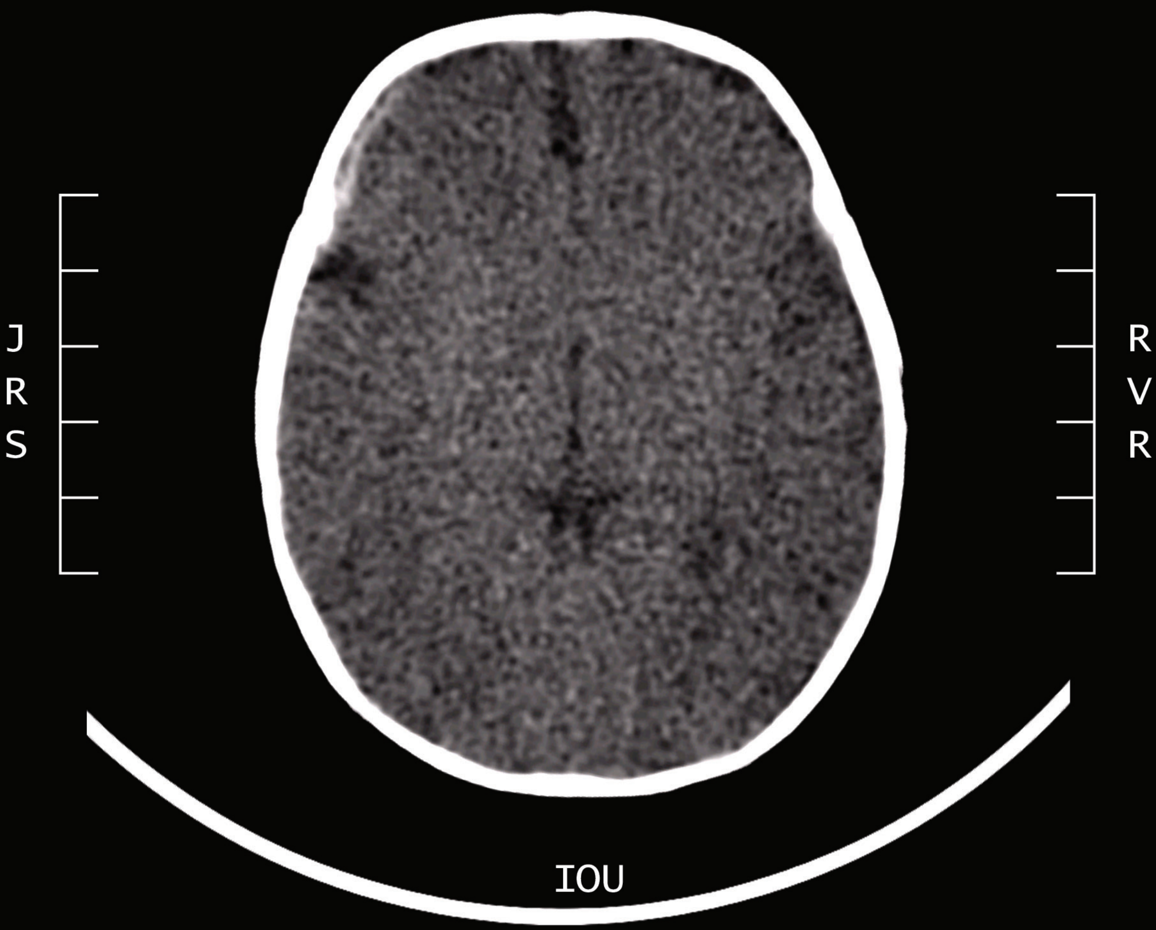
Forensic pediatric radiology

Studies in living and deceased children



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Tessa Sieswerda Hoogendoorn

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Front cover and flyleaves:

The front cover shows one image of a CT scan of the brain of one of the children described in chapter 4 and 5. The flyleaves show part of the skeletal survey of the same child. These images relate to the following case: An 8-week-old girl is brought to the pediatric outpatient clinic by her mother because of swelling of her right leg. She has not been using the leg for two days. Furthermore she has been crying and vomiting excessively. Medical history at that age includes six contacts with the healthcare system, because of not using one of her arms, crying and vomiting. No diagnosis has been established, except for a candida infection of the mouth. An x-ray of her swollen leg is made and shows three fractures. The parents do not remember a trauma. She is admitted to the hospital because of concerns for her safety. A skeletal survey is performed and shows 28 fractures in different stages of healing throughout the body: a skull fracture, a spinal fracture, 13 rib fractures, a fracture of the right arm, 2 fractures of the right hand, a fracture of the left arm, 2 fractures of the left hand, 5 fractures of the right leg and 2 fractures of the left leg. An ultrasound and CT scan of the brain are performed and initially no abnormalities are seen. The case is sent to specialists in two academic centers for a second and third opinion, both come to the conclusion that trauma, probably child abuse, is the most likely cause of the fractures. More so, because when reevaluating the CT scan of the brain, a subdural hematoma and contusion are seen. There are no signs of underlying bone disease, e.g. osteogenesis imperfecta. This combination of findings at this age can only be explained by inflicted injury. The pediatrician reports the family to the Advies- en Meldpunt Kindermishandeling (Advice and Reporting Center for Child Abuse, the Dutch Child Protection Services) and an investigation is started. As the forensic physician evaluating the case for the AMK does not have personal contact with the family, no further information is available about how the girl develops and whether a perpetrator is identified.

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Studies in living and deceased children

ACADEMISCH PROEFSCHRIFT

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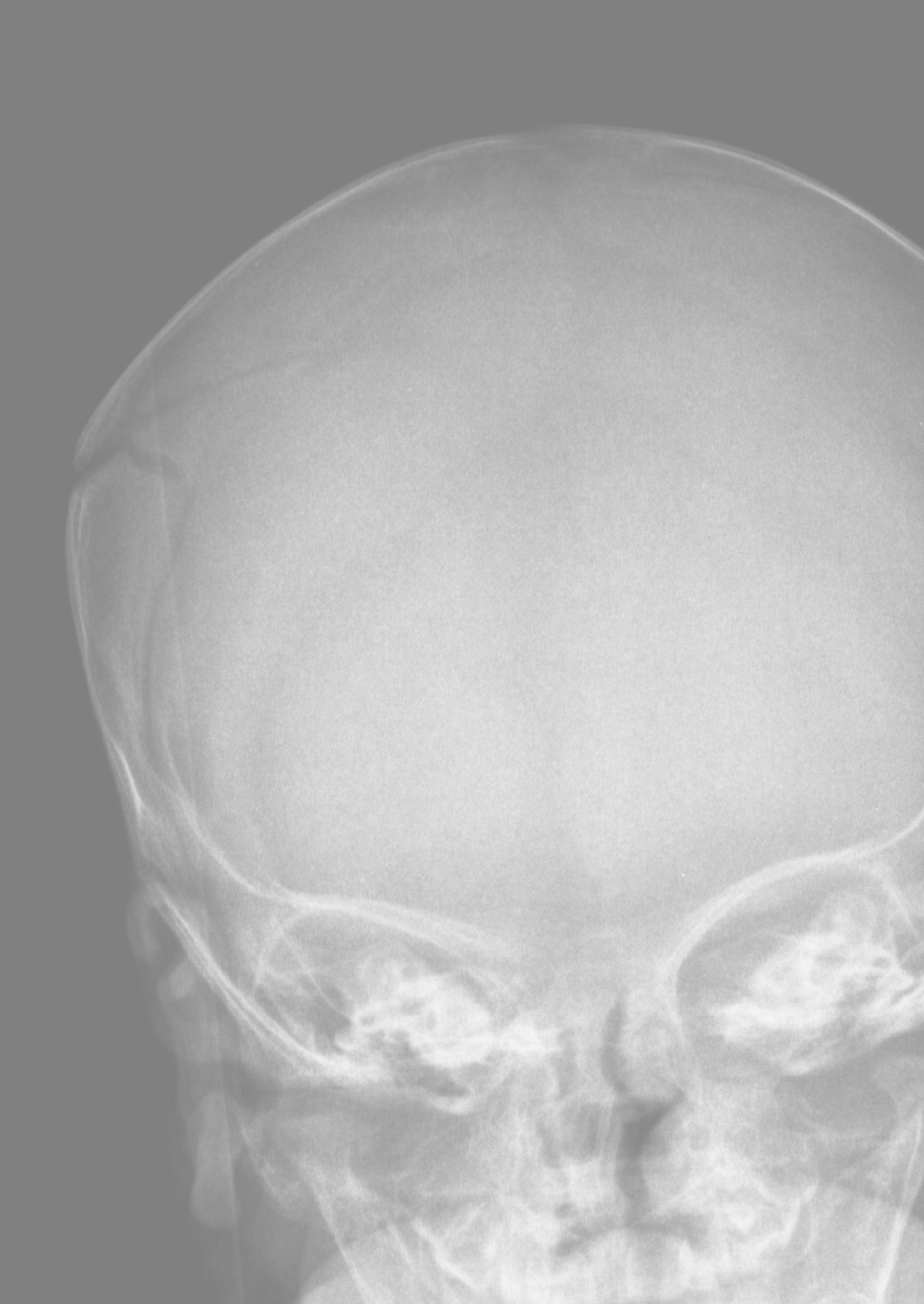

Introduction

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.[1-3] 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."[4,5] 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.[6,7] 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.[1] 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.[1] 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.[8] Despite several policy initiatives for child protection, there is no evidence of a decline in the prevalence of child maltreatment.[9] For physical child abuse specifically, studies are contradictory. Although some studies did find a decrease in both substantiated and self-reported child abuse[9], others found a significant increase in hospitalizations for severe physical child abuse in the USA between 1997 and 2009.[10]

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'.[11] 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.[12] The international incidence of AHT is estimated to be 14-40 cases per 100,000 children under the age of one year.[12] 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.[13]

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.[1] As children are often victims of several types of child maltreatment at the same time, so-called poly-victimization[14], 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.[1] 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 circumscriptive 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. [15] 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.[15] 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.[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.[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.[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[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.[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.[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.[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.[24] The first medical paper explicitly describing child abuse was published in 1962 by Kempe, who called it “the battered-child syndrome”.[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.[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.

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.

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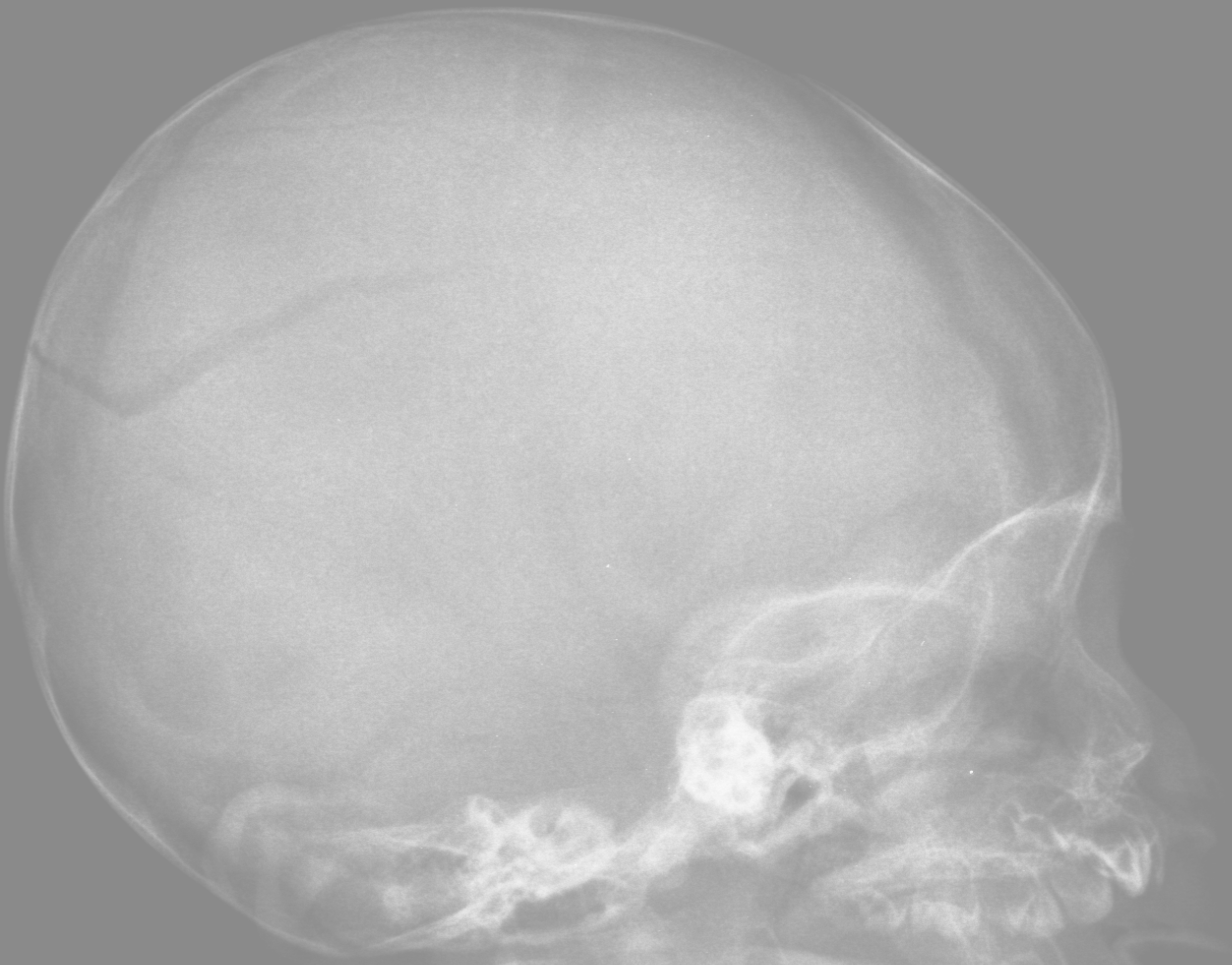
Part I

Imaging in living children



Chapter 1

Imaging in child abuse: the bare bones

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Eur J Pediatr. 2012;171:215–224

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ABSTRACT

Fractures are reported to be the second most common findings in child abuse, after skin lesions such as bruises and contusions. This makes careful interpretation of childhood fractures in relation to the provided clinical history important. In this literature review we address imaging techniques and the prevailing protocols as well as fractures, frequently seen in child abuse, and the differential diagnosis of these fractures. The use of a standardized protocol in radiological imaging is stressed, as adherence to the international guidelines has been consistently poor. As fractures are a relatively common finding in childhood and interpretation is sometimes difficult, involvement of a pediatric radiologist is important if not essential. Adherence to international guidelines necessitates review by experts and therefore is mandatory. As in all clinical differential diagnoses, liaisons between pediatricians and pediatric radiologists in order to obtain additional clinical information or even better having joint review of radiological studies will improve diagnostic accuracy. It is fundamental to keep in mind that the diagnosis of child abuse can never be solely based on radiological imaging but always on a combination of clinical, investigative and social findings. The quality and interpretation, preferably by a pediatric radiologist, of radiographs is essential in reaching a correct diagnosis in cases of suspected child abuse.

INTRODUCTION

Fractures are reported to be the second most common findings in child abuse, after skin lesions such as bruises and contusions.[1,2] Fractures resulting from physical violence can be found throughout the whole skeleton; they are likely to be multiple and can show diverse stadia of consolidation.[3-6] In the majority of cases no external physical findings, e.g. bruises or hematomas, are present.[7,8] In the United States approximately 10% of children under the age of five years visit the emergency department (ED) as a result of non-accidental injuries.[9] In children evaluated in the ED on suspicion of child abuse, over 30% appears to have fresh or healing fractures.[10] In a study on deceased children between the ages of 1–15 years (average 3.9 years) of air force personnel in the United States, it was found that 55% of these children had been seen by a physician as a result of physical trauma in the month prior to their demise.[11] In a retrospective case based analysis of 435 child abuse victims, Carthy and Pierce found that in 51 children (11.7%) the diagnosis of child abuse could have been made at their first presentation at a hospital.[12] Of these 51 children 6 (12%) died and 10 (20%) survived with handicap. Fractures in children, besides being a sign of child abuse, are a relatively common finding. In a large retrospective study in 8,642 children, the reported chance to sustain a fracture between birth and the age of 16 was 42% for boys and 27% for girls, i.e. an average 2.1% chance for a child to sustain one fracture per year.[13] These findings are in keeping with a similar study on fractures.[6] The fact that fractures on the one hand are a sign of child abuse but on the other hand are a quite common result of accidental trauma; means that it is essential that the interpretation of the type and location of a fracture, seen in the light of the clinical anamnesis, is done by an experienced and trained (pediatric) radiologist.[14,15]

In this paper we will discuss the radiological work-up in case of suspected child abuse and the main radiological findings indicative of child abuse. We will first address the different imaging techniques and then aspects of fractures (localization, type, dating and differential diagnosis) that should be evaluated when considering the diagnosis of child abuse. As radiology deals with signs of physical child abuse, child abuse should throughout the text be read as physical child abuse.

IMAGING TECHNIQUES

Conventional radiography

Conventional radiography has historically been and, to date, continues to be the mainstay in radiological imaging of suspected child abuse. Both in identifying new cases of possible child abuse, where an incidental finding on a radiograph can be the first sign of child abuse, as well as in the work-up of cases of suspected child abuse. In the latter, a skeletal survey, a systematically performed series of radiographic images that encompasses the entire skeleton, is a routine part of the work-up procedure in children under the age of two years.[16] In these cases the skeletal survey should consist of a complete depiction of each anatomic region on separate radiographs. International guidelines for the skeletal survey have been published by the American College of Radiology (ACR) as well as the Royal College of Radiologists and the Royal College of Paediatrics and Child Health (RCR and RCPCH) (Table 1).[17,18] The main difference between these two guidelines is the addition of oblique chest radiographs in the RCR and RCPCH guideline. It has been shown that implementation of oblique chest radiographs increased the sensitivity for the detection of rib fractures by 17% (95%CI 2-36%) and the specificity by 7% (95%CI 2-13%).[19] According to both protocols, a full skeletal survey consists of at least 20 radiographs. In our tertiary referral centre, where we review skeletal surveys in case of suspected child abuse, we have observed that it is quite common to perform an incomplete skeletal survey.[20] From this study, it was not clear if this is due to unfamiliarity with the international guidelines, or fear for radiation dose. Especially when child abuse is part of the differential diagnosis, a thorough workup is essential. Both making the diagnosis and missing the diagnosis can have enormous consequences for the lives of these children.

In case of equivocal findings the use of a repeat skeletal survey, in which case the skull should be excluded as fractures of the skull do not show callus formation, after 14 days has shown to increase sensitivity and specificity. In a prospective study, additional information regarding skeletal trauma was obtained in 22 of 48 patients (46%).[21] In two cases, the repeat skeletal survey exam influenced the diagnosis, and a definite diagnosis of child abuse could be made. In a retrospective study in 23 children, follow-up exams yielded additional information in 14 children.[22]

Table 1. *Imaging guidelines skeletal survey in suspected child abuse*[16,18]

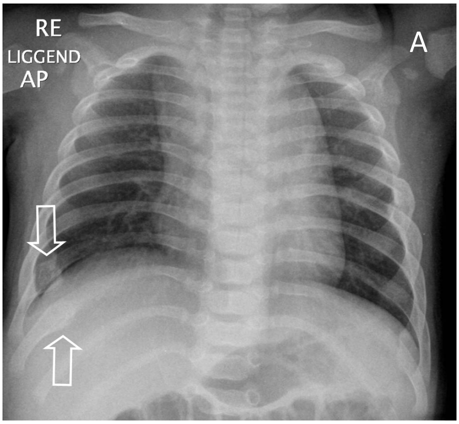
ACR	RCR and RCPCH
Thorax (AP and lateral), to include ribs[a], thoracic and upper lumbar spine	Thorax (AP), *right and left oblique*[b] views of the ribs
Pelvis (AP), to include the mid lumbar spine	Pelvis (AP)
Lumbosacral spine (lateral)	Lumbosacral spine (lateral)
Cervical spine (AP and lateral)	Cervical spine *(lateral)*
Skull (frontal and lateral), additional views if needed – oblique or Towne view	Skull (frontal and lateral), Towne view if occipital injury suspected
Humeri (AP)	Humeri (AP)[c]
Forearms (AP)	Forearms (AP)
Hands (PA)	Hands (PA)
Femora (AP)	Femora (AP)
Lower legs (AP)	Lower legs (AP)
Feet (PA or AP)	Feet *(AP)*

[a] Oblique views recommended, but not routine; [b] In 'italics' the difference between guidelines; [c] Lateral coned views of the elbows, wrists, knees and ankles may demonstrate metaphyseal injuries in greater detail. The consultant radiologist should decide this, at the time of checking the films with radiographers.

An issue not specifically addressed in the guidelines is the matter of how to deal with young siblings of abused children. In a study in 795 siblings of abused children, it has been shown that, in 37% of the children, maltreatment was not limited to the abused child but directed to all siblings; in 20% of the children the abuse was specifically directed at some but not all siblings.[23] These figures have made us decide that, in our hospital, siblings of abused children under the age of two are routinely assessed for signs of child abuse in line with the international guideline cut-off age for the skeletal survey (Fig. 1a).

Bone scintigraphy

In several countries, bone scintigraphy is used in cases of suspected child abuse. A meta-analysis found that although bone scintigraphy had a higher diagnostic yield in more anatomical complex locations, such as the pelvis and feet, it was less sensitive for classic metaphyseal lesions (CML).[24-28] The latter has been shown by Mandelstam et al., who in 20 CMLs detected on conventional radiography, only seven showed increased uptake on bone scintigraphy.[29] In the ACR appropriateness criteria, no consensus on the use of bone scintigraphy was reached by the expert panel. In the comments, it is stated: ‘Indicated when a clinical suspicion of abuse remains high and documentation is still necessary’.[30] A drawback of bone scintigraphy is that not many departments have experience with (this technique in) children; this also means that the experience in reading these studies will be insufficient, thus limiting the applicability. Another relative drawback is the radiation dose involved in this study, which is significantly higher compared to the conventional skeletal survey (3 mSv compared to 0.16 mSv effective dose).[29]



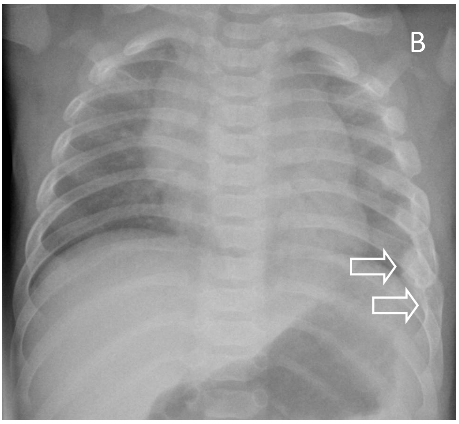


Figure 1a. *A 7-month-old child in whose twin rib fractures were seen on a chest radiograph (see Figure 1b). Based on that finding, a full skeletal survey was performed on this child and rib fractures (arrows) were found.*
Figure 1b. *A 7-month-old child with persistent signs of pneumonia. On a chest radiograph, performed to rule out pneumonia, incidental rib fractures (arrows) were found.*

Other imaging techniques

In the past few decades, the radiological arsenal has increased dramatically, and with the widespread availability of computed tomography (CT) and magnetic resonance imaging (MRI) this specialty has evolved significantly. There is an increasing use of CT in first line trauma triage, where the 'entry through the gantry' is becoming more and more a reality.[31,32] There is ample evidence that CT outperforms conventional radiology, in e.g. the detection of rib fractures.[33] In a retrospective study of 45 pediatric trauma patients, 18 of 45 patients had findings only at CT, including two patients with rib fractures.[34] An additional advantage of CT is the capability of obtaining 3-D images, which can give more information (Fig. 2a, b). Given the relatively high radiation dose involved in computed tomography (an abdominal CT scan has a reported effective radiation dose of up to 10 mSv; for comparison, the radiation dose of a single chest radiograph is approximately 0.1 mSv) and the fact that CMLs will go undetected, its use in child abuse cases will be restricted to those critically ill children who might need (neuro)surgical intervention. CT should not be used as a replacement of conventional radiography; even in cases where CT has been performed during trauma evaluation, a full skeletal survey should be performed.

For an increasing number of clinical indications, bone scintigraphy is being replaced by Whole Body Short Tau Inverse Recovery MRI (WB-STIR).[35,36] This work has attracted attention to radiologists involved in the field of child abuse. In a study comparing the conventional skeletal survey to WB-STIR in 16 children (age range, 1.5-37 months) a sensitivity of 75% (33/44) for rib fractures and 67% (2/3) for metaphyseal corner fractures was found.[37] In a recent study by Perez-Rossello et al., WB-STIR had a low sensitivity for CMLs (31%) and rib fractures (57%).[38] Given these findings, the use of WB-STIR should not routinely be performed. For the completeness of this overview of techniques, the use of ultrasonography and fluorine-18 sodium fluoride positron emission tomography should be mentioned. These techniques, on a case-by-case basis, have been reported but are not validated and should not be used in a routine work-up.[39-42]

FRACTURES

Differentiating between fractures resulting from accidental trauma or child abuse is, in most cases, only possible with knowledge of the full clinical history and in cooperation with attending clinicians. However, a list of specificity of fractures for child abuse has been published in the renowned textbook 'Diagnostic imaging of child abuse' edited by Kleinman (Table 2).[43] Table 2 should be seen as a guideline, but it is important to remember that no fracture in itself is pathognomonic for child abuse (Fig. 3). In case of a fracture, with a high specificity of abuse, a differential diagnosis should always be considered. It is important that the fracture type matches the clinical history and developmental stage of the child.
Two fractures, most indicative of child abuse, will be discussed in more detail.

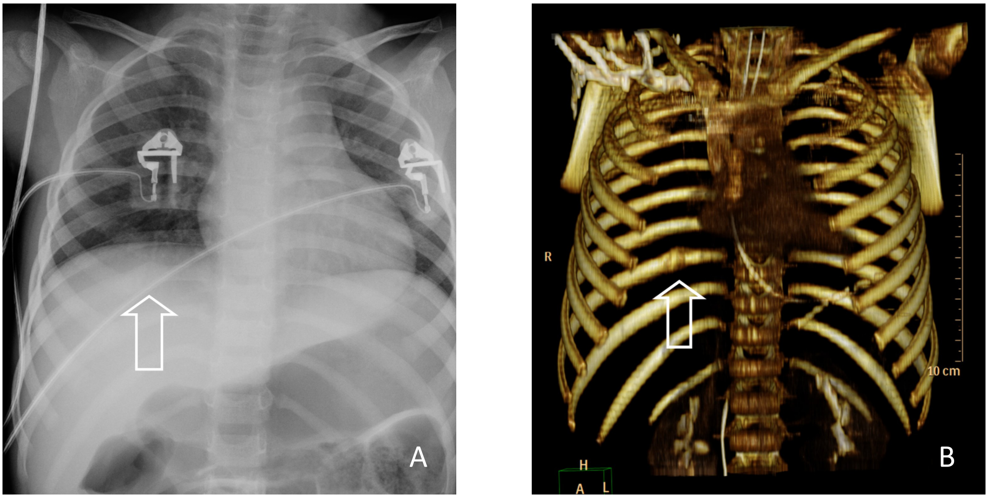


Figure 2a. *Chest radiograph in a 3-year-old girl, victim of inflicted traumatic brain injury, who was admitted to the hospital in a comatose situation. A consolidating posterior rib fracture is shown (arrow).* ***Figure 2b.*** *Three-dimensional reconstruction of the chest CT (shaded surface display) clearly demonstrates the posterior rib fracture on the right side (arrow).*

Table 2. *Specificity of radiologic findings child abuse*[43]

	Type and location of fracture
High specificity	Classic metaphyseal lesions Rib fractures, especially posterior Scapular fractures Spinous process fractures Sternal fractures
Moderate specificity	Multiple fractures, especially bilateral Fractures of different ages Epiphyseal separations Vertebral body fractures and subluxations Digital fractures Complex skull fractures
Common but low specificity	Subperiosteal new bone formation Clavicular fractures Long bone shaft fractures Linear skull fractures

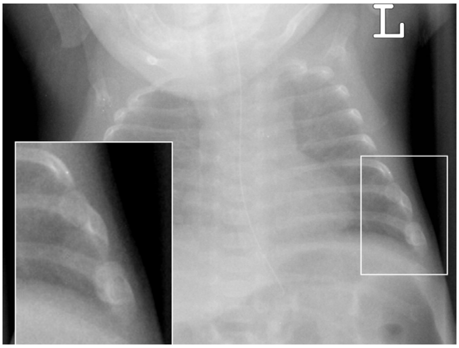


Figure 3. *Rib fractures in a 10-week-old neonate. As the child has been admitted to the ward directly after birth, child abuse was considered to be impossible. The fractures (see insert) were the result of osteopenia of prematurity.*

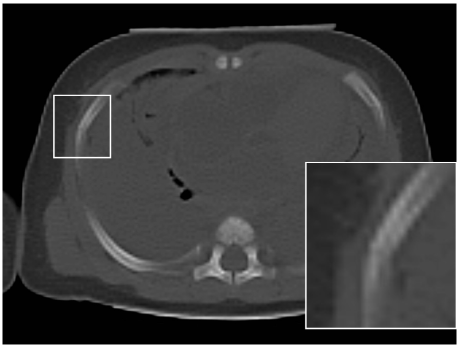


Figure 4. *Anterior rib fracture after CPR in an 8-week-old girl. Note that the fracture is located antero-lateral (see insert).*

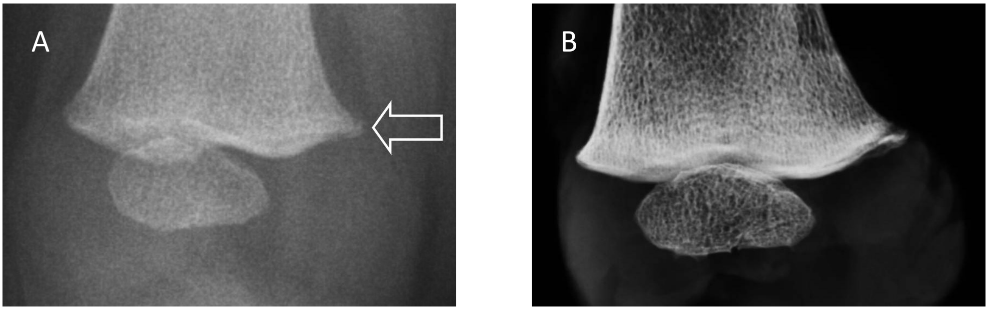


Figure 5a. *Metaphyseal corner fracture in an 8-month-old child, who died as a result of blunt abdominal trauma.*
Figure 5b. *At autopsy the femur was excised and imaged using a mammography system. The radiograph shows the metaphyseal corner fracture at the mediodorsal aspect of the distal right femur.*

Rib fractures

Rib fractures are generally seen as the hallmark of child abuse, especially in cases of inflicted traumatic brain injury. It is not uncommon that rib fractures are found incidentally as they may be clinically silent (Fig. 1b).[44,45] The most common mechanism seen in case of rib fractures is anterior-posterior compression of the chest.[46,47] In this situation, excessive leverage of the ribs over the transverse processes can lead to posterior rib fractures. In a retrospective study, Barsness et al. assessed the positive predictive value (PPV) of rib fractures in relation to child abuse.[48] In total, 316 rib fractures were identified in 62 children; in 51 (82%), the fractures were due to abuse. In children less than three years of age, the PPV of rib fractures for abuse was 95%. Their study also showed that in child abuse cases, multiple rib fractures are more likely to be seen; posterior and lateral rib fractures (78%)

were most prevalent, and in 29% of the cases were the only skeletal finding. Although rib factures have a high specificity for abuse, they have been described in other scenarios. Posterior rib fractures, although rare and only in cases of difficult labor or large babies, have been reported after vaginal delivery.[49] Rib fractures are well described in metabolic bone disease of prematurity or other metabolic disorders and skeletal dysplasias.[50,51] In these cases, rib fractures are seldom the only abnormal finding; family history, physical examination or the skeletal survey show indications for an underlying syndrome or, e.g. vitamin D deficiency.

More controversially is the issue of rib fractures as a result of cardiopulmonary resuscitation (CPR), an issue often addressed by defense lawyers in court. Until recently, rib fractures were not thought to occur as a result of resuscitation.[52,53] However, with the introduction of two handed infant encircling CPR, in which the hand position resembles the way perpetrators hold their children when they are reportedly shaken, it is becoming a relevant issue.[54] Several cases of anterior-lateral acute rib fractures as a result of resuscitation have been published (Fig. 4).[55-58] In all publications, the authors stress the fact that this is an extremely rare finding and that child abuse should be ruled out in all cases. Perhaps, even more important is the fact that even in cases in which rib fractures have been described as a result of CPR, no posterior rib fractures were seen.

