Child Abuse, Non-Accidental Trauma, and Inflicted Injuries

Bilo, Rob A.C.; Vester, Marloes E.M.; Loeve, Arjo A.J.; Teeuw, Rian A.H.

DOI
10.1007/978-3-031-12041-1_1

Publication date
2023

Document Version
Final published version

Published in
Forensic Aspects of Paediatric Fractures

Child Abuse, Non-Accidental Trauma, and Inflicted Injuries

1

Rob A. C. Bilo, Marloes E. M. Vester, Arjo A. J. Loeve, and Rian A. H. Teeuw

Contents

R. A. C. Bilo (✉)
Veilig Thuis Rotterdam Rijnmond (Center for the Reporting of Child Abuse, Domestic Violence and Elder Abuse), Rotterdam, The Netherlands

M. E. M. Vester
Forensic Physician, Voorhout, The Netherlands

A. A. J. Loeve
Department of Biomechanical Engineering, Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Delft, The Netherlands
e-mail: A.J.Loeve@tudelft.nl

R. A. H. Teeuw
Department of Paediatrics, Amsterdam UMC, University of Amsterdam, Amsterdam, The Netherlands
e-mail: a.h.teeuw@amsterdamumc.nl

R. A. C. Bilo et al. (eds.), *Forensic Aspects of Paediatric Fractures*, https://doi.org/10.1007/978-3-031-12041-1_1

1.1 Defining Child Abuse

1.1.1 Child Abuse

There is no universally accepted definition of child abuse or any of its subtypes. Definitions will vary according to the circumstances under which the definitions are used, e.g. sociological, medical, political, cultural, scientific, or legislative. Definitions may also vary from concise and to the point, to comprehensive and more descriptive.

In this book we will use the definition of the World Health Organization (WHO), which was first drafted in 1999: 'Child abuse constitutes all forms of physical and/or emotional ill-treatment, sexual abuse, neglect or negligent treatment, or commercial or other exploitation, resulting in actual or potential harm to the child's health, survival, development or dignity in the context of a relationship of responsibility, trust or power' [1]. This definition includes both active (= abuse) and passive (= neglect) behaviour of parents and others towards children.

The terms 'non-accidental trauma' and 'inflicted injuries' will be defined and discussed in Sect. 1.1.6.

1.1.2 Physical Abuse

Physical child abuse is defined as the deliberate physical violent behaviour towards a child, committed by parents, caregivers, and other individuals (such as siblings, acquaintances, and teachers) that are in a position of relationship of responsibility, trust, or power towards the child. This leads to actual or potential physical injury that is the result of interactions (acts), or a lack of interactions (omissions), which should reasonably be within the control of a parent or person in a position of responsibility, power, or trust [1, 2]. Although the physical violent behaviour is always deliberate, the resulting physical injuries are often not intended to occur.

Physical abuse also includes the deliberate poisoning or suffocation of a child, but these acts can also take place with the motive to fabricate or induce illness in the child (Sect. 1.1.6) [2].

The severity of actions may range from a single incident without or with visible physical consequences to frequent physically aggressive behaviour, such as beating, punching, kicking, biting, and burning with or without visible injuries and/or scars, up to life-threatening and sometimes fatal consequences.

1.1.3 Neglect

Neglect is the failure to provide for the needs of the child in every aspect of a child's life: health, education, emotional development, nutrition, shelter, and safe living conditions, within the context of resources generally considered available to the family or carers. This includes the failure to properly supervise and protect children from harm [3]. The actions or the omissions of the parent/caregiver cause, or have a high probability of causing, harm to the child's health or physical, mental, spiritual, moral, or social development.

In physical neglect, the parent/caregiver is unable or unwilling to provide (with regard to the physical needs of the child) minimal adequate care (concerning, e.g. food, shelter, hygiene, sleep, and clothing) and suitable medical, dental, and mental health care. The parent/caregiver may also not take suitable precautions to ensure the safety of the child indoors and outdoors according to the nature and development of the child (no supervision, unsanitary, unsafe or unhealthy environment, no substitute care).

Other types of neglect are emotional and educational neglect. Emotional neglect occurs when parents/caregivers fall short in responsiveness and giving positive attention to the child. Allowing the child to witness violence between parents is also considered to be emotional neglect, but is sometimes also defined as emotional/psychological abuse [4].

Educational (or normative) neglect is defined as being unable or unwilling to have minimal concerns about the socialization of the child including the provision of suitable education for the child. It also includes exposing or involving the child in illegal acts that induce or promote delinquency or

antisocial behaviour in the child [4]. Educational neglect also includes not exercising appropriate and sufficient parental authority or not offering sufficient structure, while raising the child [5].

1.1.4 Emotional/Psychological Abuse

Emotional or psychological abuse is described as the systemic destruction of a person's self-esteem and/or sense of safety, acceptance and respect, increasing autonomy and clear boundaries, often occurring in relationships where there are differences in power and control [6]. There is an atmosphere, in which a child is bullied, hurt, and belittled. Psychological abuse includes threats of harm or abandonment, humiliation, deprivation of contact, isolation, and other psychologically abusive tactics and behaviours [7].

Synonyms of psychological abuse are, e.g. emotional abuse, verbal abuse, mental cruelty, intimate terrorism, and psychological aggression. When the abuse occurs in a residential care setting, it is often called systemic or institutional abuse [7].

1.1.5 Sexual Abuse

The WHO defines child sexual abuse as the involvement of a child in sexual activities that he or she does not fully comprehend, is unable to give informed consent to, or for which the child is not developmentally prepared and cannot give consent, or that violates the laws or social taboos of society [8]. According to the WHO child sexual abuse is evidenced by this activity between a child and an adult or another child who by age or development is in a relationship of responsibility, trust or power, the activity being intended to gratify or satisfy the needs of the other person. This may include but is not limited to:

- The inducing or forcing of a child to engage in any unlawful sexual activity
- The exploitative use of a child in prostitution or other unlawful sexual practices
- The exploitative use of children in pornographic performance and materials

1.1.6 Fabricated or Induced Illness by Parents/Caregivers

Fabricated or induced illness by parents/caregivers is defined as the deliberate fabrication or induction/production of physical or psychological symptoms in a child by a parent or caregiver [9, 10]. Fabricated or induced illness by carers (FII) (UK terminology) was formerly known as Munchausen syndrome by proxy [11]. It is now also known as paediatric condition falsification (PCF)/factitious disorder by proxy/medical child abuse [12–14].

In this form of child abuse the child has suffered, or is likely to suffer, significant harm through the deliberate action of its parent or caregiver. The symptoms of the child are attributed by the parent or caregiver to an illness or another medical cause [13, 15]. There are three ways (not mutually exclusive) of a parent or caregiver fabricating or inducing an illness in a child:

- Fabrication of signs and symptoms, including fabrication of the child's past medical history and the past medical history of other family members, including the perpetrator's medical history
- Fabrication of signs and symptoms and falsification of hospital charts, records, letters and documents, and specimens of bodily fluid
- Induction of symptoms/illness by a variety of means, e.g.:
  - The administration of prescribed and unprescribed medication
  - The administration of substances, that are freely available at home, which can be given to the child or applied to its skin
  - Starving the child leading to malnutrition
  - Smothering

An existing diagnosed illness in a child does not exclude the possibility of induced illnesses. The presence of a real existing illness can act as a stimulus for the abnormal behaviour and also provide the parent with opportunities for inducing or aggravating symptoms.

In order to determine whether the child's signs and symptoms are fabricated or induced, it is not necessary to have insight into the perpetrator's motives for the fabrication or induction. The diagnosis of fabricated illness is based upon the investigations of the child itself and the complete (medical) history. Potential motives of the suspected perpetrator can be evident or obscure and are of relevance to the treatment of the perpetrator him- or herself, which of course is crucial for the final prognosis of the safety and health of the child.

1.2 Epidemiology

Lord Laming stated in his 2003 report on the occasion of the violent death of Victoria Climbié about the incidence and prevalence of child abuse: '*I have no difficulty in accepting the proposition that this problem (deliberate harm to children) is greater than that of what are generally recognized as*

common health problems in children, such as diabetes or asthma' [16]. The exact incidence and prevalence of child abuse is not known. One important reason for this is that in nearly every study to establish the incidence and prevalence, researchers use their own definition. If a 'broad definition' is used, the incidence and prevalence will be higher than in case of a much narrower definition.

In the Netherlands (more than 17 million inhabitants with 180,000 births per year), the most recent and third Netherlands' Prevalence study on Maltreatment of children and youth (NPM-2017) showed that in 2017 90,000–127,000 children (26–37/1000 children) were recognized by professionals as victims of child abuse [17]. A study amongst primary and secondary school students showed that 270 of 1000 of primary school students had ever experienced a form of child abuse and 123 of 1000 secondary school students had been victimized during the secondary school period [18]. During the COVID pandemic the Netherlands instituted a nationwide lockdown, a study by the same group showed that in a three-month period an estimated 40,000 children (95% CI: 24.533–54.237 or 8–19/1000 children) were recognized as victims of child abuse [19]. This represents a significant increase and supports the theory that child abuse is related to stressful events. In these studies definitions of child abuse, comparable to the WHO definitions, were used.

More exact figures will probably never be known, because there will always be a dark number of unrecognized, and therefore unknown, cases, even with an accurate definition. A large review by Hillis et al. on the international prevalence of child abuse violence over the then past year included 38 articles from 96 countries found, depending on the used definition, a minimum prevalence of 50% for Asia, Africa, and Northern America [20]. A study based on United States national child protective services records (2003–2016) combined with census data led the authors to conclude that before the age of 12 years 32.4% of children were reported at least one time [21]. In this study, the probability of subsequent reports were 13.71% for 2 reports, 7.57% for 3 reports, 4.50% for reports, 2.80% for 5 reports, and 1.79% for 6 reports. Not surprisingly the data showed that children with more prior reports were more likely to be reported again.

Among professionals in the field of child abuse there is consensus that whatever the exact incidence and prevalence numbers might be, it is one of the main threats to the well-being of children.

1.3 Clinical Aspects

Each subtype of child abuse can have negative health consequences. In Table 1.1 an overview is given of some of the health consequences of child abuse, as summarized by the WHO and by Felitti et al. [22, 23]. On the one hand, these consequences are the immediate effect of the aggressive or negligent behaviour and are visible as, e.g. physical injuries or sexually transmitted diseases. On the other hand, these consequences are a delayed effect of the child abuse, manifesting in adolescent or adult life, like alcohol and drug abuse or delinquent, violent, and other risk-taking behaviour (Fig. 1.1).

Moreover, not all physical injuries will be noticed when they are present or, when they are noticed, be recognized as such.

