Forensic pediatric radiology: studies in living and deceased children
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Introduction

Forensic pediatric radiology
Child abuse

Child abuse is a serious social problem with severe consequences for the individuals affected and for society as a whole. In Dutch law, in accordance with the WHO definition, child abuse is defined as: “Any form of threatening or violent interaction of a physical, psychological or sexual nature, actively or passively imposed upon a minor in a dependent relationship by a parent or other adult, whereby serious damage of physical or psychological nature is or might be inflicted upon the child in the future.” Several forms of child abuse are distinguished, with physical abuse being the most well known. Other forms of child abuse are emotional abuse, sexual abuse and neglect. Furthermore ‘pediatric condition falsification’ (formerly known as Munchhausen by proxy) and witnessing intimate partner violence are defined as separate forms. In the current medical literature, child abuse is increasingly referred to as child maltreatment, if all forms are addressed. The term child abuse is used to describe physical abuse only. In this thesis we therefore use the term ‘child maltreatment’ if all forms of abuse are meant, and use the term ‘child abuse’ to indicate specifically physical forms of child abuse.

In Western countries, 2.2-5.0% of all children younger than 18 years of age are referred to social services every year, because of a suspicion of child maltreatment; in 0.7-1.2% of all children, child maltreatment is substantiated. In 10-28% of all cases substantiated, this is because of physical child abuse. The majority of abused children, however, are not known to social services. Self-reported physical abuse is much higher compared to agency reports; every year 3.7-16.3% of all children report experiencing severe parental violence. This includes hitting with a fist or an implement, kicking, biting and (threatening to use or) using a weapon. Slapping, hitting and grabbing are considered ‘milder’ forms of abuse and are not included in these self-report studies. The prevalence of child maltreatment in the Netherlands is comparable with other Western countries; in 2.7% of all children, professionals have a suspicion of child maltreatment, and for 0.6% of all children maltreatment is substantiated. In 10% of these children this is due to physical abuse. The prevalence of self-reported physical abuse is 13.6%, using the same strict criteria as in other international studies. Despite several policy initiatives for child protection, there is no evidence of a decline in the prevalence of child maltreatment. For physical child abuse specifically, studies are contradictory. Although some studies did find a decrease in both substantiated and self-reported child abuse, others found a significant increase in hospitalizations for severe physical child abuse in the USA between 1997 and 2009.

The most common form of physical child abuse is hitting. As mentioned above, all forms of violence can be applied, for example, kicking, biting, burning, smothering, shaking and throwing a child against an object or on the floor. In practice, it is not uncommon for several forms of violence to be used against the same victim. A form of child abuse that receives a lot of media attention is abusive head trauma (AHT), formerly described as ‘shaken baby syndrome’. It refers to the combination of findings that can be found after extreme
violence has been applied to the head of (small) children, by shaking or through impact trauma, for example. Mortality is approximately 20% and two-thirds of the survivors are handicapped. The international incidence of AHT is estimated to be 14-40 cases per 100,000 children under the age of one year. In the Netherlands, no national data are collected, but at least 7.4 per 100 children under the age of one year come to the attention of the public prosecutor each year.

Consequences
Besides the direct consequences of child maltreatment (e.g. hospital visits, absence from school), many long-term consequences have been determined in both retrospective and prospective studies. As children are often victims of several types of child maltreatment at the same time, so-called poly-victimization, investigating the effects of one form of maltreatment is complex. In their review article, Gilbert et al. found evidence for negative effects of child maltreatment on future education and employment, mental health, physical health and criminal behavior. They found moderate evidence for long-term deficits in educational achievement, with significantly more maltreated children receiving special education and significantly fewer maltreated children finishing high school. Mental health problems associated with maltreatment include behavioral problems, depression, post-traumatic-stress disorder, suicide attempts and alcohol or drugs dependency. There is a strong association between maltreatment and obesity. The relationship between maltreatment and other physical health outcomes is less clear, except for sexual abuse, which is associated with teenage pregnancy, sex trading and sexually transmitted diseases. However, a relationship has been described between several forms of child maltreatment and increased health care utilization. In the same review it was found that child maltreatment, especially physical abuse, is associated with delinquent behavior in boys and girls.