Metaphyseal corner fractures

Next to rib fractures, the CML, first described by the pediatric radiologist John Caffey in 1957, is a highly specific finding for abuse.[59,60] These fractures are also known as corner or bucket handle fractures. CMLs are most often found in the distal femur, proximal and distal tibia/fibula and proximal humerus (Fig. 5a, b).[46] On imaging, the appearance of CML varies depending on the size of the fragment and the position of the extremity in relation to the X-ray beam.[61] The mechanism of injury for the CML involves a shearing force in manual assaults; the extremities may undergo substantial torsion and traction leading to a CML. Healing of CML is variable. If the CML is associated with significant displacement and periosteal stripping, there may be conspicuous sclerosis and subperiosteal new bone formation. However, most CML heal without radiographic findings. Since no single fracture is pathognomonic for child abuse, there is a case for a differential diagnosis for CML. CML have been described as an iatrogenic trauma after delivery and orthopedic interventions for clubfeet.[60,62,63] Also metabolic bone diseases, e.g. rickets, and bone dysplasias, especially Schmid-type metaphyseal chondrodysplasia (OMIM no. 156500) and spondylometaphyseal dysplasia corner fracture type (OMIM no. 184255), can have metaphyseal changes similar to the CML.

Dating fractures

Radiologic dating of fractures in the context of child protection, whether in a medical or in a forensic setting, is possible to a certain extent but it certainly is no exact science. Table 3 shows the radiological key findings most consistently agreed upon by radiologists.[43,64-66]

The issue of fracture dating was addressed in a meta-analysis of 1.556 papers which were reviewed systematically by a large (and varying) group of specialists.[67] After application of exclusion criteria, only three studies, with combined data on 189 children, could be included. Based on this meta-analysis, the authors concluded that fracture dating in children is not an exact science, but that radiologists should be able to differentiate recent from old fractures.

We, as authors, feel that although estimation of fracture age should be approached with caution, experienced pediatric radiologists should be able to make informed judgments whether or not fractures (excluding skull, spine fractures and some CML) are in a healing phase. Healing can usually be judged as early or mature, and when multiple fractures are present, it is often possible to state if the fractures are of similar or different ages.

Table 3. *Radiological fracture dating[43,64-66]*

Radiological finding[a]	Timing
Periosteal reaction	Minimum 1 week
Hard callus[b]	Minimum 2-3 weeks, peak 3-6 weeks
Signs of remodelling	Minimum 8 weeks

[a] Except fractures of the skull and classical metaphyseal lesions; [b] The peak can be seen after 6 weeks as well

Table 4. *Differential diagnosis in disease-related fractures*

Radiological finding[a]	Timing
Hereditary collagen disorders	Osteogenesis imperfecta Menkes syndrome Osteogenesis imperfecta with congenital joint contractures (Bruck syndrome) Copper deficiency
Genetic defects in bone mineralization	Osteopetrosis All forms of hypophosphatemic rickets Syndromatic hepatic ductular hypoplasia (Alagille syndrome)
Secondary mineralization disorders	Neuromuscular disorders Nutritional rickets Cerebral palsy Malabsorption Metabolic bone disorders of prematurity
Other at risk disorders	Muscular dystrophy Spina bifida

Differential diagnosis

As children grow up, they discover the world and accidents leading to fractures are therefore a common finding.[68] As a result of these accidents, long bone shaft fractures are the most common fractures in the emergency department. The older the child, the more likely this fracture is caused by an accidental trauma. In non-ambulatory infants, however, the same fractures are cause for concern. As the saying goes: 'those who don't cruise, don't bruise'.[69] In case of a pediatric fracture, a differential diagnosis should always be kept in mind, including child abuse. As mentioned in the introduction, about 10% of the pediatric ED visits is a result of child abuse.[9] It is known that this diagnosis is frequently missed by the treating physician due to an incomplete clinical work-up, both with respect to the physical exam as well as the anamnesis.[70,71] Next to accidental trauma, the treating physician should think of child abuse, disorders related to collagen production, bone mineralization and other diseases leading to an increased risk in bone fragility (Table 4). As mentioned previously, there are also diseases which may mimic fractures, such as skeletal dysplasias and also more common diseases such as osteomyelitis (Fig. 6) or sickle cell disease. Finally, especially for radiologists with a limited experience in pediatric radiology, normal variants, such as metaphyseal step-offs, metaphyseal spurs and physiological subperiosteal new bone formation, may present as a diagnostic dilemma (Fig. 7). The interested reader is referred to textbooks for an in-depth discussion on the differential diagnosis of pediatric fractures.[72]

DISCUSSION

Imaging child abuse is both clinically and emotionally difficult for those involved; this is one field in which an error in judgment in either way will have a detrimental effect on the overall health of the child and social system in which the child lives. That and the increasing public attention make it, in some countries, more and more difficult to find experts which are willing to be involved in this field. Radiologists play an important if not vital role in the diagnosis of child abuse. In order to fulfill this role, several criteria must be met; first of all, the pediatric radiologist should be adequately trained in this field. In this light, it is of interest to note that the American Board of Pediatrics in 2005 established certification for child abuse pediatricians; for radiologists, such a certification does not exist.[73] Second, we feel that pediatric radiologists should be seen as equal partners to pediatricians involved in child abuse, similar to the development in radiology in general. Third, if at all possible pediatric radiologists should become involved in their hospital's child abuse team, although this can be time consuming, their input will (as the first author can tell from personal experience) be highly appreciated. Finally, pediatric radiologists should set the standard in imaging child abuse and adhere to existing guidelines. Although the guidelines of the ACR and RCR and RCPCH are available on-line for free, adherence to these guidelines has shown to be poor.[20,74,75] In interpreting the results from these studies (especially European studies), it is of importance to note that pediatric radiology in general is a small subspecialty in radiology and that not all radiologists have been trained in pediatric radiology. Therefore, involvement of pediatricians in imaging of child abuse might have a positive influence on the adherence to these guidelines. In our country, as is the case in many European countries, most hospitals do not have direct access to a pediatric radiologist. We recommend that in case of suspected child abuse, the skeletal survey should be reviewed by a trained pediatric radiologist, or a radiologist with experience in pediatric musculoskeletal imaging, before a final conclusion is reported to parents or child protection services.

As in all clinical differential diagnoses, but perhaps even more important in child abuse cases, liaisons with pediatricians in order to obtain additional clinical information or even better having joint review of radiological studies will improve diagnostic accuracy. The diagnosis of child abuse is never solely based on radiological imaging but on a combination of clinical, investigative and social findings.

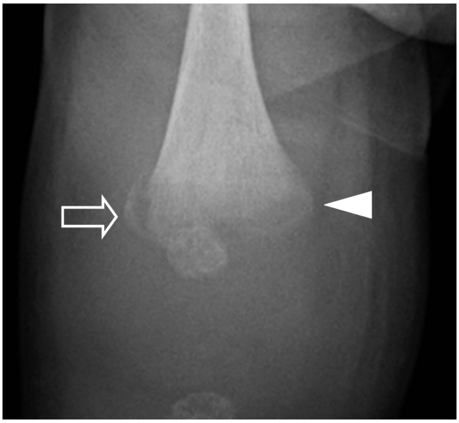


Figure 6. *Two-week-old girl with a swollen knee; initially, the radiological findings were reported to be consistent with a CML. However, as she also had a slight fever and increased infection parameters, the diagnosis was reversed to osteomyelitis. The radiographic abnormalities improved quickly after the start of antibiotic therapy.*

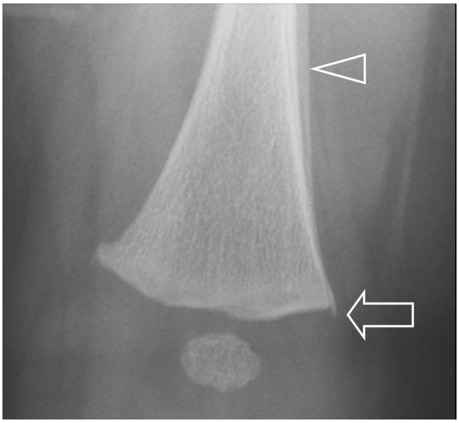


Figure 7. *Radiograph of the distal right femur of a deceased 7-week-old girl, victim of inflicted traumatic brain injury, shows a metaphyseal spur (arrow) and subperiosteal new bone formation (arrowhead). Both are normal findings at this age, which not seldomly are incorrectly interpreted as a pathological finding, i.e. metaphyseal corner fracture and a healing fracture.*

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Chapter 2

Abusive head trauma Part I: clinical aspects

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ABSTRACT

Abusive head trauma (AHT) refers to the combination of findings formerly described as shaken baby syndrome. Although these findings can be caused by shaking, it has become clear that in many cases there may have been impact trauma as well. Therefore a less specific term has been adopted by the American Association of Pediatrics.

AHT is a relatively common cause of childhood neurotrauma with an estimated incidence of 14-40 cases per 100,000 children under the age of 1 year. About 15-23% of these children die within hours or days after the incident. Studies among AHT survivors demonstrate that approximately one-third of the children are severely disabled, one-third of them are moderately disabled and one-third have no or only mild symptoms. Other publications suggest that neurological problems can occur after a symptom-free interval and that half of these children have IQs below the tenth percentile.

Clinical findings are depending on the definitions used, but AHT should be considered in all children with neurological signs and symptoms, especially if no or only mild trauma is described. Subdural hematomas are the most reported finding. The only feature that has been identified discriminating AHT from accidental injury is apnea.

AHT should be approached with a structured approach, as in any other (potentially lethal) disease. The clinician can only establish this diagnosis if he/she has knowledge of the signs and symptoms of AHT, risk factors, the differential diagnosis and which additional investigations to perform, the more so since parents seldom will describe the true state of affairs spontaneously.

INTRODUCTION

With an estimated incidence of 14-40 per 100,000 children under the age of 1 abusive head trauma is probably as prevalent in young children as neonatal meningitis (25-32 per 100,000 live births)[1-3] and lymphatic leukemia (28.7-36.6 per 100.000 children <1).[4] Still, clinicians feel uncomfortable establishing the diagnosis and performing the right additional investigations. The term ‘abusive head trauma’ is recommended by the American Academy of Pediatrics (AAP) for the combination of findings formerly described as shaken baby syndrome.[5] It has, among other things, also been described as Inflicted Traumatic Brain Injury (ITBI), Non-Accidental Head Injury (NAHI) and whiplash shaken infant syndrome. AHT can present with cerebral, cervical or cranial injuries that result from inflicted head injury, which can be shaking, impact trauma or a combination of both. The term ‘shaken baby syndrome’ implies the underlying mechanism of the findings has to be shaking. Although shaking can cause severe head injury, in some of these children there also has been impact trauma or a combination of shaking and impact. Therefore, the AAP recommends using abusive head trauma, a term that does not refer to the exact accident mechanism (shaking) but to the harming action in broader perspective (abuse).

The aim of this educational paper is to give the pediatrician, facing a possible case of AHT, a comprehensive overview of the clinical findings and differential diagnoses. The role of radiology in establishing the diagnosis of AHT will be discussed later in this journal, in ‘Educational paper: Abusive head trauma, Part II: radiological aspects’.

INCIDENCE AND CONSEQUENCES

Incidence

For several reasons it is difficult to determine the actual incidence of AHT. First of all, not all abused infants need/seek medical help and come in contact with the medical system. In a Dutch study among primary health care visitors, 5.6% of the parents of 6-month-old babies reported to have shaken, slapped or smothered their baby at least once.[6] In an American study, 2.6% of the children under the age of two were reported by their mothers to have been shaken.[7] Most of these children do not need medical attention and are therefore not represented in incidence numbers. Secondly, not all cases presented in hospitals are recognized as cases of AHT. Abuse cases may be diagnosed with other conditions, e.g. accidental trauma or Sudden Infant Death Syndrome. Finally, different definitions for AHT are in use, making comparison of incidence rates reported by different institutions difficult.

Several prospective studies have been performed to try to establish the incidence of AHT. Most of these studies collect data from both hospitals and (forensic) pathology departments. In the first population-based American study an incidence of 29.7 per 100,000 person years was found for children under the age of 1 year.[8] In a Scottish study, the incidence of children with AHT, based on hospital visits, was 24.6 per 100,000 children younger than 1 year.[9] In British and Estonian studies, the incidence rates were 14.2 and 40.0 per 100,000 in children under the age of 1, respectively.[10,11] In a prospective Swiss study an incidence of 14 per 100,000 was found in children under the age of 6 years.[12] Most incidence studies describe a higher proportion of boys being affected; range 62-77%.[8-12] Most cases manifest before the age of 6 months; median age ranges from 2.2 to 5.9 months.[8-12]

Mortality

According to Duhaime et al. 'trauma is the most common cause of death in childhood, and inflicted head injury is the most common cause of traumatic death in infancy'.[13] Reported mortality rates for AHT in the studies mentioned above are quite similar: 15-23% of all recognized cases of AHT die before or shortly after presentation.[8,10-12] In the Scottish cohort, the mortality was lower than in other studies, namely 11%.[14] This is probably due to selection bias; studies including only patients that have been admitted to a Pediatric Intensive Care Unit (PICU) will probably find worse outcomes than studies including patients with AHT from all hospital departments. The latter will probably be a better representative of mortality in the full spectrum of AHT. This means that although AHT accounts for a substantial number of pediatric deaths, it is not exactly known what percentage of the affected children die. Besides the short-term mortality, a significant amount of AHT survivors are severely handicapped and will have a lower life expectancy. Death in these children is unlikely to be registered as the result of AHT.

Morbidity

In the Swiss AHT follow-up study by Fanconi and Lips, only 36% of the survivors had a good outcome, and 64% were disabled.[12] Roughly half of these children were moderately disabled, e.g. had significant reduction in cognitive functioning, motor deficiencies, or were referred to outpatient rehabilitation therapy. The other half were severely disabled, e.g. had cognitive scores in the deficient range, severe motor deficits, or were referred to inpatient rehabilitation.[12] In the Scottish incidence study, the same distribution was found; roughly one-third had a good outcome, one-third were mildly to moderately disabled and one-third were severely disabled.[14] In a small sample of AHT survivors (only 14 of 62 AHT survivors could be contacted), Duhaime et al. also found that 36% had a good outcome, 14% were moderately disabled and 50% were severely disabled or vegetative.[15] Because of the young age of the patients and the prolonged developmental course of the brain, it has been said that the final neurological prognosis cannot be given before they reach school age. Bonnier et al. found that children who initially appear to be symptom-free can have neurological problems after this symptom-free interval.[16] Ewing-Cobbs et al. found that nearly 50% of children with early traumatic brain injury (both AHT and other causes) had IQs below the tenth percentile.[17]

Recognizing AHT

Because of (relatively) common appearance and severe consequences, all pediatricians should be able to recognize AHT. Establishing the diagnosis AHT can be very difficult, especially if no fractures are found. In a retrospective study among children with AHT by Jenny et al., 31% of abuse cases were not initially recognized.[18] AHT was more likely to be unrecognized in very young children, white children, children from intact families and in children without respiratory problems or convulsions.[18] The authors estimate that 80% of deaths in the missed AHT group could have been prevented by earlier recognition of abuse. In the majority of the cases of AHT, parents describe a relatively small trauma, e.g. fall from arms, or no preceding trauma at all.[19] Having knowledge about the expected range of injury seen following common accidents can be useful in differentiating between accidental and non accidental injury. Child abuse needs intervention; missing the diagnosis can have severe consequences for the patient and the siblings. On the other hand, wrongfully concluding that a child has been mistreated will have devastating effects on the family as well. It is therefore essential that, in each case of suspected AHT, a multidisciplinary approach is chosen. Pediatricians, radiologists, ophthalmologists, social workers and child protection workers have to work closely together, preferably in an institutional child abuse and neglect team (CAT), in order to collect as much information as possible on the facts that led to clinical manifestations. The clinical abnormalities found during physical examination have to be sorted out in detail in order to formulate an accurate differential diagnosis. It is of great importance that the right kind of additional investigation is performed to reach the right diagnosis.

CLINICAL FINDINGS AND DIFFERENTIAL DIAGNOSIS

As AHT is the most common cause of neurotrauma in children younger than two years, it should be considered in all children presenting with neurotrauma, unless the trauma is without any doubt accidental, e.g. a car accident.

Clinical signs and symptoms seen in children with AHT depend of the type of AHT and accompanying injuries. Neurological manifestations include altered state of consciousness (77%), seizures (43-50%), vomiting (15%), and delayed development (12%).[10,11] Subdural hemorrhages (SDHs), described in 77-89% of the patients, are the most common neuroradiological finding (Fig. 1).[11,12] In autopsy series, SDHs have been described in approximately 83-90% of all children diagnosed with AHT.[20,21] Other neuroradiological findings include subarachnoidal hemorrhages (12-25%), intracerebral hemorrhages (8%), epidural hemorrhage (4%), parenchyma lesions (37%), and hygroma (11%).[11,12] In a systematic review by Maguire et al., only apnea was found to be a critical distinguishing feature for AHT compared to accidental head injury, having a positive predictive value (PPV) of 93%.[22] Rib fractures and retinal hemorrhage were strongly associated with AHT, having a PPV of 73% and 71%, respectively. Though seizures are more common in AHT, this trend did not achieve statistical significance. Long bone fractures were not significantly discriminative, though

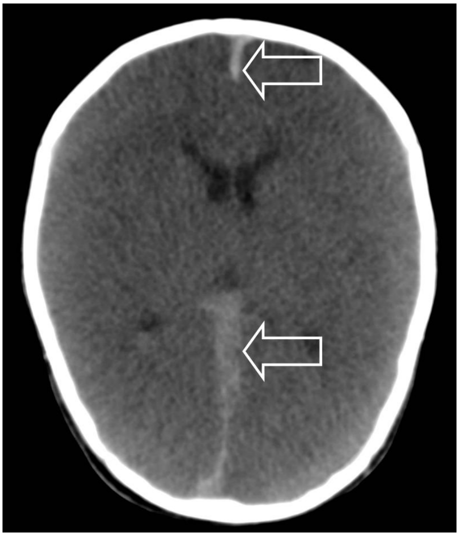

Figure 1. *Two-month-old boy, victim of abusive head trauma. The CT shows an interhemispheric subdural hematoma along the falx cerebri. Subdural hematomas in children often extend along the falx cerebri and this should not be confused with calcification, which is seen at an older age.*

the 'classical metaphyseal lesion' was not separated out in this analysis, and has been found to be highly correlated with abuse. Skull fracture and bruising on the head were more common in accidental injury, but this trend, too, did not achieve significance. Correlation between skull fractures and intracranial pathology is limited. Skull fractures can occur with and without intracranial bleeding. On the other hand, intracranial injury can be present without a skull fracture.[23]

In a recent systematic review on ocular signs in AHT, intraocular hemorrhages were seen in 74% (range 51%–100%) of 560 combined cases of AHT and in 82% (range 63%-100%) of cases in autopsy series.[24] Retinal hemorrhages are bilateral in 85% of AHT cases.[25] Injuries outside the head, e.g. bruises and fractures, are found in 35-54% and 33-48%, respectively.[11,12] This means that in a substantial number of AHT patients no other traumatic injuries are detected, although severe traumatic brain injury exists. The absence of fractures and bruises is therefore never an argument against AHT. Minns and Busutill distinguish four different types of AHT.[26]

Hyperacute encephalopathy

Approximately 6% of all children with AHT presents with this form of AHT in their study. These children are young at presentation (two to three months of age) and present with acute respiratory failure and cerebral edema; the majority of them are dead or die shortly after presentation. Hyperacute encephalopathy results from an injured brainstem after hyperflexion and hyperextension. At autopsy localized axonal damage at the craniocervical junction, in the corticospinal tracts, and in the cervical cord roots is seen, in combination with brain swelling and hypoxic injury.

Acute encephalopathy

This is the most common form of AHT, affecting approximately 53% of cases, and has been described as the classic 'shaken baby syndrome'. Children present with the findings mentioned above: a low level of consciousness, increased cranial pressure, convulsions, apnea, hypotonia, anemia, and/or shock. Trauma in body parts other than the brain are found in 35-54% of the cases.[11] The cause can be shaking injury, impact trauma or a combination of both. Extended injury is seen on MRI, with SDHs, edema, contusions and lacerations and white matter shearing.

Subacute non-encephalopathic presentation
Approximately 19% of all patients presents with sub-acute non-encephalopathic AHT. This is a less severe form of acute encephalopathy. SDHs and retinal hemorrhages are found, but other brain injuries are less recognizable. Coexistent injuries are common.

Chronic extra-cerebral presentation
The chronic extra-cerebral form of AHT (22% of cases) is the hardest to relate to abuse because of the time interval between the incident, development of complaints and establishing a diagnosis. Children present with expanding head circumference and/or signs of raised intracranial pressure, e.g. irritability, vomiting, failure-to-thrive, hypotonicity or convulsions. An isolated subdural hemorrhage is found, but retinal hemorrhages can have disappeared already. If other signs of abuse can be detected, e.g. rib fractures, it is easier to relate the SDH to abuse. If the SDH is the only sign, it is highly plausible that a trauma has happened, but limitation in the dating of SDHs makes conclusive diagnosis difficult.

History taking
AHT should be part of the differential diagnosis in children with a variety of non-neurologic presentations, such as increasing head circumference, children with failure-to-thrive, vomiting, crying excessively, poor drinking, developmental delay, children who present with other forms of physical abuse, and children with siblings who suffered severe physical abuse.

Multiple factors contribute to the recognition and diagnosis of AHT. A major determination that must be made is whether the described trauma can explain the child's injuries. The identification of other, often non-acute injuries can be of great importance to support the diagnosis of inflicted injury, although the absence of other traumatic injuries does not rule out AHT. The child's past history can contribute to suspicion of inflicted injury. In one study approximately 20% of the children who died as a result of Child Abuse had had contact with the health care system in the month before their dead. Some of these presentations were suspicious for CAN and provided a missed opportunity for intervention.[27] Oral et al. found that 8% of children who died of AHT had a medical history of abuse that was missed by health care providers.[28] It is therefore of great importance that history taking is done extremely carefully and that information should be gathered about not only this child and this event, but also about the lifelong, and family medical history.[25] Both parents and other health care professionals can give important information that can support or weaken the diagnosis of AHT. History taking should at least include the following:

Detailed history
Any reported trauma event should be absolutely clear to the treating physician. If an accident is described, the doctor should exactly be aware of the timeline and exact circumstances of the incident i.e. of which height the child fell, what material was on the floor, who was present, how the child reacted, what did the caregivers do at that moment, how many time elapsed between the incident and seeking medical help. If no accident was described but the child was found or suddenly appeared to be in a bad condition it should be clear what the first manifestations were, what was the last time the child was seen in good condition, how many time elapsed between this moment and the clinical symptoms.

Medical history
The history should document prior presentations to any hospitals, to the GP, and to routine primary health care visits. Prior traumas or signs and symptoms attributable to injury must be sought out.

Growth curve
All former measurements should be retrieved to construct a growth curve. The growth curve of the skull is most important, as the first sign of deviation from the patient's growth curve can indicate a possible event that led to an increase in head circumference.

Medical history of siblings
Unusual medical contacts of brothers and/or sisters may indicate a hereditary disorder or a history of family violence.

Family known at Child Protection Services (CPS)
Many children who present with AHT have a prior history with CPS. The team must determine if this child and/or siblings are known at the CPS, or if there are siblings placed in foster care.

Assessing risk factors
In close collaboration with, e.g. a social worker an assessment of risk factors should be made (Table 1).[29] AHT also occurs in families with little or no risk factors at all, but the presence of risk factors should increase the physicians' awareness.

Differential diagnosis
Although AHT is the most common cause of SDH in children younger than one year[30], the differential diagnosis of intracranial hemorrhage is extensive (Table 2, adapted from David).[31] After formulating a differential diagnosis, additional investigations have to be performed to confirm or rule out alternative diagnoses. The role of imaging will be discussed in Part II, to be published later in this journal. We will not address blood examination, ophthalmologic examination and genetic analysis for rare diseases.

Table 1. *Risk factors for child abuse[29]*

Parents	Environment	Child
Psychiatric problems	Partner violence	Ex-prematures
Substance or alcohol abuse	Large family	Dysmatures
Suffered from abuse in youth	Stepchildren	Physically disabled
Lack of pedagogic capacity	Poverty/financial problems	Mentally disabled
Very low level of education	Residential instability	Excessive crying
Single parent	Social isolation	Chronically ill
Young mother	Refugee families	Unwanted
Unemployment		Behavioral problems

Table 2. *Differential diagnosis of intracranial hemorrhage in children adapted from David[31]*

Category	Cause
Non accidental trauma	Shaking, impact or a combination
Accidental trauma	For example falls, motor vehicle accident
Medical and surgical interventions	Known from the medical record
Prenatal/perinatal conditions	Birth trauma Intrauterine trauma e.g. domestic violence to mother Idiopathic intrauterine subdural hematoma Intrauterine isoimmune thrombocytopenic purpura Maternal pre-eclampsia
Coagulation disorders	Hemophilia A and B von Willebrand disease Factor V deficiency Factor XII deficiency Factor XIII deficiency Hemorrhagic disease of the newborn (vitamin K deficiency) Disseminated intravascular coagulation (DIC) Hermansky–Pudlak syndrome (albinism) Alpha 1-antitrypsin deficiency
Congenital malformations	
Genetic disorders	Osteogenesis imperfecta Sickle cell anemia Alagille syndrome Ehlers–Danlos syndrome Menkes kinky hair syndrome
Metabolic disorders	Glutaric aciduria type 1 Pyruvate carboxylase deficiency
Infectious disorders	Meningitis Kawasaki disease Herpes simplex encephalitis Congenital toxoplasmosis
Intoxication	Lead poisoning Cocaine Anticoagulant therapy

All medical conditions, both congenital and acquired, should be ruled out before trauma can be considered to cause the (combination of) findings. If trauma is the only option, it should be judged carefully whether accidental trauma is a possible explanation for the abnormalities found. If no accidental trauma has been described that can cause these findings this option is excluded as well and AHT is the only remaining diagnosis. Most diagnoses listed in this table can be ruled out easily because they should have been known from medical history (medical interventions, ingestion), are accompanied by other signs and symptoms (genetic disorders) or can be rejected after simple laboratory results (coagulation disorders, infectious disorders). Furthermore, all diseases listed above are extremely uncommon. Some groups of diagnoses are more likely to cause SDHs, namely birth trauma, coagulation disorders, metabolic disorders and accidental trauma.

Birth trauma has been described as a common cause of SDHs. In prospective studies, 10% to 46% of newborns without clinical symptoms had SDH. All of these SDHs were resolved after four weeks to three months.[32-34] These hematomas were differently located compared to SDHs with clinical symptoms. Typically, they present as a thin film of blood occipital or infratentorial overlying the cerebellar hemispheres. It has been hypothesized that these clinically silent SDHs may present with delayed symptoms due to catastrophic re-bleeding, or growing chronic SDH.[31] No studies except for case reports have demonstrated the existence of these categories. It is well known that some SDHs present after birth with major clinical symptoms. These space-occupying SDHs give immediate signs and symptoms post-partum, e.g. seizures, hypotonia and coma.[31] Coagulation disorders are an important alternative cause of intracranial hemorrhage in young children. It is uncommon for bleeding disorders to present with intracranial hemorrhage except for Vitamin K deficiency.[35,36] It is mostly seen in breast-fed babies who do not receive supplemental vitamin K. In some cases an underlying disease is present.[37-40] Although most Western countries have vitamin K guidelines[41], there never is a 100% adherence. It is important to note that an abnormal coagulation time can be caused by a large hemorrhage and does not necessarily reflect an underlying problem with coagulopathy.[42] Although certain genetic and metabolic disorders can cause SDHs, most of the affected children will show other features as well. These diseases are less common than AHT and the presence of a rare disease does not rule out child abuse. In children with SDHs without signs of trauma, glutaric aciduria type 1 should be ruled out as children with glutaric aciduria type 1 can develop normally the first 6-18 months of life.[43]

Falls of limited height and AHT

An extensive overview of literature on short-distance falls and accompanying injuries has been provided in 'Forensic Aspects of Pediatric Fractures'.[23] Short distance falls (<1.5 m.) usually take place from a couch, crib or caregivers arms. Eight studies describe 3,451 children who experienced a short distance fall. Child abuse was highly unlikely in most studies, e.g. because only falls during hospital admissions were included. In 25 of these children (0.7 %)

a skull fracture was found. Skull fractures were never seen after a fall from a couch. It has to be noted that not all children underwent (skull) radiography, so fractures without clinical symptoms could have been missed. No life-threatening events or intracranial pathology have been reported in these types of falls. Serious intracranial injuries and fatalities have been reported after a fall from a baby walker and perambulator. Literature is not conclusive on potential serious or lethal consequences after falls from baby bouncers, bunk beds, high chairs, staircases, shopping trolleys and trampolines. Very few studies have been published on these specific subjects. It is clear that falls are very common in young children; about 50% of all children will experience a short distance fall in the first year of life. It has been calculated that approximately 1 in 250,000 children younger than 1 year will die from a short-distance fall. Another literature study found that the population based risk of dying after a short-distance fall for young children is less than one per million per young children per year.[44]

As (intra)cranial pathology is a necessary condition for AHT, this is described in all studies on AHT. As mentioned before, injuries other than intracranial pathology, e.g. fractures, are found in approximately 40% of all cases. The only diagnoses, in the differential, that cause both intracranial hemorrhage and fractures are severe accidents like motor vehicle accidents, and osteogenesis imperfecta.[45] As a result, the combination of these findings is highly suggestive for AHT (Fig. 2a, b). More difficult are the cases where intracranial pathology is the only abnormal finding. AHT is the most common cause of SDHs in young children, but in absence of any other signs of trauma establishing the diagnosis is more difficult for clinicians. Of all neurologic symptoms, only apnea has been found to be a critical distinguishing feature for AHT compared to accidental head trauma. After ruling out underlying disease with relatively simple additional investigations, history taking, including all the items mentioned above, is of great diagnostic value. A presenting history of no or low-impact trauma has a specificity of 0.97 and a PPV of 0.92 for AHT. In patients with

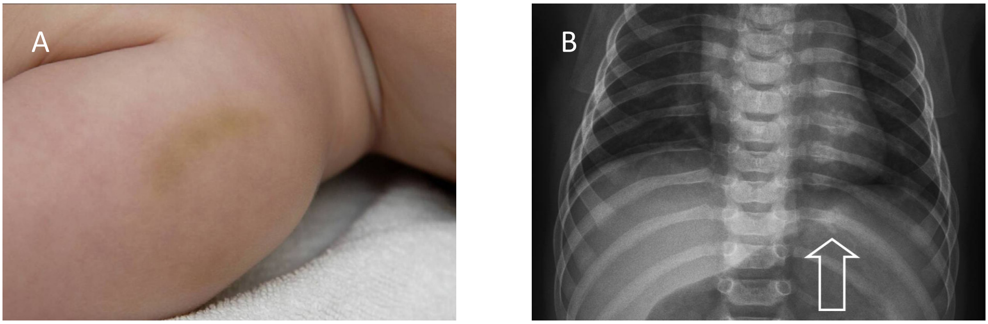

Figure 2a. *Four-month-old boy admitted with a large subdural hematoma with clinical symptoms. No trauma was described. A bite mark was found on the left shoulder. Unfortunately no measuring tape has been used while taking the picture.* ***Figure 2b.*** *Chest radiograph obtained two weeks after the initial CT scan shows a series of posterior rib fractures on the left side with callus formation (arrow).*

neurological symptoms at discharge, no or low-impact trauma histories' specificity and PPV are both 1.0 for AHT. In the same study injuries were blamed on resuscitation in 12% of AHT cases, compared to 0% in not definite abuse cases. The initial history of trauma described by caregivers was changed in 9% of definite AHT cases compared to 0% in not definite abuse cases.[19]

CONCLUSION

AHT is as prevalent in very young children as other potential lethal diseases, e.g. neonatal meningitis. It is the most common cause of neurotrauma in children younger than one year, and should therefore be considered in all children presenting with neurotrauma or unexplained neurological symptoms. The diagnosis should also be considered in children presenting with non-traumatic (aspecific) symptoms and signs such as increasing head circumference, children with failure-to-thrive, vomiting, crying excessively, poor drinking, developmental delay, as well as children who present with other forms of physical abuse and children with siblings who suffered severe physical abuse. About one-fifth of the children die and two-thirds of survivors are handicapped. The true extent of the damage cannot be assessed before school age, as neurological problems and low IQs can become apparent after a symptom-free interval. The clinician can only establish this diagnosis if he/she has knowledge on the signs and symptoms of AHT, risk factors, the differential diagnosis and which additional investigations to perform, as parents seldom will describe the true state of affairs spontaneously. AHT should be approached with as structured an approach as any other (potentially lethal) disease. History taking should be done extremely carefully and include contact with other health care providers, medical history of siblings, skull circumference growth curve and checking for CPS involvement. Physical examination should always be performed to look for additional signs of trauma. A differential diagnosis should be formulated and additional investigations should be performed to rule out or confirm alternative diagnoses. Birth trauma, coagulation disorders, metabolic disorders and accidental trauma are, besides AHT the most common causes of SDHs. All medical conditions should be ruled out before considering trauma to be the cause of the signs and symptoms. If trauma is the only option, it should be judged carefully whether accidental trauma is a possible explanation for the findings. If no accidental trauma has been described that can cause the signs and symptoms, this option is excluded as well and AHT is the only remaining diagnosis.