Table 1.1 Health consequences of child abuse [22, 23]

Physical abuse	• Abdominal/thoracic injuries • Brain injuries/injuries to the central nervous system • Bruises and contusions • Burns and scalds • Disability • Fractures • Lacerations and abrasions • Ocular damage
Physical neglect	• Failure to thrive • Dental decay • Burns and scalds • Severe diaper rash • Consequences of inadequate medical care • Drowning
Sexual and reproductive	• Mucous membrane damage • Reproductive health problems (e.g. infertility) • Sexual dysfunction • Sexually transmitted diseases, including HIV/AIDS • Unwanted pregnancy • Constipation, enuresis, abdominal pain • Pelvic floor hypertrophy
Psychological and behavioural	• Alcohol and substance abuse • Cognitive impairment • Delinquent, violent, and other risk-taking behaviours • Depression and anxiety • Developmental delays • Eating and sleep disorders • Feelings of shame and guilt • Hyperactivity • Poor relationships • Poor school performance • Low self-esteem • Post-traumatic stress disorder • Psychosomatic disorders • Suicidal behaviour and self-harm
Other longer-term health issues	• Cancer • Chronic lung disease • Fibromyalgia • Irritable bowel syndrome • Ischemic heart disease • Liver disease • Obesity • Diabetes

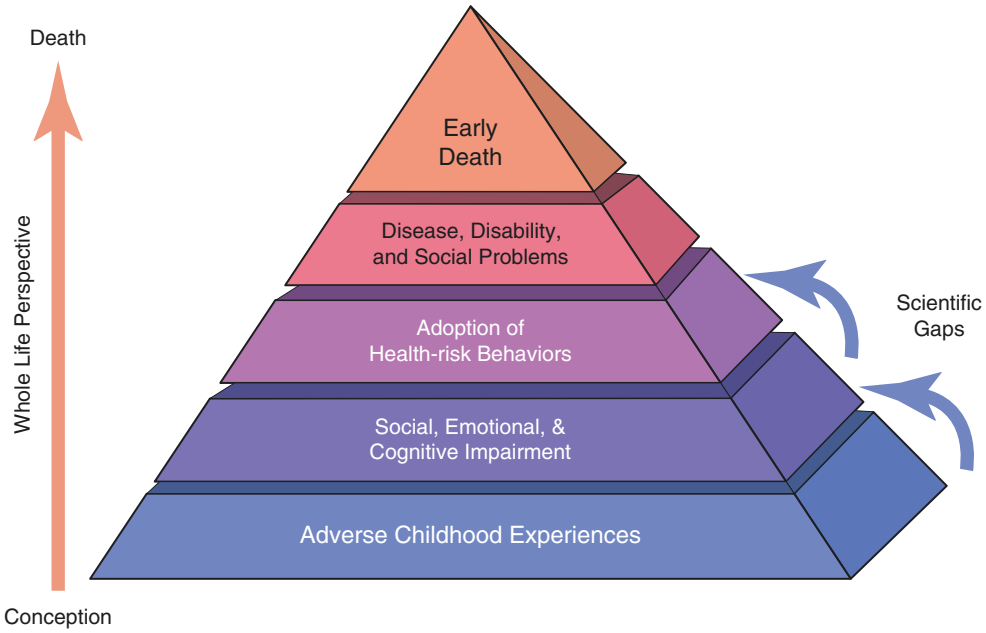

Fig. 1.1 The ACE Pyramid represents the conceptual framework for the ACE Study, which has uncovered how adverse childhood experiences are strongly related to various risk factors for disease throughout the lifespan (source: C. Whitfield, M.D., Centers for Disease Control and Prevention, http://www.cdc.gov/violenceprevention/acestudy/pyramid.html)

1.4 Defining Trauma and Injury

Trauma and injury are often used as synonyms both in daily practice and in the medical literature. This is confusing and in a forensic setting incorrect:

- A trauma is an event which can result in an injury.
- An injury is any wounding or physical damage (physical harm, bodily injury, physical injury) that results from a trauma.

It is important to recognize that cutaneous injuries may indicate damage to underlying structures, such as the skeleton, intra-abdominal organs, or intracranial (neurological) injuries.

1.5 Cause of Injury

1.5.1 Introduction

The cause (or mechanism) of an injury refers to the way a body part (skin, mucosa, or any other tissue: muscles, organs, and bones) is damaged. The cause of an injury should be differentiated from the manner (or mode) of an injury. The manner of an injury describes the circumstances under which the injury was sustained or the injury event happened (see Sect. 1.1.6).

An injury is caused by the (sudden) subjection of the body or body parts, e.g. the skin, the mucous membranes, the skeleton or internal organs, to amounts of energy that exceed the threshold of physiological tolerance. In other words, it concerns the exposure of the body to amounts of energy in which the loading (the process of transfer of energy during the contact) exceeds the maximum capacity of the body or parts of the body (and/or adjacent tissues) to absorb the transferred energy. This may occur with or without externally visible damage to the skin or the mucous membranes and with or without signs of damage to the skeleton or internal organs, e.g. fractures, intracranial bleeding, or intra-abdominal injuries [3, 24, 25].

Transfer of energy, leading to injuries, can happen due to mechanical trauma or in non-mechanical trauma (contact or near contact with physical agents) (Sect. 1.6–1.10) [25].

The nature of an injury, in other words the appearance, extent, and severity of an injury, not only depends on the type of trauma (mechanical or non-mechanical), but also on [26]:

- The amount of energy that is transferred during the contact
- The rate of energy transfer
- The duration of the exposure to the transferred energy
- The exposed body part(s)
- The size of the body surface over which the energy is distributed
- The nature of the ‘weapon’ used
- The structures under the skin (e.g. subcutaneous fat, muscle, bone, or internal organs)
- The age and (physical) developmental stage of the child
- The health status of the child and the presence of diseases

In addition to the foregoing, one should be aware that physical injuries in all body parts (including the skin and the skeleton) can also be caused by a lack, or excess, of one of the vital elements (e.g. oxygen, trace elements, vitamins, water, or warmth) [3, 24]. A lack or an excess of vital elements may even lead to death. An excess can be seen, for example in salt poisoning, hypervitaminosis, water poisoning (hyperhydration), or overheating (hyperthermia, heat stroke) [27–32].

1.5.2 Mechanical Trauma

Mechanical (blunt- or sharp-force) trauma is caused by transfer of energy due to static or dynamic loading [33, 34]. The difference between static and dynamic loading is best exemplified by the following statement of Burton: *'Consider the effect of a stationary bullet resting on your chest, compared to the effect of a moving bullet striking your chest. The stationary bullet exerts a static load on your chest. A moving bullet exerts a dynamic load'* [35].

1.5.2.1 Static Loading

In mechanics, a static load is defined as a non-varying load, e.g. a non-varying force exerted on a surface by the weight of a mass at rest. For that reason, a static load in mechanics is also known as a dead load.

In injury biomechanics and in forensic medicine, the terms static load and static loading are used slightly different. Static loading is defined as a relatively slow exertion (loading) of forces on body parts over a protracted period of time. In the paediatric literature, this protracted time is defined as more than 200 ms [36, 37]. Static loading occurs when a body part is squeezed and/or compressed, which may lead to injuries of soft tissues, bony tissues or sometimes to underlying tissues, like the intracranial or abdominal content. Just like in dynamic loading, the effect of static loading can be focal and limited to the point of compression or more extended in which not only the superficial, but also the underlying layers are damaged.

The type, severity, dimensions, and appearance of the injuries caused by static loading are not only determined by mass, weight, gravity, or force but also by:

- The surface of the compressing object (flat, curved, patterned, blunt, sharp, more or less flexible) and of the compressed skin (flat, curved, underlying tissues—connective tissue, fat, bone)
- The size of the contact surface between the compressing object and of the compressed skin
- The source that determines the applied load (gravity, human behaviour, accidental wedging)
- The load exerted on the skin

Gradual or repetitive build-up of loading or changes in loading of the skin during the time of exposure may happen, because the load that is exerted is not only determined by gravity but also by the amount of changes in pressure actively exerted on the skin, e.g. if a person is grabbed by another person, or if a person is overrun by a very slow driving car, or by movements of the person who is subjected to the load and actively resists the loading or passively changes position. This will lead to changes in the energy that is transferred from the compressing object to skin during the time of exposure (contact time) and will influence the final effect of the static load on the skin.

In physical assaults, static loading mostly will be caused by blunt-force trauma due to, e.g. compression or bending, but static loading of the skin may also be caused by pulling or twisting of the skin. Static loading may also happen in sharp-force trauma, when a sharp-pointed object (e.g. a needle) is first held and then pressed against the skin (often resulting a penetrating trauma of the skin and sometimes of the underlying tissues).

If static loading in blunt-force trauma leads to injuries of the skin and underlying tissues, including the vessels (subcutaneous veins or capillaries) and bones, the injuries are the result of direct damage by the distorting force (compressing, pulling, twisting) at the site of the distortion. The integrity of the skin and the underlying tissues may or may not be compromised during static loading.

The level of static loading is often expressed in terms of low and high pressure. These terms however are subjective and relative with a grey area between low and high pressure and depending on the context in which these terms are used. Pressure is the ratio between the exerted force and the exposed surface, in other words the distribution of force per square centimetre. The risk of injuries to the skin and the underlying tissues, for example bones or visceral organs, increases with increasing pressure (proportional relation).

In case of low-pressure static loading, e.g. in normal daily activities like handling a child, the loading caused by normal handling will not result in bruising or other skin injuries and usually not in injuries of underlying tissues, like bones. However this only accounts if there are no complicating factors added to the low-pressure loading, which decrease the capacity of the skin and the underlying tissues to absorb the transferred energy, e.g. a coagulation disorder, vascular disorders or disorders of the connective tissue, or the use of medication, e.g. corticosteroids and anticoagulants. Also, prolonged exposure to low-pressure loading, as sometimes can be seen in tight clothing, may lead to superficial skin injuries, like bruises (e.g. compression or torsion of the skin) and superficial abrasions (compression in combination with friction and shearing).

High-pressure static loading, as can be seen in accidents, e.g. resulting from prolonged wedging in motor vehicle accidents or in non-accidental trauma (e.g. in pinching, grabbing, or tying), may result in more extensive bruising or other injuries of the skin or compression injuries of underlying tissues, e.g. skull and rib fractures.

1.5.2.2 Dynamic Loading

Dynamic loading is the fast application or change of forces over a shorter period, e.g. less than 200 ms, often even less than 50 ms. Dynamic loading can be divided in dynamic impact and dynamic impulse loading.

Dynamic impact loading is defined as the application of an external force with a certain mass and velocity during a relatively short period of contact between the object and the skin/body. An injury caused by dynamic impact loading is also referred to as a kinetic injury: an injury caused by the exchange of energy during motion, leading to a transfer of energy during collision as long as the contact continues between the human body and the colliding object, e.g. an object or (parts of) another human body. Injuries due to dynamic impact loading are the result of a single impact or a series of impacts. In physical assaults, dynamic impact loading may occur in non-penetrating or penetrating blunt force or sharp force.

In dynamic impact loading, the following situations can occur during the impact between a body part and an object:

- The impacted body part is stationary, while the impacting object moves against the body part.
- The impacting body part is moving, while the impacted object is stationary.
- Both the body part and the object are moving either in the same direction with different speeds or in opposite directions.

The impact loading results in the body part changing shape with possible damage to the soft tissues, bony tissues, or the underlying tissues.

Dynamic impulse loading is the result of rapid (often repetitive) movements without (external) impact, but with a rapid alternation of acceleration and deceleration (inertial trauma), as can be seen in abusive head trauma or in some abdominal injuries due to shaking. Dynamic impulse loading has never been described as the cause of skin injuries or fractures of the calvarium, the base of the skull or orofacial bones. However, dynamic impulse loading can lead due to the rapid alternation to specific fractures, e.g. classical metaphyseal lesions (see Chap. 12). Dynamic impulse loading can occur combined with static loading: e.g. during shaking compressive forces on the ribs can result in rib fractures, but also in bruising on the thoracic wall.

1.5.3 Non-mechanical Trauma: Physical Agents

In non-mechanical trauma, injuries are the result of the transfer of energy during a direct contact of or a contactless transfer to the skin and/or other body parts, in which the skin and/or the other body parts are exposed to extremes in temperature (heat and cold) or to chemical or physical agents (acidic and alkaline chemicals, electricity, microwaves, and radiation). In a contactless transfer, the risk of injuries usually decreases with increasing distance between the body and the energy source, e.g. with radiation from an infrared heater. Chemical or physical agents may have a similar effect on the skin and the subcutaneous tissues as heat or cold: cutaneous burns, resembling burns, due to extremes in temperature (see Sect. 1.7.5).

1.5.4 Direct and Underlying Cause

While determining the cause of an injury, one should differentiate between the direct cause and the underlying cause. According to the Centers for Disease Control and Prevention, the direct cause is what produces the actual physical harm and the underlying cause is what started the chain of events that led to the actual physical harm (the injury) [38]. The direct and underlying causes can be the same or different.

