more than 60 cm from the floor. Clayton is correct in pointing out that one does not necessarily have to fall from great height to sustain life-threatening head trauma. After the fall the child cried loudly at the top of its lungs; 7 h later it died. Examination showed a large epidural haemorrhage at the left side, without skull fracture.

Fall from a High Chair

In particular children of less than 1 year of age seem to fall regularly with or from high chairs. The study of Watson and Ozanne showed that 75% of children who fell out of a high chair landed on their head [84]. The majority of those children sustained head injuries [92, 93]. In 103 children, Mayr et al. found haematomas or lacerations of the scalp or face (68.9%), skull fractures (15.5) and concussion (13.6%) [93]. Powell et al. found in 21% of children intracranial injuries [93]. In the (albeit limited) literature, serious or even life-threatening injuries have rarely been described. Only

Fig. 2.14 Bouncy chair

Fig. 2.15 Baby bouncer

Watson and Ozanne mention 1 child that died from a fall from a high chair [84].

Fall from Stairs

Many parents have experienced at some time that their young child fell downstairs. This means that annually the number of falls down the stairs must be very high. Usually it results in little or no injuries. This is probably why the paediatric literature contains but a few publications on this type of accident and the occurrence of skull fractures in these accidents.

In a prospective study, Joffe and Ludwig describe 363 children, ranging in age from 1 month to nearly 19 years, with injuries resulting from a fall downstairs (average age 55 months) [94]. Fifty-four children were <1 year old. Ten children were carried by their parent/carer. Twenty-four children were in a baby walker when they fell downstairs. Children who had been abused were excluded from the study. The majority of children sustained light superficial injuries, 73% had injuries to head and neck. Head trauma was more often seen in children that were less than 4 years of age. Six children had sustained a skull fracture (all <3 years old). Four of the six skull fractures were sustained in the ten children that fell from their parents/carers hands while going downstairs. None of the children was in a life-threatening situation. According to Joffe and Ludwig, a fall downstairs is really a series of much smaller falls. The first fall is the longest by height: the height of the child itself plus the number of steps of the stair.

Chiavello et al. studied the effects of a fall downstairs in 69 children of less than 5 years of age (average age 2 years), including three children that had taken a fall with their parent/carer [95]. They excluded accidents with baby walkers and children suspected of being abused. The majority of injuries were not serious. Fifteen children had sustained serious injuries such as concussion (11 children – 16%), skull fractures (five children – 7%), cerebral contusion (two children – 3%), subdural haemorrhages (one child – 1%) and fracture of the second cervical vertebra (one child – 1%). The three children who had been carried by their parent/carer who had fallen on the child against the stairs, had sustained the most serious injuries: two children had skull fractures. One of them also had a small subdural haemorrhage and cerebral contusion. This was also the child that had sustained a fracture of the second cervical vertebra. These injuries occurred in a fall while being carried downstairs by an adult. Chaviello et al. concluded that head and neck injuries are the most prevalent injuries, and that it is rare to have injuries on more than one body part.

Chaviello as well as Joffe concluded that a free fall causes more damage than a fall from the same height downstairs.

Fall with a Baby Walker

Accidents with baby walkers occur regularly in young children up to 1 year old. Injuries are caused by various mechanisms: going head over heels, falling down the stairs or from an elevation, or by crushing of fingers. The most prevalent location for injuries is the head and neck area, including the face [96]. The majority of the injuries concern the head or face and are relatively innocent. The majority and most serious injuries occur when falling downstairs with a baby walker [97–101]. In this context skull fractures have been mentioned frequently [99, 100, 102–104]; the fractures may be linear but also complex fractures are seen [105]. Mayr et al. found basilar fractures in 19 of the 172 children they evaluated [103]; 15 had suffered a fracture of the cranium and 4 a basilar fracture.

Smith et al. studied 271 children that had been treated for baby walker-related trauma [106]. In the 26 children in Smith's study, a skull fracture was established (17 parietal, eight frontal and one occipital). They saw three children with a depressed fracture of the skull of whom two had a second skull fracture without depression. Three children with a skull fracture also had intracranial haemorrhages, of which two were subdural haemorrhages. The skull fractures all occurred in the group of children that had fallen downstairs. Chaviello et al. found intracranial haemorrhages in 5 of the 65 children they evaluated [104]. Death is rarely reported. The study of Chaviello et al. reported one deceased child (skull fracture, subdural haemorrhage and fracture of the cervical spine) [104].

In an advice on the use of baby walkers, the American Academy of Pediatrics (AAP, 2001) reports that between 1973 and 1998 they received reports on 34 children who had died from a fall with a baby walker [107]. Due to the considerable risk for light to very serious injuries and death, the AAP issues a negative advice regarding the use of baby walkers.

Fall from a Bunk Bed

Although one may think that a fall from a bunk bed, besides the larger distance of the fall, is comparable to a fall from a lower bed, it appears that, based on data from the literature, the risk for serious injury is considerably higher for a fall from a bunk bed [108]. Injuries may be sustained by falling from the top bed or the bottom bed and from the ladder. The fall may occur during sleep, when getting out of bed or while playing.