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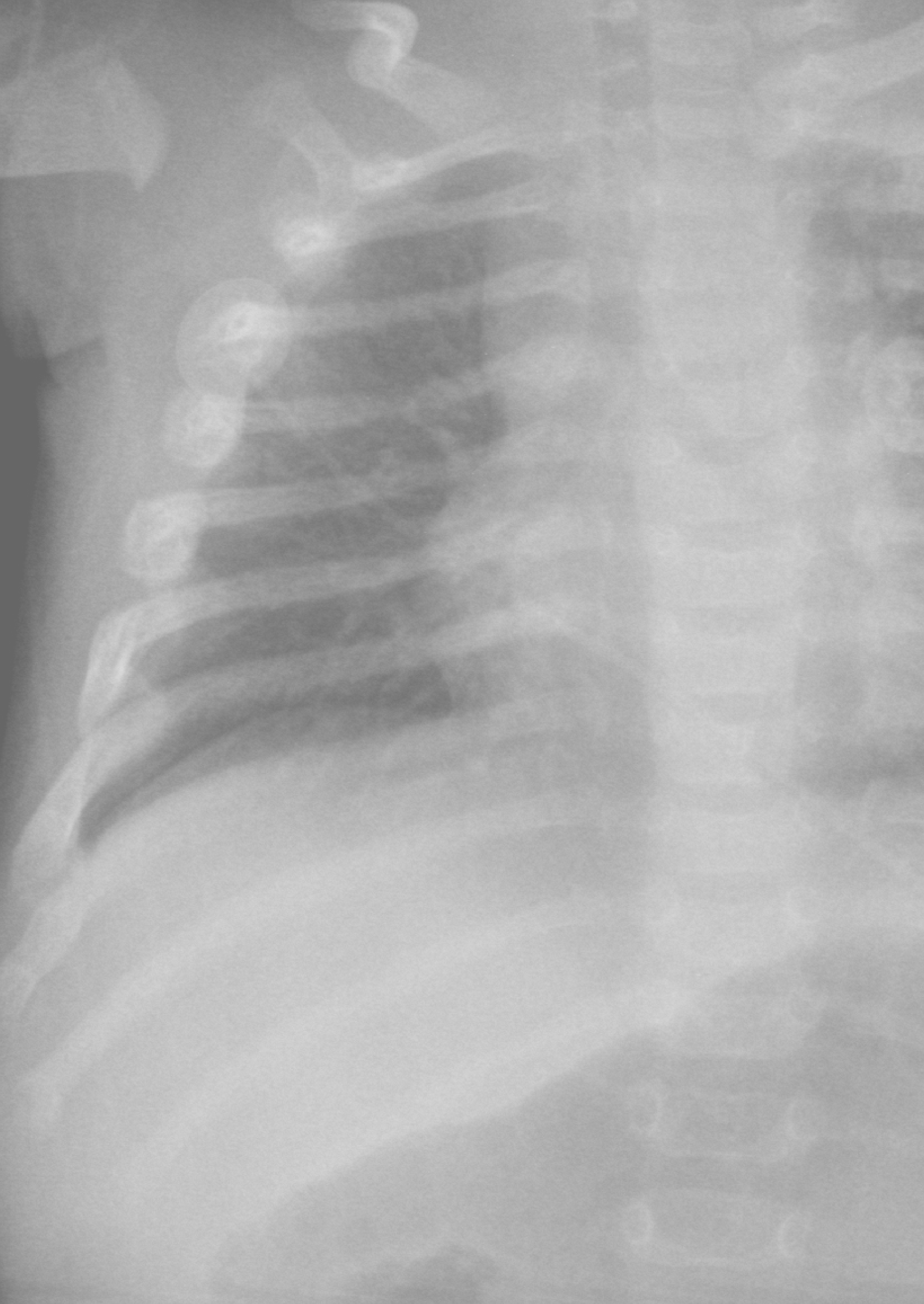

Chapter 3

Abusive head trauma Part II: radiological aspects

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ABSTRACT

Abusive Head Trauma (AHT) is a relatively common cause of neurotrauma in young children. Radiology plays an important role in establishing a diagnosis and assessing a prognosis. Computed Tomography (CT), followed by Magnetic Resonance Imaging (MRI) including diffusion-weighted imaging (DWI), is the best tool for neuroimaging. There is no evidence-based approach for the follow-up of AHT; both repeat CT and MRI are currently used but literature is not conclusive. A full skeletal survey according to international guidelines should always be performed to obtain information on possible underlying bone diseases or injuries suspicious for child abuse. Cranial ultrasonography is not indicated as a diagnostic modality for the evaluation of AHT. If there is a suspicion of AHT, this should be communicated with the clinicians immediately in order to arrange protective measures as long as AHT is part of the differential diagnosis.

The final diagnosis of AHT can never be based on radiological findings only; this should always be made in a multidisciplinary team assessment where all clinical and psychosocial information is combined and judged by a group of experts in the field.

INTRODUCTION

Abusive head trauma (AHT) is a relatively common cause of neurotrauma in young children. Incidence, long-term consequences, clinical findings and differential diagnosis have been described extensively in 'Educational paper: Abusive head trauma, Part I: clinical aspects' in this journal. After formulating a differential diagnosis, additional investigations have to be performed to confirm or rule out alternative diagnoses. Radiology is an important tool in describing the exact location and severity of the injury. It can also help in the detection of other abnormalities which can make the initial diagnosis more likely, e.g. when rib fractures are present, or it can make the initial diagnosis less plausible, e.g. when underlying bone disease is detected. Furthermore, it can help assessing a prognosis for the child, depending on the brain damage seen. The aim of this educational paper is to give the pediatrician, facing a possible case of AHT, a comprehensive overview on the significant role of radiology in establishing a correct diagnosis. We will present the clinical findings in AHT and how to discriminate between AHT and accidental injury or other pathology. We will describe the value of conventional radiology (CR), cranial ultrasonography (CUS), computed tomography (CT) and magnetic resonance imaging (MRI) in imaging abnormalities in AHT. Furthermore, the importance of interpreting, reporting and communicating radiological findings will be addressed in both a clinical and forensic perspective.

MODALITIES

Conventional Radiology

The role of conventional radiology (CR) in detecting child abuse and neglect (CAN) has recently been discussed in this journal.[1] A full skeletal survey should be performed in all children under the age of two years where AHT is part of the differential diagnosis. Its role in detecting AHT is threefold; first, it has a (limited) role in detecting injuries to the head, both fractures and intracranial pathology. A skull radiograph is obtained in order to detect possible fractures that are missed on CT because of their location in the plane of scanning. No specific type of skull fracture is pathognomonic for child abuse. The majority of all skull fractures, both accidental and abusive, are linear fractures (Fig. 1).[2] As linear fractures can occur after a short distance fall (e.g., fall from arm of caretaker or fall from stairs,

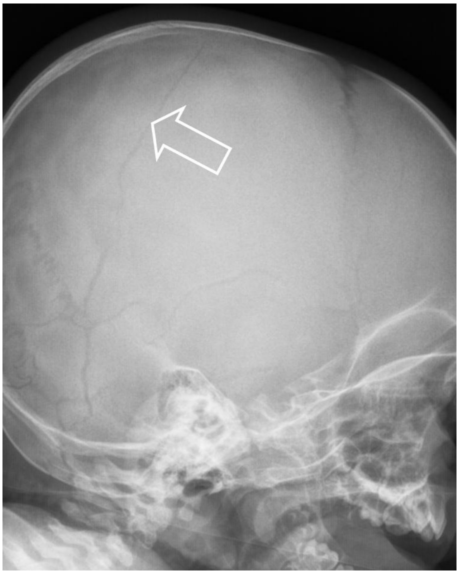

Figure 1. *A four-month-old boy with a linear skull fracture (arrow) after a 80 cm high fall on a hard surface.*

two accidents commonly described by caretakers in case of suspicion of AHT), these are not sensitive for AHT. Bilateral fractures, multiple fractures, depressed fractures, fractures with diastases smaller than three millimeters of the fracture lines or occipital fractures are more common seen in child abuse.[3-5] A rare complication of a skull fracture is a growing skull fracture, or progressive diastasis of the fracture line. They mostly occur after serious head trauma and child abuse is the most likely cause.[2] As in a growing skull fracture, there is nearly always brain damage, treatment is surgical and meant to reduce herniated brain tissue and repair injury to dura and skull.[2] As skull fractures heal without callus formation, dating of the accident based on the radiological skull findings is not possible. Therefore, in follow-up skeletal surveys, the radiographs of the skull should be omitted.[2] Secondly, the skull radiograph can be supportive in demonstrating or excluding underlying disease, e.g. wormian bones in osteogenesis imperfecta and Menke's disease.[6,7] Thirdly, an important role for CR is imaging the rest of the skeleton, which can be very informative on abnormalities in the skeleton that support diagnosis leading to an increased risk in bone fragility, or can reveal occult fractures supporting the diagnosis of CAN (Fig. 2a-c). For this purpose, it is of major importance the skeletal survey is performed according to international guidelines.[8,9]

Cranial ultrasonography

The use of cranial ultrasonography (CUS) is not primarily indicated in establishing the diagnosis of AHT. It can, however, be used in some cases for the follow up of intracranial pathology. The penumbra (from the Latin paene 'almost, nearly' and umbra 'shadow') effect makes it hard to visualize the parts of the brain located just under the convexity of the skull. These places can harbor a subdural hematoma as a result of abuse but may be overlooked with CUS. With respect to subarachnoid hemorrhage, the sensitivity of CUS is inadequate for clinical use.

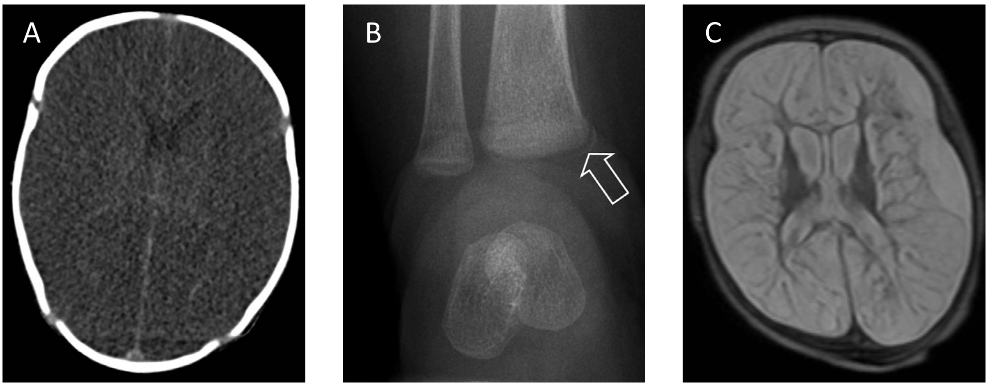

***Figure 2a.** A two-month-old girl admitted because of abusive head trauma. The CT obtained at admission shows an overall decrease in density of brain tissue and a lack of grey-white matter differentiation. This is a sign of severe hypoxia of the brain and has a poor prognosis.* ***Figure 2b.** The skeletal survey shows a metaphyseal corner fracture of the distal tibia. This, in combination with the intracranial trauma, is highly indicative of abusive head trauma.* ***Figure 2c.** Five weeks after the initial CT scan, the girl has developed extensive diffuse multicystic encephalomalacia.*

CUS is applied in children with an increased head circumference, where a diagnosis of benign enlargement of the subarachnoid space (BESS) is suspected. BESS is diagnosed in children with a rapidly growing head, enlarged subarachnoid spaces and normal or only slightly enlarged ventricles. BESS is a self-limiting condition that needs no intervention in most children. The etiology is unknown, but there seems to be a hereditary component as approximately 40% of children with BESS has a family member with a large head.[10] With the use of a high frequency linear transducer, the subarachnoid space can be evaluated at the level of the frontal fontanel. The upper level of the width of the sub-arachnoid space varies in various publications but in general four to five millimeter is used as a cutoff level from normal. BESS is a known risk factor for SDHs after minimal or no head injury.[10] On color Doppler CUS, a sign to look for are the crossing vessels, anchor veins, in the subarachnoid space. This makes differentiation between BESS and a subdural hematoma possible.[11,12] In children referred for an increase of head circumference, occasionally subdural hematomas can be diagnosed. In these cases, the crossing vessels will not be visible in the subdural collection, in many cases the border between the subdural and subarachnoid space will be visible (Fig. 3). Once diagnosed, a SDH can be evaluated over time with CUS.

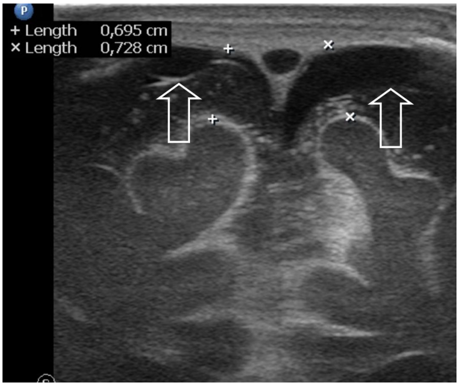

Figure 3. *Cranial ultrasound of a four-month-old boy with a subdural collection due to BESS.*

3

Computed tomography

Computed tomography (CT) is the method of first choice in imaging traumatic brain injury, for both fractures and intracranial pathology. As CT is widely available and has short scan times, it is the most appropriate modality in the acute phase of neurotrauma to assess the need for neurosurgical intervention. Both a soft tissue setting and a bone setting should be performed. CT settings should be age adjusted in order to reduce the radiation burden to a minimum (more information regarding dose reduction can be found on the website of the ‘Image Gently campaign’).[13] Standard 3-D reconstructions are highly advisable to provide insight into the relationship between fractures that can be useful to explain possible trauma mechanisms to non-medical personnel (Fig. 4a). Non-contrast-enhanced CT has a high sensitivity for detecting acute hemorrhage and midline shift (Fig. 5). It is less sensitive for the detection of non-hemorrhagic injuries, especially in the acute phase. In the setting of cranial trauma or AHT there is no need for contrast-enhanced studies.

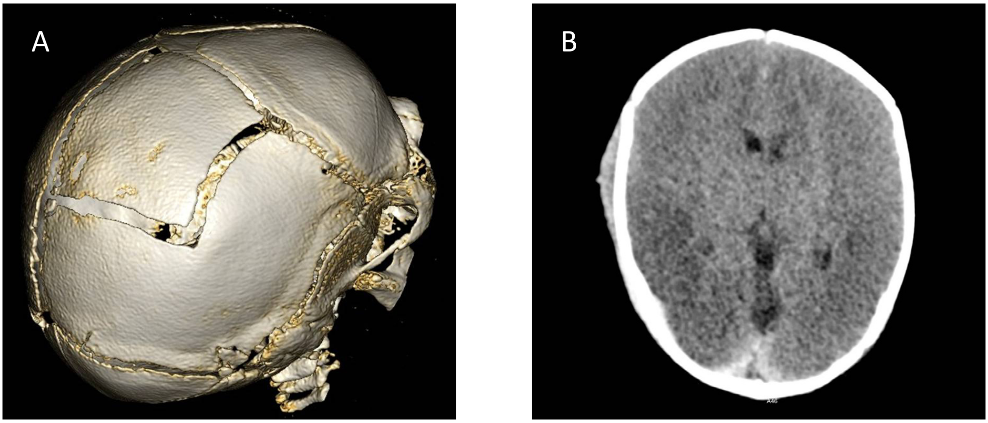

Figure 4a. *A three-dimensional shaded surface display (3D-SSD) of a skull fracture in a six-week-old boy with no history of trauma. The 3D-SSD images can be used to display the lesions to lay persons, e.g. parents or in court. These images should always be interpreted in combination with the original axial source data in order not to miss small lesions, which can be obscured in the rendering process, giving false negative results.* ***Figure 4b.*** *CT shows a relative high density of the basal ganglia, known as the reversal sign. This finding is a sign of diffuse, anoxic/ ischemic cerebral injury and carries a poor prognosis.*

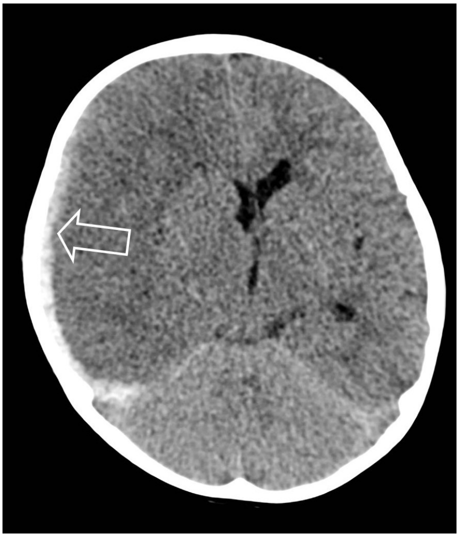

Figure 5. *A three-year-old boy with a right-sided subdural hematoma (arrow) and a shift of the midline as a result of this subdural hematoma. Note the decrease in density of the white matter on the right side and the asymmetry of the ventricles.*

Subdural hemorrhage is seen on CT in 77-89% of the cases with AHT.[14,15] However, in autopsy studies SDHs have been described in approximately 83-90% of all cases.[16,17] Subdural hemorrhage, as well as subarachnoidal and epidural hemorrhage, are seen in both AHT and after accidental trauma and are therefore not discriminating factors. Epidural hemorrhage is suggestive for impact trauma.

CT of the head should be performed in all children who present with signs of abuse in combination with signs of possible neurotrauma or intraocular hemorrhages. Routine cranial CT in all physically abused children without signs of AHT or neurotrauma is controversial. Literature is not conclusive about the additional value of CT in these children. The Royal College of Paediatrics and Child Health (RCPCH) and Royal College of Radiologists (RCR) state that CT is indicated in ‘any child under the age of one (year) where there is evidence of abuse’.[9] The American College of Radiologists, however, states that cranial CT in children without neurological symptoms is indicated only for those patients that are at ‘high risk’ for having suffered from AHT, e.g., children with rib fractures, multiple fractures, facial injury or children younger than six months of age.[18] The long-term effects of ionizing radiation can not be used as a counterargument for performing a cranial CT, because missing the diagnosis of AHT can have severe, even lethal, consequences.

Magnetic Resonance Imaging

MRI is not the first imaging tool in suspected traumatic brain injury. The most important reason is a lower sensitivity for acute hemorrhage compared to CT. Secondly, the long scan time makes it more difficult to perform successfully in children, unless general anesthesia is used. This requires MR-compatible anesthesia equipment, transferring a sometimes instable patient for a longer time from a pediatric ward to the radiology department and the presence of a doctor responsible for the anesthesia. The last mentioned demands strict arrangements between pediatricians and radiologists about responsibilities for the sedated patient. Although no international MRI guidelines exist, the Royal College of Radiologists and the Royal College of Paediatrics and Child Health from the UK have developed a protocol, which consists of standard sequences T1- and T2-weighted imaging combined with two advanced techniques, namely susceptibility weighted imaging (SWI) and diffusion weighted imaging (DWI).[9]

SWI is a technique originally developed for the analysis of small vessels and the detection of small brain tumors. This MRI technique exploits the susceptibility differences between tissues and uses the phase image to detect these differences. The application of this technique yields an enhanced contrast magnitude image which is sensitive to venous blood, hemorrhage and iron deposits.[19,20] The high sensitivity for small hemorrhages is useful in cases of suspected AHT and it has been shown that the addition of SWI sequences to the standard MRI protocol enhances detection of hemorrhagic brain lesions, such as can be seen in diffuse axonal injury.[21] The extend and number of the micro-hemorrhages detected with SWI has been shown to correlate with a poor long-term outcome in children with AHT.[22-24]

DWI plays a key role in imaging of traumatic brain injury, especially in the assessment of changes after a hypoxic event, such as stroke or AHT. In daily practice, it is the standard in stroke imaging. In DWI, each pixel on the MR image represents the rate of water diffusion, i.e., it displays the measurement of the Brownian motion of hydrogen atoms. If the diffusion is restricted, e.g. in case of cytotoxic edema resulting from an ischemic event, then the affected area will have increased signal intensity on the DWI images. On the apparent diffusion coefficient images, which always complement the DWI study, the same area will have low signal intensity. Previous studies have shown that restricted diffusion correlates with poor outcome (Fig. 6b, c).[25-27] In cases of suspected AHT, DWI, as well as SWI, should always be performed.[28]

APPROACH

Imaging strategy

Kemp et al. performed a systematic review to determine the optimal imaging strategy to identify AHT.[28] As initial CT is widely accepted as modality of first choice in an acutely ill child with neurological symptoms, they included studies that compared additional MRI, follow-up CT and CUS with initial CT. Additional MRI revealed new information in at least 25% of all children with abnormalities on the initial CT scan. Additional findings detected by MRI were a.o. further SDHs, subarachnoid hemorrhages, cranial shearing, ischemia, infarction, parenchymal hemorrhages and cerebral contusions. DWI, a relatively new MRI technique described above, demonstrated more extensive injury than could be seen on normal MRI, correlated with poor outcome (Fig. 6a-f). The question whether children with no abnormalities on CT should undergo MRI cannot sufficiently be answered from the literature. The authors did find some studies that described children that had abnormalities on MRI in the presence of a normal CT, but study quality was too low to include these studies in the review. The role of repeat CT if early MRI was performed remains unclear from today's literature. Studies on high-resolution CUS described only 21 children who had CUS in total, but CUS failed to identify abnormalities in 6 cases. It can be concluded that there is evidence that the most solid way to identify intracranial injuries as a result of AHT is to perform initial CT. If CT is abnormal, early MRI including DWI should be performed. The role of MRI, if initial CT is normal, is unclear as is the role of repeat CT if early MRI is performed.

Dating hemorrhages

Dating injuries can be very important to relate radiological findings to the trauma described. In court, this topic is extremely important as it will be of great value to relate the injuries to possible perpetrators that had had contact with the child. However, the scientific base for unconditional statements on dating intracranial pathology based on radiological findings only is not validated. Current knowledge on dating SDHs is primarily based on two studies.[29] These studies, however, were performed in adults suffered from conditions different from AHT and exact timing of the incident was not always known.[30,31] In a clinical setting, the general accepted theory that acute SDH is hyperdense and that older hemorrhage is hypodense on CT is sufficient, as are the temporal changes that have been described on MRI. In the setting of AHT, where a legal procedure is likely to occur, this knowledge is not solid enough. In a study where 29 cases of AHT with a confessing perpetrator were analyzed, in more than half of the cases the shaking was repetitive in a period of weeks or even months. No relation between repetitive shaking and SDH densities was found.[32] Vinchon et al. tried to develop a time scale model for SDHs in children by performing repeat CT and MRI, but their group consisted of 20 children only. Furthermore, there was an overlap between the different time phases, so no firm conclusions can be drawn from their model.[29]

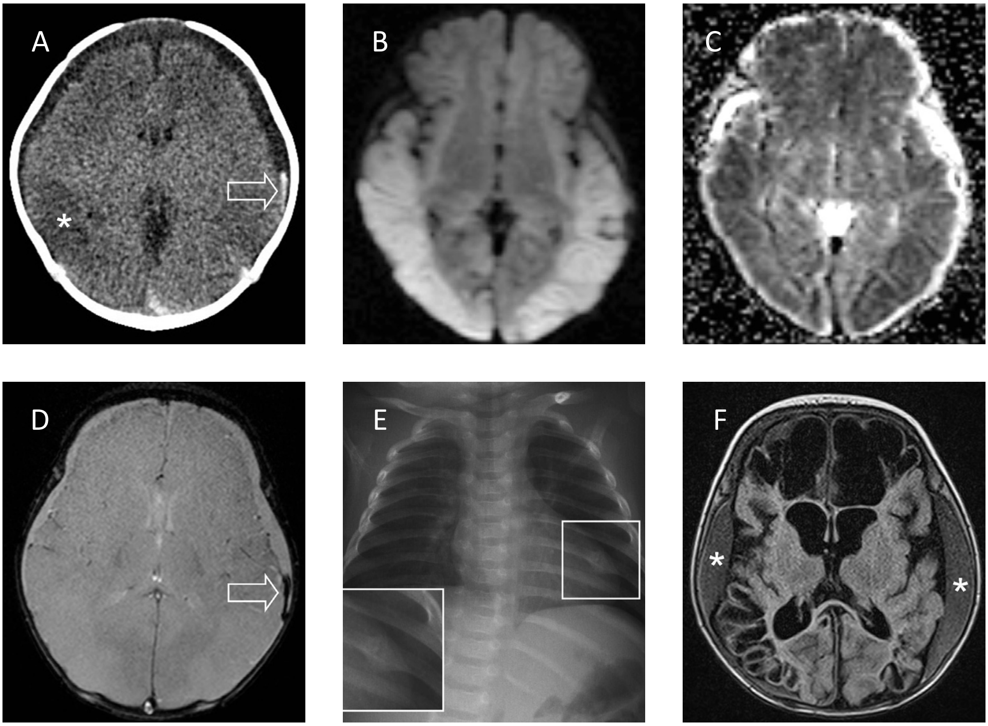

Figure 6a. *A two-year-old girl with a subdural hematoma along the left convexity (arrow) and diffuse ischemia (asterisk), as a result of abusive head trauma.* ***Figure 6b.*** *Diffusion-weighted MRI, obtained on the same day as the MRI, shows extensive temporo-parietal cytotoxic edema as a result of disturbed perfusion (restricted diffusion).* ***Figure 6c.*** *Diffusion-weighted MRI (apparent diffusion coefficient) shows a corresponding decrease in signal intensity.* ***Figure 6d.*** *Blood clot in the subdural hematoma shown on the FLuid Attenuation Inversion Recovery (FLAIR) image. This sequence uses a long T1 in order to suppress the effect of fluid on the images. It can be used to show lesions that are normally obscured by the high signal intensity of fluid.* ***Figure 6e.*** *Chest radiograph obtained three weeks after the incident shows a consolidating posterior rib fracture (see insert). This was not visible on the initial skeletal survey and this shows the importance of a repeat skeletal survey in case of inconclusive findings.* ***Figure 6f.*** *MRI obtained after two months of the incident shows extensive diffuse multicystic encephalomalacia and bilateral subdural hygromas (asterisk).*

Interpretation and reporting

Interpretation of imaging in case of suspected AHT cannot be done without access to complete clinical information. The radiologist should be informed on the trauma mechanism described by caregivers, in order to be able to assess whether this is a plausible explanation for the abnormalities or not. A suspicion of AHT arisen from radiological imaging should be communicated with the clinician immediately, to ensure the child’s safety while other additional investigations can be performed. The final diagnosis of AHT can never be based solely on radiological findings. Other additional findings, medical history, growth curve and risk factors for child abuse all have to be taken into account, in relation with the trauma described by caregivers. A multidisciplinary child abuse and neglect team (CAT) should collect these data and advice the clinician. It is of great value that a (pediatric) radiologist is part of the CAT. Although radiological findings are only part of an extensive workup combining many findings, the radiologist should be aware that radiological findings, and therefore his/her report, can be crucial in the decision to establish the diagnosis of AHT.[33,34] It is not uncommon that the radiological report becomes part of legal proceedings. It is, therefore, essential that the report is objective and that it reflects the level of uncertainty as it is reported in medical literature.[35] The report should state the quality of the study and, in case of the skeletal survey, if performed according to international guidelines. The reporting radiologist should have experience in pediatric radiology and child abuse. In case of doubt, an expert in child abuse should be consulted.

CONCLUSION

AHT is a relatively common cause of neurotrauma in young children with severe consequences. Imaging has an important role in establishing the diagnosis and assessing the prognosis. CT, followed by MRI including DWI, is the best tool for neuroimaging. There is no evidence-based approach for the follow-up of AHT, both repeat CT and MRI are currently used but literature is not conclusive. A full skeletal survey according to international guidelines should always be performed to obtain information on possible underlying bone diseases or injuries suspicious for child abuse. Communication between radiologists and clinicians is extremely important. If there is a suspicion of AHT, this should be communicated with the clinicians immediately in order to arrange protective measures as long as AHT is part of the differential diagnosis. The final diagnosis of AHT can never be based on radiological findings only; this should always be made in a multidisciplinary Child Abuse and Neglect Team where all clinical and psychosocial information is combined and judged by a group of experts in the field.

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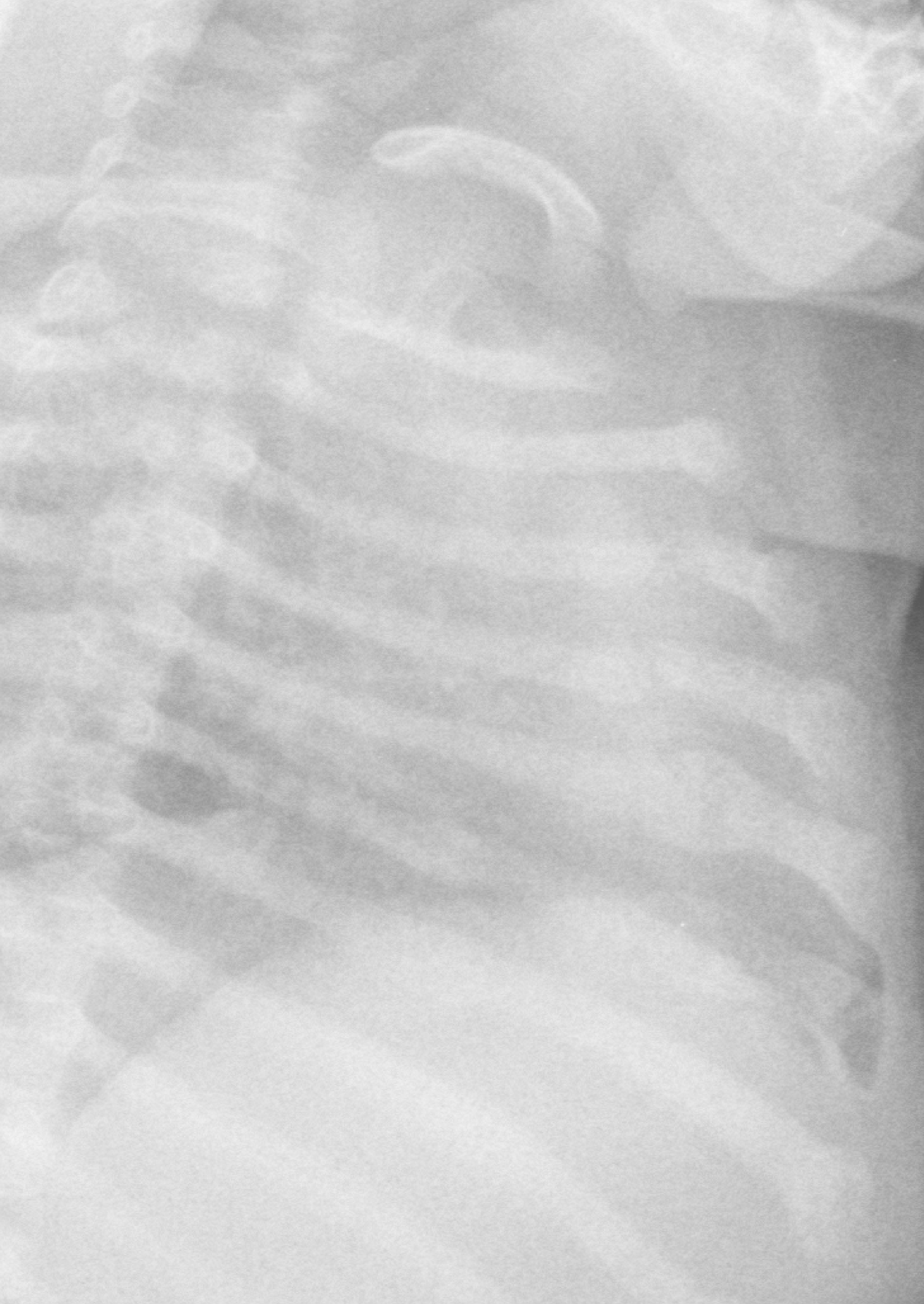

Chapter 4

Abusive head trauma in young children in the Netherlands: evidence for multiple incidents of abuse

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ABSTRACT

We investigated the prevalence of risk factors for and the prevalence of prior abuse in abusive head trauma victims in the Netherlands.