If a child sustained bruising on the forehead after he or she stumbled while walking and hitting his or her head on a coffee table, the fall, caused by the stumbling, is the underlying cause (the action that started the chain of events leading to the injury, i.e. stumbling and falling), leading to the contact with the table, which is the direct cause of the bruising (the action that caused the actual physical harm, i.e. impact trauma). The cause of a certain injury does not have to say anything about the manner of that injury. Determining that the child fell and hit the table (causing a bruise to the forehead) does not define under which circumstances the stumbling took place. The stumbling may have been caused, for example by the unstable walking of the child (developmental level), just being wild during play, being pushed by another child during play or during a fight, or intentionally or unintentionally being pushed by an adult. The resulting injury will often be the same, because it is caused by an impact trauma (cause of injury), despite the different circumstances (manner of injury).

1.6 Manner of Injury

As stated before in Sect. 1.5.1, the manner of injury describes the circumstances under which the injury was sustained or the injury event happened. The manner can be divided in three types of circumstances [39]:

- Accidental trauma (often used synonyms: non-inflicted, non-intentional or unintentional, or non-abusive)
- Non-accidental trauma (often used synonyms: inflicted, intentional, deliberate, abusive, or negligent)
- Unexplained trauma (undetermined)

Using the term ‘accidental’ is factually misleading. It may suggest that the events leading to the injury were inevitable

and could not be avoided. In case of minors, especially younger children, most accidents (perhaps even all) are, at least in retrospect, preventable and sometimes even predictable [40]. 'Non-inflicted' is also a misleading term: the use of this term implies that the injury was not inflicted and that nobody was involved in causing the injury, although, for example in a motor vehicle accident, the driver is involved in causing the injury and the injury was inflicted. 'Non-intentional or unintentional' are more neutral terms: the injury event happened but there was no intention for it to happen, despite the fact that the incident could have been prevented if the necessary precautions had been taken. Despite the fact that the term 'accidental' is factually misleading, in this book this term will be used to describe the circumstances in which injuries resulted from an 'unintended, non-abusive' incident.

Using the term 'intentional' as synonymous for 'non-accidental', 'inflicted', or 'abusive' in the evaluation of injuries is also misleading. It would mean that the motivation of the perpetrator ('intentional: willingly, consciously, deliberately') to inflict an injury can be determined by evaluating certain characteristics of the injury. This is almost never possible based purely on the findings during the physical examination, except probably for pinch marks, bite-marks, or multiple stab wounds. In a physical assault, the action that led to an injury is almost always the result of a conscious decision of the perpetrator and therefore intended, but it is rarely the intention to inflict (serious) injuries. 'Inflicted' is a more appropriate term, because it states that the injury was the result of an action by a person (and perhaps an animal in bite-marks), without saying anything about the intention ('to inflict = to give or impose something unpleasant and unwanted, for example to inflict serious injuries'). In this book, the terms 'non-accidental' or 'inflicted' will be used to describe the circumstances in which injuries resulted from an abusive incident (an event resulting from violent behaviour of an adult towards a child).

The evaluation of the circumstance under which an injury or injuries were sustained, is a (forensic) medical task, in which injury characteristics and the patient's or parent's (clinical) history can be used to differentiate to a certain extent between non-accidental trauma/inflicted injuries, accidental trauma/non-inflicted injuries, and unexplained injuries. Beforehand disease, which can mimic injury, has to be ruled out. In each step of the evaluation, a carefully taken and comprehensive (clinical) history may add information, which may enable differentiation (see also Sect. 1.9). The following aspects should be taken into account during the evaluation, concerning the manner:

- The age and developmental level of the child
- Explanations given by the child (if possible), the parent(s), and others (people involved in the case, regardless of their background: professionally involved or not)
- Other (historical) physical signs and symptoms: e.g. stress-related physical signs or older bruises and/or other soft tissue injuries, fractures, head injury, and abdominal injury
- Past medical history and family history
- Additional findings during physical examination/forensic medical examination
- Findings during laboratory examination: e.g. testing of blood tests (e.g. blood clotting) or urine
- Findings during imaging: skeletal survey, CT/MRI, nuclear medicine, ultrasonography (brain, abdomen, total body)
- Assessment by social work/child protection services
- Inquiry by the police
- Data from (preferably evidence based) clinical and forensic paediatric literature about the differential diagnosis of physical findings and the possibility and probability of certain injuries in certain circumstances
- In case of suspicions of fatal abuse: findings during a forensic autopsy

Even if all medical findings and other data are properly evaluated, including an extensive (clinical) history, a comprehensive clinical examination, and/or forensic autopsy, it will not always be possible to draw reliable conclusions about the manner of the injury. For example, a young child (age 3) becomes a victim of a house fire and dies. The cause of the injuries and of the death of the child will probably be clear after autopsy, e.g. injuries due to heat and/or carbon monoxide intoxication. In other words, the injuries and death of the child were sustained due to the house fire. The following circumstances, under which the child sustained the injuries and died, should be considered to determine whether the house fire occurred in accidental or non-accidental circumstances:

- The fire resulted from a suddenly and unexpectedly malfunctioning of an electrical device. The parents were at home and tried everything to save the child. The manner of the injuries and the dying of the child can be defined as accidental and unintended.
- The child was left alone in house without any supervision and had easy access to matches. The parents were already warned by child protection to never leave the child alone at home. The injuries and the dying could have been prevented if the child had been taken care of in a proper way. The manner will be non-accidental, due to negligence.
- The fire was started deliberately. The manner of death will be manslaughter, if the death of the child was not intended to happen, or homicide, if the death of the child was intended to happen.

1.7 Cutaneous Injuries

1.7.1 Introduction

The most injured organ due to physical assault is the skin, irrespective of the age of the assaulted victim. The skin is also the easiest organ to examine in case of a suspicion of

Table 1.2 Cutaneous injuries caused by mechanical trauma [45]

Blunt-force trauma	Resulting injuries
• Closed injuries	• Erythema
	• Bruises
	• Petechiae
• Open injuries	• Abrasions
	• Lacerations and avulsions
	• Injuries due to a blunt penetrating trauma
Sharp-force trauma	**Resulting injuries**
• Open injuries	• Incisions and stab wounds
	• Gunshot wounds

non-accidental trauma. In paediatric patients, bruises are the most common injuries in physical assaults, followed by other cutaneous injuries, like abrasions and burns [41–44]. However, bruises and other cutaneous injuries due to non-accidental trauma are also common injuries due to accidental circumstances. An overview of cutaneous injuries resulting from mechanical trauma is given in Table 1.2.

When suspicious cutaneous findings are evaluated, a number of findings are seen more often in inflicted than in accidental injuries:

- Multiple injuries in various stages of healing
- Injuries of various kinds, e.g. bruises, abrasions, and burns
- Injuries on different body surfaces: front-back, left-right)
- Injuries with a clearly recognizable pattern, e.g. a hand-print or an iron
- Self-defence injuries: injuries that arise because the child adopts a body posture that reduces the risk of serious injury during a violent incident
- Injuries to body parts that would normally not be damaged in an accident or only in exceptional cases, e.g. the perianal area
- Injuries/bruises in non-mobile children, especially children under the age of 4 months old

1.7.2 Blunt-force Trauma: Closed Skin Injuries

1.7.2.1 Erythema

Erythema is defined as redness of the skin and/or mucous membranes caused by dilatation of the underlying capillaries. It is caused by a non-specific local reaction, which occurs with any cutaneous trauma (e.g. by heat, friction, rubbing, pressure, or by the application of irritating chemical substances), infection, or inflammation. Contrary to bruises and petechiae, erythema does blanch under diascopy, because there is no leakage of erythrocytes in erythema. In case of a traumatic cause, erythema will vanish within minutes to hours after the incident. For that reason, erythema is only rarely seen during the medical evaluation of suspect child abuse cases, unless the child is examined by a physician within minutes to hours after the incident that caused the erythema.

1.7.2.2 Bruises

A bruise is an injury of soft tissues (skin, underlying tissues, mucous membranes), in which vessels (capillaries and venules) are damaged by trauma (usually blunt-force trauma: collision/compression or stretching), causing leakage of erythrocytes into the surrounding interstitial tissues. Because of the leakage of erythrocytes, bruises will not blanch under diascopy. Synonyms that are used for bruises are hematoma, contusion, purpura, and ecchymosis. In this book the terms bruise or hematoma will be used.

Bruising occurs when the loading of soft tissues exceeds the maximum load-bearing capacity of these tissues. This means that traumatic bruising can occur in children with and without congenital or acquired medical conditions in which the maximum load-bearing capacity of vessels is diminished, in clotting disorders or in a combination of both, e.g. systemic disorders with clotting problems. In children with a medical condition trauma is often still needed to create bruising, but the acquired threshold value to cause bruising in these children is less than in children without such a condition. The manner of traumatic bruising in young children with or without a medical condition can be either accidental (injury, e.g. due to a fall during daily activities) or non-accidental (injury due to a human act or omission). In other words, finding a medical condition does not exclude non-accidental circumstances [45].

The total number of bruises (including bruises of the shins) in a young child due to age-appropriate motor behaviour (such as playing) (accidental bruises) typically ranges from a few to about 15 [46].

One should, however, realize that spontaneous bleeding and bruising can sometimes also occur in children with, e.g. immune related thrombocytopenia (ITP), sepsis, or Henoch–Schönlein purpura.

Cutaneous bruises generally are located superficially in the skin and subcutaneous tissues, with usually externally visible discoloration, changing in colour over time (days to weeks). More extensive extravasation of blood will be seen in areas with increasing laxity and loose subcutaneous elements in the tissues, e.g. bruising around the eyes is more obvious than bruising of the hand palm [47].

If bruising is found symmetrically on the whole body, this usually indicates an underlying condition. If symmetrical bruising is found on a limited part of the body, e.g. only in

the head-neck region or on the inside of the upper arms or thighs, inflicted injury is more likely than an accidental injury or a medical condition [45].

Traumatic bruising results from either blunt force (impact trauma, e.g. due to falling, bumping, or punching) or compressive force (compressing, tightening, or twisting of the skin, e.g. when squeezing the skin) [25].

Kemp et al. published the results of a systematic review of the medical literature concerning the circumstances under which bruises can occur in children (manner of bruising) [48]. They also evaluated the specific characteristics of bruises, related to the manner of injury. Accidental bruising occurred very rarely (<1%) in non-mobile children. Clustering of bruising was often found in children in whom the bruising was sustained in non-accidental trauma. Frequently, other types of recent and old injuries were found in these children such as scars from burns or (healing) scrapes, or scratches.

Pierce et al. showed that bruises on the trunk (chest, abdomen, back, buttocks, anogenital region, and hips), ears, and/or neck in children under 4 years of age (TEN-4) were indicative of non-accidental circumstances (specificity of 84%; sensitivity of 97%) [49]. The authors stated that the indicative nature of bruising at these locations applied if a statement about plausible accidental circumstances, including observation of the causing incident by an independent observer, was missing. Based on the findings of Pierce et al., it can be calculated the finding of a bruise in the TEN-region in a child under the age of 4 years is approximately 6 times more likely under the hypothesis of a non-accidental trauma than under the hypothesis of an accidental trauma. Pierce et al. further concluded that bruises in children under the age of 4 months, regardless of the location of the bruises, always are suspect for non-accidental circumstances, especially if no plausible accidental explanation is present or no evidence is found for a condition with an increased bleeding tendency.

In 2021, Pierce et al. published the results of the evaluation of an extended 'bruising clinical decision rule', TEN-4-FACESp (Table 1.3) [50]. The new BCDR has a sensitivity of 95.6% (95%CI, 93.0–97.3%), a specificity of 87.1% (95%CI, 85.4–88.6%), a negative predictive value (NPV) of 98.8% (95%CI, 98.1–99.3%), and a positive predictive value (PPV) of 63.9% (95%CI, 60.3–67.7%). Based on these new findings, it can be calculated that the finding of one bruise in the body parts covered by 'TEN-4-FACESp' in a child under the age of 4 years of age, or regardless of the location on the body in a child under the age of 5 months, is approximately 7.5 times more likely under the hypothesis of a non-accidental trauma than under the hypothesis of an accidental trauma (LR+ 7.41). Finding a bruise in a child under the age of 5 months is always suspect, irrespective of the location.