The majority of children suffers head trauma, including facial injuries, in particular in a fall from the top bed [109, 110]. A fall from the top bed also often causes more serious injuries [109]. Skull fractures are not often reported. Mayr et al. found seven skull fractures in a total of 218 children [111]. MacGregor did not find any skull fractures at all, in spite of the fact that a number of children showed notable neurological symptoms: unconsciousness, drowsiness or vomiting [110].

In spite of the high number, the severity and diversity of the injuries that occur when children fall from a bunk bed, hardly any mention of intracranial injury can be found in the medical literature. Selbst mentions a child with a skull fracture and a subdural haemorrhage [109]. In none of the children MacGregor found intracranial haemorrhages, not even in complex falls; for example, when during the fall a child hits another piece of furniture before hitting the ground [110]. Mayr et al. too did not find any intracranial haemorrhages [111].

In conclusion, it is remarkable that none of the earlier-mentioned studies reported the death of a child after a fall from a bunk bed.

Fall from a Great Height

The fall distance necessary to cause damage in young children in a free fall has been a continuous subject of discussion [112]. Williams evaluated the data of 398 consecutive victims of a fall. In the end, 106 children were selected for further evaluation [112]. In this group the fall had been witnessed by another person than the carer, and the context of the fall had been documented. In Table 2.2 Williams' findings are specified. Williams also evaluated the data of 53 children with an anamnesis that indicated a fall as the cause of the sustained injuries, without an independent eye witness to confirm this cause. In this group 2 children had died after a fall of less than 3 m (both fell over a distance of even less than 1.5 m). In the group with the independent eye witness, there were 44 children that had fallen over less than 3 m. In this group, three children had sustained a small depressed fracture; however, none of the children in this group died. It appeared that the children that sustained a depressed fracture had fallen against a sharp edge. In the group of children whose fall had been witnessed by an independent observer, one child died after a fall of over 20 m (Table 2.3).

Williams concluded that 'infants and small children are relatively resistant to injuries from free falls, and falls of less than 10 ft are unlikely to produce serious or life-threatening injury'.

Table 2.3 Injuries in falls witnessed by others than the carer (distance fall: 0.5–20 m) [112]

Severity of injury	N		<3 m	>3 m
None	15		8	7
Mild	77	Haematomas, abrasions, simple fractures	24	43
Serious	14	Intracranial haemorrhages, brain oedema Depression fractures, compound skull fracture	3	11

The majority of injuries sustained by a child who falls from a great height are injuries in the head-neck area [113, 114]. The most prevalent injury, besides visible injuries, is the skull fracture, which may be accompanied by intracranial symptoms (subdural, subarachnoidal and epidural) and cerebral contusions [113, 115–117]. There may be fractures of the cranium as well as of the base of the skull [117]. The risk for a fatal course increases with distance of fall, for example a fall from a balcony, roof, stairs, diving board or from an open window or tree [115]. Hereby intracranial injuries are the main cause of death [117].

The majority of children who fall from a great height is less than 5 or 6 years old and fall over a distance of 3–7 m (one or two floors) in or in the direct vicinity of the home, mostly during the warm seasons [113–115, 118]. On the whole parents do not witness the fall, unless they are directly involved in the fall. Mayr et al. describe three cases in which a parent is directly involved (a mother who jumped with the child, and two mothers threw their child out of the window) [118].

2.6.3.7 Dynamic Impact Loading: Crush Injuries Caused by Toppling Televisions and Other Heavy Objects

Various publications warn for the risk that a child runs with toppling televisions. In particular wide-screen televisions on unstable cupboards or cupboards that the child can climb on are notorious [119–124]. Although Duhaime et al. call the cause of the skull/brain trauma static loading [67], this type of accident has more in common with dynamic loading, as found in accidental falls. It is not rare for a double impact to occur: first the moment that the child falls on top of its head of the cupboard and then the moment that the television and/or the cupboard topple(s) over on the child. Both contact forms lead to dynamic impact loading.

Injuries by toppling televisions are predominantly found in children between 1 and 3 years of age (see Table 2.4). The most common cause of death in these children is severe skull-/brain trauma [122]. Bernard et al. report in a retrospective study of in total 73 incidents (average age 36 months) the death of 28 children (average age 31 months). In their study population the head was the most prevalent anatomical location for injuries (externally visible injury, skull fractures and intracranial injuries) (72%) [119]. In the end, they evaluated 14 deceased children in their study. Thirteen of the children died from skull/brain trauma, while the remaining child died from generalised crush injuries (injuries in which several body parts and organs are seriously damaged and/or crushed). In their article they do not specify why only 14 deceased children were chosen for further evaluation.

DiScala et al. also carried out a retrospective study in 183 children under the age of 7 [120]. In their study 68.7% had a skull-/brain trauma, and 43.7% had injuries to one or more body parts or organs (see Table 2.4). More than a quarter of children had injuries with an injury-severity score of 10–75 (Table 2.4).