We performed a retrospective file review of all abusive head trauma cases in the Netherlands in which forensic medical expertise was requested by the courts, between 2005 and 2010. Outcome measures were risk factors and indicators for prior abuse.

Eighty-nine cases were included; 62% boys, median age 3.5 months. Impact trauma was found in 48% of cases, with a male perpetrator in 79%. Prematurity, dysmaturity and twins/triplets were found in 27%, 23% and 10% of cases, respectively, maternal age under 20 years in 17%. Of the parents, 60% had completed only primary or secondary education, 38% of the families were known to child welfare authorities. There was evidence for prior abuse in 81% of the cases.

The high number of families with prior abuse indicates that both the healthcare system and child welfare authorities failed to protect some of the children that have been in their care. Our results highlight the importance of training healthcare and child welfare professionals in recognizing physical abuse, as well as the importance of optimizing abusive head trauma prevention strategies.

INTRODUCTION

Abusive head trauma (AHT) is relatively common in childhood with an estimated incidence of 14–41 cases per 100,000 children under the age of 1 year.[1–3] Approximately 15–23% of these children die within days after the incident.[2,3] One-third of the survivors have a good clinical outcome, one-third are mildly handicapped, and one-third become severely handicapped.[1,4,5] Extracranial injuries, for example bruises and fractures, are found in 35–54% and 33–48% of AHT cases, respectively.[1,3] Due to its variable presentations and nonreliable clinical history, AHT is frequently missed by physicians.[6] Studies have described clinical features and radiological findings associated with AHT[7], but social risk factors have been identified for AHT as well (Table 1).[2,8–12] Several studies found that there are multiple incidents of abuse in families in which AHT occurs.[11,13–15] Risk factors, (preventive) healthcare systems and social interventions for families at risk vary among countries. No studies on risk factors for AHT have been performed in the Netherlands. Knowledge about risk factors for AHT will enable healthcare providers to recognize AHT earlier and will help policy makers to improve prevention strategies. We therefore conducted a retrospective file review to gain insight into social risk factors in AHT victims in the Netherlands. We aimed to describe the prevalence of social risk factors and prior abuse in a population of children under five years of age with a forensic diagnosis of AHT.

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Table 1. *Risk factors associated with abusive head trauma*[2,8-12]

Pediatric risk factors	Parental risk factors	Family risk factors
Age younger than 1 year	Young motherhood	Socioeconomic deprivation/poverty
Boys	Mother being unmarried	History of child abuse and neglect
Prematurity	Low education	Previous social service intervention
Multiple birth	Alcohol or drug abuse	
Being the first child	Unemployment	
Minority children	Being enrolled in Medicaid	

METHODS

We performed a retrospective file review of all AHT cases for which the Dutch courts of law requested forensic medical expertise in the period January 1, 2005 to December 31, 2010. We used two inclusion criteria: (1) a diagnosis of AHT confirmed by a forensic physician and (2) children's age under five years. Forensic medical expertise for children in the Netherlands is available in two centres: the Forensic Medical Child Abuse Center (FMCAC, Utrecht) and the Netherlands Forensic Institute (NFI, the Hague). Both institutes provide forensic reports for courts by a physician specialized in forensic pediatrics. A forensic physician evaluates the complete set of medical data (records of the medical evaluation in the clinical setting,

__Table 2.__ Variables and definitions

Variables and outcomes	Definition	Descriptive	Data
Pediatric risk factors			
Age at admission	-	Years, months, days	Numeric
Gender	Male gender	Yes/no	Dichotomous
Prematurity	Born < 37 weeks	Yes/no	Dichotomous
Dysmaturity	Birth weight < 10th percentile	Yes/no	Dichotomous
Multiple birth	Being one of a multiple birth	Yes/no	Dichotomous
Parental risk factors			
Maternal age	At admission	Years, months, days	Numeric
Age father/male caregiver	At admission	Years, months, days	Numeric
Young motherhood	Mother <20 at time of birth	Yes/no	Dichotomous
Marital status	Of mother	Married/living together/ living apart together/ divorced/separated/ other/unknown	Categorical
Single parent	Primary caregiver without partner	Yes/no	Dichotomous
Highest completed education mother	-	primary/secondary/VET[a]/ BSc/MSc/unknown	Categorical
Highest completed education father/ male caregiver	-	primary/secondary/VET[a]/ BSc/MSc/unknown	Categorical
Psychiatric diagnosis mother	-	Yes/no	Dichotomous
Psychiatric diagnosis father	-	Yes/no	Dichotomous
Alcohol/drugs dependency mother	-	Yes/no	Dichotomous
Alcohol/drugs dependency father	-	Yes/no	Dichotomous
Contact with police mother	-	Yes/no	Dichotomous
Contact with police father	-	Yes/no	Dichotomous
Family risk factors			
Number of children in the household	Including the victim		Numeric
Characteristics indicating prior abuse			
Prior suspicion of child abuse in the family	-	Yes/no	Dichotomous
Prior involvement of child welfare authorities	-	None/voluntary youth care/AMK[b]/CPS[c], support/ CPS[c], child placed outside home	Categorical
Custody	Whether this child or a sibling ever had been under state custody	Yes/no	Dichotomous
Contact with health care system	Contact with any health care provider prior to diagnosis of AHT[d]	No contact with hcs[e]/ contact with hcs[e] not suggestive of abuse/ contact with hcs[e] suggestive of abuse	Categorical
Indication of former abuse at medical examination	Indication of prior abuse at medical examination (physical or radiological) at admission	Yes/no	Dichotomous

Table 2. *Variables and definitions*

Variables and outcomes	Definition	Descriptive	Data
Other			
Delay	Unexplained delay	Yes/no	Dichotomous
Time between care and death	-	Days	Numeric
Perpetrator	Suspected perpetrator	Mother/father/new partner of mother/new partner of father/friend of the family/someone else/ unknown	Categorical
Outcomes			
Intracranial injury	-	Yes/no	Dichotomous
Skull fracture	-	Yes/no	Dichotomous
Fractures elsewhere	Any fracture(s) outside the skull	Yes/no	Dichotomous
Injuries of retina	Any retinal injuries	Yes/no	Dichotomous
Injuries outside the head	Both on physical examination and additional investigations	Yes/no	Dichotomous
Injuries during physical examination	-	Yes/no	Dichotomous
Mechanism of trauma	Based on conclusions of forensic physician, categorized as evidence of impact (skull fractures, bruising of the head)	Yes/no	Dichotomous
Outcome	-	No AHT[d] related problems/handicapped/ death/not known at moment of discharge from the hospital	Categorical

[a] VET: Vocational Education and Training; [b] AMK: Child Abuse Counseling and Reporting Center (in Dutch: Advies- en Meldpunt Kindermishandeling); [c] CPS: Child Protection Services; [d] AHT: abusive head trauma; [e] hcs: health care system

past medical care and autopsy reports) and police files, from a forensic point of view. As the verdict of a judge is based on nonscientific information as well as on the forensic report, a diagnosis of AHT established by a forensic physician is considered to be the best reference standard for AHT in the Netherlands. In most cases, imaging studies are reviewed by a pediatric radiologist. Past medical care consists of contacts with the general practitioner (GP), primary healthcare system and hospitals. Police files consist of interrogations of suspects and witnesses, transcripts of wiretaps and all other forensic information collected by the police.

We collected data on social risk factors based on literature and our own experience. Table 2 provides a list of variables and outcomes. Impact trauma was defined as signs of blunt force trauma to the head, for example a skull fracture or scalp bruising. We included five indicators for multiple incidents of abuse; (1) prior suspicion of child abuse in the family, (2) prior involvement of child welfare authorities (3) prior custody measures, (4) prior contact with the healthcare system that could have raised a suspicion of abuse and (5) an indication of prior abuse at medical evaluation. Prior involvement of child welfare authorities included involvement for siblings. Contacts with the healthcare system that could have raised a suspicion of abuse were a prior diagnosis of AHT, injuries without (plausible) explanation, conspicuous trauma history, failure to thrive and neurological problems without explanation. Contacts with the healthcare system not considered to be suggestive for abuse were infections, routine pediatric OPD check-ups after prematurity/dysmaturity and GP/primary care visits due to common questions about nutrition or crying without referral to a pediatrician. Indications for prior abuse at medical evaluation were either findings during physical examination, for example older injuries, or findings during additional investigations, for example fractures with callus. Data were analyzed using IBM SPSS Statistics (Armonk, NY, USA) 19 for Windows. Continuous data were expressed as means and standard deviations or medians and interquartile ranges when appropriate. Missing data were reported for each variable. We did not impute any information to replace missing data.

RESULTS

We identified 89 patients that met the inclusion criteria (Table 3). Median age at admission was 3.5 months (range 8 days–3.25 years). Sixty-two percent were boys (n=55). Types of injuries are provided in Table 2. Twenty-eight percent (n=25) of our study group died, 7% (n=6) had an apparently good outcome at the point of discharge from the hospital, in 25%, (n=22) no prognosis could be given at the point of discharge from the hospital and in 40%, (n=36) some level of handicap was described. These ranged from visual impairment and developmental delay to tetraplegia and tube feeding dependency.

Table 3. Characteristics of the cases included

Variable	Result n (%)[a]	Sample n
Age		
Age at admission	Median =3 .5 months (IQR[b] = 3 months 11 days)	89
Gender		
Male	55 (62)	89
Intracranial injuries		
Yes	84 (94)	89
Skull fracture(s)		
Yes	28 (32)	89
Other fracture(s)		
Yes	37 (42)	89
Retina injury		
Yes	68 (81)	84
Extracranial injuries		
Yes	52 (70)	74
Visible injuries		
Yes	56 (71)	79
Mechanism of trauma		
Impact	43 (48)	89
Outcome		
Deceased Handicapped Good Alive, unknown if handicapped	25 (28) 36 (40) 6 (7) 22 (25)	89
Time between seeking medical care and death		
Days	Median = 2 (IRQ[a] = 26.5)	25[c]

[a] Unless otherwise specified; [b] IQR: interquartile range; [c] this number represents all deceased children

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Table 4. *Social risk factors*

Variable	Result n (%)[a]	Sample n
Gestational age		
Weeks + days	Median = 39 + 1, IQR[b] = 4 weeks 2 days	69
Prematurity		
Yes	20 (27)	74
Dysmaturity		
Yes	19 (23)	73
Twins/ triplets		
Yes	9 (10)	88
Age mother		
Years	Mean = 26.4, SD[c] = 5.9	84
Age father/male caregiver		
Years	Mean = 28.3, SD[c] = 5.8	74
Age mother under 20		
Yes	14 (17)	84
Type of relationship mother		
Married Living together Living apart together Divorced Separated Other	21 (25) 44 (52) 11 (13) 2 (2) 5 (6) 1 (1)	84
Single parent		
Yes	4 (5)	86
Education mother		
Primary Secondary Vocational Bachelor Master	14 (23) 23 (37) 20 (32) 5 (8) 0 (0)	62
Education father/male caregiver		
Primary Secondary Vocational Bachelor Master	12 (22) 20 (37) 18 (33) 4 (7) 0 (0)	54
Psychiatric diagnosis mother		
Yes	19 (21)	89
Psychiatric diagnosis father		
Yes	17 (19)	89
Alcohol/ drugs dependency mother		
Yes	9 (10)	89
Alcohol/ drugs dependency father		
Yes	27 (30)	89

Table 4. Social risk factors

Variable	Result n (%)[a]	Sample n
Contact with police mother		
Yes	5 (6)	89
Contact with police father		
Yes	28 (32)	89
Number of children		
Number of children in the household	Median = 2, IQR[b] = 1	86
Delay		
Yes	53 (60)	86
Perpetrator		
Mother	11 (15)	72
Father	49 (68)	
Boyfriend of mother	8 (11)	
Girlfriend of father	0 (0)	
Friend of family	0 (0)	
Other	4 (6)	

[a] Unless otherwise specified; [b] IQR: inter-quartile range; [c] SD: standard deviation

Table 5. Indicators for multiple incidents of abuse

Variable	Result n (%)	Sample n
Prior suspicion of abuse in the family		
Yes	35 (41)	85
Prior involvement of child welfare authorities		
None	53 (62)	86
Voluntary youth care	4 (5)	
AMK[a]	11 (13)	
CPS[b], support	10 (12)	
CPS[b], child placed outside home	8 (9)	
Custody		
Parents	75 (87)	86
Parents and guardian	8 (9)	
Guardian	3 (4)	
Contact with health care system		
No	20 (27)	73
Yes, not suspicious of abuse	14 (19)	
Yes, suspicious of abuse	39 (53)	
Indication of prior abuse at medical evaluation		
Yes	53 (60)	89

[a] AMK: Child Abuse Counseling and Reporting Center (in Dutch: Advies- en Meldpunt Kindermishandeling); [b] CPS: Child Protection Services

Social risk factors

Social risk factors are listed in Table 4. Prematurity, dysmaturity and twins/triplets were found in 27%, 23% and 10% of the cases, respectively. Young maternal age was found in 17% of cases. The highest completed level of education was primary or secondary school for 60% of the parents. The suspected perpetrator was the father in 68%, the mother in 15% and the new partner of the mother in 11% of the cases. In 19% and 21% of mothers and fathers, respectively, there was information about a psychiatric diagnosis, in 10% and 30% (former), alcohol or drugs dependency were involved and in 6% and 32%, there was a documented history with the police. However, as this information is not part of a standard medical file, underreporting may have occurred.

Multiple incidents of abuse

In 81% of cases, there was evidence of at least one of the indicators for multiple incidents of abuse (Table 5). In 41% of the families, there had been a prior suspicion of abuse, leading to the involvement of child welfare authorities in 38% (Table 6). In six cases, this was due to prior AHT in this child or a sibling. In 82% of the cases, we had information on past medical care. In 72% of the cases, there had been a documented contact with healthcare services. The majority of these presentations (39/73 or 53%) were found to be suggestive of abuse retrospectively (Table 7). In 60% (53/ 89), it was clear from medical data that there had been several incidents (Table 8). If contacts with the healthcare system are omitted, because the outcome bias could have influenced the likelihood of a presentation being classified as being suggestive of abuse, there was still an indication of multiple incidents of abuse in 75% of the cases.

Missing data

Tables 3–5 list the number of cases for which the results were known. Information on the educational level of parents was most commonly missing; this was documented for 70% of mothers and 61% of fathers/male caregivers only.

DISCUSSION

The results of our study show that this Dutch cohort of AHT victims resembles other cohorts that have been described on demographic characteristics, outcome[1–5] and most of the social risk factors.[2,8–12] We found that in the vast majority of cases, there is evidence for multiple incidents of abuse. This is in line with prior studies that describe AHT as mainly a problem in groups of parents with very low education, often known to child welfare authorities.[2,8–12]

Outcome

Due to differences in describing the outcomes of children in medical data, we were not able to classify the types of handicaps. Consequently, the classification in outcomes differs slightly from other publications.[1,4,5] In half of the cases, there was evidence of impact trauma. In the other cases where there was no evidence of impact trauma, these injuries were most probably caused by shaking. However, impact trauma without any visible injuries could not be ruled out. This number of children with impact trauma is higher than in other studies, in which percentages of up to 24 have been found.[15] If visible head injuries are omitted and impact trauma is defined as the presence of a skull fracture only, the number of cases with impact trauma in our study is 32%.

Social risk factors

Some of the social risk factors for AHT that have been identified in other studies are equally overrepresented in our sample as well. Due to the design of the study, we were not able to test the differences between our results and the general population or a control group, but these results give directions for further prospective research. (Ex)premature and dysmature children and children that are part of twins/triplets were found in 27%, 23% and 10% of this sample, respectively, compared to 7.7%[16], 10% and 1.8%[17] in the Dutch population as a whole. Parental age was low compared to the average Dutch parental age; the mean age of mothers and fathers was 26 and 28 years, respectively, whereas the mean age at which women and men in the Netherlands have their first child is 29.4 and 32.4 years.[18,19] As our study group does not contain only first children, and parental age was determined at the point of admission and not at birth, the difference is even larger in reality. Seventeen percent of mothers were under 20 years of age when their child was born, compared to 1.4% in the Netherlands.[20] Parents had a low level of education: 60% completed only primary or secondary school, compared to 26% of individuals aged 25–34 in the Netherlands.[21] The number of single parents and the number of large families were not notably different from the general population in the Netherlands.[22]

Of all known perpetrators, in 79% of cases, this was the father or the mother's new partner. This number of male perpetrators is higher compared to other studies, in which 40–63% has been described.[13,23] We have no explanation for this difference. In 19% of cases where the perpetrator was unknown, this was mainly due to the fact that both parents were present when the child became critically ill, and police interrogations did not reveal who harmed the child. Another group with unknown perpetrators is the group of children with mild symptoms only; as the onset of symptoms could not reliably be determined, many people had been in contact with these children in the period before admission.

Multiple incidents of abuse

Evidence for repetitive abuse has also been found by other researchers[11,13–15] and suggests that parents who are causing AHT seem to have developed a pattern of repetitive abuse. However, we found a higher number of contacts with the healthcare system to be suggestive of abuse; 39/73 or 53%, compared to 8–30% in other studies.[13,24] This may be due to the fact that, not only hospital visits, but also GP and primary care visits were taken into account.

Table 6. Reasons for prior involvement of child welfare authorities

Voluntary youth care
Alarming parenting capacities Support because of inter-partner violence Support for sibling because of parenting problems Support for this child, asked for by parents because of parenting problems
Other Support because of teenage mother
AMK[a]
Injuries/abuse Report because a sibling died because of AHT[b] Report because of burning wound sibling Support because of multiple fractures in baby Report because of hygroma and bruises Report because of extensive bruising Report because of skin lesions sibling and neglect airway infection
Parenting capacities giving cause for alarm Report because both parents mentally disabled Report during pregnancy because of mentally disabled mother Report by grandfather because of concerns about parenting problems
Other Report because of social situation giving cause for alarm Report because of homelessness
CPS[c], support (custody measure)
Injuries/abuse Support because prior AHT[b] in this child (2 cases) Support because of maltreatment siblings (3 cases)
Other Support because of teenage mother (4 cases) Support because of lack of water and electricity
CPS[c]- child placed outside home
Injuries/abuse Child had been placed outside home because of AHT[b], back in the family with support Sibling(s) had been placed outside home because of AHT[b], back in the family with intensive support (2 cases)
Other Sibling(s) placed outside home (5 cases)

[a] AMK: Child Abuse Counseling and Reporting Center (in Dutch: Advies- en Meldpunt Kindermishandeling); [b] AHT: Abusive head trauma; [c] CPS: Child Protection Services

__Table 7.__ Contact with health care system for this child, which could have raised a suspicion of abuse

Type of abuse	Diagnosed as abuse
AHT[a]	
Admission because of AHT[a] (3 children)	Yes
Fractures	
Fracture of radius at age of 4 weeks	No
Nine fractures and bleeding of conjunctiva at age of 2 months	Yes
Bruises	
Sent to pediatrician by AMK[b] for evaluation of extensive bruising	Unclear
ED[c] visit because of bruising of ear at age of 3 weeks	No
GP[d] visit because of swelling lip, admission and OPD check-ups because of extensive bruising	Yes
GP[d] visit because of bruising of the face	No
GP[d] visit because of bruising of ear and red marks on the head	No
Bruising of the legs noticed in primary care at age of 1 month	No
Admission because of cellulitis, hematoma of the head seen during admission	No
Bruising of the face noticed in primary care at age of 2 months	Unclear
Other injuries	
Blood crusts in ears noticed in primary care	No
Circular bite mark, (mis)diagnosed as fungal skin infection in primary care	No
Admission because of vomiting of blood at age of 2 weeks, bruises detected in neck of twin brother during same admission	No
Admission because of blood loss from nose and mouth	No
GP[d] visit because of blood in mouth, unexplained excessive screaming leading to prescription of NSAIDs	No
GP[d] visit because of burning wound thorax at age of 6 weeks	No
Petechiae and edema in the face	No
GP[d] visit because of burn wounds and bruises at age of 6 weeks	Unclear
Admission because of hematoma in mouth at age of 1 month, extensive bruising was found all over body	Unclear
Conspicuous trauma described by parents	
ED[c] visit because of flip-over with baby seat located on the floor, with baby turning the seat upside down herself during the fall, leading to petechiae in her neck at age of 6 months	No
Admission because father fell against a chair carrying the baby	No
ED[c] visit because of fall of baby from changing table at age of 3 weeks	No
GP[d] and pediatrician visit because of fall from stairs or hands (2 different stories) at age of 3 months	No
GP[d]/ED[c] visit 2 times because of fall of baby from couch at age of 5 months, on one of these presentations a hematoma on the abdomen was seen	Unclear
Failure-to-thrive	
Failure to thrive, in combination with sad-looking child and injuries in mouth, noticed in primary care	No
Admission because of failure to thrive	No
Symptoms and signs linked to neurological problems	
Vomiting without a cause, sibling died of AHT shortly before this child was born	No
Admission because of unexplained seizures	No
GP[d] visit because of floppiness, vomiting and low body temperature	No
Admission because of unexplained vomiting and crying	No
Fast-growing head circumference noticed in primary care	No
GP[d] visit because of excessive crying and irritability	No
Admission because of feeding difficulties, hygroma and bruises detected during admission	Yes
Contact pediatrician because of seizure	Yes
Two admissions because of vomiting without a cause	No
PICU[e] admission because of ALTE[f], increased head circumference in primary care	No

[a] AHT: Abusive head trauma; [b] AMK: Child Abuse Counseling and Reporting Center (in Dutch: Advies- en Meldpunt Kindermishandeling); [c] ED: Emergency department; [d] GP: General practitionar; [e] PICU: Pediatric intensive care unit; [f] ALTE: Apparent Life-Threatening Event

Table 8. Indicators for multiple incidents of abuse at medical evaluation

Variable	Result n (%)
Physical examination	
Bite wound, bruises, burn wound (old)	1 (1)
Bruises of different ages	1 (1)
Neuroimaging	
Intracranial pathology (old, known from prior scans), new SDH[a]	2 (2)
Intracranial pathology (known from prior scans), new fractures in different stage of healing	1 (1)
SDH[a] at CT that had been missed at prior evaluation	1 (1)
Hygroma (old, known from prior scans), new SDH[a] and healing fracture	1 (1)
Hygroma with new SDH[a] and fractures in different stage of healing	3 (3)
Hygroma with new SDH[a]	9 (10)
Old bleeding/hygroma	2 (2)
Skeletal survey	
Fractures at different stage of healing	18 (20)
Healing fracture(s)	3 (3)
Autopsy	
Old and new intracranial hematomas	5 (6)
Old and new intracranial and skin hematomas	1 (1)
Old and new intracranial hematomas, fractures at different stage of healing	1 (1)
Old and new intracranial hematomas and healing fracture	1 (1)
Multiple traumatic events	1 (1)
Extensive old and new hematomas	1 (1)
Other	
Bleeding in the eye, old and new	2 (2)

[a] SDH: subdural hematoma

Strengths and limitations

We included all cases in which forensic medical advice was requested by the courts over a period of six years. This is therefore a homogeneous sample, resulting in a high certainty of abuse. To maximize the correct estimation of diagnostic accuracy, we endeavoured to minimize the impact of incorporation bias by selecting those AHT cases confirmed by a forensic physician: the forensic physician does not have a personal relationship with the family and, contrary to the suspicion of abuse raised in a clinical setting, risk factors are not part of the assessment. It has to be noted, however, that the forensic physicians were not blinded for the risk factors, so this could have influenced their conclusion. The fact that this is a selected group also has its limitations; our group does not contain all children diagnosed with AHT in the Netherlands and precourt selection bias could have occurred at three levels. First, it is possible that clinicians are more likely to recognize and report the more severe forms of AHT or AHT in families with risk factors.[25] The Netherlands does not have a mandatory reporting system for cases of suspected child abuse or neglect. If a physician has a suspicion of child abuse or neglect, he can report this to the Child Abuse Counseling and Reporting Center (AMK), part of the Dutch Child Protection Services (CPS).

Although reporting is not required by law, reporting guidelines have been formulated by the Royal Dutch Medical Association.[26] In case of AHT, practically all physicians will report this to the AMK. The AMK can arrange voluntary support, request protective measures from the CPS and/or report the abuse as a crime to the police. The latter is not a standard procedure; the AMK has its own guidelines for reporting a crime to the police.[27] Second, selection bias could occur if the AMK is more likely to report the abuse to the police in severe AHT cases or in families with risk factors. Contrarily, one could argue that the AMK is more likely to report the abuse to the police in cases where both incident and perpetrator are vague, to obtain extra information to protect the child. This could lead to underestimation of risk factors. Third, not all police reports will lead to a forensic report. Whether the public prosecutor starts proceedings and asks for a forensic medical report can be influenced by several, mainly legal, factors. It is unclear in which way this could influence our findings. On average, 14.8 cases per year (13.7 children under the age of 1 year) were referred for forensic medical expertise by the court. Based on birth rates during the study period[28], this results in 7.4 cases per 100,000 children under the age of one. Other international studies reported 14–40 AHT cases per 100,000 children under the age of one. As no Dutch epidemiological data on AHT are available, we can roughly estimate that we are describing 19–50% of all Dutch cases, if the incidence of AHT in the Netherlands is within this internationally reported range. Another limitation is that data were collected retrospectively. Many items we wanted to collect were not documented systematically, resulting in missing data for some variables. We do not expect that this will cause bias in a specific direction, as for example documentation of educational level of parents was probably not influenced by the educational level itself. Therefore, the data are missing completely at random.

Generalizability

We assume that by describing the forensic patient group, we have given a representative overview of risk factors associated with AHT in the Netherlands. Baseline characteristics (age, gender and outcome) are compatible with studies describing clinical samples. We therefore hypothesize that the other variables are comparable with clinical samples as well and that the findings are not merely the result of selection bias. We have no explanation for the overrepresentation of male perpetrators compared to previous studies. However, the results have to be confirmed in a prospective cohort or a case-control study in order to be able to define the predictive value of each of the risk factors.

Implications

This is the first study on social risk factors in AHT in the Netherlands. The same social risk factors that have been found in other studies are overrepresented in this sample as well. Although the risk factors identified in this study need to be confirmed in subsequent studies, they do have implications for the way in which child welfare authorities and healthcare providers deal with AHT.

First, these results underline the need for improvement of the recognition of AHT by both child welfare authorities and the healthcare system. The fact that nearly 40% of the families were known to child welfare authorities has been found by others as well[11] and is alarming. It is even more worrisome because involvement of CPS in the majority of these families was due to severe abuse, for example the demise of a sibling as a result of AHT. As the majority of the healthcare presentations (39/73 or 53%) were found to be suggestive of abuse retrospectively, this suggests that healthcare providers in the Netherlands are not adequately trained in recognizing child abuse. Either the healthcare system does not recognize that the signs and symptoms are caused by trauma, or it does not recognize that the trauma is abuse, or it does not appreciate the severity of the abuse. Implementing the topic of child abuse in the medical curriculum is an issue that is currently being discussed in the Netherlands. These results show that this topic should remain high on the agenda: particular attention should be paid to the fact that injuries in nonambulatory children are proof of trauma, and if no adequate trauma is described, child abuse needs to be high in the differential diagnosis.

Second, the results can be used to develop or improve AHT prevention projects. Studies on the effect of AHT prevention projects are conflicting.[29,30] In the Netherlands, no AHT prevention project has yet been implemented. These results indicate that it may not be necessary to address information on the negative effects of shaking to the whole parental population, but it could be addressed to a selection of families at increased risk. Further research is needed to determine the predictive value of each of the risk factors to develop targeted prevention programmes. International prevention programmes mainly reach (pregnant) women[29], although in our study the suspected perpetrator was the male caregiver in 79% of all cases. In addition, we found evidence for impact trauma in half of the AHT cases. Although we do not doubt that shaking alone can cause intracranial injury, other forms of violence should be covered in prevention programmes as well. Secondary prevention of AHT in families already known to child welfare agencies is essential, as the high number of families known to child welfare agencies is consistent with prior publications[11], and involvement is due to severe forms of abuse.

In conclusion, future research is needed to identify risk factors for AHT in a prospective cohort or case-control design, in order to predict which children are at risk of sustaining AHT. Effective strategies for both primary and secondary prevention and identification of AHT are needed.

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Chapter 5

Abusive head trauma: differentiation between impact and non-impact cases based on neuroimaging findings and skeletal surveys

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ABSTRACT

To determine whether imaging findings can be used to differentiate between impact and non-impact head trauma in a group of fatal and non-fatal abusive head trauma (AHT) victims.

We included all AHT cases in the Netherlands in the period 2005–2012 for which a forensic report was written for a court of law, and for which imaging was available for reassessment. Neuroradiological and musculoskeletal findings were scored by an experienced pediatric radiologist.

We identified 124 AHT cases; data for 104 cases (84%) were available for radiological reassessment. The AHT victims with a skull fracture had fewer hypoxic ischemic injuries than AHT victims without a skull fracture (p=0.03), but the relative difference was small (33% vs. 57%). There were no significant differences in neuroradiological and musculoskeletal findings between impact and non-impact head trauma cases if the distinction between impact and non-impact head trauma was based on visible head injuries, as determined by clinical examination, as well as on the presence of skull fractures.

Neuroradiological and skeletal findings cannot discriminate between impact and non-impact head trauma in abusive head trauma victims.

INTRODUCTION

Background

Abusive head trauma (AHT) is defined by the American Academy of Pediatrics as an inflicted injury to the head and its contents, including those injuries caused by both shaking and blunt impact.[1] Imaging plays an important role in establishing the diagnosis of AHT. In the absence of any other plausible explanation, the diagnosis in most cases is based on clinical and radiological findings associated with abuse.[2-4] The radiological findings are both intracranial findings on CT or MRI and fractures found with conventional radiographs. Furthermore, retinal hemorrhages can be diagnostic of AHT[5] and bruises on the body have been found in 35% of the cases.[6] Neuroradiological findings associated with AHT have recently been described in two systematic reviews that compared AHT and non-AHT patients.[4,7] The study by Kemp et al. analyzed 21 studies, focusing specifically on neuro-imaging. They found subdural hematomas (SDHs) (OR 8.2), multiple SDHs (OR 6), SDHs over the convexity (OR 4.9), interhemispheric SDHs (OR 9.5), posterior fossa SDH (OR 2.5), hypoxic-ischemic injury (OR 3.7) and cerebral edema (OR 2.2) to be significantly associated with AHT.[4] The systematic review by Piteau et al. looked for a wider range of radiological findings. They describe 24 studies, of which 17 are also described by Kemp et al. They found SDHs (OR 8.9), cerebral ischemia (OR 4.8) and cerebral edema (OR 2.2) to be associated with AHT. However, these reviews do not evaluate the difference between impact and non-impact AHT. Skeletal survey reveals new information in 11% of all children evaluated for possible physical abuse.[8] In the same study, however, children evaluated for possible AHT had positive skeletal surveys in 23% of the cases. In other studies, the number of positive skeletal surveys in AHT victims ranges between 9 and 50%, depending on inclusion criteria, e.g. whether the skeletal surveys are obtained during life or postmortem.[9,10]

Objectives

Although it is widely recognized that AHT can be caused by either shaking or impact head trauma or a combination of both, in the individual patient the cause of the injury is often unknown without a confessing perpetrator.[11] Unfortunately, there is no tool yet for such differentiation. If we would be able to differentiate between non-impact and impact head trauma, we would overcome the need for confession or a witnessed assault. Knowing what happens exactly at the moment a caregiver severely harms a child can help to both improve the treatment for the perpetrator as the development of prevention projects. Furthermore it can help in formulating a charge against the accused. As imaging findings are the cornerstone for the diagnosis of AHT, we tried to determine whether imaging findings can be used to differentiate between non-impact (shaking) and impact head trauma. We conducted a retrospective cohort study in which we describe the neuroradiological findings associated with AHT[4,7] and the number and type of fractures in AHT victims in the Netherlands. The aim of this study is to investigate whether there is a difference in imaging findings between children with and without impact head trauma, defined as the presence of skull fractures or visible head injury upon clinical examination.

MATERIALS AND METHODS

We performed a retrospective file review of all AHT cases for which the Dutch courts of law requested forensic medical expertise in the period 1-1-2005–31-12-2012. We used three inclusion criteria: (1) a diagnosis of AHT confirmed by a forensic physician, (2) children's age under five years and (3) imaging available for reappraisal by a pediatric radiologist with experience in child abuse (RR or SR). Forensic pediatric medical expertise in the Netherlands is only available in two centres: the Forensic Medical Child Abuse Centre (FMCAC, Utrecht) and the Netherlands Forensic Institute (NFI, The Hague). Both Institutes provide forensic reports for courts, performed by a physician specialized in forensic pediatrics. A forensic physician evaluates the complete set of medical data (records of the medical evaluation in the clinical setting, past medical care and autopsy reports) and police files, from a forensic point of view. As the verdict of a judge, besides the forensic report, is based on non-scientific information as well, a diagnosis of AHT established by a forensic physician is considered to be the most objective and best reference standard for AHT in the Netherlands. Past medical care consists of contacts with the general practitioner, the primary health care system and hospitals. Police files consist of interrogations of suspects and witnesses, transcripts of wire-taps and all other forensic information collected by the police.