Table 1.3 TEN-4-FACESp [50]

T	Torso which includes chest, abdomen, back, buttocks, and genitourinary area
E	Ears
N	Neck
4	The 4 represents any bruising anywhere to an infant of 4 months or younger
F	Frenulum
A	Angle of jaw
C	Cheeks (fleshy)
E	Eyelids
S	Subconjunctivae
p	Patterned injuries

One of the most common explanations of bruising, according to the caregiver, in young and pre-mobile children is that the child itself was responsible for the occurrence of the bruising. Depending on the age and the level of development of a child, it is possible that an accidental fall occurs unnoticed as a result of the child's own actions. An accidental trauma in a young child with limited mobility will almost always be a non-serious and often observed event, such as bumping the head when rolling over or after lifting the head. For young children with this level of development, a 'spontaneous fall' from a short distance, e.g. from a changing table, can occur if the child turns over on the changing table. However, such a fall can only occur in case of lacking supervision: the child has been left in an unsafe situation.

A young pre-mobile child will have a limited control concerning the movements of the head and neck because the head is large compared to the rest of the body and the child does not have complete control over the neck muscles. There may be bumping contacts against persons or objects during the daily handling and care of a child, though there are no indications in the literature that bruising will occur due to these bumping contacts. It should be noted here that if a child has a clotting problem, bruising may occur during these bumping contacts.

It is possible that a young and pre-mobile child falls out of the hands of a parent/caregiver. This can be seen as a short distance fall (about 1.5 m). This type of accidental fall occurs regularly [51]. In such a fall, injuries (including bruising) can occur in those body parts that first come into contact with an object or surface during the fall. While being in the arms of the caregiver, the fall of the caregiver him/herself can increase the momentum of the fall and thereby the possible injuries.

With regard to the moment of the appearance of a bruise after a trauma and the possibilities for determining the age of a bruise based on visible characteristics, the following can be noted:

- Superficial bruises are usually visible as a discoloration soon after the causative event (almost immediately, up to minutes, e.g. on the forehead). With deeper bruising this

can take many hours to a few days (such as on a buttocks) [47, 52]. Furthermore, deeper bruising sometimes will not become visible, except when the skin is incised, e.g. during a forensic autopsy [47].
- Superficial bruises fade gradually and are usually no longer visible after 2 to 3 weeks.
- To date no scientific basis exists for dating bruises based on colour changes in young children, neither in visual assessment of findings during physical examination nor in review of photographic material [42].

1.7.2.3 Petechiae

Petechiae are small red, purple, or brown spots caused by minor bleeding (0.1–2 mm, pinpoint bleeding/punctate bleeding) in the skin, the mucous membranes, and/or the serosa surfaces, due to leakage of blood from damaged post-capillary venules. Because of leakage of erythrocytes in the surrounding tissues, petechiae will not blanch under diascopy.

Petechiae are common and can be caused by a large number of medical or traumatic conditions, ranging from minor to very serious [53]. Medical conditions include viral and bacterial infections, haematological disorders (e.g. immune thrombocytopenia, vitamin K deficiency), malignancies (e.g. leukaemia), vasculitis and inflammatory conditions (e.g. Henoch–Schönlein purpura), and disturbance of collagen synthesis, due to vitamin C deficiency, side-effects of some drugs (e.g. anticoagulants or some antibiotics). They can also be caused by heavy coughing (e.g. in whooping cough) or straining (e.g. in severe constipation). Petechiae can also be self-inflicted, e.g. due to suction, especially in elderly children. Petechiae in the skin around the eyes, sometimes combined with conjunctival haemorrhages may also occur in patients with eating disorders, due to self-induced vomiting [54].

In trauma the damage to the post-capillary venules is primarily due to an acute rise of the venous pressure in these venules. This sudden increase can result from several mechanisms:

- Back pressure, caused by mechanical obstruction of venous return to the heart that leads to over-distension and rupture of the thin-walled peripheral venules, which in its turn leads to rapid extravasation of blood, especially in lax tissues, such as the eyelid, or in unsupported serous membranes, such as the pleura and the epicardium (e.g. in strangulation or choking)
- Back pressure, caused by gravitational obstruction of venous return to the heart (e.g. in upside down hanging)
- Locally acting external colliding and/or compressing and/or (partly) crushing force action with or by a blunt object (e.g. in a slap mark)
- External, local acting, suction on the skin (e.g. 'love bite')

The manner of trauma can be accidental or non-accidental. 'Accidental' petechiae can occur e.g. in hanging upside down during play or sports on a horizontal bar, weightlifting, or in accidental drowning. 'Non-accidental' petechiae can be seen, e.g. in strangulation or choking but also in physical abuse. In a retrospective study of 506 children under the age of 6 years suspected of inflicted bodily injury, petechiae were present in 15.4% of the children for whom inflicted injury was deemed proven (54 of 350 children) and 1.9% of the children for whom an accidental trauma was deemed proven (3 of the 156 children). This corresponds to a likelihood ratio of almost 10 [48]. Petechiae can also be found as a result of, what can be considered to be a specific type of non-accidental trauma, medical procedures, in which local physical pressure is applied, e.g. due to a tight tourniquet or being held tightly.

Sometimes a medical condition and trauma coexist, e.g. in illnesses with vomiting and coughing (e.g. in pertussis), in which petechiae can be found in the head and neck region.

It is not possible to date petechiae based on externally visible characteristics. Petechiae due to trauma appear fairly quickly (within several seconds to minutes) after the loading and usually disappear within a couple of days up to about one week. Any accompanying redness that may occur simultaneously is visible almost immediately for up to 1 or 2 days.

1.7.3 Blunt-force Trauma: Open Injuries

1.7.3.1 Abrasions

An abrasion is a superficial injury to the skin, characterized by the traumatic removal, detachment, or destruction of the epidermis and sometimes underlying parts of the skin. Abrasions are also known as erosions, excoriations, or crab, scratch and scrap injuries.

Abrasions are located at the site of contact with the object and are caused by a blunt-force trauma, in which there is:

- Rubbing, sliding, scraping, wiping, or other lateral movement of the skin relative to an object with a high friction surface (e.g. a brick) or relative to a more or less sharp or pointed object (e.g. barbed wire, fingernail, tip of a nail or knife, piece of glass or animal-claws). In the lateral movement an object can be moving along the body surface, the body surface along the object or a simultaneous movement of object and body surface.
- Compression/crushing of the skin, where there is a force acting more or less perpendicular to the skin.
- A combination of both mechanisms.

Only rarely a child will sustain abrasions due to non-accidental circumstances. If these injuries are inflicted, the injuries will be found in particular in the head and neck region (head, face, mouth, and neck) and on or near the upper

arms [55, 56]. The most common injuries of this type are sharp, line-shaped injuries due to scratching with the nails or 'imprint' injuries, specifically nail imprints due to pinching. In elderly children, self-harm has to be ruled out.

If an abrasion is caused by a fingernail, the width and depth depend on the width and sharpness of the nail and the amount of pressure during the contact. If only pressure is applied and no lateral movement is made, the skin is often only superficially damaged and a superficial linear or curved (crescent-shaped) shape will be visible ('static fingernail imprint') [56]. A child usually sustains a fingernail abrasion in accidental circumstances. Newborns and young infants can have relatively long and sharp nails from birth. The child can scratch himself through non-directed movements, particularly in the face. These injuries are almost always limited in number and size, usually with a maximum of 0.5 cm long.

Dating of abrasions in children, either living or deceased, is not reliable if based on externally visible characteristics.

1.7.3.2 Lacerations and Avulsions

A laceration is a full-thickness injury of the skin and subcutaneous tissues, characterized by tearing of tissue in a frayed and irregular pattern and often associated with abrasions, contusions, and crushing of the wound margins. A laceration is also known as a tear or tear wound. A laceration is caused by blunt-force trauma (collision/compression or stretching—shearing force).

An avulsion is a laceration in which skin and subcutaneous tissues are not just separated but torn away from the underlying tissues. An avulsion is caused by the same mechanism as a laceration.

Usually lacerations and avulsion are sustained in accidental circumstances and are only rarely seen in non-accidental circumstances. A child may incur a laceration in non-accidental circumstances, e.g. while being whipped. Another non-accidental cause can be sexual abuse with penetration (digital, penile, object, etc.) resulting in a laceration of the hymen or the anal ring and surrounding tissues.

Dating of lacerations in children, either living or deceased, is not reliable, if based on externally visible characteristics.

1.7.3.3 Blunt Penetrating Trauma

A blunt penetrating trauma happens when a more or less pointed object pierces the skin. The diameter of the penetrating object may vary from a few millimetres (e.g. pin or nail) up to more than 10 cm (e.g. a wooden stake). The result of the piercing varies from deep narrow wounds that are sometimes hard to identify due to a small entry hole without clinical consequences via the same narrow wounds with penetrating and life-threatening injuries to underlying tissues to large injuries with extensive damage to underlying organs, e.g. in a blunt penetrating trauma of the abdomen [57].

Puncture wounds caused by blunt penetration should be differentiated from injuries caused by a sharp penetrating trauma (stab wound). As far as known from the literature and from case work done by the authors injuries due to a blunt penetrating trauma always occur in accidental circumstances.

1.7.4 Sharp-force Trauma

1.7.4.1 Incisions and Stab Wounds

An incision (incised wound), if caused by sharp-force trauma with a clean, sharp-edged object (e.g. a knife, a razor, or a glass splinter), is a slicing injury usually with sharp edges (clean cut), in which the injury is longer than deep, varying from superficial (paper cut) to significant (surgical incision). A sharp-edged incised wound will give little or no information about the object that caused the injury. If an incision is caused by a sharp serrated object (e.g. a bread knife), the incised wound will have laceration-like edges.

A stab wound (puncture wound or penetrating injury) is a deep, narrow injury, which is deeper than its length visible in the skin, caused by a sharp-pointed object puncturing the skin (e.g. needle, knife, or broken glass). A stab wound usually is sharp edged, except in case of a sharp serrated object. Stab wounds caused by sharp penetrating trauma should be differentiated from injuries caused by blunt penetrating trauma (puncture wounds).

Incisions and stab wounds are found in more than 10% of children with accidental injuries [58]. Incised wounds usually occur in accidental circumstances, usually due to broken glass (drinking glass, window pane), but may also occur due to cutting on paper or grass, a knife, broken glass, or lid of a can. Often these occur during household activities. Incisions can also be caused by sharp edges of equipment or tools during leisure time and work. Accidental incisions are often more irregular in shape. Deep penetrating accidental stab wounds can occur if a child falls on a knife or other sharp object, such as a sharp pencil or a knitting needle.

Inflicted incisions or stab wounds usually are caused with a knife, razor, or broken glass by a perpetrator. In children, this type of injury is only rarely inflicted. Nevertheless, one should consider non-accidental circumstances, if these injuries are found in children, especially if other suspicious injuries are found [59, 60]. An incised wound in the neck of a young child is highly suspicious for an attempted homicide or murder [61–63].

In case of self-inflicted injuries, any object can be used that can lead to incised wounds. 'Cutting/carving' with a sharp object (e.g. knives, razors, and glass fragments) is probably the most common form of self-infliction. The resulting injuries can exist on the entire body, but mostly

only on the wrists and forearms. It is more common in girls than in boys and can occur at any age, although it is usually seen in adolescents and young adults [64, 65].

Sometimes the term 'cut' is used. This term is confusing if used in a forensic setting, because this term is not well defined and commonly used for any injury in which the integrity of the skin is compromised. A 'cut' can result from either a blunt-force trauma (laceration, avulsion) or a sharp-force trauma (incision, stab wound).