Approximately one third of the children had to be admitted to an intensive care unit; five children died due to massive intracranial haemorrhages.

Table 2.4 Anatomical location of injuries and 'injury severity score' in toppling televisions [120]

Anatomical location of the injury	N	%
Skull/brain	58	31.7
Arms or legs	28	15.3
Face, abdomen, skin	17	9.3
Combination of more than two injuries: skull/brain, face, chest, abdomen, arms, legs, skin	80	43.7
Total head/neck area	125	68.3
Injury severity score	N	%
1–9 (mild)	127	69.4
10–15 (moderate)	32	17.5
16–24 (severe)	13	7.1
25–75 (life-threatening)	7	3.8
Unknown	4	2.2

Based on their study, Scheidler et al. maintain that the most prevalent injuries are to the head, abdomen and arms/legs (fractures) [121]. Their study mentions five deceased children in a total of 43, all resulting from skull/brain trauma. Four children sustained an abdominal trauma, and in three children surgical intervention was indicated. None of the children with an abdominal trauma died.

Ota et al. pose that the injuries sustained from toppling televisions are usually not serious or life-threatening [124]. However, the earlier cited medical literature shows that life-threatening injuries occur regularly (3–>35%).

Yahya et al. indicate that when televisions topple on children, skull/brain trauma is the most prevalent cause of death [123]. Only the article of Bernard gives another cause of death, namely generalised crush injury [119]. Furthermore, earlier-mentioned literature shows that children that die as the result of toppling televisions instantly show clinical symptoms and are in near immediate need of intensive care.

2.6.3.8 Dynamic Impact Loading: Skull Fractures in Utero

In utero skull fractures due to maternal trauma have been mentioned in the medical literature for over a century [125]. These fractures may be accompanied by serious injury that is sometimes incompatible with life. Intracranial (subdural/subarachnoidal, intraventricular) haemorrhages, cerebral oedema, hypoxic ischaemic damage and parenchymal injuries have been reported [126–128].

Although it is possible for fractures to occur in every all bone of the unborn child, skull fractures appear to be the most prevalent in in utero trauma [129, 130]. In utero skull fractures may be found in all skull bones [127]. Multiple depressed skull fractures may also occur [131].

With the increase in the number of traffic accidents, the majority of skull fractures in utero are related to severe maternal injuries (fractures of the pelvis). As a result of the fracture and dislocation of the pelvic bones, the skull is pressed with a great deal of force against the sacrum [125]. The highest risk is during the third trimester, when the skull has descended into the pelvis. This is often accompanied by severe maternal trauma, although this is not always the case. Härtle and Ko describe the case of a 19-year-old pregnant woman without significant injuries who had been involved in a traffic accident. Due to foetal distress it was decided to perform a Caesarean section. The child was found to have a linear fracture in the left parietal bone plus a skull haematoma on the left side at the location of the fracture. The authors assumed that the fracture was caused by blunt trauma directly through the abdominal wall during the accident [125].

Staffort et al. describe eight cases of in utero foetal trauma (two children had sustained skull fractures with cortical lacerations and focal contusion) that were fatal secondary to traffic accidents [128]. In all cases, the mother survived, usually with only limited injuries.

The incidence of trauma during pregnancy was earlier estimated to be 6–7% [129–132]. The majority of these trauma appeared to be the result of traffic accidents, followed by falling and physical violence.

2.6.3.9 Anatomic Variants and Other Findings in Differential Diagnostics

In radiological differential diagnostics one should be aware of so-called pseudo-fractures, such as impressions of blood vessels, but also different aspects of sutures and connective tissue fissures [133]. Also, super-positioned externally localised objects may cause confusion. For example, this may the case with plaids or hair bows.

2.7 Growing Fractures of the Skull

Most skull fractures sustained during childhood heal without any complications. A growing fracture of the skull is a relatively rare complication of a skull fracture and is usually found in children up to the age of toddler/small child. In a growing fracture there is progressive diastasis of the fracture line (Fig. 2.16a and b). In 1816, John Hopkins was the first to describe a growing fracture in a child as a complication of head trauma (from 137).

A growing fracture is also called a leptomeningeal cyst for the frequently present relation with a cyst-like mass filled with cerebrospinal fluid. Other terms in use are a.o.: cerebrocranial erosion, traumatic meningocele, growing skull fracture, diastatic fracture, cranial-burst fracture and cephalhydrocele [134, 135].