Diagnosis of child abuse
As the definition of child maltreatment is circumspective and no uniform diagnostic criteria exist, establishing the diagnosis of child maltreatment in many situations does not take place in the health care setting exclusively, but within a multidisciplinary team approach, involving child protection services and sometimes the police. The presence of certain injuries is highly suggestive of physical abuse and these should alert health care providers. However, no single injury is 100% specific for abuse, and alternative diagnoses should always be considered. The type of injury should always be related to the history described by parents/caregivers and to the developmental stage of the child. For example, bruises are present in the majority of in children of school age and do not often give reason for concern. In non-ambulatory children, however, any bruise should alert the treating physician and should lead to a thorough examination. In school-aged children, the location of the injury becomes more important. Bruises on knees, elbows and other bony protrusions can most often be explained by playing or falling, whereas bruises on the backside or soft parts of the body are more worrisome if an adequate trauma is not described. Recently, several systematic
reviews and prospective studies have been performed in order to determine the positive and negative predictive value of different signs and symptoms in case of suspected abuse.\textsuperscript{16} Where a diagnosis of abuse previously used to be based on probably true, but not validated, arguments, the aim of these studies is to develop clinical prediction rules to calculate abuse probability. For example, Hymel et al. are currently validating a clinical prediction rule for AHT, based on discriminating variables.\textsuperscript{17}

Radiology in establishing the diagnosis of child abuse
Radiology is an important tool in establishing the diagnosis of physical abuse, as one can objectively depict fractures or internal injuries. Radiological investigations in child abuse have mainly focused on neuroradiological (AHT) and skeletal findings; furthermore intra-abdominal injuries can also be demonstrated.\textsuperscript{18,19}

Although child abuse is not a new problem - it has recently been diagnosed in the 2000-year-old skeletal remains of a toddler in Egypt\textsuperscript{20} - medical attention for the subject is relatively new. The possibility of using medical techniques to depict injuries was already being practiced shortly after the discovery of ‘X-rays’ by Röntgen in 1895.\textsuperscript{21} In this first forensic case in which radiology played a role, physicians were searching for a bullet in the leg of an adult patient.\textsuperscript{22} In order to locate the bullet, an X-ray of the leg was made, with an exposure time of 45 minutes. By demonstrating the presence of the bullet, forensic evidence was obtained and it was possible to operate on the patient successfully. The first radiological publication regarding child abuse did not, however, appear before 1946, written by the pediatric radiologist Caffey.\textsuperscript{23} He described six children under two years old with long-bone fractures and subdural hematomas, without a history of trauma to explain the findings. Although he was convinced that there was a traumatic origin, and reported precisely on the circumstances under which the injuries appeared, he did not mention the possibility of abuse in his paper, conceivably because of fear of legal repercussions.\textsuperscript{24} The first medical paper explicitly describing child abuse was published in 1962 by Kempe, who called it “the battered-child syndrome”.\textsuperscript{25} In this publication he describes the incidence, clinical manifestations, parental aspects, radiological features and management of physical child abuse. The first Dutch publication on child abuse appeared in 1964; the authors describe 12 children with fractures in different stages of healing, which could co-occur with subdural hematomas.\textsuperscript{26} In recent decades, child abuse research has expanded from fewer than 100 publications per year in the sixties of the last century, towards over 1,000 retrievable publications in PubMed per year since 1994. With radiology being one of the cornerstones in establishing a diagnosis of physical child abuse, we wanted to investigate some of the gaps in knowledge in forensic pediatric radiology.
Introduction

Aim of the thesis
In this thesis we will try to provide some insight into the possibilities and impossibilities of (forensic) pediatric radiology in establishing a diagnosis of physical child abuse, in both living and deceased children.

Outline of the thesis
The thesis is divided into two parts, with the first part describing several aspects of imaging in living children, suspected of being a victim of child abuse, and the second part describing imaging in deceased children in a forensic setting. In part I, chapter 1 we give an overview of imaging techniques used to depict fractures in suspected physical abuse, and the specificity of different types of fractures. In chapters 2 and 3 we describe the social-pediatric and radiological aspects of AHT. In chapter 4 we describe in how many cases of AHT, prior abuse had occurred within the family. In chapter 5 we try to determine the radiological difference between the two commonly described causes of AHT, shaking and impact trauma. In chapter 6 we perform a systematic review to identify the evidence for dating of subdural hematomas (SDHs) on imaging findings, as SDHs are the most common manifestation of AHT. Age determination can be used to check if there is a consistent history and can relate the injuries to possible perpetrators. In chapter 7 we describe the knowledge and practice of Dutch radiologists regarding dating SDHs. The first part of the thesis ends with a case report (chapter 8) of a classic metaphyseal lesion, a fracture of the long bones with a high specificity for child abuse, which in this case was detected after vaginal breech delivery. A diagnosis of child abuse was rejected. In part II we describe imaging in deceased children in a forensic setting. In chapter 9 we review the current techniques used in postmortem imaging. In chapter 10 we describe the normal cranial postmortem findings seen on postmortem CT (PMCT) in children who received a PMCT as part of a forensic examination because of a suspected non-natural death. In chapter 11 we describe the diagnostic value of PMCT in this group, by addressing the correlation between cause of death diagnosed with PMCT and cause of death diagnosed with autopsy. In chapter 12 we describe the value of PMCT in neonaticide with delayed finding of the body, causing severe decomposition changes. Finally, in chapter 13, we present a case report illustrating one of the additional values of PMCT compared to autopsy, demonstrating a pneumomediastinum and soft tissue emphysema after pediatric hanging, findings that were not detected with the conventional autopsy.
REFERENCES