1.7.4.2 Gunshot Wound

A gunshot wound (missile wound, velocity wound) is an injury caused by an object entering, and often leaving, the body at a high speed; typically a bullet or similar projectile. Often two wounds are found, one at the site of entry and one at the site of exit (through-and-through injury). Wound characteristics depend on the firearm (handgun, rifle, or shotgun) and ammunition (mass and design) used, bullet direction, range, and sequence of fire [66]. Analysis of gunshot wounds should, given the multitude of parameters involved, only be done by experts. Gunshot wounds may occur under accidental and non-accidental circumstances and are almost exclusively seen in countries with liberal firearm legislation like the United States, where it ranks third as cause of death for children [67–71]. Based on data from the Kids' Inpatient Database from 2000, 2003, 2006, and 2009 for children <19 years of age a total of 27,566 firearm-related injuries were recorded [72]. In children <5 years, most injuries were accidental (59.3%). In another study, it was shown that most fatal accidental shootings in children (89%) occur in the child's house while the child is playing with a loaded weapon [73].

1.7.5 Non-mechanical Trauma: Near Contact with Physical Agents

As already stated in Sect. 1.5.3, injuries are the result of the transfer of energy during a direct contact of or a contactless transfer to the skin and/or other body parts, in which the skin and/or the other body parts are exposed to extremes in temperature (heat and cold) or to chemical or physical agents (acidic and alkaline chemicals, electricity, microwaves, and radiation). In a contactless transfer the risk of injuries usually decreases with increasing distance between the body and the energy source, e.g. with radiation from an infrared heater. Chemical or physical agents may have a similar effect on the skin and the subcutaneous tissues as extremes in temperature (heat or cold): cutaneous burns, resembling heat or cold-related burns (Table 1.4). Chemical or physical agents may create heat at the moment of contact with the skin [74–76]. Besides external burns, internal burns may arise due to swallowing and inhalation of chemicals or electrocution.

Table 1.4 Injuries resulting from non-mechanical trauma

Trauma	Resulting injuries
Thermal	Heat: burns and scalds Cold: chilblains and frostbite
Chemical	Burns Allergic reactions (topical and generalized) Generalized poisoning manifestations
Electrical	Burns High- and low-voltage injuries
Electromagnetic and ionizing (radiation)	Burns

In this section, we will only shortly pay attention to the effects of thermal trauma, which may occur in accidental and in non-accidental trauma. Injuries due to accidental exposure to chemical and physical agents are rare in paediatric patients. As far as is known from the existing medical literature, injuries due to non-accidental exposure to these agents are extremely rare (chemical and electrical trauma), or even non-existing (electromagnetic and ionizing trauma).

In a thermal skin trauma, the damage to cells is caused by the transfer of thermal energy to the skin and/or the subcutaneous tissues, as a result of the exposure of tissue to high or low temperatures. The extent of the damage is determined both by the temperature and the duration of exposure. Thermal trauma can also be caused by low or freezing temperatures (cold-related injuries). Thermal trauma may result from:

- Direct contact (transfer of energy by conduction) with a dry, hot, and solid heat source (dry burns due to, e.g. iron or a curling iron), hot liquids (e.g. soup, hot tea), vapours, or gases (scalds or wet burns), and open fires (cigarette burns, fire and flame burns)
- Exposure of the skin and the subcutaneous tissues to the radiant heat of an object, e.g. the close proximity to a radiant fire or electrical heater or the prolonged sun exposure

1.8 Other Injuries

1.8.1 Introduction

In paediatric patients, the same type of injuries can be found in accidental trauma as in non-accidental trauma. However, with increasing age, injuries due to accidental trauma become more common than injuries due to non-accidental trauma.

Fractures probably are, next to bruises and other cutaneous injuries, the second most common injury in paediatric

patients due non-accidental trauma [77]. The cause and manner of fractures will be described in Chaps. 5 to 12. Intracranial and thoracoabdominal injuries can also be found in paediatric patients due to non-accidental trauma, but are less common than non-accidental cutaneous injuries and fractures. In this section, a short overview of thoracoabdominal injuries will be given without the intent of being complete. In Chap. 5 a short overview will be given of intracranial injuries, due to non-accidental trauma.

In paediatric patients, the most common cause of death, irrespective of the circumstances (accidental or non-accidental), is trauma [78]. Death due to accidental trauma is most commonly caused by intracranial injuries, followed by intrathoracic and intra-abdominal injuries as second and third most common cause [79, 80]. Death due to non-accidental trauma is also most commonly caused by intracranial injuries, but intra-abdominal injuries are the second most common cause [81, 82]. Rosenfeld et al. evaluated the findings in 678,503 children who were admitted with injuries, due to a physical trauma. Nineteen thousand one hundred and forty-nine children (3%) sustained injuries in a non-accidental trauma. According to Rosenfeld et al. non-accidental trauma is a major cause of death in young children, with polytrauma being common [83]. In 43% of trauma deaths in children under the age of 1 year and in 31% of children under the age of 5 years, death was due to non-accidental trauma, with traumatic brain injury being the most common cause (50%), followed by hollow viscus and thoracic injuries.

1.8.2 Thoracoabdominal Injuries

According to Milroy, thoracoabdominal injuries caused by blunt-force trauma are an important cause of morbidity and mortality in children [82]. Milroy also stated that isolated thoracic or abdominal injuries are less common than combined thoracoabdominal injuries and that thoracic injuries have a higher mortality than abdominal injuries.

Thoracoabdominal injuries are either caused by static or by dynamic loading (see Sects. 1.8.2.1 and 1.8.2.2) and can be sustained in accidental and in non-accidental circumstances. Usually thoracoabdominal injuries are sustained in accidental trauma, e.g. motor vehicle accidents [82]. When no plausible accidental explanation is given, non-accidental trauma should be considered in paediatric patients with blunt thoracoabdominal injuries, with intra-abdominal injuries being more common than intrathoracic [78, 82].

Sinha and Lander also stated that, even if a plausible cause of the injuries is present, neglect should be considered if the injuries were sustained in unusual circumstances, e.g. injuries due to a skateboard accident in an 8-year-old at 23:00 h.

Shenoi et al. evaluated the findings in 12,044 children with blunt-force trauma to the torso [84]. In 720 children (6%) the injuries were determined to be inflicted, in 9563 children (79.4%) unintentional (accidental), and in 148 children (1.2%) indeterminate. In 1613 children (13.4%), no data were found concerning the circumstances under which the injuries were sustained. In their study, children with accidental thoracoabdominal injuries had a lower median age than children with inflicted thoracoabdominal injuries (10 versus 14 years of age). There was no difference in mortality rates between both groups. The risk of pelvic fractures in the group of children with inflicted injuries was 96% less than the group with accidental injuries. Children with accidental injuries were more likely to be hospitalized.

1.8.2.1 Intrathoracic Injuries

(Intra)thoracic injuries are caused by static loading (compression) or to dynamic impact loading (blunt-force or penetrating trauma), irrespective of the circumstances under which the injuries are sustained (accidental or a non-accidental trauma).

Around 85% of all thoracic injuries in paediatric patients, that are serious enough to warrant medical attention and/or treatment, are due to blunt-force trauma (compression or impact), and around 15% are due to penetrating trauma (see also Chap. 7) [78, 85]. Blast injuries are very rare in paediatric patients.

Thoracic trauma may cause injuries of the intrathoracic organs (lungs, heart, aorta and great vessels, oesophagus, tracheobronchial tree), and of the structures of the chest wall. The most common injuries due to blunt-force trauma are fractures of ribs and sternum, contusions of the lungs or the heart, pneumothorax, and/or haemothorax [82, 86]. Thoracic injuries account for less than 10% of all paediatric trauma-related injuries but comprise up to 15% of paediatric trauma-related deaths [85, 86]. According to Milroy, mortality is higher in children with damage to the heart and to the aorta [82].

Several studies have shown that there is a clear difference between (intra)thoracic injuries sustained in accidental and in non-accidental trauma (see Sect. 7.3.3). Non-accidental intrathoracic injuries are more common in children under the age of 5 years than in children over the age of 5 years [87].

1.8.2.2 Intra-abdominal Injuries

Most intra-abdominal injuries are the result of a serious traumatic event, irrespective of the circumstances under which the injuries are sustained (accidental or a non-accidental trauma). The most common injuries are contusions and lacerations to the solid organs (liver, spleen, and kidneys), and less common injuries to the hollow viscera, irrespective of the circumstances.

In the United States in about 90% of the children with intra-abdominal injuries, these injuries are caused by blunt-force abdominal trauma [88]. In the remaining 10%, the injuries are due to several other causes, like sharp penetrating trauma or chemical trauma, such as the ingestion of objects like batteries or etching substances.

Intra-abdominal injuries in blunt-force abdominal trauma can be due to several causes [89–91]:

- Static loading (compression) with damage to hollow viscera ('bursting' injuries): if the abdomen is compressed, a hollow organ filled with liquid, air, or partially digested food can be compressed against a hard structure, e.g. the spine. This can lead to bursting of the organ, due to an increase in intraluminal pressure. 'Bursting' injuries most commonly occur in fluid-filled intestinal loops.
- Dynamic impact loading with damage to hollow viscera ('bursting' injuries): these injuries resemble the bursting injuries, due to static loading, and are usually caused by a direct blunt-force trauma to the abdomen, e.g. a 'single point blow' or a blow in the midline of the abdomen.
- Dynamic impact loading with damage to solid organs ('crushing' injuries): 'crushing' injuries of solid abdominal organs occur due to the impact of blunt-force trauma on the upper abdomen or on the lower ribs, in which the organs are violently and suddenly compressed against a hard structure, e.g. the spine or the ribs. This may result in lacerations and ruptures of the liver, spleen, pancreas, or kidneys. Bleeding in the intestinal wall, especially the duodenum wall, may also occur.
- Dynamic impact loading due to a rapid change of the velocity or direction of motion of the body, resulting in shearing and tearing forces created in areas of relative fixation inside the body [91]. This can occur in an event in which, e.g. something hits the child with a high speed and the child hits a solid object, e.g. a wall or a cupboard, resulting in a sudden and immediate deceleration. The sudden deceleration of the body and the inertia of the organs may lead to a sudden application of a large inertial load, causing the bowel to rupture on the antimesenteric side close to the posterior abdominal wall attachment point, e.g. at the Treitz ligament or the ileocecal junction [92, 93]. In such an event, the upper abdominal organ vascular supply can also tear off. Bleeding into or perforation of the small intestine may also occur.

Blunt-force trauma with damage to either hollow visceral and/or to solid organs can occur in accidental trauma, e.g. due to the impact of the end of a bicycle handlebar to the abdominal wall, or in non-accidental trauma, e.g. due to a punch or kick [81, 92, 94, 95].

Dynamic impact loading with a rapid change of the velocity or direction of motion of the body can occur in accidental trauma, e.g. in motor vehicle accidents, when the child is restrained with the aid of a two-point seat belt, or in motor vehicle versus pedestrian accidents or in a fall from a height [92]. It may occur when a child is violently thrown against a wall or on the floor. This may happen in non-accidental trauma, e.g. due to a bomb blast or during a physical assault, but is probably very rare [82].

In 1 to 8% of children who were hospitalized because of accidental blunt abdominal trauma, intra-abdominal injuries are found [92, 94, 95]. Intra-abdominal injuries were found in up to 65% of children who were hospitalized with a non-accidental blunt abdominal trauma [96]. In a systematic review concerning visceral injuries in paediatric patients due to non-accidental trauma, it was found that children with abdominal injuries due to non-accidental trauma were younger than children with abdominal injuries due to accidental trauma (2.5–3.7 years vs. 7.6–10.3 years) [87]. Lane et al. found that the rates of non-accidental abdominal trauma were higher for infants than for any other age group. They also found that in their study infants had higher rates of hospitalization because of non-accidental abdominal injuries, despite the fact that often toddlers are considered to be at highest risk for non-accidental abdominal injuries. They also found that more than 25% of all abdominal trauma in children <1 year of age was due to non-accidental trauma [97].

In children with non-accidental trauma duodenal injuries, especially in the third or fourth part, were commonly reported, but also injuries of the ileum and jejunum have been described. Duodenal injuries, due to accidental trauma, were not found in children under the age of 4 years [87]. Duodenal hematoma, caused by blunt-force abdominal trauma, may lead to obstruction of the lumen and may result in weakening and finally rupturing of the wall. Ruptures may present as peritonitis [82].