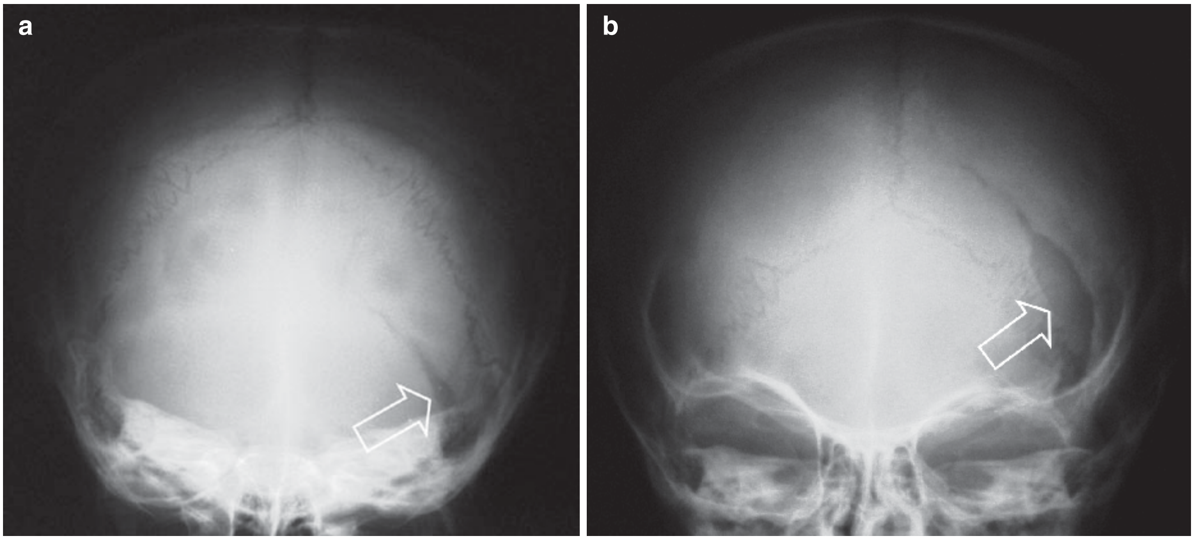

Fig. 2.16 (**a**) Two-year-old girl who presented at the emergency department after a fall on the head. The skull view showed a diastatic fracture on the left side (*open arrow*). (**b**) Follow-up view after 3 months, clearly shows the growing skull fracture (*open arrow*)

2.7.1 Epidemiology

The literature reports an incidence that ranges from 0.05% to 1.6% for all skull fractures. Usually, it concerns children in the first 3 years of their life, with a notable preference for the first year. A growing fracture is hardly ever seen in children >8 years [136–140]. There may be a considerable period of time between the moment the clinical pathology is inflicted and the moment the diagnosis is made [141, 142]. Sometimes the diagnosis is not made until the patient is >60 years old [143, 144]. Consequently, in certain cases it is impossible to relate to the initial trauma.

2.7.2 Etiology

Growing fractures usually occur after serious head trauma, most frequently after a fall, a traffic accident or in child abuse. There are case reports on the origin of growing fractures following the occurrence of skull fractures in utero (this concerned a child with bilateral parietal fractures and a one-sided leptomeningeal cyst at birth) [145], or from a difficult delivery with vacuum extraction [60, 61, 146, 147].

A growing fracture can also occur as complication after neurosurgery for corrective cranial vault reshaping [148].

2.7.3 Growing Skull Fractures and Child Abuse

Hobbs evaluated 89 children under the age of 2 with skull fractures [37]. In 60 cases he found an accidental cause. In the remaining children, child abuse was the cause of the fractures. In the group children with accidental causes, he did not find but one growing fracture, whereas the six abused children did have a growing fracture (see Table 2.1).

Hobbs's results seem to contradict the results of the study of Donahue. He evaluated 13 children with a growing fracture, ranging in age from 1 to 17 months with an average age of 5.7 months. Seven children had suffered serious injuries in traffic accidents, and five were victims of child abuse. In one child the physicians were not clear about the cause [135]. The children in Donahue's study were all seen when acute. They showed a conspicuous haematoma of the scalp and a Glasgow Coma Score of 10 points or less, indicating recent serious trauma.

When the data of Hobbs and Donahue are combined [37, 135], they show that in young children head trauma with herniation of intracranial tissue (either in the acute phase or at a later stage) is the result of severe trauma. It must be possible to objectify the circumstances of the trauma in order to accept an accidental cause. In other circumstances, child abuse is the most likely cause in this group of young children.

2.7.4 Pathogenesis

The exact pathophysiology of growing fractures is still under discussion. It appears that skull fractures are not inclined to show diastasis when the underlying dura is intact. The origin of growing fractures seems to depend on many factors. The factors involved are: head trauma with a large fracture, the presence of a dura laceration (Fig. 2.17a and b), damage to the parenchyma at the location of the skull fracture and the dura laceration, and damage sustained at the time of maximal brain growth [134, 149].

Muhonen et al. maintain that herniation of brain tissue/leptomeningeal cyst, without indications for increased intracranial pressure, points to physiological growth and to pulsations of the cerebrospinal fluid as the cause of diastasis/growth of the fracture [142]. The force of the pulsations widens the skull fracture. The pulsations also push intracranial tissue into the fracture line. This makes it impossible for the osteoblasts to migrate to the fracture; hence, there is no new-bone formation and consequently no healing. Finally, there is resorption of the adjacent bone as a result of the continuous pressure of the tissue herniation through the defect in the bone [149].