We collected variables describing demographic characteristics, mechanism of injury, outcome and type of imaging performed. The independent variable, mechanism of injury, was defined as evidence for impact head trauma in two different ways: (1) a skull fracture was present, and (2) other (non-radiological) signs of blunt force trauma to the head were documented, e.g. bruising or swelling of the soft tissue of the head. The last category also includes children with a skull fracture. This way of classification does not rule out that children who underwent impact trauma but did not sustain a skull fracture or other signs of blunt-impact trauma to the head were classified as no evidence for impact trauma. A detailed list of dependent variables, intracranial injuries, was collected, based on two recent systematic reviews describing imaging findings associated with AHT (Table 1). Variables collected for the skeletal survey were whether the skeletal survey was performed according to the American College of Radiology (ACR) or the Royal College of Radiologists (RCR) guidelines, and the number and type of fractures including the number of classic metaphyseal lesions (CMLs). We included CT and MRI images obtained when the children were alive because several neuroradiological features will change after demise. Postmortem skeletal surveys were included. A bilateral SDH over the convexity was classified as one SDH. Focal parenchymal injury was defined as intraparenchymal hemorrhage or brain contusion. Closed head injury was defined as any intracranial injury without skull fracture. Only fractures of which the radiologist was certain they were present were included. Findings considered to be 'suggestive of' fractures were omitted, unless they were proven to be a real fracture during follow-up skeletal survey or autopsy. All images were reassessed by a pediatric radiologist (either RR or SR) with extensive experience with pediatric forensic cases. All studies were available in an electronic form.

Table 1. *Intracranial injuries in children with and without a skull fracture and children with and without signs of impact AHT[g].*

Variable, *n* group	Descriptive	All, 99	Skull fracture, 30	No skull fracture, 69	*p*	Signs of impact AHT[g], 54	No signs of impact AHT[g], 45	*p*
SDH[a] (including hygroma)	*n/n* group	86/99	23/30	63/69	0.06[f]	45/54	41/45	0.3
	(%)	(87)	(77)	(91)	-	(83)	(91)	-
Number of SDHs[a]	Median	2	2	2	0.3	2	2	0.3
	(IQR)	(1–3)	(0.8–3)	(1–3)	-	(1–3)	(1.5–3)	-
Multiple SDHs[a]	*n*	66/99	18/30	48/69	0.4	32/54	34/45	0.09
	(%)	(67)	(60)	(70)	-	(59)	(76)	-
Bilateral SDHs[a]	*n*	56/99	15/30	41/69	0.4	26/54	30/45	0.06
	(%)	(57)	(50)	(59)	-	(48)	(67)	-
SDH[a] convexity	*n*	75/99	20/30	55/69	0.2	37/54	38/45	0.07
	(%)	(76)	(67)	(80)	-	(69)	(84)	-
SDH[a] inter-hemispheric	*n*	56/99	15/30	41/69	0.4	32/54	23/45	0.6
	(%)	(57)	(50)	(59)	-	(59)	(53)	-
SDH[a] posterior fossa/ infratentorial	*n*	11/99	2/30	9/69	0.5[f]	3/54	8/45	0.05
	(%)	(11)	(7)	(13)	-	(6)	(18)	-
SAH[b]	*n*	30/99	10/30	20/69	0.7	19/54	11/45	0.3
	(%)	(30)	(33)	(29)	-	(35)	(24)	-
EDH[c]	*n*	1/99	1/30	0/69	0.3[f]	1/54	0/45	1.0[f]
	(%)	(1)	(3)	(0)	-	(2)	(0)	-
Number of EDHs[c]	Median	0	0	0	0.1	0	0	0.4
	(IQR)	(0–0)	(0–0)	(0–0)	-	(0–0)	(0–0)	-
Number of extra-axial hemorrhages	Median	2	2	2	0.6	2	2	0.7
	(IQR)	(1–3)	(0.8–3)	(2–3)	-	(1–3)	(2–3)	-
Hypoxic ischemic injury/ cerebral ischemia	*n*	49/99	10/30	39/69	0.03	25/54	24/45	0.5
	(%)	(50)	(33)	(57)	-	(46)	(53)	-
Cerebral edema	*n*	77/99	23/30	54/69	0.9	41/54	36/45	0.6
	(%)	(78)	(77)	(78)	-	(76)	(80)	-
Focal parenchymal injury[d]	*n*	13/99	7/30	6/69	0.06[f]	9/54	4/45	0.3
	(%)	(13)	(23)	(9)	-	(17)	(9)	-
Diffuse axonal injury	*n*	9/99	2/30	7/69	0.7[f]	4/54	5/45	0.7[f]
	(%)	(9)	(7)	(10)	-	(7)	(11)	-
Closed head injury[e]	*n*	67/99	-	-	-	-	-	-
	(%)	(68)	-	-	-	-	-	-

[a] SDH: Subdural hematoma; [b] SAH: Subarachnoid hematoma; [c] EDH: Epidural hematoma; [d] Intraparenchymal hemorrhage or brain contusion; [e] Intracranial injury without skull fracture; [f] Nominal data are tested with Pearson's Chi square. If the expected values in any of the cells of a contingency table was below 5, a Fisher's exact test was used. These outcomes are marked; [g] AHT: Abusive Head Trauma

This study was not subject to medical ethical review, as it is a retrospective study and according to Dutch law no Institutional Review Board approval is required for retrospective studies in which patients are described anonymously and do not have to change their behavior in any way.[12] Data were analyzed using IBM SPSS Statistics 19 for Windows. Continuous data were expressed as means and standard deviations or medians and interquartile ranges (IQR) when non-normally distributed, demonstrated with a Kolmogorov–Smirnov test. Differences between groups were tested with Chi square for dichotomous data, Mann–Whitney U test for numeric data because of non-normal distribution, Pearson's Chi square for nominal data and Fisher's exact test for nominal data when the expected values in any of the cells of a contingency table was below five.

RESULTS

In the period 2005–2012, 124 reports diagnosing AHT had been written for the law courts. In 104 of these cases (84%) radiological information was available for reassessment. There were 73 boys (70%) and 31 girls (30%), median age at admission was 91 days (range 8 days–3 years 7 months). Ninety-nine of the 104 children (95%) had intracranial injury, 34/104 had one or more skull fractures (33%) and 43/104 (41%) had one or more fractures elsewhere. Twenty-seven of the 104 children (26%) died, 11/104 (11%) had a good outcome, 34/104 (33%) were disabled and for 32/104 (31%) no prognosis could be given based on medical information in the forensic report.

Neuroimaging

In 99/104 children (95%) neuro-imaging available for reassessment (CT and/or MRI) had been performed while they were alive. In 83/99 children (84%) at least 1 CT was performed; in 47 children 1 CT was performed, in 19 children 2 CTs, in 10 children 3 CTs, in 5 children 4 CTs, in 1 child 6 CTs and in 1 child 8 CTs. In 53/83 children (64%) the first CT was made on the day of admission. In two children, the CT was made eight and nine days respectively before admission, and the diagnosis of AHT was established retrospectively. In the other children, the range of days on which the first CT was performed was 1–25 days. In 71/99 children (72%), at least 1 MRI was performed; in 52 children, 1 MRI was performed, in 10 children 2 MRIs, in 7 children 3 MRIs, in 2 children 5 MRIs. In 9/71 children (13%), the first MRI was made on the day of admission; in 20/71 children (28%) the MRI was performed on the next day. In the other children, the range of days on which the first MRI was performed was 2–49 days.

Intracranial injuries

Intracranial injuries described in the 99 included cases in which neuro-imaging was available are presented in Table 1. In the group with skull fractures, the number of patients with hypoxic ischaemic injury was significantly lower (33% vs. 57%, OR 0.39, 95%CI 0.16–0.94, p=0.034). If the distinction between impact and non-impact head trauma cases was based on skull fracture and/or other signs of blunt force trauma to the head, no significant differences in any of the variables were found.

Skeletal survey

In 98 children (94%), a skeletal survey was performed and available for reassessment. Fifty-five skeletal surveys (56%) were performed according to international guidelines; in 43 cases (44%), one or more images were missing.

Fractures

Fifty-six children (57%) had one or more fractures, 42 children (43%) had no fractures. In total, 254 fractures were identified with skeletal surveys. The median number of fractures for the whole group was 1 (IQR 0–3), with a maximum of 28 fractures. The median number of fractures for the children with at least 1 fracture was 3 (IQR 1–5.8). The number and distribution of the fractures in these 56 children is provided in Fig. 1.

Of all children who had a skeletal survey (n=98), there was no significant difference in the number of coexisting fractures elsewhere in the skeleton between children with (n=30) and without (n=68) a skull fracture (p=0.8). In all children who had a skeletal survey with at least one non-skull fracture (n=36), there was no significant difference in number of coexisting fractures elsewhere in the skeleton between children with and without a skull fracture (p=0.8). There was no significant difference in the number of CMLs between children with and without a skull fracture, neither for the whole group of children who had a skeletal survey (p=0.9) nor for the children with at least one coexisting fracture elsewhere in the skeleton (p=0.8). In children in whom fractures elsewhere in the skeleton were present, there was no significant difference in the distribution of coexisting fractures between children with and without a skull fracture (p=0.6).

Of all children who had a skeletal survey (n=98), there was no significant difference in the number of coexisting fractures elsewhere in the skeleton between children with (n=54) and without (n=44) signs of an impact head trauma (p=0.7). In all children who had a skeletal survey with at least one non-skull fracture (n=36), there was no significant difference in the number of coexisting fractures elsewhere in the skeleton between children with and without signs of an impact head trauma (p=0.9). There was no significant difference in the number of CMLs between children with and without signs of an impact head trauma, neither for the whole group of children who had a skeletal survey (p=0.9) nor for the children with at least one coexisting fracture elsewhere in the skeleton (p=0.5). In children in whom fractures elsewhere in the skeleton were present, there was no significant difference in the distribution of coexisting fractures between children with and without signs of impact head trauma (p=0.5).

DISCUSSION

To the best of our knowledge, this is the first study to investigate the difference in radiological features, both in neuroimaging and conventional radiographs, between impact and non-impact AHT cases. Differences in neuroimaging between AHT and accidental head injury have been described in several recent articles.[4,7] SDHs in particular, including their number and location, proved to be associated with AHT. In our study, except for hypoxic-ischemic injury, neither SDH appearance nor other brain injuries reported to be characteristic for AHT are different between impact and non-impact head trauma cases. If the distinction between impact and non-impact head trauma is solely based on the presence or the absence of skull fractures, we found that only hypoxic-ischemic injury was seen significantly more frequently on neuroimaging in patients without skull fractures. Although significant, the relative difference in the proportions between the two groups is small and cannot be used to discriminate between impact and non-impact head trauma in clinical practice. The difference disappears when the definition of impact head trauma is extended to other external injuries of the head as well. An explanation might be that impact forces causing a fracture are partially absorbed by the skull (resulting in a fracture), leaving less kinetic energy to damage the brain. There was no difference in the number and location of co-existing fractures in the skeleton between impact and non-impact head trauma cases and this can therefore not be used to differentiate between the different forms of violence.

An explanation for the homogeneity among impact and non-impact head trauma cases is the possibility of infliction of both forms of violence (shaking and impact head trauma) in the majority of the cases. As AHT has for a long time been, and in many court proceedings still is, called ‘shaken baby syndrome’, it is possible that doctors and police officers question suspects mostly about shaking. Furthermore, it is possible that shaking is regarded to be less violent and therefore more easily confessed to, compared to impact violence e.g. hitting, kicking or throwing. It might be possible that in many cases the violence starts with shaking, as described by Adamsbaum[11], and ends with a final impact head trauma. If this is the case, for many AHT victims both forms of violence are applied and our distinction, based on the presence of a skull fracture or visible injury, might not correctly identify all impact head trauma cases.

Strengths and limitations

We describe a relatively large group of AHT cases, in which all diagnoses are confirmed by an independent forensic physician who does not have a personal relationship with the parents. This is therefore a homogenous group with a high certainty of abuse. As this is a retrospective study of all cases in the Netherlands, radiological data were obtained from different hospitals using different protocols. Therefore, and because imaging is performed based on clinical characteristics, there was low uniformity in the number of CT and MRI scans and adherence to skeletal survey protocols. This could have resulted in certain neuroradiological features or fractures being underestimated. For example, diffuse

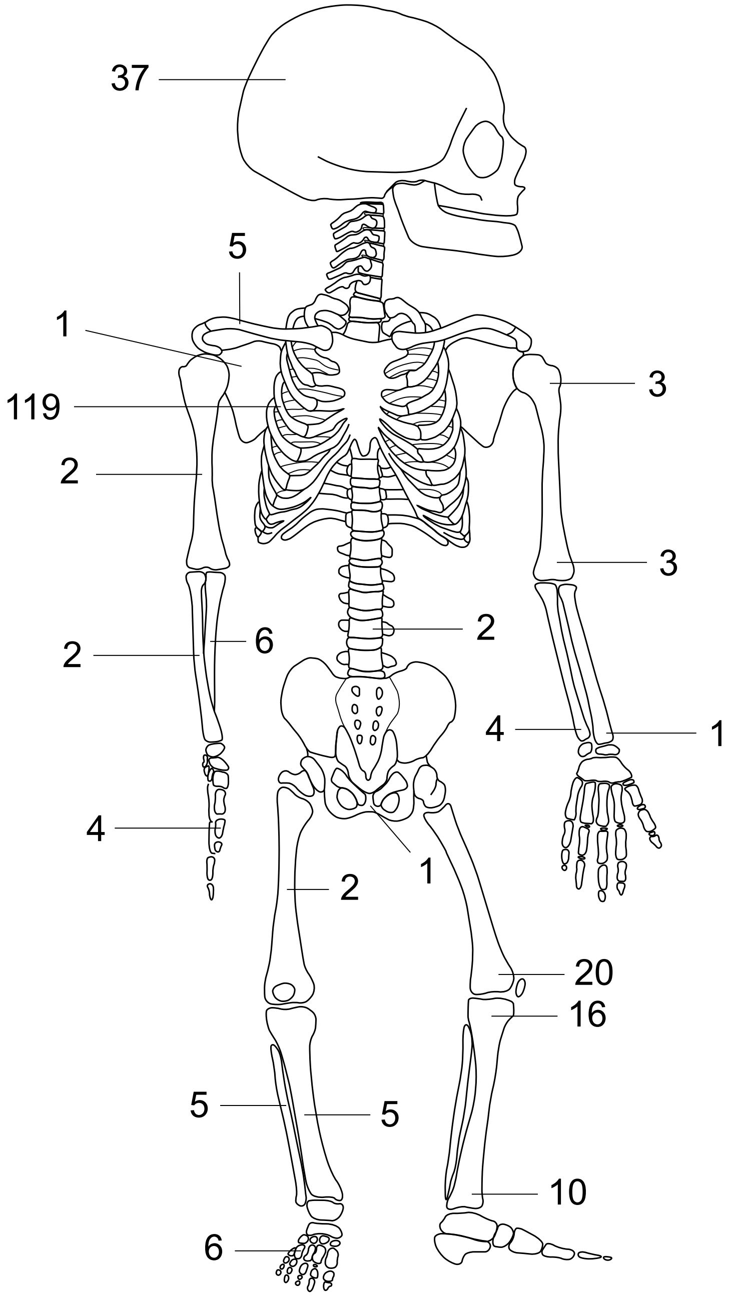

Figure 1. *Distribution of 254 fractures in 56 AHT cases Numbers shown are the total number fractures of both left and right side, the sides on which the numbers are displayed are randomly chosen*

axonal injury is best detected by means of susceptibility weighted imaging sequences[13], but this is not a routine sequence in daily clinical practice in the Netherlands and it could therefore be under detected in this study. However, this problem would probably cause an underestimation of all parameters described and would not cause a biased underestimation in any of the subgroups. Therefore we think the results describing the differences between impact and non impact head trauma are generalizable to other populations as well. Another limitation of this study is the fact that we do not know the exact trauma mechanism, including intensity and frequency. We classified our groups on the presence of skull fractures or other external head injuries. However, we do not know how well this correlates with the true cause of the injury.

CONCLUSION

In patients with AHT, skull fractures and traumatic soft tissue changes of the skin of the head are indicative (or direct proof) of impact head trauma. We found that other neuroradiological and skeletal imaging findings are not of additional value in discriminating between impact and non impact head injury as these differences were non-existent or too small for a radiological distinction. The question about the origin of the injury in AHT can therefore at the present time not be answered by the radiologist. The low uniformity in type of imaging performed in this retrospective series, underlines the need for evidence-based imaging guidelines in (suspected) AHT.

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Chapter 6

Age determination of subdural hematomas with CT and MRI: a systematic review

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ABSTRACT

To systematically review the literature on dating subdural hematomas (SDHs) on CT and MRI scans.

We performed a systematic review in MEDLINE, EMBASE and Cochrane to search for articles that described the appearance of SDHs on CT or MRI in relation to time between trauma and scanning. Two researchers independently screened the articles, assessed methodological quality and performed data extraction. Medians with interquartile ranges were calculated. Differences were tested with a Mann-Whitney U or Kruskal Wallis H test.

We included 23 studies describing 1070 SDHs on CT and 5 studies describing 126 SDHs on MRI. Data from 17 studies (413 SDHs) could be pooled. There were significant differences between time intervals for the different densities on CT ($p<0.001$). Time interval differed significantly between children and adults for iso- and hypodensity ($p=0.000$) and hyperdensity ($p=0.046$). Time interval did not differ significantly between abused and non-abused children. On MRI, time intervals for different signal intensities on T1 and T2 did not differ significantly ($p=0.108$ and $p=0.194$ respectively).

Most time intervals of the different appearances of SDHs on CT and MRI are broad and overlapping. Therefore CT or MRI findings cannot be used to accurately date SDHs.

INTRODUCTION

Abusive head trauma (AHT) is a severe form of inflicted neurotrauma with a mortality rate around 20%[1,2] and severe long-term consequences for the survivors.[3-5] Subdural hemorrhages (SDHs) are identified in 80% of cases.[6,7] The presence of an SDH in young children is highly associated with AHT compared to accidental trauma.[8] Radiology is an important tool to diagnose AHT, as history provided by parents/caretakers is in many cases lacking or unreliable. One important theme, especially in police investigations and legal proceedings, is the timing of the injury. In children, a discrepancy between clinical information and the radiological report can raise a suspicion of AHT. Furthermore, the age determination of an SDH can lead to the identification of a suspect. Four appearances of SDH are distinguished on CT: hypo-, iso- and hyperdense and mixed density. It is assumed that SDHs follow a general evolution in time, starting hyperdense on CT, becoming isodense and finally over time becoming hypodense.[9-11] On MRI it is assumed that SDHs start hypo- or isointense on T1, become hyperintense after two to three days and finally become iso- or hypointense after a few weeks. On T2, SDHs start hyperintense, become hypointense, followed by a high signal intensity after one to two weeks, and finally become hypo- or hyperintense.[12] These data are mainly based on temporal evolution of other intracranial hemorrhages, but others have found that temporal evolution of SDHs is not identical.[13,14]

Furthermore, little is known about the temporal aspects of SDH evolution in children[15-17], or differences between the appearance of SDHs in adults and children. Therefore, dating SDHs should be done cautiously. In our tertiary referral centre we noticed, both in a clinical as well as in a forensic setting, a practice variation among radiologists from different hospitals regarding dating of SDHs. Where some radiologists do not date at all, others date up to days or even hours specific. If studies describing time between trauma and the appearance of SDH on CT or MRI are combined, this could provide an insight into the temporal evolution of SDHs and enhance uniform reporting among radiologists. The purpose of our study was to describe the relationship between the time interval between trauma and scanning and the appearance of SDHs on CT and MRI scans, based on a synthesis of all original publications on this subject. We therefore performed a systematic review to address the following research questions. (1) Does the time interval between trauma and scanning differ between the four different SDH appearances on CT? (2) Does the time interval between trauma and scanning differ between the four different SDH appearances on MRI? (3) Do these time intervals differ between children and adults? (4) Do these time intervals differ between AHT and non-AHT cases in children?

MATERIALS AND METHODS

Search strategy

We systematically searched the MEDLINE (through Pubmed), EMBASE (through OvidSP) and Cochrane electronic databases for articles and abstracts published up to 1-11-2013 using indexed search terms for MRI, CT, intracranial hemorrhage, and subdural hematoma.

A detailed search strategy can be presented upon request. There was no restriction on date of publication, as although over time scanners have improved, the appearance of SDHs on CT is not likely to have changed. There was no language restriction. Studies were not excluded based on publication status. We hand-searched the reference lists of the articles included and performed citation tracking (in Web of Science or Google Scholar) to identify other potentially relevant articles. Furthermore, several key authors and experts in the field were approached and asked if they knew of any relevant studies in this area. In addition, the most commonly used textbooks on imaging, including neuro-imaging, and/or child abuse in the Netherlands were searched for information on dating SDHs.

Study selection

Two reviewers (FP and TS) independently screened all search hits for eligibility. Full text versions of potentially eligible articles were obtained (and translated if necessary) for further evaluation. Studies were included if all of the following inclusion criteria were met: (1) human study objects; (2) CT and/or MR imaging was performed; (3) SDH was present; (4) time between trauma and imaging was reported; (5) density or intensity of the SDH was reported. Studies were excluded if: (1) only one patient was described or met the inclusion criteria; (2) contrast enhanced imaging was used; (3) an intervention had been performed before imaging; (4) structural anomalies of the brain were present; (5) study objects were premature at the time of scanning. In the event of disagreement between the reviewers, a third reviewer (RR) was consulted.

Quality assessment

Two reviewers (FP and TS) independently assessed the methodological quality of the articles included using an adapted version of the Newcastle-Ottawa Scale (NOS).[18] This scale is developed to assess the methodological quality of cohort studies, and consists of 9 items. Three of the items included statements about a control group; these items were omitted since the studies included did not involve a control group. We used three articles on another type of hematomas for piloting to enhance uniform utilization of the adapted NOS among the reviewers.

Data extraction

Two reviewers (FP and TS) independently extracted data from the studies included, by using a structured case report form. Disagreement was solved by consensus. If no consensus was reached, a third reviewer (RR) was consulted. We extracted the following characteristics:

- *Study design and patient characteristics:* country, period, setting, type of imaging performed, number of patients with SDH, age and gender.
- *Imaging characteristics:* basic technical characteristics (CT and MRI), slice thickness (CT), and MRI sequences (MRI).
- *Characteristics of SDH:* density (CT) or intensity (MRI) of the SDH. For CT studies this was either density expressed in Hounsfield Units (HUs) or categorized as hyperdense, isodense,

hypodense or mixed density. We categorized the studies providing HUs in the above mentioned categories, to be able to perform a pooled analysis. SDHs with a density below 23 HU were considered to be hypodense, SDHs between 23 and 41 HU isodense and SDHs with a density of more than 41 HU hyperdense.[19] For MRI studies, the signal intensity of the SDH (expressed as hyperintense, isointense, hypointense or mixed intensity) was recorded. We only included studies that reported density/intensity in text, tables or figures; we did not extract data from CT or MRI images. In the case of sedimentation, we recorded the sediment instead of the supernatant, based on a study by Vinchon.[17] If multiple SDHs were reported for one patient, we extracted data for all SDHs.

- *Time between trauma and scanning:* the time between trauma and imaging was recorded in days. The onset of symptoms in spontaneous SDH was not considered to be a reliable determining factor for the moment of origin of SDH. These cases were excluded. If a patient was scanned shortly after trauma, and no interval was presented, we set the time interval at two hours. If a SDH was considered to be older than a certain date, we chose the stated minimum date (e.g. time interval of >40 days was analyzed as 40 days).

Statistical analysis

For the studies providing individual patient data, we performed a pooled analysis. We recorded density or intensity of the SDHs in combination with the time in days between the onset of the SDH and scanning in IBM SPSS Statistics 19. Normality was assessed using the Kolmogorov-Smirnov test. Medians with interquartile ranges (IQR) were calculated for all time intervals, as data were non-normally distributed. Differences between different subgroups were tested with a Mann-Whitney U test for two groups and a Kruskal Wallis H test for more than two groups. For the studies not providing individual patient data, we extracted the time interval for each density/intensity for the whole group. These data were presented in the measure they were presented in the original article.

RESULTS

Study identification

We included 23 studies describing densities of SDHs on CT (1070 cases)[9-11,15-17,20-36] and 5 studies describing intensities of SDHs on MRI in 126 cases.[17,22,36-38] Three studies described both CT and MRI data, meaning that in total 25 studies were included. The flow chart of study selection is illustrated in Figure 1. Study characteristics of the studies included are described in table 1. (Table 1 can be found at the end of this paper.)

Study quality

All studies included in this review were retrospective or prospective observational cohort studies. None of the studies defined a control group. The mean score of the studies was four out of six points on the adapted NOS, see table 2. (Table 2 can be found at the end of this paper.) The most common methodological problem was, as expected, that none of the included studies could demonstrate that the outcome of interest (SDH) was not already present before the trauma.

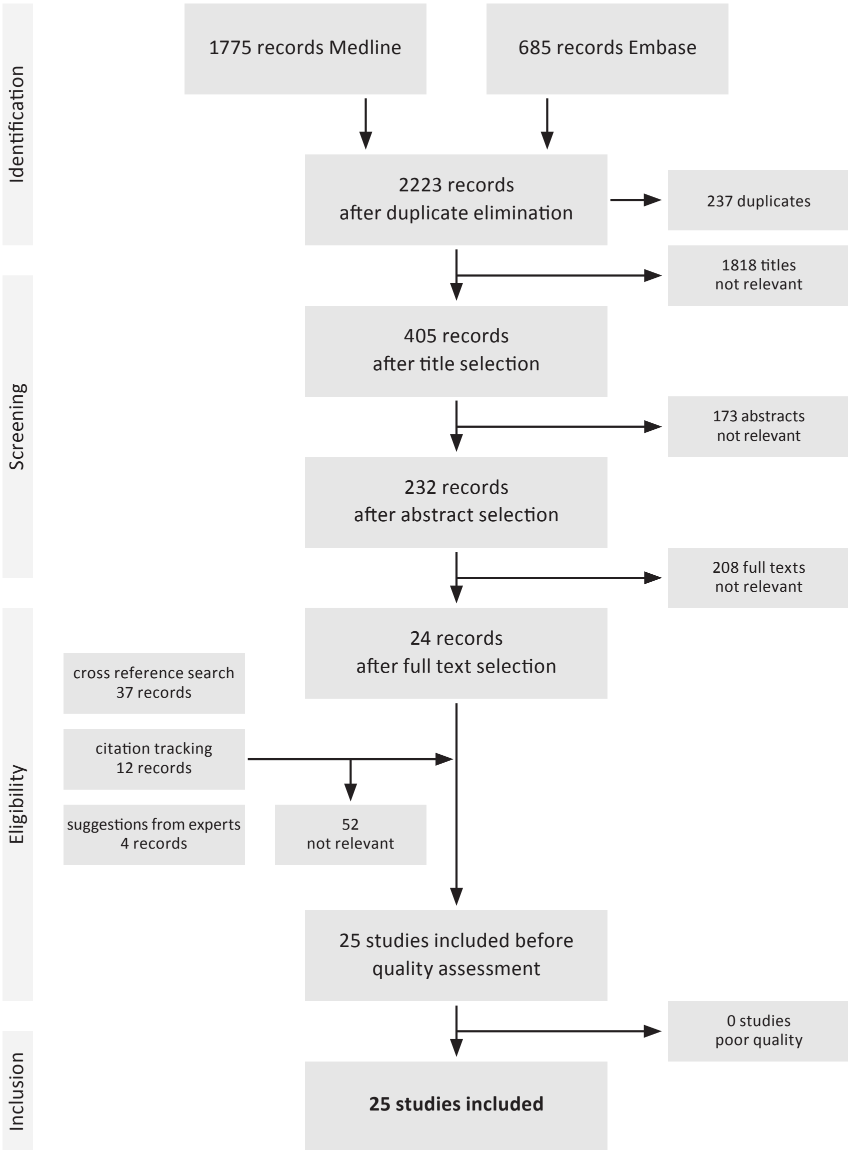

Figure 1. *Flow diagram of study selection*

Densities and time intervals between trauma and scanning on CT

All studies

Data of 17 studies describing 413 SDHs did provide information at individual level and could be pooled.[9,15,17,20,22-24,26-35] There were significant differences between the median time intervals (IQR) for the different densities (p<0.001) (Table 3). The main differences were between hyper and mixed density both appearing significantly earlier than iso- and hypodensity. Studies describing the temporal evolution of SDH that did not provide information at individual patient level report values close to our pooled estimates (Table 4).[10,11,16,21,25,36] One exception is a study by Lee et al, which reports isodense SDHs after a mean time interval of 5 days, with a maximum of 140 days.[25]

Differentiation by age group:

Of the 17 pooled studies, 15 described the age or age group of 339 cases. Of the 339 cases, 148 related to children.[15,17,22,24,32,33,35] Since most studies only reported an age range, no median age could be calculated. All children were younger than 3 years, except 4, who were aged respectively 7, 8, 12 and 13 years. Individual data from adults (n=191) showed a median age of 62 (IQR 48-72).[20,22-24,26-31,35] The median time interval differed significantly between children and adults for iso- and hypodensity (p=0.000) and hyperdensity (p=0.046) (Table 5). In children, time intervals per density did not differ significantly (p=0.955). In adults, time intervals per density did differ significantly (p<0.001) (Table 5). As in the analysis of the whole group, the main differences were between hyper and mixed density, both of which appeared significantly earlier than iso- and hypodensity. Figure 2 depicts the time intervals for the different densities for children and adults graphically. Two pediatric studies that did not provide individual patient data, describing AHT cases only, considered the time of contact with the emergency services as the moment of trauma.[16,36] They describe hyper- and hypodense SDHs within the time ranges of the pooled estimates (Table 4, studies by Bradford et al and Dias et al).