Injuries to liver, spleen, and pancreas are also frequently seen in non-accidental trauma [98]. Lane et al. even found that the organs that were most commonly injured were the liver (64% of hospitalizations), kidney (19%), and stomach/intestines (12%) [97].

Non-accidental blunt-force trauma, e.g. due to blows or kicks, may cause contusion, laceration, or transection of the pancreas [82]. The damage to the pancreas may be complicated by pancreatitis or pancreatic pseudocyst formation [82, 87].

Coexisting findings in children with inflicted abdominal injuries include malnutrition, fractures, burns, and head injuries [87].

Lane et al. stated that mortality rates of non-accidental abdominal trauma reported in the medical literature are 13–45% [97]. Maguire et al. found that the mortality from inflicted abdominal injuries was significantly higher than accidental injuries (53% vs. 21%) [87]. Post-mortem examination shows that often there has been more than 1 event in

which previous, unrecognized abdominal injuries were sustained [87, 99]. Gilbert-Barnes stated: 'Many of these children have received repeated blows to the abdomen, and careful examination and microscopic sampling of the abdominal contents has revealed extensive fibrosis confirming subacute or remote injury'.

Often it is stated that intra-abdominal injuries in a child are sustained in a fall. Carter and Moulton evaluated the findings in 180 paediatric patients under the age of 5 years with blunt-force abdominal trauma [100]. In 65 patients the intra-abdominal injuries were due to non-accidental trauma and in 115 patients due to accidental trauma (fall casualties). They found that non-accidental trauma should be considered, if the child was under the age of 5 years, had a hollow viscus, pancreatic and/or intracranial injury with a high injury severity score. They also found that in their population solid organ injuries and isolated splenic or renal injury were more likely in accidental than in non-accidental trauma.

Externally visible injuries are often absent in children with abdominal injuries, due to blunt-force trauma, irrespective of the circumstances under which the injuries were sustained [82]. Bruising can be absent in up to 80% of children with inflicted abdominal injuries [87].

It is not exactly known how often intra-abdominal injuries are sustained in non-accidental trauma. Estimates are that between 1% and 9% of children that are admitted to hospital because of non-accidental injuries will have intra-abdominal injuries [81, 101–104]. Because abdominal injuries in non-accidental trauma are often severe and arrive often late in hospital, there is a high rate of surgical interventions [105]. According to Sivit et al., around 5% of all abdominal injuries in need of a surgical intervention are sustained in non-accidental trauma [102].

1.9 Objectifying Suspicions of Inflicted Injuries and Non-accidental Trauma

Any suspicion of inflicted injuries/non-accidental trauma in a child should always be taken seriously. A correct and evidence-based interpretation of these signs and symptoms ('fact finding') is in the interest of the child but also in the interest of its parents/caregivers.

Some suspicions will be easy to reject, e.g. when the physical findings can be explained as disease-related symptoms or as injuries due to an accidental trauma, observed by an independent eye-witness. Other suspicions will be easy to confirm, e.g. when somebody admits to have inflicted the injuries or when an independent eye-witness observes the infliction of the injuries.

In many cases however, suspicions will require an elaborate investigation before a conclusion can be reached. This investigation requires taking of an extensive clinical history (see also Sect. 1.10). A forensic medical evaluation demands the same careful considerations as the making of a clinical medical diagnosis, with a meticulous weighing of alternative explanations, as in a clinical medical differential diagnosis.

The forensic medical evaluation of a suspicion is based on both a clinical and a forensic medical scientific framework and concerns the evaluation of cause and manner of the findings (Sects. 1.5 and 1.6). And, in the end, also of the motivation of the person who inflicted the injuries. The evaluation of the motivation (intention), however, is not a forensic medical task, but is the task of a behavioural analyst (forensic psychologist or psychiatrist) and/or of law enforcement.

Many signs and symptoms may lead to a suspicion of inflicted injuries in a child. A suspicion of injuries due to non-accidental trauma in a child may arise, based on individual findings or combinations of findings, e.g. bruises, fractures, and subdural haemorrhages. These individual findings or the combinations of these individual findings have their own clinical and forensic medical differential diagnosis and demand a careful differential diagnostic process, which is done in a systematic way.

In Tables 1.5 and 1.6, an example is given of a systematic approach of the diagnostic process in case of a suspicion. This process is based on the principles of diagnosis by exclu-

Table 1.5 Clinical scientific framework: clinical medical diagnosis

Step 1: Collecting as much clinical data as possible, incl. all data from the medical history	
• Whole body examination, incl. registration and photography of all external injuries and the absence of injuries	• The complete set of medical data is necessary, incl. all original source information (laboratory data, radiology, and retina photos)
• Registration of growth and development	• Only medical correspondence is insufficient
• Extensive neurological evaluation	
• Laboratory tests	
• Radiology (X-skeleton—RCPCH/ACR criteria, CT, MRI, US)	
• Ophthalmology	
• (Forensic pathology, neuropathology, ophthalmopathology)	
• Other data	
Step 2: Determination of the cause of the medical findings	
• Differential diagnosis of the individual and combined medical findings	
• Evaluating all the available medical data	
• Cause of medical findings	• Medical condition (congenital or acquired)
	• Trauma (trauma during or after birth)
	• Undetermined
Formulation of the weight of the evidence regarding the cause of the medical findings:	
• The individual findings or the combination of findings give no (or moderate or strong or very strong) support to hypothesis 1 (e.g. medical condition) against hypothesis 2 (e.g. trauma)	

Table 1.6 Forensic scientific framework (in case of trauma): forensic medical differential diagnosis

Step 3: Determination of manner of injury
• Medical findings (injuries and injury-patterns) compared to what is known in medical science
• Medical findings compared to the statements of parents, carers, or others to medical staff (medical history) & others (incl. police interrogations)
Manner of injury
• Trauma during birth
• Trauma after birth: accidental, inflicted
• Undetermined
Formulation of the weight of the evidence regarding the manner
• The individual findings or the combination of findings give no (or moderate or strong or very strong) support to hypothesis 1 (e.g. inflicted injury) against hypothesis 2 (e.g. accidental injury)
Step 4: Determination of mechanism of injury
• Medical findings (injuries and injury-patterns) compared to what is known in medical science
• Medical findings compared to the statements of parents, carers, or others to medical staff (medical history) and others (incl. police interrogations)
Mechanism of injury
• Static loading
• Dynamic impact loading: impact trauma (acceleration and/or deceleration trauma)
• Dynamic impulse loading: repetitive acceleration-deceleration trauma
• Undetermined
Formulation of the weight of the evidence regarding the mechanism
• The individual findings or the combination of findings give no (or moderate or strong or very strong) support to hypothesis 1 (e.g. dynamic impact loading) against hypothesis 2 (e.g. dynamic impulse loading)

sion and by inclusion and on the use of Bayes Theorem to formulate the conclusions, concerning the suspicion:

- Diagnosis by exclusion: a diagnosis reached by a process of elimination of other possibilities, related to the probability of these possibilities.

  A diagnosis by exclusion is a major component in the performing of a clinical or forensic medical differential diagnosis and necessary if the presence of a certain medical condition cannot be established with complete confidence from confirmatory physical examination, radiology, or laboratory testing.
- Diagnosis by inclusion: a diagnosis based on the results of confirmatory physical examination, radiology, or laboratory tests. In forensic medicine, statistical analysis of individual findings or combinations of findings offer the possibility of a diagnosis by inclusion under the condition that the results of the analysis of the findings do fulfil the normal statistical standards of accepting a diagnosis in clinical practice (see also Chap. 17).

  A diagnosis by inclusion is to a certain height also possible by applying the 'duck principle' as described by Minns and Brown in 2005 (Table 1.7) [106].

Table 1.7 Combinations of findings: the Duck principle [106]

	Characteristics	Conclusion
A bird	That waddles	Possible duck
	That waddles + swims on water	Suspected duck
	That waddles + swims on water + quacks	Strongly suspected duck
	That waddles + swims on water + quacks + has webbed feet	Few doubts of being a duck
	That waddles + swims on water + quacks + has webbed feet + a flat bill	Beyond reasonable doubt it is indeed: a duck!!

While evaluating a suspicion of inflicted injuries/non-accidental trauma, one should always keep in mind that, given the findings and circumstances, a possibility is not always a (medical) probability and a probability will not always be a (medical) possibility. A good example of the difference between certain possibilities and the probability of these possibilities was given in 2008 by David in an article on the evidence in non-accidental head trauma [107]. In this publication David gave two tables, one with causes of subdural bleeding and one with causes of retinal haemorrhages. Although David explicitly stated that he did also include causes in adults and that these were not relevant in children (possibilities without probability), the medical conditions in the tables are sometimes used as starting point in the differential diagnosis (*'diagnosis by exclusion'*) if inflicted head injury is suspected in a child. This leads to a confusion of tongues, in which possibilities and probabilities are used as synonyms. One might wonder how realistic (how probable) included possibilities like breakdancing, head banging, weightlifting, or boxing, described in the medical literature as causes of subdural bleeding in adolescents and adults, are as a cause of subdural bleeding in a young child under the age of 1 year. The same accounts for the listed caused by retinal haemorrhages. How realistic (how probable) is bungee jumping, high altitude, crushing injury to chest, or chest compression from safety belt as causes in a young child, despite their description in the adolescent and adult medical literature? Even if one looks at causes that were quoted by David and that could be relevant in infants, one should always ask how probable (how realistic), e.g. ECMO (ExtraCorporeal Membrane Oxygenation), diabetes, and sickle cell anaemia are as possible causes in infants, given the findings and circumstances in a specific child.

1.10 Characteristics of the Clinical History

Most physicians will positively identify injuries as inflicted when these injuries are of the most severe clinical category, such as extensive bruising or multiple fractures without identifiable medical history or cause in young, non-mobile chil-

dren. Problems arise mainly in children that sustained less severe injuries and have less obvious symptoms. To this category belong, e.g. mobile children that have some bruises or just one fracture without a clear clinical history [108].

1.10.1 Clinical History

A child is often not able to explain how (inflicted) injuries were sustained. This applies in particular to children in a life-threatening situation, making a conversation with the child (virtually) impossible. Besides, many children with serious inflicted injuries are preverbal. When children are able to relate the situation, there is a fair chance that they will keep silent out of, e.g. loyalty to the parents or out of fear for the perpetrator.

When inflicted injuries are suspected, it is important to pay attention to the clinical history of the child and the other family members. In case of inflicted injuries, it is possible that the child has sustained (multiple) previous trauma and has had prior hospitalizations. Various studies have shown that approximately 50% of all children in which child abuse was established had been seen by a physician for (in retrospect suspect) injuries [109]. Also, a child with inflicted injuries who returns to a non-safe home setting in which the infliction occurred, has a 30–50% chance to suffer additional injuries and an up to 10% increased risk for fatal violence [110].

Very regularly, earlier injuries and hospitalizations are found in other members of the family as well, such as the other parent or other siblings [111]. When compared to other men, it appears that men who use physical violence against their wife will frequently also use physical violence against their children. Furthermore, women who were physically assaulted by their husband appeared to be twice as likely to use physical violence themselves against their children compared to non-abused women. Likewise, 76% of the physically abused children allegedly used violence against a sibling [112].

1.10.2 The Origin of the Injuries

When a child makes a direct and spontaneous statement on how the injury was sustained, he or she will most likely tell the truth. This also applies to a witness making a statement regarding the origin of the injury. Yet, the statement of the witness should be closely examined, since the person will speak from his/her own set of values. Observed situations might be downplayed or, on the contrary, exaggerated. Also, the witness may serve his or her own self-interest by giving the statement.