It seems that insufficiently closed dura lacerations during craniotomy can also lead to growing fractures of the skull. These findings support the idea that traumatic damage to the dura is the most important risk factor in the development of a growing fracture [149].

2.7.5 Clinical Symptoms

Most growing fractures can be found in the calvaria, in particular in the parietal bone (50%) [150]. Sometimes they can be found at the base of the skull or in the roof of the orbit. It is very rare for a growing fracture to be present in the posttraumatic diastasis of a suture [149]. Generally, it concerns linear fractures. Normally, a depressed fracture will not develop into a growing fracture [151]; however, a linear fracture that originates from a depressed fracture can develop into a growing fracture [152]. In a fracture with a diastasis >4 mm, there is an increased risk for the development of a growing fracture [153, 154].

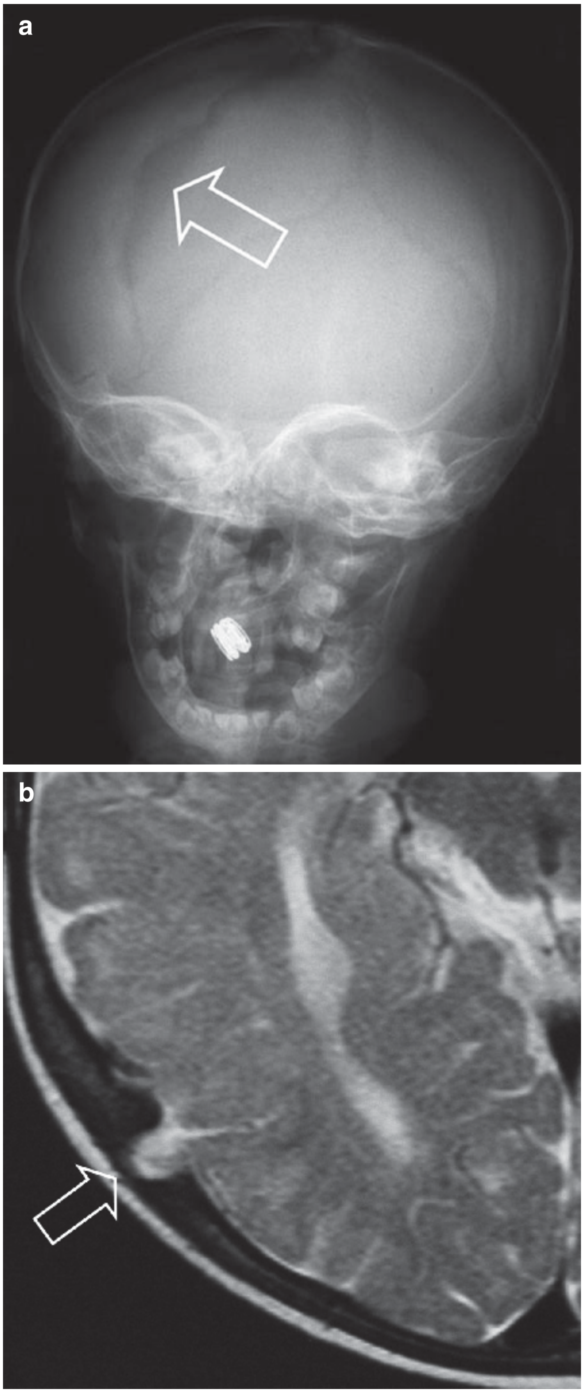

Fig. 2.17 (**a**) One-year-old girl with a growing skull fracture. The skull view shows a diastatic fracture on the right dorsal parietal side. (**b**) Pre-operative MRI shows a dura defect and prolapsed meninges and brain tissue in the diastatic fracture (*open arrow*)

The clinical symptoms develop gradually, unless in the acute phase there is a cranial-burst fracture with acute herniation of intracranial tissue through the fracture towards subgaleial, or if there is a dura defect with a high risk for herniation and development of a growing fracture. It seems that in acute situations MRI imaging is the most reliable manner to show dura defects [135]. The MRI images enable instant evaluation of damage to the dura, and an immediate referral of the patient for surgical correction, so as to prevent additional damage [134].

Children may present with the following symptoms: gradual increase of the subgaleal mass, headache and signs of neurological pathology. Pezzotta et al. did a retrospective study of the literature in 132 children with a growing fracture [150]. They established that normally the initial clinical symptoms were the development of seizures (40%), focal neurological deficits (43%), unconsciousness (38%) or combinations of the afore-mentioned. Asymptomatic presentation was more common in frontal-parietal and frontal-parietal-occipital locations. In 50% of children, the delay between the occurrence of the fracture and appearance of the first symptoms ranged from a day to a year.

The externally visible lesions of a growth fracture are a cyst-like non-firm swelling, visible some time after the initial trauma, with an underlying palpable bone defect (see Sect. 2.7.1) [149].

There is a proportional relation between the severity of the neurological deficits and the size and 'growing time' of the defect [139].