Table 3. *Pooled analysis of time intervals for each density on CT*

Density	n	Time interval in days, median (IQR)	Min	Max
Hyperdense	105	2 (1-5)*	0	365
Isodense	53	11 (2-40)	0	122
Hypodense	206	14 (3-33)	0	177
Mixed density	49	1 (0-4)*	0	243

* Significant difference with isodensity (p=0.000) and hypodensity (p=0.000)

n: number; IQR: interquartile range; Min: minimum; Max: maximum

***Table 4.** Time intervals of SDHs[a] on CT in studies that did not provide individual patient data suitable for pooling*

Author	Results
Bradford, 2013[36]	- 27 SDHs hyperdense after average 6.4 hours - 5 hyperdense components in SDHs disappeared after 2-40 days - 14 SDHs hypodense after average 6.4 hours - 11 hypodense components in previously hyperdense SDHs after 0.3-16 days - 56 SDHs mixed density after average 6.4 hours - 24 hyperdense components in mixed density SDHs disappeared after 1-181 days
Dias, 1998[16]	- 12 SDHs hyperdense after average 2.7 hours - 1 SDH hyperdense after 18.4 hours - 5 SDHs hypodense after average 2.7 hours - 1 SDH hypodense after 12 days
Haar, 1977[21]	- 14 SDHs hyperdense after average 5 days - (Hypodense not included in this review because time after trauma not known)
Lee, 1997[25]	- 350 SDHs hyperdense after average 0.5 days, SD[b] 1.6, range 0-12 - 26 SDHs isodense after average 54.6 days, SD[b] 33.1, range 11-140 - 23 SDHs hypodense after average 20.9 days, SD[b] 20.7, range 4-81 days - 19 SDHs mixed density after average 59.9 days, SD[b] 57.7, range 4-216
Reed, 1986[10]	- 33 SDHs hyperdense within 24 hours - 10 SDHs hyperdense after 24-72 hours - 24 SDHs mixed density within 24 hours - 4 SDHs mixed density after 24-72 hours
Scotti, 1977[11]	- 11 SDHs hyperdense after 0-7 days - 1 SDH hyperdense after 7-22 days - 2 SDHs hyperdense after > 22 days - 7 SDHs isodense after 7-22 days - 3 SDHs isodense after > 22 days - 2 SDHs hypodense after 7-22 days - 16 SDHs hypodense after > 22 days

[a] SDH: subdural hematoma; [b] SD: standard deviation

***Table 5.** Pooled analysis of time intervals for each density on CT for children and adults separately*

Density	Group	n[a]	Time interval in days, median (IQR[b])	Min[c]	Max[d]	p[$] Children vs adults
Hyperdense	Children	50	2 (1-3)	0	11	0.046
	Adults	37	3 (1-30)*	0	365	
Isodense	Children	4	2 (0-5)	0	6	0.000
	Adults	18	46 (26-90)[#]	7	122	
Hypodense	Children	63	2 (0-9)	0	122	0.000
	Adults	118	16 (8-33)	1	177	
Mixed density	Children	31	2 (1-3)	0	11	0.332
	Adults	18	0 (0-11)*	0	243	

[$] MWU test was used to test the differences between children and adults for each density.
* Significant difference with isodensity (p=0.000) and hypodensity (p=0.000)
[#] Significant difference with hypodensity (p=0.001)

[a] n: number; [b] IQR: interquartile range; [c] Min: minimum; [d] Max: maximum

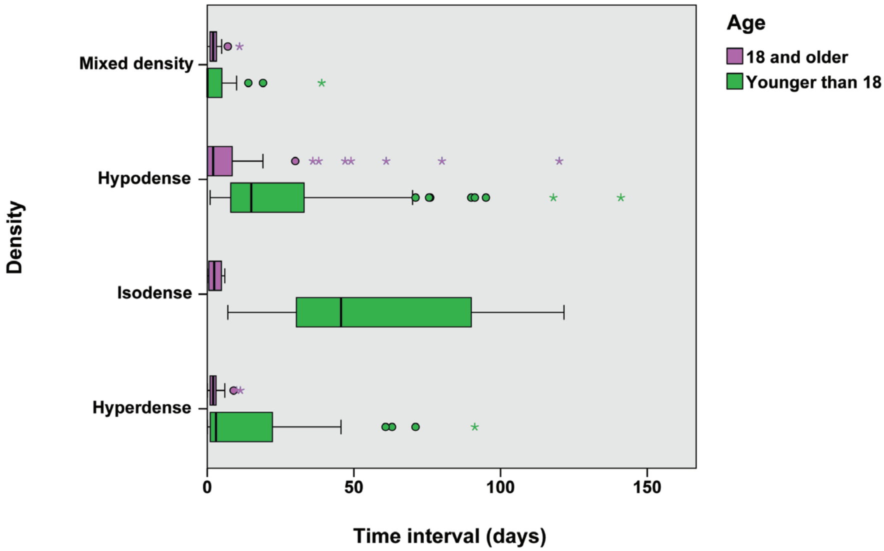

Figure 2. *Boxplot showing the different time intervals for the four appearances of SDHs on CT in children and adults separately. Selected time interval is first 150 days. Hyper-, iso- and hypodense are significantly different from each other between children and adults.*

AHT vs. non-AHT in pediatric cases:

For 63% of pediatric cases (n=93), it was known whether the cases were AHT cases (n= 19)[17] or non-AHT cases (n=74).[17,22,24,32,33,35] The median time interval per density did not differ significantly between AHT and non-AHT cases (Table 6). In AHT cases, the time intervals per density did not differ significantly (p=0.114). In non-AHT cases, the time intervals per density did differ significantly (p=0.002) (Table 6). Hyper-, iso- and mixed density were seen significantly earlier than hypodensity (p<0.001, p=0.024, and p=0.001 respectively). Figure 3 depicts the time intervals for the different densities for AHT and non-AHT cases graphically.

6

Signal intensities and time intervals on MRI

All studies

We identified five studies describing signal intensities on MRI related to time of injury. Three of these, describing 34 SDHs on T1 and T2, could be pooled (Table 7).[17,22,37] Time intervals for different signal intensities on both T1 and T2 did not significantly differ from each other (p=0.108 and p=0.194 respectively). Figure 4 depicts the time intervals for the different intensities for T1 and T2 sequences graphically. Vinchon et al also describe FLAIR and Gradient Echo sequences besides T1 and T2 sequences.[17] On FLAIR, they found 7 cases of hypointense SDH, after a mean time interval of 4 days (SD 2.6, range 2-9) and 5 cases of hyperintense SDHs after a mean time interval of 14 days (SD 13.1, range 3-35). On Gradient Echo, they

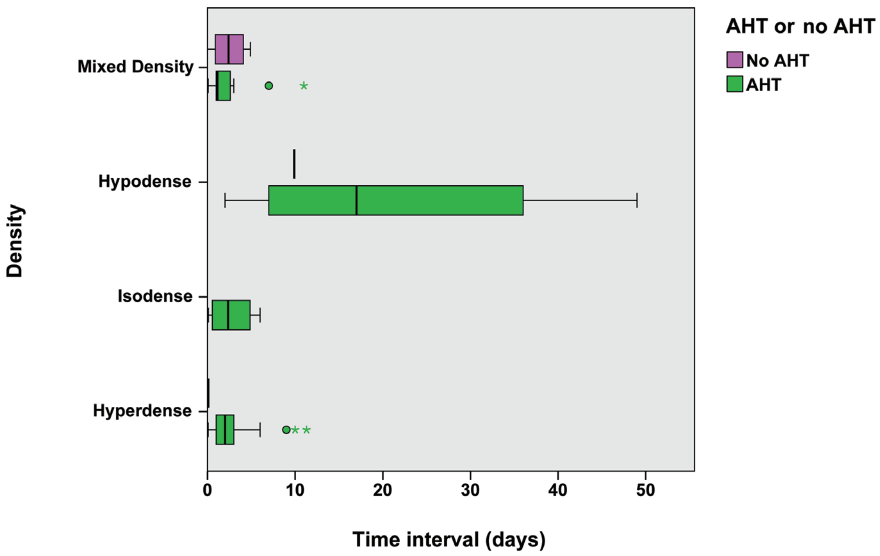

Figure 3. *Boxplot showing the different time intervals for the four appearances of SDHs on CT in pediatric AHT and non-AHT cases separately. Selected time interval is first 60 days.*

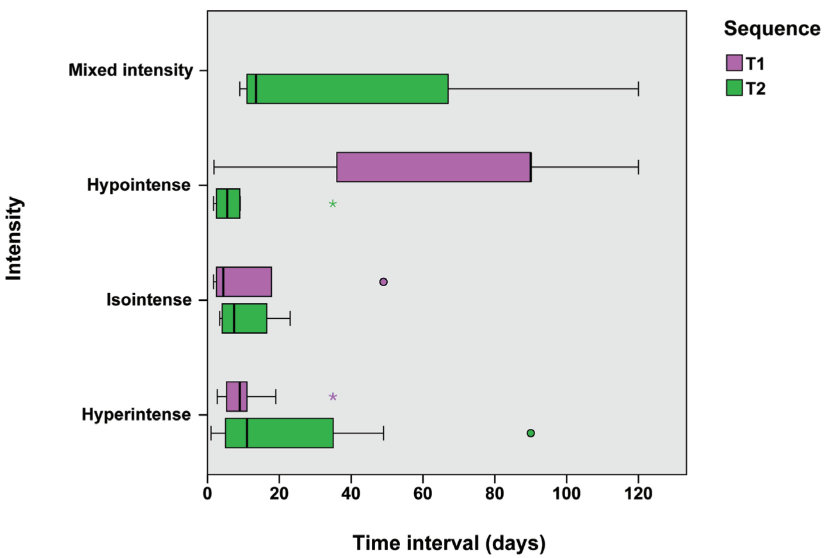

Figure 4. *Boxplot showing the different time intervals for the four appearances of SDHs on MRI on T1 and T2.*

Table 6. *Pooled analysis of time intervals for each density on CT for AHT[a] and non-AHT pediatric cases separately*

Density	Group	n[b]	Time interval in days, median (IQR[c])	Min[d]	Max[e]	p[$] AHT vs non-AHT
Hyperdense	AHT	1	0	-	-	0.08
	Non-AHT	49	2 (1-4)*	0	11	
Isodense	AHT	-	-	-		-
	Non-AHT	4	2 (0-5)[#]	0	6	
Hypodense	AHT	1	10			0.75
	Non-AHT	7	36 (7-61)	2	120	
Mixed density	AHT	17	2 (1-4)	0	5	0.54
	Non-AHT	14	1 (1-3)[†]	0	11	

[$] MWU test was used to test the differences between AHT and non-AHT cases for each density.
* Significant difference with hypodensity (p=0.000)
[#] Significant difference with hypodensity (p=0.024)
[†] Significant difference with hypodensity (p=0.001)

[a] AHT: abusive head trauma; [b] n: number; [c] IQR: interquartile range; [d] Min: minimum; [e] Max: maximum

Table 7. *Pooled analysis of time intervals for each intensity on MRI for T1 and T2 sequences*

Sequence	Intensity	n	Time interval in days, median (IQR)	Min	Max
T1	Hyperintense	14	9 (5-13)	3	35
	Isointense	5	4 (2-33)	2	49
	Hypointense	5	90 (19-105)	2	120
T2	Hyperintense	14	11 (5-39)	1	90
	Isointense	4	7 (4-20)	3	23
	Hypointense	10	6 (2-9)	2	35
	Mixed intensity	4	14 (10-49)	9	120

n: number; IQR: interquartile range; Min: minimum; Max: maximum

found 13 hypointense SDHs after a median time interval of 8 days (IQR 3-9, range 2-35) and 1 hyperintense SDH after 18 days. Two studies that did not provide data at individual level report time intervals that fall within the range of the studies included, except that they report mixed intensity earlier and also report mixed intensity SDHs on T1, which were not reported in other studies (Table 8).[16,36]

DISCUSSION

In this systematic review, we observed that the time intervals reported for the different appearances of SDHs on CT and MRI show a wide range and overlap. However, there is a significant difference on CT between mixed and hyperdense SDHs being reported after a median time interval of one and two days respectively and iso- and hypodense SDHs, being reported

Table 8. *Time intervals of SDHs on MRI in studies that did not provide individual patient data suitable for pooling*

Author	Results
Bradford, 2013[36]	- 6 SDHs hyperintense on T1 and hypointense on T2/Flair after 0-5 days - 6 SDHs hyperintense on T1 and hyperintense in T2/Flair after 2-30 days - 16 SDHs with equal volumes of mixed hyper- and hypointense on T1 and mixed hyper- and hypointense on T2/Flair after 0-30 days - 14 SDHs with unequal volumes, mostly hypointense on T1 and hyperintense on T2/Flair, smaller component hyperintense on T1 and hypointense on T2/Flair after 0-30 days
Kaminogo, 1999[38]	- 11 SDHs hypo or isointense on T1 and hypointense on T2 after average 5 days, SD 4.1 - 5 SDHs hyperintense on T1 and hyperintense on T2 after average 27.8 days, SD 20 - 1 SDH hypointense on T1 and hyperintense on T2 after 37 days - 5 SDHs mixed intensity on T1 and mixed intensity on T2 after average 17.8 days, SD 12.2

SDH: subdural hematoma

after 11 and 14 days respectively. The time intervals change substantially when pediatric and adult cases are analyzed separately. In the pediatric group, all densities were reported after a median time interval of 2 days; there was no significant difference between these time intervals. In adults, iso- and hypodense SDHs were found significantly later compared to other SDHs, but the time intervals between iso- and hypodense SDHs did not differ. The early appearance of hypodense SDHs in children seems to be caused by one study describing mainly children with AHT.[15] No statistically significant differences were found between the time intervals for the different intensities on MRI. The broad and overlapping time intervals found in this systematic review are not in line with previously published tables in textbooks and articles 9-11. In particular, the overlap between iso- and hypodense SDHs and the absence of any difference between the different densities in children have not been described before. These broad and overlapping time intervals are not immediately evident when assessing individual articles. Some articles only describe one type of density[15,26], and others only have a short follow-up time for most patients.[10,16,32] However, time intervals different from the prevailing views have been described previously.[10,15] Vinchon was the first to address this in a study specifically designed to investigate the temporal evolution of SDHs.[17] Although he reports a trend on both CT and MRI, time intervals were broad and partially overlapping as well. Bradford and Choudhary did the same, but only included AHT victims.[16,36] They also describe the first and last day on which a certain density/intensity was found. Although did not provide individual patient data and therefore could not be included in the pooled analysis, their reported values are close to the results of our pooled estimates. Although some authors have reported that temporal evolution of SDHs is somehow comparable with that of other intracranial hematomas[12,13], others found that there are considerable differences between the appearance of SDHs and parenchymal hematomas on MRI, especially in the first week.[14] The appearance of hematomas on MRI is, besides technical characteristics (field strength, type of signal and technique used), based on the type of hemoglobin present (i.e. oxyhemoglobin, deoxyhemoglobin or methemoglobin) and whether the red cells are intact or not.[13] It has been stated that the difference between parenchymal and subdural hematomas might be explained by the vascularized dura, causing a high oxygen tension in the subdural space[13], but the scientific base for extrapolating data regarding parenchymal hematomas to SDHs is, to our knowledge, unclear.

Several limitations to our review should be mentioned. First, the moderate quality of the included studies suggests that one should be cautious with the interpretation of results. A high expected degree of heterogeneity as well as the lack of control groups within the studies especially notifies to be cautious with the interpretation of the pooled estimates. Furthermore, not all studies provided detailed information on how the time interval between trauma and imaging was determined. Although we selected only studies that described a clear trauma as start of the SDH, in none of the studies was it demonstrated that the outcome of interest (the SDH) was not already present before this trauma, or developed some time afterwards. An inaccuracy we accepted was that the exact HUs matching the different densities (or cut-off values for the different intensities) were not provided in the studies. These could have varied among the studies, but we do not expect that this would influence the results. In all but one study it was unclear whether radiologists were blinded for clinical information regarding the moment of trauma. Knowledge of the moment of trauma could have influenced their reporting. Another limitation is that most studies were not designed for our purpose. Therefore individual patient data were not available for all studies, or age or origin of trauma were not documented. This resulted in fewer cases that could be included in the pooled estimate. Due to small groups, subgroup analyses for age groups or AHT vs non-AHT could not be performed on MRI studies. The limited number of studies describing MRI data, of which only one study reported the use of FLAIR and gradient-echo sequences, is remarkable, as MRI is considered to be a more precise instrument to date SDHs. Our results do not support this view.

CONCLUSIONS

By demonstrating the broad range in the time between trauma and scanning for the different appearances of SDHs in the different studies, the question is raised of which factors influence the appearance of SDHs on CT and MRI. Variety in study populations might have influenced this broad range, as demonstrated by the difference between adults and children. A prospective study, as proposed by Vinchon[17], in which patients with SDHs are scanned at several moments over time could help to gain insight into the temporal evolution of SDHs. However, the design of a prospective study will be limited by methodological issues as well, as it will not be possible to perform CT scans at fixed time intervals for research purposes, because of radiation exposure issues.[39] The clinical situation will dictate how often and at which moment patients will be scanned. In view of the fact that time intervals of the four different imaging appearances of SDHs are broad and overlapping, CT or MRI findings cannot be used to accurately date SDHs. In the event of legal proceedings it is important to know at what time exactly a trauma occurred, and this information can, at this moment, not be provided with reasonable certainty based on imaging findings.

Table 1. *Characteristics of studies included*

First author	Year	State	Type **	CT/ MRI	Setting	Inclusion criteria	Sample size
Bergström[9]	1977	SWE	ret	CT	Nr	Nr	41 patients 43 SDHs
Bradford[3]*	2013	USA	ret	CT	Level I pediatric trauma center	- Children younger than 2 years - Admitted with AHT - Neuro-imaging studies available - Identifiable date of injury	105 patients 97 included
Dias[16]*	1998	USA	ret	CT	Tertiary referral center, children's hospital	Nr	33 patients 9 included
Fujioka[20]	1990	JAP	CR	CT	Nr	Rapid resolution of SDH	2 patients 5 SDHs
Haar[21]*	1977	USA	ret	CT	Nr	- Consecutive patients - SDH on CT scan, confirmed by angiography and/or surgery	26 patients 15 included
Hosoda[22]	1987	JAP	ret	CT	General hospital	Chronic SDH confirmed by operation	18 patients 9 patients (10 SDHs) included
Hyodo[23]	1979	JAP	ret	CT	Nr	External head injury	2 patients 2 included
Izumihara[24]	1997	JAP	ret	CT	Nr	External injury	20 patients 20 included
Lee[25]*	1997	Korea	ret	CT	Nr	CT scans from patients with SDH	429 patients 429 included
Marcu[26]	1977	DEU	ret	CT	Nr	Hare ear lateral ventricles on CT	3 patients 2 included
Markwalder[27]	1981	CHE	pro	CT	Nr	Patients receiving surgical treatment for chronic SDH	32 patients 26 patients (28 SDHs) included
Masuzawa[28]	1984	JAP	ret	CT	Nr	Nr	2 patients (8 CTs) all included

* Studies did not provide data at individual patient level and were not included in pooled analysis.
** ret: retrospective; CR: case report; pro: prospective

Age	Gender	Scanning parameters	Timing	Remarks
Nr	Nr	Mark I EMI Scanner, 160 x 160 matrix, HU range -500 to + 500	"Patients without traumatic history or in whom the time of trauma was not known were excluded."	Patient data read from figure.
Whole cohort: Mean 4 months, range 0.3-23 months	Nr	Nr	"Both the date and, whenever possible, the time of the injury were sought within a reasonable certainty based upon information provided in medical record, ambulance trip sheets and emergency department records from referring hospitals."	- Only AHT cases - Time of injury based on medical records
Whole cohort: Mean 7 months, range 1-26 months	Whole cohort: 73% male	Nr	The exact time at which the injury was reported to have occurred was established through 1) direct statements in the medical chart; 2) the time of calls made to the Emergency Medical Services, and/or 3) the time the ambulance received a call or arrived at the scene.	- Only AHT cases - Only 9 cases in which time of injury could be pinpointed and in which no older injuries on CT scan were found are included in the review - Timing of incident might be unreliable
78, 84 years	50% male	Nr	Head injury in adults	
Nr	Nr	EMI- Mark I brain scanner, 80 x 80 matrix, 160 x 160 matrix	High density group: time after head injury. Low density group: "only 2 had a known history of head injury; for the others time that symptoms began was used." Layering group: injury in one case and symptoms in other case	Only patients with head injury are included in the review.
Median 70 years, range 0.4-81	67% male	GE 8800 Toshiba 60A-27	Days after trauma known for 9 patients	Only patients in whom days after trauma are documented are included in the review.
31, 56 years	100% male	Nr	Patients who suffered from external head injury	
Median 70 years, range 12-87	65% male	Nr	All cases were admitted to hospital within 3 hours after injury	
Nr	Nr	Nr	Cases were excluded if patients "could not remember the trauma or if there was no history of trauma."	Mean age of SDH is reported, but data are non-normally distributed.
23, 69	50% male	Siretom I, 128 x 128 matrix	Head injury in adults	Only patients with history of head injury included in review.
Mean 60, SD 15, range 20-78	73% male	Nr	Head injury in adults	Only patients in whom interval between trauma and scanning was known are included in the review.
18, 28	100% male	Nr	Head injury in adults: fall and traffic accident	

Table 1. *Characteristics of studies included*

First author	Year	State	Type **	CT/ MRI	Setting	Inclusion criteria	Sample size
Nakamura[29]	1980	JAP	ret	CT	Several hospitals	Patients with chronic SDH	8 patients 2 (6 SDHs) included
Poljaković[30]	1992	HRV	pro	CT	Nr	The material obtained from the operation of SDH was […] and compared with the picture of the same hematoma on CT scan	32 patients 26 included
Reed[10]*	1986	CAN	ret	CT	Nr	- CT scans and medical records of patients with acute SDHs were retrospectively evaluated - Inclusion only if an adequately documented time of a single acute head injury was present end if CT performed within 72 hours of the trauma	71 patients 71 included
Scotti[11]*	1977	CAN	ret	CT	Neurological hospital	We reviewed the CT scans […] in patients with SDHs who were surgically treated	42 patients 42 included
Sipponen[31]	1984	FIN	pro	CT	University hospital	[…] CT findings in five patients with chronic SDHs	5 patients 2 included
Tung[32]	2006	USA	ret	CT	University hospital	Through a computer-assisted search of the radiology information system we identified 162 non-contrast CT examinations in children <= 3 years of age in which the term SDH was contained in the body or conclusion of the report	47 patients 38 included
Vinchon[33]	2002	FRA	ret	CT	University hospital, PICU	We selected cases of infantile SDH secondary to traffic accident	18 patients (33 SDHs) 13 patients (18 SDHs) included
Vinchon[17]	2004	FRA	pro	CT	University hospital, PICU	We included patients younger than 12 months of age who were hospitalized in our institution for head injury	20 patients (32 CTs) 7 non-AHT cases (11 SDHs) included 12 AHT cases (19 SDHs) included

* Studies did not provide data at individual patient level and were not included in pooled analysis.
** ret: retrospective; CR: case report; pro: prospective

Age	Gender	Scanning parameters	Timing	Remarks
30, 69	100% male	Nr	Head injury in adults	Only patients who underwent CT and had a history of head injury are included in the review.
Mean 56 years, SD 15 years, range 25-83 years	81% male	Nr	Head injury in adults: "fall, traffic accident or fight." We did not include cases without a trauma.	Only patients in whom interval between trauma and scanning was known are included n the review.
Mean 43, no dispersal reported	75% male	General Electric 8800 or 8900	"Patients were included in the study only if review of their histories could adequately document the time of a single acute head injury…"	
Nr	Nr	EMI head scanner, 160 x 160 matrix	"[…] note was taken of the time interval between the date of the possible trauma and the date of the CT examination. In cases in which no history of trauma could be obtained, the interval between the beginning	It is unclear how many of the patients did not have a history of trauma.
53, 60	50% male	Nr	"There was a recent history of trauma in two patients."	Only patients in whom time after trauma was known were included in the review.
Whole cohort: mean 5 months, range 0-34 months	Whole cohort: 64% male	Nr	"A definite date and time of head injury was recorded for subjects who had sustained witnessed or corroborated injury from birth, fall from a height, or motor vehicle crash. For the birth-related injury cohort, the time of delivery was recorded."	Only cases for which densities were reported were included in the review; these were all accidental trauma.
Median 5 months, range 1-21 months	39% male	Nr	"We selected cases of children less than 24 months of age on admission who had been involved in a traffic accident. "	- Scans on the first day are reported in the study as being performed on day 0. To enhance comparability with other studies we added 1 day extra to every day - Only patients for which density was described are included in the review
Median 2 months, range 0-10 months	53% male	Nr	"We included patients […] for whom the date of trauma was corroborated by sources."	- One patient without SDH was not included in the review - Individual patient data for both non-AHT and AHT cases available

Table 1. Characteristics of studies included

First author	Year	State	Type **	CT/ MRI	Setting	Inclusion criteria	Sample size
Weichert[34]	1978	DEU	ret	CT	Nr	Patients with SDH were studied	51 patients 30 included
Wells[15]	2003	USA	ret	CT	Regional children's hospital	Nr	55 patients 55 included
Yamada[35]	1980	JAP	pro	CT	General hospital and research center	Subdural collection of low density on CT scan	40 patients 36 (84 SDHs) included
Bradford[36]*	2013	USA	ret	MRI	Level I pediatric trauma center	- Children younger than 2 years - Admitted with AHT - Neuro-imaging studies available - Identifiable date of injury	105 patients 43 included
Fobben[37]	1981	USA	ret	MRI	Nr	The MR images of 24 patients with SDHs and hygromas were reviewed	24 patients (33 SDHs) 9 cases included
Hosoda[22]	1987	JAP	ret	MRI	General hospital	Nr	18 patients (20 SDHs) 9 patients (10 SDHs) included
Kaminogo[38]*	1999	JAP	ret	MRI	Nr	Nr	38 patients 40 MRIs
Vinchon[17]	2004	FRA	pro	MRI	Nr	Nr	20 patients (32 CTs) 7 non-AHT cases (11 SDHs) included 12 patients with AHT included

* Studies did not provide data at individual patient level and were not included in pooled analysis.
** ret: retrospective; CR: case report; pro: prospective

Age	Gender	Scanning parameters	Timing	Remarks
Nr	Nr	Siemens Sieretom I Scanner, 128 x 128 matrix	All patients were scanned "post-trauma".	- Patient data read from figure. - Only patients in which time after trauma were known are included in the review - 6 patients with an interval of > 40 were classified as 40 days
Median 4 months, no dispersal reported, all < 3 years	60% male	Nr	"We also excluded children for whom the date of head injury could not be determined. […] The mechanism of injury was intentional trauma in 41 patients (75%), unintentional trauma in 10 (18%), and of uncertain intent in 4 (7%)."	¾ AHT, cases unclear which of the patients these were.
Median 61 years, range 7-96 years	81%	EMI Scanner CT-1010, Hitachi CT-H 20	Head injury in adults	Only hypodense SDHs included, 'increased density' was not otherwise specified.
Whole cohort: Mean 4 months, range 0.3-23 months	Nr	Nr	"Both the date and, whenever possible, the time of the injury were sought within a reasonable certainty based upon information provided in medical record, ambulance trip sheets and emergency department records from referring hospitals. "	- Only AHT cases - Time of injury based on medical records
Median 5 years, IQR 0.3-44, range 0.1-55	Nr	1.5T GE imager Spin echo 600/20 TR/TE 2500/3000/ 30-80/2 matrix 128 x 156	"Hemorrhages were classified by the patients'clinical history […]."	
Median 70 years, IQR 1.5-72, range 0.4-81	67% male	0.15 T matrix 256 x 256	Nr	
Mean 69.3 years, SD 12 years, range 32-96	80% male	1.5T 300-500/ 20-30 ms (TR/ TE) 2000-2200/ 30-90ms/2	"A history of head trauma was obtained from 25 patients. The interval from between head trauma and onset of symptoms was 23-120 days (mean 49.7 +/- 26.1 days)"	
Median 2 months, IQR 1-5 months, range 3 days-10 months	60%	Some of the patients have AHT; the AHT cases are known	20 patients, 32 CTs; 7 non-AHT cases with 11 SDHs included and 12 patients with AHT included.	

Table 2. *Assessment of studies included, with adjusted NOS scale*[18]

First author	Modality	Patient selection		Outcome				
		Representativeness	Exposure	Outcome of interest not present before study	Assessment of outcome	Time of follow-up	Adequacy of follow-up	Total
Bergström, 1977[9]	CT		*			*	*	3
Bradford, 2013[36]	CT	*	*		*	*	*	5
Dias, 1998[16]	CT	*	*		*	*	*	5
Fujioka, 1990[20]	CT	*	*			*	*	4
Haar, 1977[21]	CT		*		*	*	*	4
Hosoda, 1987[22]	CT		*			*	*	3
Hyodo, 1979[23]	CT	*			*	*	*	4
Izumihara, 1997[24]	CT	*	*			*	*	4
Lee, 1997[25]	CT		*			*	*	3
Marcu, 1977[26]	CT	*	*			*	*	4
Markwalder, 1981[27]	CT	*	*			*	*	4
Masuzawa, 1984[28]	CT	*	*		*	*	*	5
Nakamura, 1981[29]	CT	*	*			*	*	4
Poljaković, 1992[30]	CT	*	*			*	*	4
Reed, 1986[10]	CT		*			*	*	3
Scotti, 1977[11]	CT	*	*			*	*	4
Sipponen, 1984[31]	CT	*	*			*	*	4
Tung, 2006[32]	CT	*	*		*	*	*	5
Vinchon, 2002[33]	CT	*	*			*	*	4
Vinchon, 2004[17]	CT	*	*		*	*	*	5
Weichert, 1978[34]	CT		*			*	*	3
Wells, 2003[15]	CT	*	*		*	*	*	5
Yamada, 1980[35]	CT	*	*			*	*	4
Bradford, 2013[36]	MRI	*	*		*	*	*	5
Fobben, 1981[37]	MRI	*	*			*	*	4
Hosoda, 1987[22]	MRI	*	*			*	*	4
Kaminogo, 1991[38]	MRI	*	*			*	*	4
Vinchon, 2004[17]	MRI	*	*			*	*	4

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Chapter 7

Age determination of subdural hematomas: survey among radiologists

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ABSTRACT

Abusive head trauma is a severe form of child abuse. One important diagnostic finding is the presence of a subdural hematoma. Age determination of subdural hematomas is important to relate radiological findings to the clinical history presented by the caregivers. In court this topic is relevant as dating subdural hematomas can lead to identification of a suspect. The aim of our study is to describe the current practice among radiologists in the Netherlands regarding the age determination of SDHs in children.

This is a cross-sectional study, describing the results of an online questionnaire regarding dating subdural hematomas among pediatric and neuro-radiologists in the Netherlands. The questionnaire consisted of sociodemographic questions, theoretical questions and 8 pediatric cases in which the participants were asked to date subdural hematomas based on imaging findings.

Fifty-one out of 172 radiologists (30%) filled out the questionnaire. The percentage of participants that reported it was possible to date the subdural hematoma varied between 58 and 90% for the 8 different cases. In 4 of 8 cases (50%) the age of the subdural hematoma as known from clinical history fell within the range reported by the participants. None of the participants was 'very certain' of their age determination.

The results demonstrate that there is a considerable practice variation among Dutch radiologists regarding the age determination of subdural hematomas. This implicates that dating of subdural hematomas is not suitable to use in court, as no uniformity among experts exists.

INTRODUCTION

Abusive head trauma (AHT) is one of the most severe forms of physical child abuse. It is the most important cause of traumatic brain injury in young children, with a reported incidence of 14-40 per 100,000 children under the age of one per year, leading to significant mortality and morbidity.[1] Radiological imaging plays a pivotal role in the diagnosis of AHT.[2] An important diagnostic finding is the presence of a subdural hematoma (SDH). A systematic review by Kemp et al showed a clear association of SDH with AHT, expressed by an OR of 8.2.[3]

One important issue, especially in legal proceedings, is the issue of timing of the injury. Age determination of SDHs is important in order to relate radiological findings to the clinical history presented by the parents/caregivers. It is not uncommon for expert witness radiologists to be requested by court to date SDHs based on imaging findings. In court this topic is relevant, as it will be of great value to relate the injuries to possible suspects that might have had contact with the child. Incorrect age determination of a SDH, conflicting with available clinical history, can lead to an incorrect suspicion of child abuse or an incorrect identification of a potential perpetrator. Obviously, a false positive diagnosis of child abuse or indicating a wrong potential perpetrator can cause severe social and emotional problems for the involved child and parents/caregivers.

To our knowledge, no definite time line for dating SDHs has been published, although some authors proposed a method to develop an evidence-based time line.[4] Publications on the age determination of SDHs are mainly based on intracerebral, i.e. parenchymatous, hematomas[5,6], or studies in adults or in which patients characteristics are not reported.[7-9] Recently, Bradford et al reported that the validity of previously accepted concepts regarding dating SDHs have elapsed, as the studies these concepts were based on had been performed in specific settings and are not applicable to a general population.[10] In our tertiary referral centre we noticed, both in a clinical as well as in a pediatric forensic setting, a practice variation among radiologists regarding dating of SDHs. Where some radiologists do not date at all, others date up to days or even hours specific. As it can have legal implications if different conclusions are drawn, it is of interest to assess the potential variation between radiologists.

If the variation in practice between radiologists would be known, this would give insight in the value of radiological reports dealing with dating SDHs in a forensic setting. Also, knowledge of the variation in practice can help to provide recommendations for adequate radiological reporting in case of suspected AHT. We therefore conducted a survey among pediatric and neuroradiologists in the Netherlands. The aim of our study is to describe the current practice among radiologists in the Netherlands regarding the age determination of SDHs in children, using an anonymous on-line questionnaire. Based on clinical experience, we hypothesized that a significant practice variation among radiologists regarding the age determination of SDHs exists.

METHODS

This study is a cross-sectional study, describing the outcomes of an anonymous online questionnaire on dating SDHs among pediatric radiologists and neuroradiologists practicing in the Netherlands.

Participants

In the Netherlands, neuroimaging of children is performed by pediatric radiologists as well as neuroradiologists. Therefore the questionnaire was distributed per e-mail among all pediatric radiologists and neuroradiologists that are registered in the Netherlands as member of their subspecialty section within the Dutch Radiological Society (n-total=183). In order to be registered for a subspecialty section the radiologists needs to be clinically involved in the specific radiological subspecialism. Although membership is not a prerequisite to work in a subspecialty field of radiology, the majority of radiologists active in a subspecialty are member of their sections. Approval for the use of the email-addresses was obtained from the chair of the sections of pediatric radiology and neuroradiology of the Dutch Radiological Society. The radiologists were invited to participate anonymously in this study, with a link to the online questionnaire. The questionnaire has been online for four weeks in the beginning of 2013. In this period, the eligible participants received two reminders to fill out the questionnaire. We specifically asked eligible participants not willing to participate in the study to open the questionnaire and opt out after filling in their sociodemographic data, in order to be able to compare the participants and radiologists who did want to participate. No compensation was offered to the radiologists to participate in the study.