The following items in the clinical history, concerning the origin of the injuries, can be considered as red flags for inflicted injuries:

- Contradictions between the statements of the child and the parent(s), between both the parents, or between parents and a witness.
- The absence of an explanation.
- Constantly varying statements, when further prompted or when taken on consecutive days.
- Different statements of parents to different people, or the withdrawal of statements.
- The absence of an adequate explanation for previous injuries detected physical or radiological examination.
- A statement in contradiction with the developmental stage of the child.
- A statement in contrast with the nature and/or location of the injury.
- A statement which only partially explains the injuries.
- A statement of the parents in which the child himself/herself or one of the siblings is stated to be responsible for the injury.

1.10.3 Delay in Seeking Medical Help

Another red flag for inflicted injuries can be a delay in seeking medical care. The latency period can vary from hours to days after the injury was sustained. Sometimes it may take weeks to months before injuries are ‘diagnosed’, e.g. in case of fractures. In these cases no treatment was sought initially, but injuries were incidentally recognized, e.g. during a complete workup because of a suspicion of child abuse. This is due to various reasons: shame, wrongly evaluated situation, hope for spontaneous recovery, and hope that the injury will no longer be recognized as resulting from child abuse. On the other hand, some accidentally sustained fractures cause only mild symptoms for which parents logically do not seek medical care.

Other red flags are the seeking of help by other persons besides the parent(s), such as the grandparents or a teacher. Or the seeking of help by the caregivers from others than their own general practitioner or paediatrician, thus a professional without previous knowledge of the child, without providing a plausible reason. Often this help is sought at odd times, such as during the evening at an ER.

1.10.4 Attitude and Reaction of the Parents/Caregivers

The attitude and reactions of parents vary and no typical pattern distinguishing between accidental and inflicted injuries

can be recognized. The contradiction between the severity of the injury and the reaction of the parent may indicate that the circumstances in which the injury was sustained are suspicious.

A parent may totally overreact to a minor injury. On the other hand, the carer may have hardly any or a very inadequate (remote, indifferent) reaction to (very severe) injuries.

A maltreating parent may react aggressively to innocent questions and the non-maltreating parent may react in a similar manner.

Sometimes parents can refuse further medical care when the possibility of child abuse/inflicted injuries is discussed.

When a physician speaks to the parents about a specific injury, he/she should be aware of the possible reactions of parents. Most parents realize that the physician doubts their statement and may suspect child abuse. This applies to parents who maltreat as well as to parents who do not maltreat. This may cause the parents to take a defensive attitude directly at the start of the interview. The reactions may vary from denial and a tendency to isolation and then proceed via anger, bargaining, and resignation to acceptance. Also, the physician will have to be aware that the parent to whom he speaks may be ignorant of the maltreating behaviour of the partner.

References

1. World Health Organization (WHO), International Society for Prevention of Child Abuse and Neglect (ISPCAN) (2006) Preventing child maltreatment: a guide to taking action and generating evidence. World Health Organization, Geneva
2. Hobbs CJ, Hanks HGI, Wynne JM (1999) Physical abuse. In: Hobbs CJ, Hanks HGI, Wynne JM (eds) Child abuse and neglect – a clinician's handbook. Churchill Livingstone, London, pp 63–104
3. World Health Organization (2006) Violence and Injury Prevention Team & Global Forum for Health Research - Unintentional child injuries in the WHO European Region. World Health Organization, Geneva
4. Baartman HEM, Hoefnagels C (2012) Emotionele mishandeling; een lastig te duiden begrip [Emotional abuse, a difficult to define concept]. Tijdschrift Kindermishandeling 2012:5
5. Van Wert M, Fallon B, Trocmé N, Collin-Vézina D (2018) Educational neglect: understanding 20 years of child welfare trends. Child Abuse Negl 75:50–60
6. Follingstad D, DeHart D (2000) Defining psychological abuse of husbands toward wives: contexts, behaviors, and typologies. J Interpers Viol 15:891–920
7. Doherty D, Berglund D (2008) Psychological abuse: a discussion paper. https://www.canada.ca/en/public-health/services/health-promotion/stop-family-violence/prevention-resource-centre/family-violence/psychological-abuse-discussion-paper.html. Accessed 5 Aug 2021
8. World Health Organization. Violence and Injury Prevention Team & Global Forum for Health Research (1999) Report of the Consultation on Child Abuse Prevention; Consultation on Child Abuse Prevention. World Health Organization, Geneva
9. Davis P, Murtagh U, Glaser D (2019) 40 years of fabricated or induced illness (FII): where next for paediatricians? Paper 1: epidemiology and definition of FII. Arch Dis Child 104:110–114
10. Royal College of Paediatrics and Child Health (RCPCH) (2012) Fabricated or induced illness by carers (FII): a practical guide for paediatricians. Royal College of Paediatrics and Child Health, London
11. Meadow R (1977) Munchausen syndrome by proxy. The hinterland of child abuse. Lancet 2:343–345
12. Bass C, Glaser D (2014) Early recognition and management of fabricated or induced illness in children. Lancet 383:1412–1421
13. London Child Protection Procedures (2017) Fabricated or induced illness. https://www.londoncp.co.uk/fab_ind_ill.html. Accessed 5 Aug 2021
14. Roesler TA, Jenny C (2008) Medical child abuse – beyond Munchausen syndrome by proxy. https://www.uptodate.com/contents/medical-child-abuse-munchausen-syndrome-by-proxy/print. Accessed 5 Aug 2021
15. Glaser D, Davis P (2019) For debate: Forty years of fabricated or induced illness (FII): where next for paediatricians? Paper 2: Management of perplexing presentations including FII. Arch Dis Child 104:7–11
16. Laming H (2003) The Victoria Climbié inquiry. Report of an inquiry. Presented to parliament by the secretary of state for health and the secretary of state for the home department by command of Her Majesty. http://www.victoria-climbie-inquiry.org.uk/
17. Alink L, Prevoo M, van Berkel S, Linting M, Klein Velderman M, Pannebakker F (2018) Nationale Prevalentiestudie Mishandeling van kinderen en jeugdigen (NPM-2017) [Prevalence study on Maltreatment of children and youth]. Leiden University, Institute of Education and Child Studies TNO Child Health, The Hague
18. Schellingerhout R, Ramakers C (2017) Scholierenonderzoek Kindermishandeling 2016 [2016 Pupils on abuse]. Wetenschappelijk Onderzoek- en Documentatiecentrum (WODC), Ministerie van Veiligheid en Justitie. The Hague
19. Vermeulen S, van Berkel S, Alink L (2021) Kindermishandeling tijdens de eerste lockdown [Child abuse during the first lockdown]. Instituut Pedagogische Wetenschappen, Leiden
20. Hillis S, Mercy J, Amobi A, Kress H (2016) Global prevalence of past-year violence against children: a systematic review and minimum estimates. Pediatrics 137:e20154079
21. Kim H, Drake B (2019) Cumulative prevalence of onset and recurrence of child maltreatment reports. J Am Acad Child Adolesc Psychiatry 58:1175–1183
22. Felitti VJ, Anda RF, Nordenberg D, Williamson DF, Spitz AM, Edwards V, Koss MP, Marks JS (1998) Relationship of childhood abuse and household dysfunction to many of the leading causes of death in adults. The Adverse Childhood Experiences (ACE) Study. Am J Prev Med 14:245–258
23. World Health Organization (WHO) (2002) World Report on Violence and Health – Child abuse and neglect by parents and other caregivers. World Health Organization, Geneva
24. Health Canada (2003) Injury surveillance in Canada: current realities, challenges. http://www.injuryresearch.bc.ca/docs/3_20090910_100541Report%20HC%20Inj%20Surveillance%20in%20Can%20Aug%202003.pdf. Accessed 5 Aug 2021
25. Bilo RAC, Oranje AP, Shwayder T, Hobbs CJ (2013) Evaluating suspicions skin findings in children. In: Bilo RAC, Oranje AP, Shwayder T, Hobbs CJ (eds) Cutaneous manifestations of child abuse and their differential diagnosis – blunt force trauma. Springer, Berlin, pp 25–61
26. DiMaio VJM, DiMaio D (2001) Blunt trauma wounds. In: DiMaio VJM (ed) Forensic pathology. CRC Press, Boca Raton, pp 91–116
27. Arieff AI, Kronlund BA (1999) Fatal child abuse by forced water intoxication. Pediatrics 103:1292–1295