2.7.6 Complications

The severity of the underlying trauma is a risk factor to the child. A linear fracture combined with haemorrhagic contusion foci in the underlying brain tissue suggests a trauma severe enough to cause dura lacerations. The presence and the severity of the associated damage determine the risk of complications.

In a growing fracture there is nearly always underlying brain damage. At the place of the fracture scar tissue may develop in brain tissue and meninges. Cyst-like changes at the place of the fracture may be the result of encephalomalacia. Posttraumatic aneurysms and subdural haematomas have also been reported in relation to growing fractures [155, 156].

In all children they examined, Muhonen et al. found damage to the cortex at the location of the fracture; although, without signs for increased intracranial pressure [142].

Although in most children signs for damage to the underlying brain tissue can be found, this finding is not a prerequisite for developing a growing fracture [157].

A growing fracture of the base of the skull may cause eye proptosis or cerebrospinal fluid leakage from the nose or the ear. After reaching their maximal size, growing fractures tend to remain stable for the rest of one's life [137].

2.7.7 Diagnostics and Treatment

The diagnostics are based on the clinical presentation and radiological images. In order to avoid neurological complications, immediate recognition and early treatment are required [156]. Treatment is always surgical and directed at reducing the herniated brain tissue and repair of the damage inflicted to skull and dura. It may be necessary to place a shunt to alleviate the cyst and to treat local dilatation of the ventricles [149].

2.8 The Dating of Skull Fractures

The dating of skull fractures is not very reliable. In principle, new fractures have sharp edges that fade away during the healing process. The time in which this occurs varies [158]. Skull fractures do not heal as fast as other fractures. In a young child the healing process is faster than in older children [159].

Cameron maintains that the first radiological signs that point to healing (fading of the edges of the fracture) are only visible after 4–6 weeks [160]. As mentioned earlier, an uncomplicated linear fracture, sustained during birth, is no longer distinctly visible after 2 months and has completely disappeared after 6 months [27]. In older children it may take as long as a year before the fracture is no longer visible on a radiograph [161].

2.9 Basilar Fractures

In 6–14% of all children with head trauma (accidental as well as non-accidental) that require medical intervention, a basilar fracture can be found [17]. Basilar fractures seldom occur in child abuse. The fracture is usually sustained by a blunt trauma to the back of the head, such as a blow or a fall. A basilar fracture may also occur as the continuation of a fracture of the cranium, in a contact trauma at the top of the head or a blow in the region of the temporoparietal bone that resonates through the temporal bone into the base of the skull [14]. Furthermore, these fractures can also occur in static loading crush injuries in traffic accidents or in dynamic loading crush injuries in a fall from great height (>3 m) [67–69, 117]. It is possible for a growing fracture to develop in the base of the skull [150].

A basilar fracture may lead to loss of cranial nerve functions (such as facial paralysis, anosmia, nystagmus and loss of hearing) and incarceration of the cranial nerves.

Clinical signs may be:

- Nausea, vomiting, general malaise
- Unconsciousness, seizures, loss of neurological functions [17]

At physical examination, various pathognomical defects can be found, such as:

- 'Battle sign'
- Racoons's eyes
- Blood behind the tympanic membrane
- Leakage of cerebrospinal fluid via ear and nose

2.9.1 'Battle's sign'

'Battle sign' is a haematoma directly behind the ear on the mastoid process and is an indication for a fracture of the middle part of the base of the skull in the posterior cranial fossa. In a fracture of the pars petrosa of the temporal bone there is often deformation of the external auditory canal which may cause a rupture of the tympanic membrane. On inspection, the tympanic membrane will show discolouring (haemotympanium). With further posterior extension of the fracture, involving the sigmoid sinus, the tissue behind the ear and over the mastoid process may assume a blue-brown colour as a result of blood that collects underneath the fascia. This is called 'Battle sign' [199–201].

Although the 'Battle sign' is usually visible 8–12 h after the fracture is sustained, it may also take as long as 48–72 h [202, 203].

2.9.2 'Racoon's Eyes'

'Racoon's eyes' or peri-orbital ecchymosis is a haemorrhage of the loose connective tissue around the eyes, which causes a red to purple swollen ring around the eye, similar to the rings around a racoon's eyes. It is a clinical symptom indicative for a a basilar fracture in the anterior cranial fossa [17, 198, 204]. It occurs when blood seeps from a fracture in the frontal cranial fossa in the loose connective tissue of the orbit. The haemorrhage is sharply outlined due to the connection between the periosteum and the bony margins of the orbit. Usually, Racoon's eyes are bilateral, since blood seeps via the paranasal sinus into the contralateral orbit. Irrespective of finding a fracture on a radiograph or CT scan. Racoon's eyes will show within a few hours, but a time delay from 48 to 72 h has also been reported [203, 205]. There may also be loss of cerebrospinal fluid from the nose (rhinorrhea) or loss of smell due to damage to the terminalis filaments of the olfactory nerve at the cribrous lamina [201, 204]. Rhinorrhea is not necessarily instantly present. It may develop some time (days to weeks) after the fracture was sustained [198].