Questionnaire

We developed a questionnaire using SurveyMonkey® (www.surveymonkey.net), an online survey software and questionnaire tool. Questions were based on clinical experience. The questionnaire consisted of three parts (see the appendix at the end of this chapter). In the first part we collected sociodemographic data on type of hospital where the radiologists practiced, number of years of clinical experience, and sub specialization. The second part of the questionnaire consisted of theoretical questions regarding SDHs with mixed densities, and the possibility of distinction between hygroma, subdural effusion and a SDH based on CT or MRI images only. The third part consisted of eight pediatric cases (four CT and four MRI images), in which the participants were asked to date SDHs based on imaging findings (Figs. 1-8, which can be found at the end of the paper). We added arrows in the images for this publication; the arrows were not visible in the questionnaire. Age, gender and (concise) reason for hospital visit were provided in all cases. Participants were asked to give an approximate age of the SDH, and a minimum and maximum age for this SDH. Furthermore they were asked how certain they were about this age estimation, scored on a five point Likert scale, subdivided in 'very uncertain', 'uncertain', 'neutral', 'certain' and 'very certain'. CT and MRI images were selected by an experienced pediatric radiologist (RRvR) and neuroradiologist (CBLMM), from the PACS database (Impax 6.5.0, Afga, Mortsel, Belgium) from the Academic Medical Center Amsterdam, the Netherlands. The timing of the incident leading to the SDH was derived from the forensic analysis. It is not certain for all cases if this is correct, but for the purpose of this research, describing the variation among radiologists, this was not of influence. The questionnaire was piloted among two radiologists in order to enhance intelligibility; subsequently these radiologists were excluded from the eligible study participants.

Statistical analysis

Data obtained by SurveyMonkey® were collected in excel and analyzed with the use of IBM SPSS Statistics 20 (Statistical Product and Service Solutions, IBM Software Group's Business Analytics Portfolio). Continuous data were expressed as means and standard deviations or medians and minimum- maximum when appropriate. Differences between groups were tested using a t-test (normally distributed data) or Mann-Whitney U test (non-normally distributed data) for numerical data and by using a Chi square test for categorical data. Not all participants filled out all questions; the number of participants for each question is listed in tables 2, 3 and 4. We did not impute any data to replace missing values.

RESULTS

Response rate

We sent the questionnaire to the 183 e-mail addresses of the members list from the sections of pediatric radiology (n= 48) and neuroradiology (n=135) of the Dutch Radiological Society. The flow scheme of excluded persons, participants, those who opted out and non-responders is provided in figure 9. Nine e-mail addresses were incorrect, one radiologist was in the list with two different e-mail addresses and another radiologist appeared to be retired. These 11 email-addresses were excluded. A total of 172 radiologists (39 pediatric radiologists and 133 neuroradiologists) received the e-mail, of which 51 (30%) participated and completed the questionnaire. Twenty-seven radiologists (16%) rejected the questionnaire through either the 'opt out option' or by emailing the research group. In case of ending the questionnaire after filling out sociodemographic data only, the radiologists were classified as opting out as well. Sociodemographic data of 21 radiologists who opted out were available. There were 94 non-responders (55%).

Sociodemographic characteristics

The characteristics of participants and radiologists who opted out are listed in table 1. Twenty-three of 51 participants were working in a university hospital (45%). Ten participants reported to be a subspecialist in pediatric radiology (20%), and 37 in neuroradiology (73%). Median number of years of clinical experience was 8 (range 0-35 years). The participants did not significantly differ in working situation and working experience from the radiologists who opted out, but there were significantly more radiologists in the participants group with a subspecialism compared with the radiologists who opted out (p=0.02). The participants spent a median of 16 hours a week on neuroradiology (range 1–70 hours); 63% dated SDHs in clinical practice. Knowledge regarding dating SDHs was mainly obtained from supervisors during radiology training (Table 2).

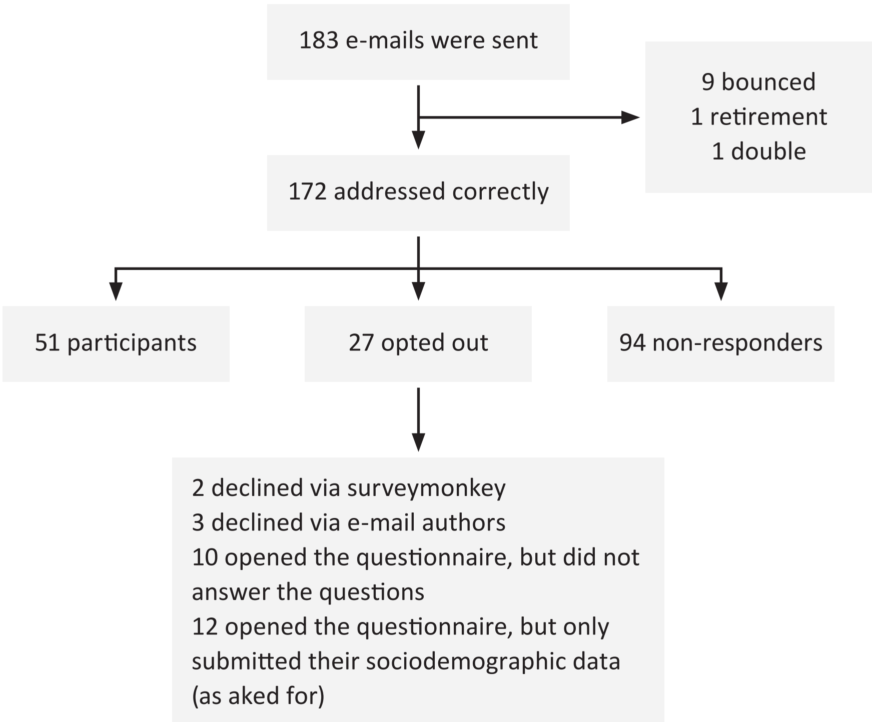

Figure 9. *Flow diagram depicting in- and excluded questionnaires with reasons for exclusion.*

Table 1. *Sociodemographic characteristics of participants and radiologists who opted out*

	Participants	Radiologists who opted out	p
n	51	21	-
Working in an university hospital, n (%)	23 (45)	9 (43)	0.86
Years of working experience, median (min-max)	8 (0-35)	15 (0-45)	0.2
Sub specialism, n (%)*			
Pediatric radiology	10 (20)	3 (14)	0.02
Neuroradiology	37 (73)	11 (52)	
None of these	4 (8)	7 (33)	

* Because of rounding of the decimals, the total adds to more than 100%

Table 2. *Experience with dating SDHs for participants*

Question	Result n (%)[a]	Sample n
Time spend on neuroradiology		
Hours, median (range)	16 (1-70)	50
Source of knowledge (various options possible)		
During training, supervisors	39 (77)	51
During training, literature	31 (61)	
After training, continuing medical education	28 (55)	
During clinical practice, discussions with colleagues	23 (45)	
Other	0(0)	
Dates in practice		
Yes	32 (63)	51
In what setting?		
Clinical	30 (91)	33
Forensic	0 (0)	
Both	3 (9)	

[a] Unless otherwise specified

Table 3. *Results theoretical questions*

Question	Result n (%)[a]	Sample n
Is it possible to date a mixed density on a CT scan		
Yes	20 (43)	46
Is it possible to date a mixed intensity on a MRI scan		
Yes	21 (46)	46
Number of intervals when dating mixed density		
1	5 (11)	46
>1	20 (44)	
Cause of mixed density (various options possible)		
Bleed-rebleed	41 (94)	44
Repeated trauma	38 (87)	
Sedimentation	33 (75)	
Natural resorption	21 (48)	
Admixture CSF	20 (46)	
Other	3 (7)	

Theoretical questions

Answers to the theoretical questions are listed in table 3. Nearly half of the participants responded that, in theory, it was possible to date a SDH of mixed density on CT or MRI. The reported causes for mixed density SDHs are listed in table 3.

Practice of dating SDHs

The medians of the reported estimated ages and the medians of reported minimum and maximum estimates as reported by the participants for the different cases are provided in table 4 and 5. For the 4 CT cases, the percentage of the participants that reported it was possible to date the SDH was 63, 58, 64 and 83% for cases 1-4 respectively. This resulted in 40, 40, 40 and 53% of the participants actually reporting an estimated age and 40, 40, 45 and 47% reporting a range only for CT case 1, 2, 3 and 4 respectively. In 2 of 4 CT cases (50%, case 1 and 4) the age of the SDH as known from clinical history fell within the range reported by the radiologists. In the CT case with the highest consensus (case 4, figure 4), age of the SDH was estimated 12 hours (range 5 hours – 3 days). According to clinical information this SDH was indeed 12 hours old. In the CT case with the lowest consensus (case 2, figure 2), age of the SDH was estimated 2 days (range 1.5 days – 8 days). According to clinical history the SDH was 9 days old. For the 4 MRI cases, the percentage of the participants that reported it was possible to date the SDH varied was 63, 90, 69 and 88% for cases 5-8 respectively. This resulted in 35, 62, 50 and 67% of the participants actually reporting an estimated age and 33, 70, 52 and 73% reporting a range only for MRI case 5, 6, 7 and 8 respectively. In 2 of 4 MRI cases (50%, case 6 and 8) the age of the SDH as known from clinical history fell within the range reported by the radiologists. In the MRI case with the highest consensus (case 6, figure 6), age of the SDH was estimated 6 days old (range 6-17 days). According to clinical information this SDH was 9 days old. In the MRI case with the lowest consensus (case 5), age of the SDH was estimated 4 weeks old (range 1 – 10 weeks). According to the clinical information, this SDH was two days old. The radiologists did not report to be very certain on their age determination. The most reported value for all cases was 'neutral'; none of the radiologists considered themselves to be 'very certain' in one of the cases. There was no difference in certainty between pediatric and neuroradiologists ($p=0.3$ for CT and $p=0.8$ for MRI). There was no correlation between number of years of working experience and certainty ($p=0.61$ for CT and $p=0.42$ for MRI). There was no difference in certainty between university hospital and non-university hospital radiologists ($p=0.30$ for CT and 0.89 for MRI).

DISCUSSION

We investigated the variation in both theory and knowledge among pediatric and neuroradiologists regarding age determination of SDHs. The results of our study demonstrate that there is a considerable practice variation among radiologists, and therefore suggest that dating of SDHs is not a topic about which radiologists currently agree. This is supported by several aspects of the questionnaire. First, 63% of the participants reported to date SDHs in clinical practice. This means that 37% of the participants are either not confronted with the request to determine the age of a SDH, or they do not think they can reliably do this. Second, for the cases presented in the questionnaire, 58-83% of the participants reported they could date the 4 different CT cases and 63-90% of the participants reported they could date the 4 different MRI cases. However, not all participants who reported they could date the SDH, subsequently did so. Eventually only 40-53% of the participants actually reported an estimated age and 40-47% reported a range for the CT cases. For the 4 MRI cases, 35-67% of the participants reported an estimated age and 33-73% reported a range only. This could be either due to indifference in completing the whole questionnaire, or it could be due to uncertainty about the dating. We assume that the participants, who did fill out both age estimation and a range, are in general the radiologists who are most certain about their dating. Thirdly, the estimates and corresponding ranges that were reported did not overlap very well and did not include the age of the SDH as deduced from clinical history in four out of eight cases. The uncertainty of participants about their age determination is furthermore confirmed by the fact that the most reported level of certainty for all cases was 'neutral' and that none of the participants reported to be 'very certain' about any of their reported ages. It is furthermore remarkable that the reported age ranges based on MRI data were broader than those based on CT data, although MRI is generally considered to be more useful for age estimation.

To our knowledge, no evidence-based guideline or decision tree for the age determination of SDHs has been published. Estimates are based on intracranial hematomas.[5,6,11] Conflicting information can be found as well. Although most studies report a progression from hyperdense, via isodense to hypodense on CT images[7,9] in a large study by Lee et al the majority of hypodense SDHs appeared before isodense SDHs.[12] Other studies describing the relationship between age of the SDH and CT/MRI appearance are often small[13,14], or the moment of origin of SDH is not reliably determined.[15,16] In a small but well-designed study by Vinchon et al, 20 pediatric SDH cases in which time of trauma was known, CT and MRI data were studied in order to describe time-related modifications that could be used to date the trauma.[4] They found that hyperdensity was found in all cases studied less then 7 days after the trauma and was absent after day 11. For MRI they also report a specific temporal evolution on T1, T2 and flair. However, hypo- and hyperdensities/intensities were overlapping for all modalities and sequences. They propose a method to develop an evidence-based time scale to date SDHs. To our knowledge, no follow-up study on their research has been published yet.

The lack of well-designed studies regarding age determination of SDHs might be an explanation for the practice variation among radiologists. On the other hand, lack of evidence in the current medical literature for dating of SDHs could have also lead to more people reporting not being able to date, instead of dating without certainty. It might be possible that the participants applied knowledge of dating intraparenchymal hematomas on SDHs, as an analogy between these two has been described.[11] Unfortunately, we did not

Table 4. *Results practical questions CT*

Case	It is possible to date this SDH Yes: n (%)	Median of the reported estimated age (range)	Median of the reported minimal age (range)	Median of the reported maximal age (range)	Self-confidence Scale: n (%)	Age SDH according to history/ forensic evaluation
Case 1 A 5-month-old boy; Alleged history: fell from a carry cot	n = 48	n = 19	n = 21	n = 19	n = 31	-
	30 (63)	2 days (1 hour – 1 week)	16 hours (0 hours – 5 days)	8 days (2 hours – 10 weeks)	-2: 4 (13) -1: 9 (29) 0: 13 (42) 1: 5 (16) 2: 0 (0)	1 day
Case 2 A 3-week- old girl; Alleged history: suddenly pallor, weakness, convulsions	n = 48	n = 19	n = 20	n = 19	n = 28	-
	28 (58)	2 days (1 hour – 2 weeks)	1.5 days (1 hour – 1 week)	8 days (1 day – 6 weeks)	-2: 2 (7) -1: 5 (18) 0: 19 (68) 1: 2 (7) 2: 0 (0)	9 days
Case 3 A 7-month-old girl; Alleged history: choking during feeding	n = 47	n = 19	n = 21	n = 21	n = 26	-
	30 (64)	3 days (1 hour – 5 weeks)	2 days (0 hours – 4 weeks)	2 weeks (1 day – 20 weeks)	-2: 1 (4) -1: 8 (31) 0: 15 (58) 1: 2 (8) 2: 0 (0)	Several hours
Case 4 A 3-year-old boy; Alleged history: fell from the stairs	n = 47	n = 25	n = 22	n = 26	n = 36	-
	39 (83)	12 hours (0 hours – 2 days)	5 hours (1 hour – 1 day)	3 days 6 hours – 1 week)	-2: 0 (0) -1: 10 (28) 0: 18 (50) 1: 8 (22) 2: 0 (0)	12 hours

Table 5. *Results practical questions MRI*

Case	It is possible to date this SDH Yes: n (%)	Median of the reported *estimated* age (range)	Median of the reported *minimal* age (range)	Median of the reported *maximal* age (range)	Self-confidence Scale: n (%)	Age SDH according to history/ forensic evaluation
Case 5 A 5-month-old boy; Alleged history: fell from a carry cot	n = 51	n = 18	n = 17	n = 17	n = 30	-
	32 (63)	4 weeks (2 hours – 24 weeks)	1 week (0 hour – 4 weeks)	10 weeks (6 hours – 100 weeks)	-2: 0 (0) -1: 9 (30) 0: 12 (40) 1: 9 (30) 2: 0 (0)	2 days
Case 6 A 1-year-and-3-month old boy; Alleged history: fell from a bunk bed	n = 50	n = 31	n = 35	n = 36	n = 45	-
	45 (90)	6 days (5 hours – 6 weeks)	3 days (0 hour – 3 weeks)	17 days (2 hours – 24 weeks)	-2: 1(2) -1: 10 (20) 0: 19 (42) 1: 15 (33) 2: 0 (0)	9 days
Case 7 A 10-month-old boy; Alleged history: fell from high chair	n = 48	n = 24	n = 27	n = 25	n = 35	-
	33 (69)	17 days (1 hour – 24 weeks)	6 days (0 hour – 4 weeks)	3 weeks (12 hours – 36 weeks)	-2: 0 (0) -1: 6 (17) 0: 20 (57) 1: 9 (26) 2: 0 (0)	3 days
Case 8 A 3-year-old boy; Alleged history: fell from the stairs	n = 48	n = 32	n = 36	n = 35	n = 41	-
	42 (88)	10 days (3 hours - 4 weeks)	5 days (0 hour – 3 weeks)	4 weeks (4 hours – 34 weeks)	-2: 2 (5) -1: 8 (20) 0: 20 (49) 1: 11 (27) 2: 0 (0)	2.5 weeks

include detailed questions about the origin of the knowledge of the participants. Part of the practice variation in this study might be explained by the fact that in two cases multiple SDHs were visible, so that the different radiologists might have referred to different SDHs in the same case.

Limitations

A possible limitation of this study is that, despite two reminders sent by email, we had a 30% response rate. Although radiologists not willing to participate were asked to opt out through the questionnaire and to leave their sociodemographic data, only 16% of the eligible participants rejected the questionnaire this way. The majority of the radiologists did not respond at all. Another limitation is that out of the 51 participants, not all of them filled out the complete questionnaire. Some did report an estimated date for the SDH but did not report a range or vice versa. Not all participants filled out all cases, resulting in different numbers suitable for analysis per case. The first question for each image was whether the participant was able to date this SDH. Not everyone answered this question and even if they did, not all participants subsequently filled out an answer to the next question. We hypothesize that this is partly due to 'survey weariness' and partly due to uncertainty about the right answer. Another limitation is the fact that per case only two images could be displayed in the questionnaire. Under normal circumstances more images (and for MRI more sequences) would be available. We did try to overcome this problem by selecting the most relevant images/sequences. This could have resulted in less reliable answers compared to a clinical situation with all images available. Due to the lack of consensus about which range of answers is acceptable, this is a descriptive study of the variance among radiologists and not a study in which the accuracy of the individuals is tested.

Generalizability

The participants did not differ significantly from the radiologists who opted out on the items working situation or working experience, but there were more neuroradiologists among the participants compared to the radiologists who opted out. As the subspecialty sections of the Dutch Radiological Society represent the majority of the active radiologists in this field, the results are likely to be representative for Dutch radiological practice. It seems reasonable to assume, that radiologists with interest in and therefore knowledge about this topic would be most willing to participate. This would cause more uniform results than in clinical practice. However, people with less experience in the field might not be asked as expert witnesses in court, so we cannot predict exactly how our results relate to the practice variation among all Dutch or all European pediatric and neuroradiologists dating SDHs for court. There is no reason to assume that radiological practice and interpretation in the Netherlands differs significantly from the rest of Europe. This is especially true for neuroradiology, which has a very active European Society of Neuroradiology with a charter for education and training in clinical neuroradiology and a European subspecialty diploma.[17]

New steps

We did not investigate why participants do date SDHs, although no guidelines exists. A survey is a difficult way to answer this question, as one is always trying to gain as much information as possible on one side, and is keeping the questionnaire as short as possible on the other side, to raise the number of complete forms. In-depth interviews with radiologists might give the answer to this question. A systematic literature search for the evidence of dating SDHs might provide insight in the possibility of dating SDHs on imaging findings and might clarify the level of certainty that can be applied to statements regarding this topic. If no literature on this topic exists, a prospective study in which patients with a known head trauma are scanned repeatedly could provide insight in the development of SDHs over time. If there is evidence for dating SDHs this knowledge should be made generally known to radiologists (either during initial training or with CME), in order to enhance uniform reporting concerning this controversial topic.

CONCLUSION

We conclude that there is lack of consensus on the possibility of dating SDHs on imaging findings only among Dutch radiologists and that their answers regarding dating SDHs in pediatric cases vary widely. The large practice variation reported here makes the radiological statement with respect to dating SDH less valuable in court, as only evidence that is considered to be beyond reasonable doubt according to professionals is accepted. Besides the large practice variation, the broad time ranges reported makes dating SDHs less valuable in court as well, as the judicial system needs information that can pinpoint a trauma to a certain moment in time. This underlines the current opinion that a diagnosis of child abuse cannot be made based on radiological findings only, but should always be made in multidisciplinary team approach taking into account all of the available medical data.

ACKNOWLEDGEMENTS

The authors would like to thank all radiologists who were willing to spend their time on answering the questionnaire and thereby participated in this study. Without their efforts this publication would not have been possible. Furthermore we thank J. van Schuppen for his valuable advice on the development of the questionnaire.

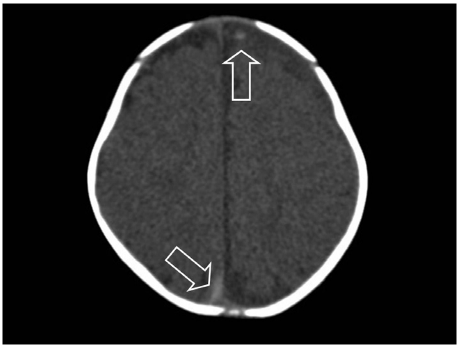

Figure 1. *Case 1. Axial CT image of a 5-month-old boy who fall from a carry cot. Information not available to the participating radiologists: The boy was brought to the emergency department after a trauma with immediate neurological signs. The clinical history later changed into an abusive incident. The CT scan was performed 1 day after the incident. CT scan shows a left frontal and right posterior SDH (open arrows).*

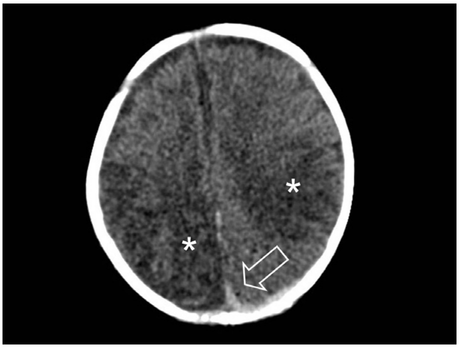

Figure 2. *Case 2. Axial CT image of a 3-week-old boy who presented with pallor, weakness and convulsions. Information not available to the participating radiologists: The boy was admitted because of the persisting convulsions. This CT scan was performed on day 9 after admission. Police investigations ruled this to be an AHT case. Based on the police investigations the time of the accident was dated as 9 days old. CT shows a SDH along the left posterior convexity (open arrow). Note the bilateral hypodens areas indicating edema of the brain (asterisks).*

Figure 3. *Case 3. Axial CT image of a 7-month-old girl who according to parents choked during feeding. Information not available to the participating radiologists: According to the clinical history the girl choked during feeding and became comatose. Before this she had been healthy. Her father took her to the hospital and reportedly accidentally bumped her head against the car. She was admitted to the hospital in comatose state and discharged severely handicapped. This CT scan was made immediately after arrival at the hospital. Police interrogations revealed this was an abusive head trauma case. CT shows a SDH with hypo- and hyperdense components (open arrow). The SDH extends to the right posterior convexity (arrow).*

Figure 4. *Case 4. Axial CT image of a 3-year-old boy who fell from the stairs. Information not available to the participating radiologists: The boy was brought to the hospital comatose, according to parents he had fallen from the stairs that night. Signs of physical abuse (bruises and burning wounds) were found all over his body. He was admitted for several weeks, this CT scan was made 12 hours after the incident. Police investigations revealed that the day before admission he had been seen in good condition by several people. In the night before admission the neighbors had heard him crying for several hours. CT shows a thin hyperdense SDH along the right convexity (open arrow) and a SDH along the falx cerebri (arrow).*

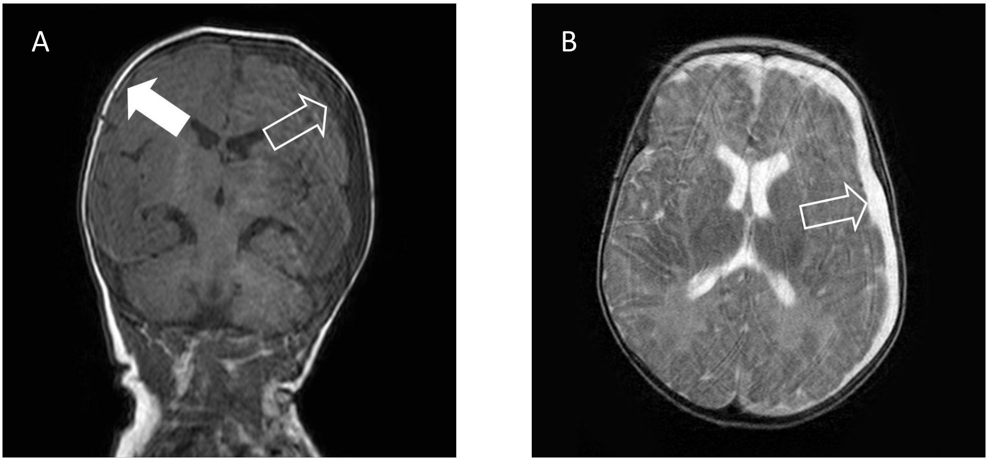

Figure 5a. *Case 5. Coronal T1-weighted MR image of a 5-month-old boy who fell from a carry cot. Information not available to the participating radiologists: The boy was brought to the emergency department after a trauma with immediate clinical signs. He was pale, weak and unresponsive and was admitted to the pediatric ward. The clinical history later changed into an abusive incident. The MR scan was performed after 2 days. MRI, hampered by motion artefacts, shows a left sided hypo-intense SDH (open arrow). A thin right sided hyper-intense SDH is seen on the right side (arrow).* ***Figure 5b.*** *Axial T2-weighted MR image of the same boy shows a hyper-intense SDH along the left convexity (open arrow). The thin right sided SDH is not visible on this image.*

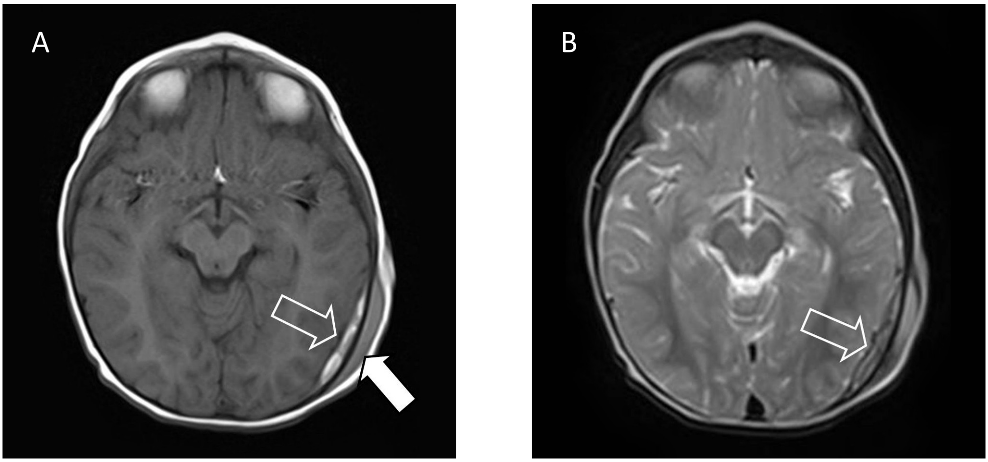

Figure 6a. *Case 6. Axial T1-weighted MR image of a 1-year-and-3-month-old boy who fell from a bunk bed. Information not available to the participating radiologists: The history revealed that the boy was put on a bed (1.60 meter high) by a sibling. He fell of and cried immediately; parents took him to the GP but were referred to the ED because of swelling on the head. The child was admitted to the pediatric ward for one night for observation. Parents noticed a new swelling of the head after some days, and therefore a MRI was performed on day 9. No other trauma was described. MR shows a mixed intensity SDH along the left convexity (open arrow). There is a significant subcutaneous haematoma present (arrow).* ***Figure 6b.*** *Axial T2-weighted MR image of the same boy also shows a mixed intensity SDH (open arrow).*

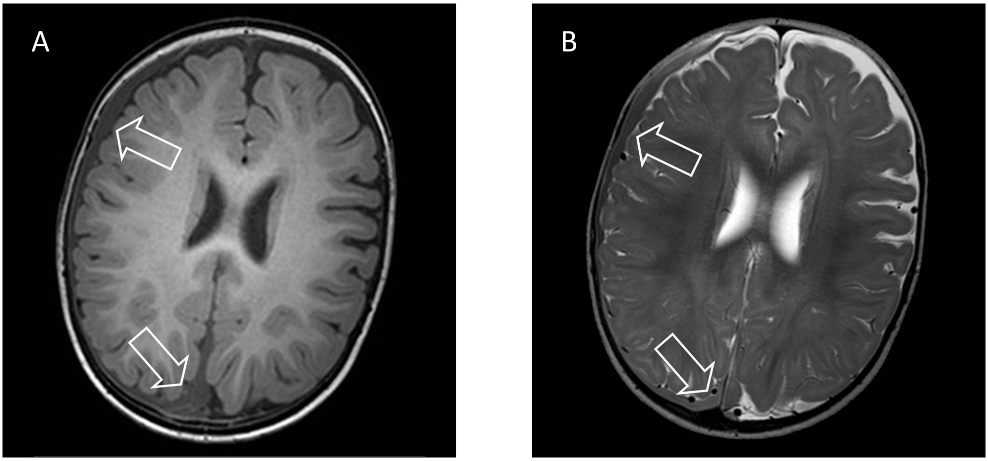

Figure 7a. *Case 7. Axial T1-weighted MR image of a 10-month-old boy who fell from a high chair. Information not available to the participating radiologists: The boy sat on a high chair and tipped himself backwards by pushing the table with his feet. He landed with his head on a concrete floor. Mother took him to the GP, but was sent home because there were no clinical signs of head trauma. The mother thought he was not comfortable and went back to the GP the next day. On the third day she went to the hospital because she was worried about her son. At that time an MRI was performed. MR image shows a hypo-intense SDH along the complete length of the right convexity (open arrows).* ***Figure 7b.*** *Axial T2-weighted MR image of the same boy shows a hypo-intense SDH (open arrows).*

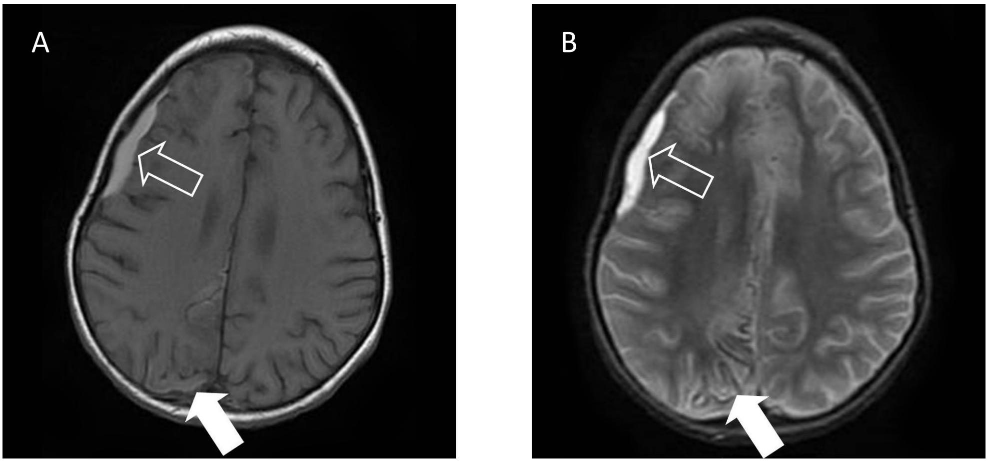

Figure 8a. *Case 8. Axial T1-weighted MR image of a 3-year-old boy who fell from the stairs. Information not available to the participating radiologists: The boy was brought to the hospital comatose, according to parents he had fallen from the stairs that night. Signs of physical abuse were found all over his body. He was admitted for several weeks, this MR scan was made 2.5 weeks after the incident. Police investigations revealed that the day before admission he had been seen in good condition by several people. In the night before admission the neighbors had heard him crying for several hours. MR image shows a hyper intense right sided SDH (open arrow). Subcortical laminar necrosis is visible (arrow).* ***Figure 8b.*** *Axial T2-weighted MR image of the same boy shows a hyper intense SDH (open arrow) and hemosiderin depositions in the subcortical laminar necrosis (arrow).*

APPENDIX - QUESTIONNAIRE

The following is an overview the questions asked in the questionnaire. The text and lay-out have as been slightly altered to better correspond with the text and lay-out of this book:

Demographics

1. Where do you work?
   - o In an university/teaching hospital
   - o In a non- university/teaching hospital
2. How many years have you been working as radiologist?
3. What is your subspecialsm?
   - o Paediatric radiologist
   - o Neuroradiologist
   - o None of the above
4. For the remainder of this questionnaire, click ‘yes’. This will take a maximum of 10 minutes of your time. To leave this survey, click ‘no’.
   - o Yes
   - o No
5. How many hours a week do you spend on neuroradiology?
6. Where did you gained your knowledge on dating SDHs? [multiple options possible]
   - o During my training, from literature
   - o During my training, from my supervisors
   - o After my training, through medical education
   - o During clinical practice, through discussions with colleagues
   - o Other, namely
7. Do you date SDHs?
   - o Yes
   - o No
8. In what setting do you date SDHs?
   - o Clinical
   - o Forensic
   - o Both
   - o None of the above

Theory

1. Can you date mixed density on an MRI scan?
   - o Yes
   - o No
2. Can you date mixed density on a CT scan?
   - o Yes
   - o No
3. If you date a mixed density, do you date over one or more time intervals?
   - o I do not date mixed densities
   - o I date over one time interval
   - o I date over several time intervals
4. What is the cause of a mixed density image? [multiple options possible]
   - o Admixture CSF
   - o Sedimentation
   - o Bleed-rebleed
   - o Natural resorption
   - o Repeated trauma
   - o Other, namely

Practice
In the next part of this questionnaire you will be asked to date 8 scans (4 MRI, 4 CT) and to estimate the age of the SDH. It concerns all pediatric radiological imaging.