28. el Awad ME (1994) Overheating in neonates in Saudi Arabia. East Afr Med J 71:805–806
29. Martos Sánchez I, Ros Pérez P, Otheo de Tejada E, Vázquez Martínez JL, Pérez-Caballero C, Fernández Pineda L (2000) Hipernatremia grave por administración accidental de sal común [Fatal hypernatremia due to accidental administration of table salt]. An Pediatr 53:495–498
30. Meyer-Heim A, Landau K, Boltshauser E (2002) Aknetherapie mit Folgen–Pseudotumor cerebri durch Hypervitaminose A [Treatment of acne with consequences – pseudotumor cerebri due to hypervitaminosis A]. Praxis 91:23–26
31. Quereshi UA, Bhat JI, Ali SW, Mir AA, Kambay AH, Bhat IN (2010) Acute salt poisoning due to different oral rehydration solution (ORS) packet sizes. Indian J Pediatr 77:679–680
32. Zhu BL, Ishida K, Fujita MQ, Maeda H (1998) Infant death presumably due to exertional self-overheating in bed: an autopsy case of suspected child abuse. Jpn J Leg Med 52:153–156
33. Ommaya AK, Gennarelli TA (1974) Cerebral concussion and traumatic unconsciousness. Correlation of experimental and clinical observations of blunt head injuries. Brain 97:633–654
34. Hymel KP, Bandak FA, Partington MD, Winston K (1998) Abusive head trauma? A biomechanics-based approach. Child Maltreat 3:116–128
35. Burton D (2007) Static v. dynamic loading: why the WTC towers fell so fast. http://www.burtonsys.com/staticvdyn/. Accessed 5 Aug 2021
36. Duhaime AC, Eppley M, Margulies S, Heher KL, Bartlett SP (1995) Crush injuries to the head in children. Neurosurgery 37:401–406. discussion 407
37. Prasad MR, Ewing-Cobbs L, Baumgartner J (1999) Crush head injuries in infants and young children neurologic and neuropsychologic sequelae. J Child Neurol 14:496–501
38. Center for Disease Control and Prevention (2007) Injury center. http://www.cdc.gov/ncipc/wisqars/nonfatal/definitions.htm. Accessed 16 Sep 2021
39. Nordic Medico-Statistical Committee (2007) Classification of external causes of injuries. NOMESCO, Copenhagen
40. WHO Regional Office for Europe (2013) In: Sethi D, Bellis M, Hughes K, Gilbert R, Mitis G, Galea G (eds) European report on preventing child maltreatment. https://www.euro.who.int/__data/assets/pdf_file/0019/217018/European-Report-on-Preventing-Child-Maltreatment.pdf Accessed 16 sept 2021
41. Hobbs CJ, Hanks HGI, Wynne JM (1993) Child abuse and neglect – a clinician's handbook. Churchill Livingstone, London
42. Maguire S, Mann MK, Sibert J, Kemp A (2005) Can you age bruises accurately in children? A systematic review. Arch Dis Child 90:187–189
43. Maguire S, Mann MK, Sibert J, Kemp A (2005) Are there patterns of bruising in childhood which are diagnostic or suggestive of abuse? A systematic review. Arch Dis Child 90:182–186
44. Hammond H (2009) Clinical assessment in suspected child abuse cases. In: Busutil A, Keeling JW (eds) Paediatric forensic medicine & pathology. Hodder Arnold, London, pp 1–23
45. Bilo RAC, Oranje AP, Shwayder T, Hobbs CJ (2013) Cutaneous manifestations of child abuse and their differential diagnosis – blunt force trauma. Springer, Cham
46. Labbé J, Caouette G (2001) Recent skin injuries in normal children. Pediatrics 108:271–276
47. Langlois NE, Gresham GA (1991) The ageing of bruises: a review and study of the colour changes with time. Forensic Sci Int 50:227–238
48. Kemp AM, Maguire SA, Nuttall D, Collins P, Dunstan F (2014) Bruising in children who are assessed for suspected physical abuse. Arch Dis Child 99:108–113
49. Pierce MC, Kaczor K, Aldridge S, O'Flynn J, Lorenz DJ (2010) Bruising characteristics discriminating physical child abuse from accidental trauma. Pediatrics 125:67–74
50. Pierce MC, Kaczor K, Lorenz DJ, Bertocci G, Fingarson AK, Makoroff K, Berger RP, Bennett B, Magana J, Staley S, Ramaiah V, Fortin K, Currie M, Herman BE, Herr S, Hymel KP, Jenny C, Sheehan K, Zuckerbraun N, Hickey S, Meyers G, Leventhal JM (2021) Validation of a clinical decision rule to predict abuse in young children based on bruising characteristics. JAMA Netw Open 4:e215832
51. Warrington SA, Wright CM (2001) Accidents and resulting injuries in premobile infants: data from the ALSPAC study. Arch Dis Child 85:104–107
52. Wilson EF (1977) Estimation of the age of cutaneous contusions in child abuse. Pediatrics 60:750–752
53. McGrath A, Barrett MJ (2019) Petechiae. https://www.ncbi.nlm.nih.gov/books/NBK482331/. Accessed 5 Aug 2021
54. Strumia R, Felitti F (2013) Skin signs due to self-induced vomiting. In: Strumia R (ed) Eating disorders and the skin. Springer, Berlin
55. Cairns AM, Mok JY, Welbury RR (2005) Injuries to the head, face, mouth and neck in physically abused children in a community setting. Int J Paediatr Dent 15:310–318
56. Saukko P, Knight B (2004) The pathology of wounds. In: Saukko P, Knight B (eds) Knight's forensic pathology. Arnold, London, pp 136–173
57. Bilo RAC, Oranje AP, Shwayder T, Hobbs CJ (2013) Blunt penetrating injuries. In: Bilo RAC, Oranje AP, Shwayder T, Hobbs CJ (eds) Cutaneous manifestations of child abuse and their differential diagnosis – blunt force trauma. Springer, Cham, pp 215–216
58. Coniglio MA, Bonaccorso A, Scillieri R, Giammanco G, Pignato S (2005) Incidenti domestici nell'infanzia. Risultati di un'indagine condotta nell'area etnea [Domestic injuries in childhood. Results of a survey carried out in a Sicilian area]. Ann Ig 17:261–267
59. Makkat S, Vandevenne JE, Parizel PM, De Schepper AM (2001) Multiple growing fractures and cerebral venous anomaly after penetrating injuries: delayed diagnosis in a battered child. Pediatr Radiol 31:381–383
60. Thomas M, Cameron A (1977) Rarity of non-accidental penetrating injury in child abuse. Br Med J 1:375–376
61. Navarro B, Urban R (2004) "Overkill" im Rahmen einer Neugeborenen-Tötung ["Overkill" in a case of neonaticide]. Arch Kriminol 213:129–137
62. Rougé-Maillart C, Jousset N, Gaudin A, Bouju B, Penneau M (2005) Women who kill their children. Am J Forensic Med Pathol 26:320–326
63. Tournel G, Desurmont M, Bécart A, Hédouin V, Gosset D (2006) Child barbarity and torture: a case report. Am J Forensic Med Pathol 27:263–265
64. Koblenzer C (1987) Psychocutaneous disease. Grune & Stratton, Orlando, USA
65. Louman S, Fredriks AM, van Bellegem ACM, Teeuw AH (2018) Zelfbeschadiging bij kinderen en adolescenten [Self-harm among children and adolescents]. Ned Tijdschr Geneeskd 162:D2609
66. Berryman HE (2019) A systematic approach to the interpretation of gunshot wound trauma to the cranium. Forensic Sci Int 301:306–317
67. DiMaio VJM (1998) Gunshot wounds: practical aspects of firearms, ballistics, and forensic techniques. CRC Press, Boca Raton
68. Bayouth L, Lukens-Bull K, Gurien L, Tepas JJ 3rd, Crandall M (2019) Twenty years of pediatric gunshot wounds in our community: have we made a difference? J Pediatr Surg 54:160–164

69. Cook A, Hosmer D, Glance L, Kalesan B, Weinberg J, Rogers A, Schultz CS, Gilligan CT, Gross B, Vernon T, Ward J, Osler T, Rogers F (2019) Population-based analysis of firearm injuries among young children in the United States, 2010–2015. Am Surg 85:449–455
70. Fowler KA, Dahlberg LL, Haileyesus T, Gutierrez C, Bacon S (2017) Childhood firearm injuries in the United States. Pediatrics 140:e20163486
71. Resnick S, Smith RN, Beard JH, Holena D, Reilly PM, Schwab CW, Seamon MJ (2017) Firearm deaths in America: can we learn from 462,000 lives lost? Ann Surg 266:432–440
72. Tseng J, Nuño M, Lewis AV, Srour M, Margulies DR, Alban RF (2018) Firearm legislation, gun violence, and mortality in children and young adults: a retrospective cohort study of 27,566 children in the USA. Int J Surg 57:30–34
73. Li G, Baker SP, DiScala C, Fowler C, Ling J, Kelen GD (1996) Factors associated with the intent of firearm-related injuries in pediatric trauma patients. Arch Pediatr Adolesc Med 150:1160–1165
74. Panke TW, McLeod CG (1985) Pathology of thermal injury – a practical approach. Grune & Stratton, Orlando
75. Pounder DJ (2000) Burns and scalds. In: Siegel J, Knupfer G, Saukko P (eds) Encyclopedia of forensic sciences. Elsevier Academic Press, London
76. Richardson AC (1994) Cutaneous manifestations of abuse. In: Reece RM (ed) Child abuse. Lea & Febiger, Philadelphia, pp 167–184
77. Loder RT, Feinberg JR (2007) Orthopaedic injuries in children with nonaccidental trauma: demographics and incidence from the 2000 kids' inpatient database. J Pediatr Orthop 27:421–426
78. Sinha CK, Lander A (2013) Trauma in children: abdomen and thorax. Surgery (Oxford) 31:123–129
79. Overly FL, Wills H, Valente JH (2014) 'Not just little adults' – a pediatric trauma primer. R I Med J (2013) 97:27–30
80. Yu YR, DeMello AS, Greeley CS, Cox CS, Naik-Mathuria BJ, Wesson DE (2018) Injury patterns of child abuse: experience of two Level 1 pediatric trauma centers. J Pediatr Surg 53:1028–1032
81. Cooper A, Floyd T, Barlow B, Niemirska M, Ludwig S, Seidl T, O'Neill J, Templeton J, Ziegler M, Ross A (1988) Major blunt abdominal trauma due to child abuse. J Trauma 28:1483–1487
82. Milroy CM (2014) Blunt abdominal and thoracic injuries in children. In: Collins KA, Byard RW (eds) Forensic pathology of infancy and childhood. Springer, Berlin, pp 291–325
83. Rosenfeld EH, Johnson B, Wesson DE, Shah SR, Vogel AM, Naik-Mathuria B (2020) Understanding non-accidental trauma in the United States: a national trauma databank study. J Pediatr Surg 55:693–697
84. Shenoi RP, Camp EA, Rubalcava DM, Cruz AT (2017) Characteristics and outcomes of acute pediatric blunt torso trauma based on injury intent. Am J Emerg Med 35:1791–1797
85. Sharma MS (2016) Pediatric thoracic trauma. https://emedicine.medscape.com/article/905863-overview#showall. Accessed 5 Aug 2021
86. Reynolds SL (2018) Pediatric thoracic trauma: recognition and management. Emerg Med Clin North Am 36:473–483
87. Maguire SA, Upadhyaya M, Evans A, Mann MK, Haroon MM, Tempest V, Lumb RC, Kemp AM (2013) A systematic review of abusive visceral injuries in childhood–their range and recognition. Child Abuse Negl 37:430–445
88. Merten DF, Carpenter BL (1990) Radiologic imaging of inflicted injury in the child abuse syndrome. Pediatr Clin N Am 37:815–837
89. Clark RE, Clark JF (1989) The encyclopedia of child abuse. New York, Fact on File Inc.
90. Cooper A (1992) Thoracoabdominal trauma. In: Ludwig S, Kornberg AE (eds) Child abuse – a medical reference. Churchill Livingstone, New York, pp 131–150
91. Huntimer CM, Muret-Wagstaff S, Leland NL (2000) Can falls on stairs result in small intestine perforations? Pediatrics 106:301–305
92. Grosfeld JL, Rescorla FJ, West KW, Vane DW (1989) Gastrointestinal injuries in childhood: analysis of 53 patients. J Pediatr Surg 24:580–583
93. Hamilton A, Humphreys WG (1985) Duodenal rupture complicating childhood non-accidental injury. Ulster Med J 54:221–223
94. Ford EG, Senac MO Jr (1993) Clinical presentation and radiographic identification of small bowel rupture following blunt trauma in children. Pediatr Emerg Care 9:139–142
95. Cobb LM, Vinocur CD, Wagner CW, Weintraub WH (1986) Intestinal perforation due to blunt trauma in children in an era of increased nonoperative treatment. J Trauma 26:461–463
96. Ledbetter DJ, Hatch EI Jr, Feldman KW, Fligner CL, Tapper D (1988) Diagnostic and surgical implications of child abuse. Arch Surg 123:1101–1105
97. Lane WG, Dubowitz H, Langenberg P, Dischinger P (2012) Epidemiology of abusive abdominal trauma hospitalizations in United States children. Child Abuse Negl 36:142–148
98. Trokel M, Discala C, Terrin NC, Sege RD (2006) Patient and injury characteristics in abusive abdominal injuries. Pediatr Emerg Care 22:700–704
99. Gilbert-Barnes E (1991) Potter's pathology of the fetus and infant. Mosby
100. Carter KW, Moulton SL (2016) Pediatric abdominal injury patterns caused by "falls": a comparison between nonaccidental and accidental trauma. J Pediatr Surg 51:326–328
101. Caniano DA, Beaver BL, Boles ET Jr (1986) Child abuse. An update on surgical management in 256 cases. Ann Surg 203:219–224
102. Sivit CJ, Taylor GA, Eichelberger MR (1989) Visceral injury in battered children: a changing perspective. Radiology 173:659–661
103. Rothrock SG, Green SM, Morgan R (2000) Abdominal trauma in infants and children: prompt identification and early management of serious and life-threatening injuries. Part I: injury patterns and initial assessment. Pediatr Emerg Care 16:106–115
104. Roaten JB, Partrick DA, Bensard DD, Hendrickson RJ, Vertrees T, Sirotnak AP, Karrer FM (2005) Visceral injuries in nonaccidental trauma: spectrum of injury and outcomes. Am J Surg 190: 827–829
105. Sheybani EF, Gonzalez-Araiza G, Kousari YM, Hulett RL, Menias CO (2014) Pediatric nonaccidental abdominal trauma: what the radiologist should know. Radiographics 34:139–153
106. Minns RA, Brown JK (ed) (2015). Shaking and other non-accidental head injuries in children. Clinics in Developmental Medicine No. 162. Cambridge University Press, p. 17
107. David TJ (2008) Non-accidental head injury – the evidence. Pediatr Radiol 38:370–377
108. Kocher MS, Kasser JR (2000) Orthopaedic aspects of child abuse. J Am Acad Orthop Surg 8:10–20
109. Loder RT, Bookout C (1991) Fracture patterns in battered children. J Orthop Trauma 5:428–433
110. McClain PW, Sacks JJ, Froehlke RG, Ewigman BG (1993) Estimates of fatal child abuse and neglect, United States, 1979 through 1988. Pediatrics 91:338–343
111. Lindberg DM, Shapiro RA, Laskey AL, Pallin DJ, Blood EA, Berger RP (2012) Prevalence of abusive injuries in siblings and household contacts of physically abused children. Pediatrics 130:193–201
112. Baartman HEM (1993) Opvoeden met alle geweld: Hardnekkige gewoonten en hardhandige opvoeders [Raising children with violence – stubborn habits and tough nurtures]. SWP uitgeverij