Racoon's eyes may be distinguished from an orbital haematoma or 'black eye' by its sharply defined margins and the moment at which the 'black eye' appears. A normal 'black eye' is usually instantly visible (rarely there is a delay of a few hours at most); Racoon's eyes are generally visible after a few hours, possibly even after as much as 2–3 days. Moreover, in a standard 'black eye', bleeding and swelling may spread to the front and face, whereas Racoon's eyes will be restricted to the direct vicinity of the eye.

2.10 Facial Fractures and Dental Damage

Various studies show that >45% of all children who suffer injuries due to child abuse have orofacial injuries [162–174]. In child abuse this area is possibly the most battered part of the body [175]. The face seems to be the most vulnerable part and the least protected part of the body when submitted to trauma. The main reason for the high incidence of injuries in non-accidental trauma in the head/neck area is that the head, and in particular the face, is the defining part of the body for recognising a person. Moreover, human behaviour and emotions are recognised and interpreted via facial expressions. No wonder that aggression is mainly directed to this part of the body. In children this plays even a greater part: when a child cries in a stressful situation, aggression may be directed at the face in general and the mouth in particular. According to Vadiakis et al., the oral cavity is the main target in physical violence because of its role in feeding and communication [176].

Injuries to the head/heck area can be: haematomas, contusions, excoriations, bites and lacerations of the lip and frenulum, fractures of the teeth [174, 177], loose or missing teeth [172], fractures of the orofacial bones: upper and lower jaw [172, 177–179], zygomatic arch [180], orbit, nasal septum [182, 183] and the nasomaxillary bones [183]. However, in child abuse, orofacial fractures and dental damage are hardly ever reported.

In 1946, Caffey was the first to report the relation between multiple fractures of the long bones and subdural haematomas [184]. He suspected the combination to be of traumatic origin. Three of the children described by Caffey also showed injuries in the mouth. In 1966, Cameron et al. described 29 cases of fatal child abuse [164]. Of the children examined (average age 14.5 months), 50% had clearly visible abrasions, bruising and haemorrhages and bumps on the head, face and neck (Table 2.5). The areas on the jaw and neck that Cameron et al. describe were clearly defined fingertip-like anomalies. These prints may be found when a child is grabbed forcefully by the jaw or neck. They may be present unilateral (e.g. grabbing hold of the child) or bilateral (e.g. in a strangling attempt). It is noteworthy that Cameron et al. found a large number of children (45%) with damage to the frenulum. In later studies this high percentage is no longer found.

Since the article of Cameron et al., there has been a plethora of publications on this subject. In 44–86% of publications, injuries to the head/neck area are discussed; however, a dentist is hardly ever consulted (see Table 2.6) [167]. The article with the highest percentage (86%) is from Malecz, but in this article a dentist was involved (see Table 2.6) [167].

Table 2.5 Injury location, irrespective of type of injury [164]

Location ($n = 29$)	Percentage
Skull	79
Neck	52
Maxilla	49
Mandible	48
Upper lip	45
Frenulum	45

Table 2.6 Location of injuries [167]

Location	Percentage
Dental fractures	32
Oral lacerations	14
Fractures of mandible or maxilla	11
Oral burns	5

Table 2.7 Injuries in head/neck area [185]

Location	Percentage
Contusions and ecchymosis	37
Benign fractures (no further specification)	15
Abrasions	13
Burns	6
Subdural haematomas	3
Dental damage	1

Based on a large number of publications, Needleman (1999) presents a cumulative overview of orofacial and intracranial trauma in abused children (Table 2.7) [185].

2.10.1 Dental Trauma

Dental trauma is a regular feature in children. Widmar provides three reasons for this fenomenon: accident, sports and child abuse. In 1:3 children there is damage to the deciduous teeth, while in 1:5 children over 6 years of age there is damage to the permanent teeth. Widmar maintains that in 30% of cases of child abuse there is trauma to the teeth [186]. It is near impossible to differentiate between non-accidental and accidental dental trauma when evaluating the damage out of context (patient histories from patient and others, age and level of development of the child).

Studies of Green et al. showed that the victims of child abuse and neglect have an 8 times higher risk for bad permanent teeth [187].

2.10.2 Orbit and Zygomatic Arch Fractures

The force of blunt mechanical trauma on the orbit and surrounding tissues can lead to orbital fractures (Figs. 2.16 and 2.17). Usually these are fractures of the orbital floor and medial side of the maxilla [188]. In the acute phase, the externally visible signs are abrasions of the eye lid, haematomas and oedema [189].

At the moment that a blunt object, such as a fist or a baseball, hits the eye and the eye ball is not ruptured, the intra-orbital pressure is suddenly considerably increased (a so-called 'blow-out' fracture). This increase will spread equally over all orbital sides. The weakest side, the orbital floor (thickness only 0.5–1 mm) will fracture first. This may result in herniation of the intra-orbital tissues into the antrum, which could result in a growing fracture of the side of the orbit [150]. There may also be haemorrhaging into the orbit, which will present as a nasal bleed on the side of the fracture [189].

According to Klenk and Kovacs, blow-out fractures of the orbital floor are rare in children under 8 years of age [190], due to the anatomical characteristics of growing bone at an early age [190]. Zygomatic fractures often accompany a blow-out fracture of the orbital floor. There must be a severe blunt trauma in the anamnesis (Fig. 2.18) [189].

When there is a fracture of the orbital roof, one must be aware of the presence of intracranial damage. In 50% or more of the orbital fractures there is also (intra)ocular damage [188]. It is possible for the ocular muscles to get incarcerated in the fracture [191–194].

The anamnesis will show the impact of blunt trauma directly unto the orbit [188]. This usually occurs as a sports injury, physical violence or a traffic accident. When a child presents with an orbital fracture, and the anamnesis does not mention a blunt trauma, one should, based on the earlier-mentioned data, always consider child abuse (Fig. 2.19).

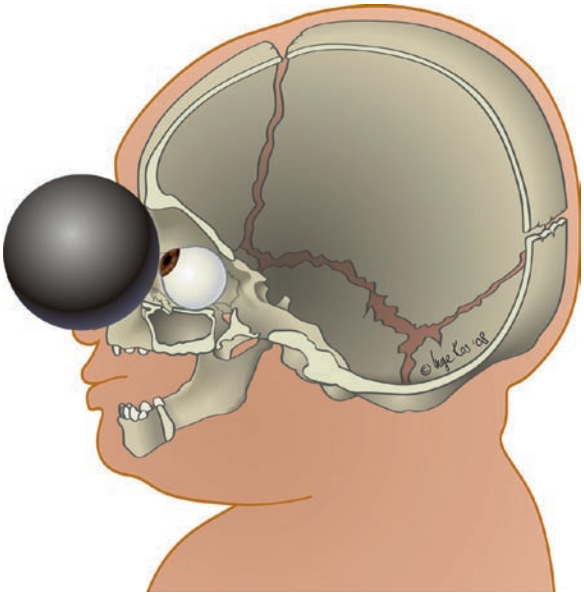

Fig. 2.18 Schematic representation of direct orbital trauma

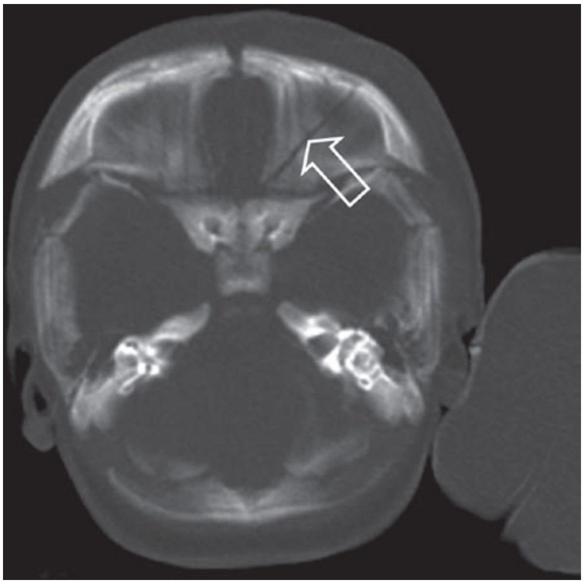

Fig. 2.19 Three-month-old infant girl who sustained a severe neurological trauma and presented in coma at the emergency department. CT of the orbit showed a left basilar fracture (*open arrow*). Interrogation by the police revealed that the girl had been hit by a steel petanque ball

2.10.3 Fractures of the Nasal Septum

Blunt mechanical trauma on the nose may lead to externally visible superficial (abrasions) and deeper (lacerations) damage to the skin, and to haematomas and fractures of the bony or cartilage part of the nose [206, 207]. After direct trauma, a haematoma or the development of an abscess in the nose septum is a rare complication.

In young children, damage to the cartilage of the nose septum is rare, irrespective of whether it is accidental or non-accidental. In the medical literature there are only a few case reports on nasal septum injuries due to child abuse [182, 183]. However, according to Nathanson, fractures of the bones and cartilage of the nose of young children strongly suggest a non-accidental cause [208]. This it certainly true when there is no serious trauma in the anamnesis. In their article, Canty and Berkowitz describe 20 children with a post-traumatic haematoma of the nasal septum [182]. In two children, the septum haematoma (and the consequent development of an abscess) resulted from child abuse. Compared to children that presented with a septum haematoma and developed an abscess after a minor and isolated nasal trauma (14 children, 1–14 years old) and after a sports injury (four children >10 years old), the abused children were all young (<2 years old). Moreover, the abused children had sustained severe additional injuries in the head/neck area (face, neck, nose) and the patient history recorded child abuse.

Child abuse injuries of the nose, and of other inflicted injuries to the face, are often accompanied by further extracranial injuries, such as fractures and haematomas on trunk and extremities [209].

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