The following questions were asked for each of the eight cases:

1. Is it possible to date this SDH?
   - o Yes
   - o No
2. What, in your opinion, is the age of this SDH? Displayed in:
   - o Hours
   - o Days
   - o Weeks

   Amount:
3. How certain are you about this dating?
   - o Very uncertain
   - o uncertain
   - o Neutral
   - o certain
   - o very certain
4. What is the MINIMUM age of this SDH that you can give with certainty? Displayed in:
   - o Hours
   - o Days
   - o Weeks

   Amount:
5. What is the MAXIMUM age of this SDH that you can give with certainty? Displayed in:
   - o Hours
   - o Days
   - o Weeks

   Amount:

The eight cases were as follows:

CT scan 1:	A 5 months old boy, fell from carry cot
CT scan 2:	A 3 weeks old boy, syncope, pale, week, eye movement
CT scan 3:	A 7 months old girl, choking during feeding
CT scan 4:	A 3 years old boy, fell from stair
MRI scan 1:	A 5 months old boy, fell from a carrycot
MRI scan 2:	A 1 year and 3 months old boy, fell from a bunkbed
MRI scan 3:	A 10 months old boy, fell from high chair
MRI scan 4:	A 3 year old boy, fell from stairs

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Chapter 8

Classic metaphyseal lesion following vaginal breech birth: a rare birth trauma

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ABSTRACT

A six day old male neonate, born after attempted external version (ECV) and vaginal breech birth, was evaluated for pain during diaper changes. US of the leg showed a small subperiosteal fluid collection at the distal right femur. Conventional radiographs demonstrated the presence of a classic metaphyseal corner fracture (CML). This case is, to our knowledge, the first to report a CML after ECV and vaginal delivery.

INTRODUCTION

The finding of a classic metaphyseal lesion (CML) in a young child is generally considered to be highly specific for child abuse.[1] However, like in any radiological finding a differential diagnosis exists. In neonates birth trauma is one of the causes of fractures that should be considered. A Dutch analysis, between 1997 and 2004, among 158,035 full-term neonates showed an overall fracture incidence of 0.74%, that was not otherwise specified.[2] It is a well-known fact that, although the incidence is low, long bone fractures are associated with breech and forceps delivery.[3] In the Term Breech Trial it was shown that there was a 0.1% incidence of long bone/clavicular fractures in the caesarean birth group com- pared to 0.6% in the vaginal delivery group.[4] Several cases of CML following CS have been reported in literature.[5–8] However, to date no cases have been reported following vaginal delivery. In this case report we present an otherwise healthy neonate with a CML after breech vaginal delivery.

CASE REPORT

A term male neonate (40 week gestational age) was born to a 38 year old primigravid. Pregnancy was uncomplicated except for breech position. After an unsuccessful external cephalic version (ECV) the parents, after counselling, opted for vaginal delivery. At 39 4/7 week gestational age rupture of membranes occurred without signs of impeding labour, after 24 hour labour was induced using misoprostol. Three days thereafter oxytocin was started and epidural anesthesia was administered. During cervical dilation a deceleration on the cardiotocogram was noted and subsequently an assisted breech delivery was performed. This procedure was complicated by prolonged development of the arms, taking approximately two minutes. After the baby was born, with a birth weight of 3750 gram was pale, showed bradycardia and no spontaneous breathing, the APGAR scores were 1/3/5.

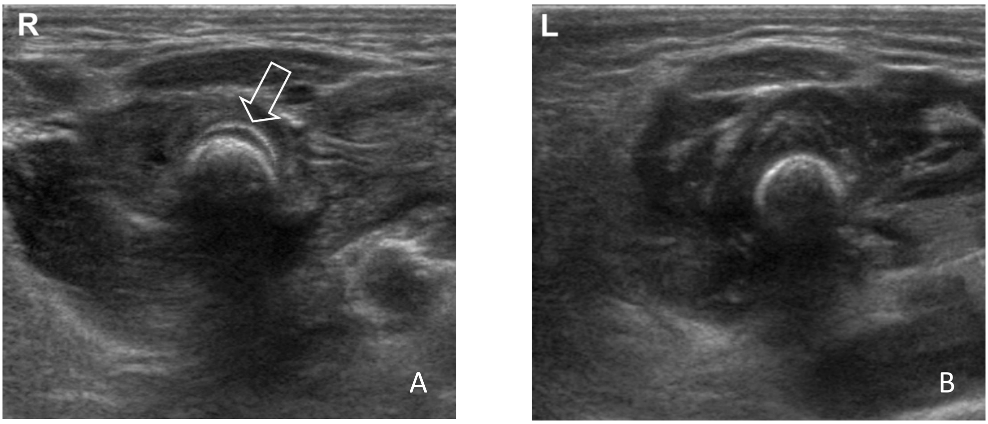

Figure 1a. *Transverse ultrasonography image of the right distal femur showing a small subperiosteal fluid collection (arrow).* ***Figure 1b.*** *Transverse ultrasonography image of the left distal femur showing no abnormal findings.*

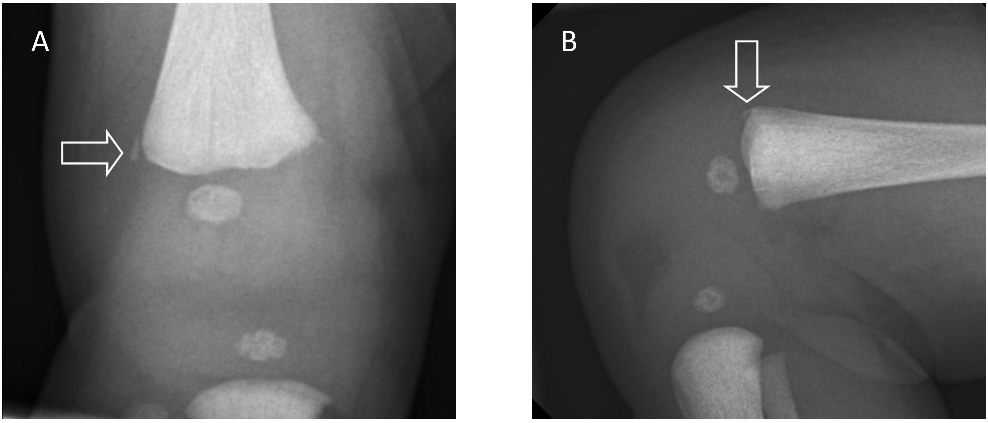

Figure 2a. *Radiograph AP of the right knee show a classic metaphyseal lesion (arrow).* ***Figure 2b.*** *Radiograph lateral of the right knee show a classic metaphyseal lesion (arrow).*

He was subsequently admitted to the neonatal intensive care unit (NICU). At the NICU the nurses noted that during diaper changing he was irritable and kept crying. Due to the fact that these complaint remained, on day six of life, an ultrasound study of the right leg to assess the hip was performed. This US exam showed a normal aspect of the hip, but upon further evaluation of the right leg a subperiosteal fluid collection, with signs of some callus formation, at the level of the distal femoral diaphysis was noted (Fig. 1a, b). Under the differential diagnosis of osteomyelitis or a fracture, additional conventional radiography was obtained which showed a CML (Fig. 2a, b). As the baby had been in the care of the NICU, the complaints were noted after birth and the fact that there was no concern at all for child abuse no further radiological imaging was performed. On follow-up outpatient clinic visit the baby showed a normal development.

DISCUSSION

In case of a fracture in an infant, it is important to differentiate between a birth trauma or trauma after birth, may it be accidental or non-accidental. Given the strong relation between CML and child abuse this is especially of importance in potential legal proceedings. It is therefore extremely important that a complete clinical and obstetrical history is obtained, as it is well-known that fractures can occur as a result of birth trauma.

This case is to our knowledge the first to report a CML after ECV and vaginal delivery. Several cases of CML following caesarean section (CS), both with and without ECV, have been reported (Table 1).[5–7,9] Additionally several case reports of epiphyseal separation fractures (ESF) of the distal femur, as a birth trauma have been reported (only English, French and German literature is included, Table 1).[10–12] These fractures, which can be classified as Salter-Harris type I and II fractures, have reportedly a similar causative mechanism, i.e.

Table 1. *Reported cases of CML and epiphyseal fracture separation of the femur as result of birth trauma.*

Author	Foetal position	External version	Birth	Lesion	Location
Present case	Breech	Yes	Vaginal	CML	Distal
[6]	Breech	Yes	CS	CML	Distal
[5]	Breech	No	CS	CML	Distal
	Breech	No	CS	CML	Distal
	Cephalic	No	CS	CML	Distal
[7]	Breech	Yes	CS	CML	Distal
[9]	Breech	No	CS	CML	Distal
[10]	Breech	No	CS	EFS	Distal
[11]	Cephalic	No	CS	EFS	Distal
[12]	NR	NR	Vaginal	EFS	Distal*

* Diagnosed at age of three months. The authors state that there was a difficult delivery. Given the time between birth and diagnosis other causes, including child abuse, cannot be ruled out.

CML: Classic metaphyseal lesion; CS: Caesarean section; EFS: Epiphyseal fracture separation; NR: Not reported

shearing and torsion forces exerted on the affected long bone and are therefore included in Table 1. Given the policy of many medical journals not to publish case reports or only extremely rare cases and the lack of clinical findings, we feel that it is more than likely that the incidence of CML as a result of birth trauma is more common than the reported rate of 0.0016% (calculation based on paper by O'Connell & Donoghue). Furthermore, it is thought that most CML will not produce complaints, this implies that cases will not be noticed directly after birth and in the persisting absence of clinical findings might remain undiagnosed.[13] In existing literature CML is described as a result of caesarean section, irrespective of the fact whether a previous ECV was attempted or not. One case of distal femoral ESF following vaginal delivery has been described in literature.[12] However, this case was diagnosed at three months of age and no specific details, apart from a difficult birth, are provided. Given the absence of relevant clinical information and imaging following birth, it cannot be excluded that this case is not birth related but the result of trauma, e.g. non-accidental injury, suffered later in life. Based on the literature findings we hypothesise that the CML in our case most likely occurred as result of breech delivery and not from ECV.

From a forensic perspective the importance of this case report lies in the fact that if a case of CML is encountered in a new-born, birth trauma – even if after vaginal delivery – is a possible, albeit extremely rare, aetiology. Birth injury, of course, must be considered in context of all findings, such as the absence of additional injuries suggestive of abuse and a consistent history of difficult delivery.

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Part II

Postmortem imaging

Chapter 9

Current techniques in postmortem imaging with specific attention to pediatric applications

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ABSTRACT

In this review we discuss the decline of and current controversies regarding conventional autopsies and the use of postmortem radiology as an adjunct to and a possible alternative for the conventional autopsy. We will address the radiological techniques and applications for postmortem imaging in children.

INTRODUCTION

The number of autopsies has been declining worldwide. In a study performed at the Agency for Healthcare Research and Quality, Shojania et al.[1] found an autopsy rate in the United States below 6%, compared with 40–50% a few decades ago. This trend is supported by other sources verified by the author.[2] In a review by Burton and Underwood[3], similar rates were found in other Western countries as well (Table 1). The pediatric and neonatal autopsy rates have always been higher than those in adults.[4] A general trend towards declining pediatric autopsy rates has been noticed as well.[5,6] The reason for this decline is twofold—a decrease in willingness of the attending physician to ask permission for an autopsy in combination with a decrease in parental willingness to give consent.

Little research has been done on the diminished willingness of doctors to ask permission to perform an autopsy. In a study by Snowdon et al.[7], neonatologists said that although autopsies are important, they believed it was secondary to parental needs. They felt especially uncomfortable if the cause of death could be determined without an autopsy. This is supported by several other authors.[8,9] Other factors that are mentioned are budget cuts, fear of legal consequences, lack of communication training, and prior negative experiences with poorly performed autopsies or delayed autopsy reports.[10] Refusal of parents/guardians to agree to an autopsy is influenced by several factors, including religion[11,12], fear of unethical practices (influenced by the Alder Hey scandal in the UK[13-17]), and an increasingly individualistic culture in which personal life and experience precedes gain in scientific knowledge[9]. An important reason for relatives to refuse permission is the feeling that the deceased "has suffered enough".[18] Many of these reasons have not changed during the last decades and therefore do not explain the decrease in the number of autopsies. Perhaps the most important reason for the decline in autopsies is the fact that, with increasing diagnostic and imaging techniques, both doctors and parents/guardians are under the assumption that they already know the cause of death. This assumption is known

Table 1. *The worldwide decline in autopsy rates*[a]

Country	Initial autopsy rate (period)	Subsequent autopsy rate (period)
Australia	21.0% (1992–93)	12.0% (2002–03)
France	15.4% (1988)	3.7% (1997)
Hungary	100% (1938–51)	68.9% (1990–02)
Ireland	30.4% (1990)	18.4% (1999)
Jamaica	65.3% (1968)	39.3% (1997)
Sweden	81.0% (1984)	34.0% (1993)
UK	42.7% (1979)	15.3% (2001)
USA	26.67% (1967)	12.4% (1993)

[a] Autopsy rate is expressed as a percentage of all deaths. Figures in brackets denote the years in which the data were reported (adapted from Burton and Underwood[3] with permission.)

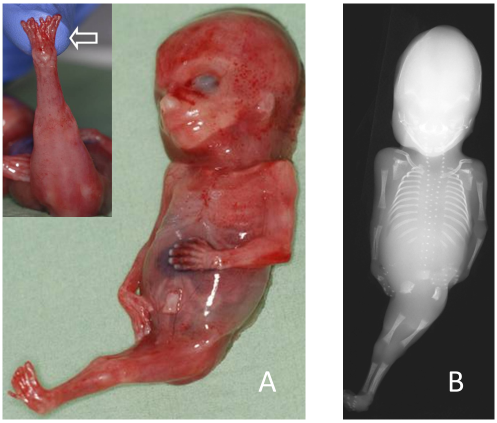

Figure 1a. *A neonate aborted at 14 weeks gestational age. a Antenatal US showed severe dysmorphological changes. Photograph of the foetus shows the fused lower extremity. The insert depicts the size of the foetus in relation to the fingertip of the pathology assistant (arrow).* ***Figure 1b.*** *Radiography, performed on a mammography system, shows a sirenomelia. The skeleton is exquisitely depicted.*

not to be true for adults in about one-third of the cases.[19-21] For neonates and children, discrepancies between clinical diagnosis and diagnosis at autopsy are found in about one-quarter of the cases.[6,22] The autopsy reveals new information in pediatric deaths in about 44% of the cases.[23] An alternative for conventional autopsy could be postmortem radiology (also known as virtual autopsy or Virtopsy®) or minimally invasive autopsy (CT and MR imaging followed by ultrasonographic-guided biopsies) (www.virtopsy.com).[13,24–26] In this review article we address the radiological techniques, conditions and applications for postmortem imaging in children.

TECHNIQUES

Conventional radiography

Conventional radiology (CR) is the mainstay of postmortem imaging. The radiographs are reported by a pediatric radiologist and emphasis is placed on skeletal development, both with regard to the gestational age as well as the presence of anomalies, such as skeletal dysplasias. In foetuses up to a gestational age of approximately 24 weeks, we make use of the mammography system, as this has a high resolution and exquisitely depicts the foetal skeleton (Fig. 1). In these cases a babygram, which visualizes developmental anomalies of the entire skeletal system in two or more views, is acceptable. In older foetuses and neonates a direct digital radiography system (Triathlon DR, Oldelft Benelux, the Netherlands) is used. In babies and toddlers postmortem radiography is reserved for cases of sudden infant death syndrome (SIDS) or suspected child abuse. In these cases a full skeletal survey according to either the American College of Radiology or the Royal College of Radiologists should be performed, even if a whole-body CT is obtained.[27–29] In older children (older than four years of age) postmortem CR plays a minor role and is only performed on special indications. Finally, pathologists may request radiographs of autopsy specimen. These radiographs should preferably be obtained in close cooperation with the attending pathologist and if size permits should be made on a mammography system. These specimen radiographs can yield additional information that initially was not visible on either CR or CT (Fig. 2).

Conventional angiography

Since conventional autopsy examination of the vascular system is difficult to perform, postmortem angiography could be a useful technique.[30] In most cases postmortem angiography will consist of a single organ study in which the organ can be in situ or removed from the body. Whole-body postmortem conventional angiography has been described in foetuses and neonates.[31] A special technique worth mentioning is the art of cast angiography in which a resin is injected into the vasculature and the tissues are removed by maceration, thus yielding a cast of the vasculature.

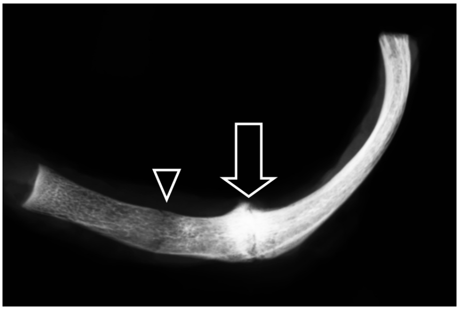

Figure 2. *A 3½-month-old girl died under suspicious circumstances. Judicial autopsy was warranted. Contact radiograph (performed on mammography system) shows a fracture of the second rib on the left with consolidation (arrow) but also a fresh fracture (arrowhead). The latter was, even in retrospect, not visible on CR or CT (not shown here) (Reprinted with permission from Bilo RA, Robben SG, van Rijn RR [2009] Forensic aspects of pediatric fractures: differentiating accidental trauma from child*

Ultrasonography

The use of US in postmortem imaging, to date, has been limited (Fig. 3).[32,33] Implementation is hindered by a relative lack of knowledge about the possibilities of US by (forensic) pathologists. Not only can US be used as an inexpensive imaging method in the absence of CT and/or MRI, but it can also be used to guide biopsy procedures in case of a minimal invasive autopsy (MIA).

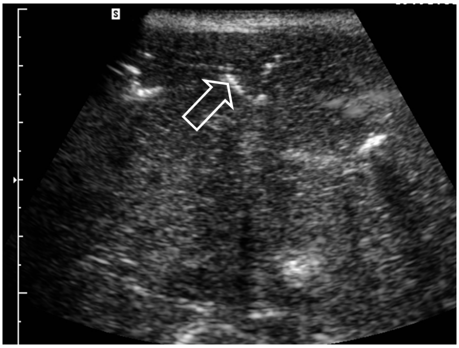

Figure 3. *Postmortem US shows portal air (arrow), a common finding in postmortem imaging.*

Computed tomography

Postmortem CT is a fast technique that allows imaging of the whole body inside a body bag or coffin. This makes access to the scanner relatively easy and technicians appreciate the fact that they are not confronted with the deceased person. In general, straightforward CT protocols are used. In our hospital we routinely perform these exams and use separate protocols for the brain and the rest of the body (Table 2). The use of 3-D reconstructions can be very illustrative. One of the clear disadvantages of postmortem CT is the absence of blood flow; this makes CT angiography (CTA) difficult. In the Virtopsy® project, postmortem use of CTA has been explored.[34] Using a pressure-controlled modified heart–lung machine and femoral access, postmortem angiography is a feasible option in specialized centres.

Table 2. Postmortem CT parameters[a]

Anatomical location	kV	mAs	Slice thickness	Increment	Pitch	Collimation	Rotation time
Head & neck	120	285	0.9 mm	0.45 mm	0.392	64*0,625 mm	0.75 sec
Thorax & abdomen[b]	120	250	3.0 mm	2.0 mm	0.983	64*0,625 mm	1.0 sec

[a] Protocol for Philips Brilliance (64 channel CT, Philips Medical Systems, Best, the Netherlands); [b] Lower extremities will be scanned upon special request only In all cases, coronal and sagittal reconstructions, using appropriate kernels, are performed In selected cases 3-D SSD reconstructions are performed

Table 3. Postmortem MRI parameters[a]

Anatomical location	Sequence	FoV (mm)	Slice thickness (mm)	TR (ms)	TE (ms)	NSA	FA (°)	AT[b] (min)
Head & neck								
Axial	T2	180	3	4000	96	4	150	3:18
Sagittal[c]	T1-3D	256	1	1990	2.92	1	15	4:06
Axial[d] Flash	2D	180	3	660	26	2	20	5:39
Body								
Coronal[f]	3D-T2	300	1	750	108	1	150	8:26
Coronal	3D-T1	300	3	1500	13	2	90	6:27

[a] Protocol for Siemens Magnetom Avanto 1.5 T (Siemens, Erlangen, Germany); [b] TA: Acquisition time; [c] Coronal and axial reconstructions; [d] In case of clinical suspicion of intracranial haemorrhage only; [e] Lower extremities will be scanned upon special request only; [f] Axial and sagittal reconstructions

Magnetic resonance imaging

We feel that CR still has an important role and therefore should be obtained in all cases in which postmortem MRI of foetuses and neonates is performed. In some instances pathology will be difficult, if not impossible, to detect on MRI, whereas CR can be diagnostic (Fig. 4). The MRI protocol is divided into two separate parts. First of all the neurocranium (in a significant number of cases neuropathology will be present) (Table 3) (Fig. 5). The thorax and abdomen are imaged separately (Table 3) (Fig. 6). The extremities are only imaged upon special request. In general this protocol can be scanned within a one hour time frame. Protocols should be fine-tuned if specific questions need to be answered. To date, in our hospital, we have only performed postmortem MRI in fresh cadavers that can be placed in the bore without problems. However, it is possible to obtain an MRI while the corpse is in the body bag.

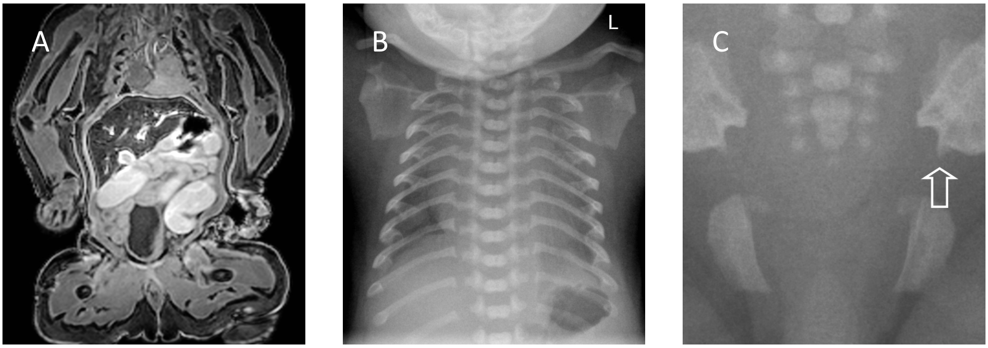

Figure 4a. *A neonate, born at 41 weeks gestational age, who died shortly after birth. Antenatal US showed an underdeveloped thorax and short stature (T2-W 3-D, slice thickness: 1 mm, TR: 4000, TE: 80).* ***Figure 4b.*** *Chest radiograph shows a severely constricted thoracic cage, underdeveloped scapulae and flattened vertebrae.* ***Figure 4c.*** *Radiograph of the pelvis shows hypoplastic iliac wings and sciatic notch spurs (arrow). Based on the conventional radiological findings, the diagnosis thanatophoric dysplasia type II is most likely (OMIM #187601).*

Technicians and local guidelines

Before a postmortem radiology service is offered in a department of radiology, the radiological technicians and other involved personnel should be informed. It should be made clear to all involved that postmortem imaging is an important aspect of medical care and that the outcome of the exam can seriously impact the life of parents/guardians. In our department we have the policy that these exams are performed on a voluntary basis. However, to date none of our technicians has refused to do these exams. Handling of the deceased foetus, neonate or child is done in all instances by either the mortuary personnel or the attending pediatric radiologist. The referring clinician should be aware that postmortem imaging is not a routine procedure and that normal clinical work will have priority over these exams. In general this means that the exams will be done before or after the normal radiology schedule.

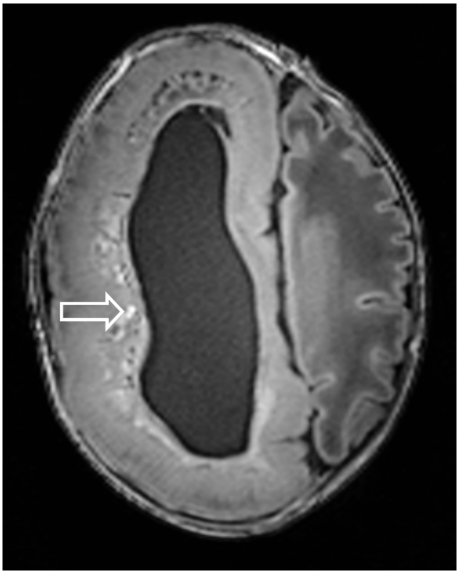

Figure 5. *A neonate aborted at 31 weeks gestational age. Antenatal US showed abnormal brain development. Autopsy was refused by the parents. T1-W MRI shows asymmetrical development of the brain with overgrowth of the right side, in keeping with hemimegalencephaly. On the right side multiple focal hemorrhagic lesions are seen (arrow) (slice thickness: 1 mm, TR: 9, TE: 4,1)*[58]

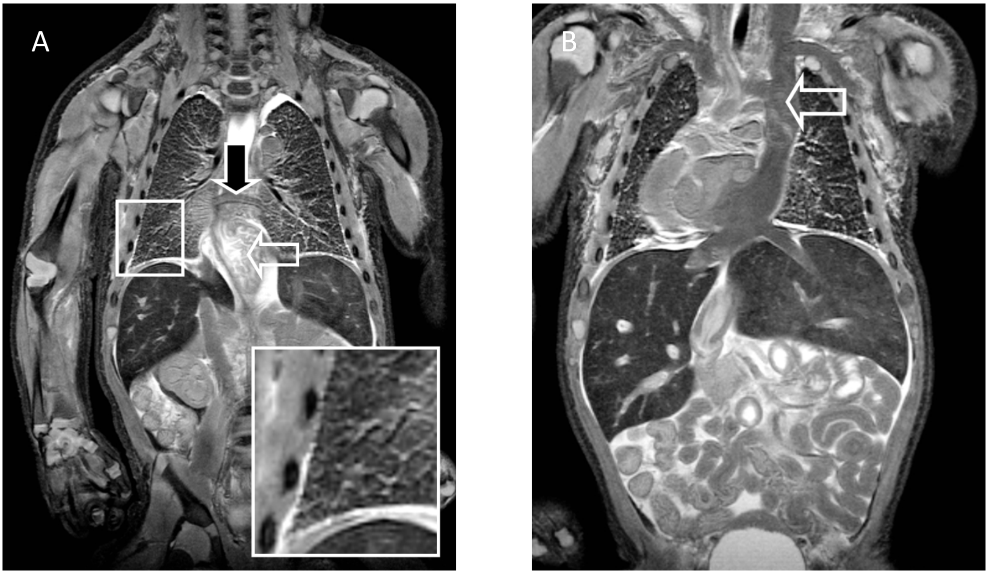

Figure 6a. *A neonate with a congenital cyanotic heart disease born at 39 weeks. Maximum support and 100% oxygen did not lead to clinical improvement and the child died. T2-W coronal MRI shows a complete anomalous venous return (arrow) with pulmonary interstitial oedema (insert). A central tendon defect is seen (open arrow) (slice thickness: 2 mm, TR: 5500, TE: 54, FA: 180°).* ***Figure 6b.*** *T2-W coronal MRI shows a persistent left superior caval vein (arrow), a dextrocardia and situs intermedius of the liver. Asplenia was also noted.*

CLINICAL POSTMORTEM RADIOLOGY

If postmortem imaging proves to be an adequate alternative for the conventional autopsy, this will probably lead to more investigations of deceased children. This way, major improvements could be made in studying clinically challenging diagnoses, e.g. sudden infant death syndrome. At the present time, postmortem imaging can be an interesting addition to conventional autopsy. Comparison studies show that for certain diagnoses imaging is superior, while in others the cause of death cannot be determined. Most information comes from perinatal (neuro-)imaging and imaging in trauma patients.

Conventional radiography

It is widely known that conventional radiology plays an important role in the diagnosis of skeletal dysplasias and the detection of fractures in cases of child abuse.[35] Detailed discussion of conventional radiology lies outside the scope of this review as this is a widely accepted and utilized technique.[36–38]

Ultrasonography

To date only a few articles on postmortem US have been published. Uchigasaki et al.[33] state that although CT and MRI can provide much more information than US (especially in decomposed bodies), US is inexpensive and easy to handle, and therefore might provide some information before an autopsy is performed. Farina et al.[32] studied 100 cases in which US and US-guided biopsy were performed.[32] In this study the concordance rate between US and conventional autopsy with regard to the cause of death and the main pathological findings reached 83%.

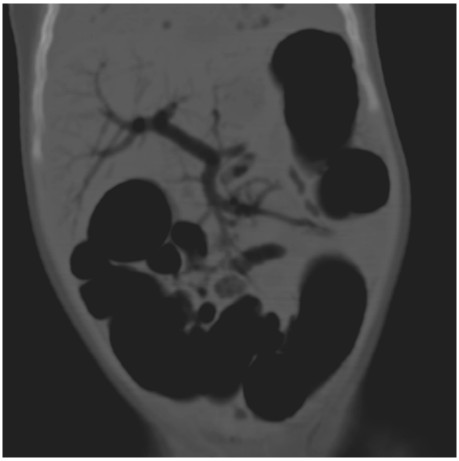

Figure 7. A 6-month-old boy who died after attempted resuscitation. On postmortem, CT air is seen in all major vessels. On autopsy a positive blood culture for S. aureus was found. The cause of death was a fulminant sepsis.

9

Computed tomography

Compared to autopsy CT is superior in detecting fractures, as it can detect fractures in places that are generally not examined during a conventional autopsy (e.g. the face). Bolliger et al.[39] conclude from their study that CT examination has proven "to be an invaluable tool in three areas of forensic pathology; namely, in the detection and demonstration of fractures, the detection of foreign bodies and the detection of gas" (Fig. 7). Furthermore, 3-D reconstructions can be made, which can be helpful in demonstrating the type of injury during court cases, for example.

Magnetic resonance imaging

Obtaining permission for an examination of the brain during an autopsy can be especially difficult because it takes several weeks to fixate the brain properly, and many parents/guardians request that all organs be replaced before burial.[40] It is therefore encouraging that several studies have shown that structural anomalies of the brain can be adequately detected with MRI.[26,41] Griffiths et al.[42] have been examining neuropathology in foetuses and deceased neonates since 2003. In their first series they found complete agreement between MRI and autopsy in 28 of 32 cases. In 2005 they examined more than 200 foetuses and neonates with similar results. They found that MR provides detailed information about all organ systems, except for the heart (Figs. 8 and 9).[13] Cohen et al.[25] found that although MR is very good in detecting brain and spine anomalies, if it is not combined with the results of autopsy, 71% of essential information will not be detected. Breeze et al.[43] determined kappa values to assess agreement between MRI and autopsy for different organ systems. They were high for the brain (0.83), moderate for lungs (0.56) and fair for the heart (0.33). The relative inability of postmortem MRI to detect cardiac pathology is described by several other authors.[43,44] This is a major shortcoming because cardiac disease is a major cause of death in the Western world.

Figure 8. *A 2-month-old neonate presented at the emergency department in severe cardiac and respiratory distress. Resuscitation was unsuccessful. Coronal T2-W MRI shows hematopericard (open arrow), hematothorax (arrow) and a pleural effusion (arrowhead) (slice thickness: 1 mm, TR: 4000, TE: 80, FA: 90°). There is an aberrant pulmonary vein draining into the left ventricle (open arrowhead). The abdomen shows ascites (asterisk).*

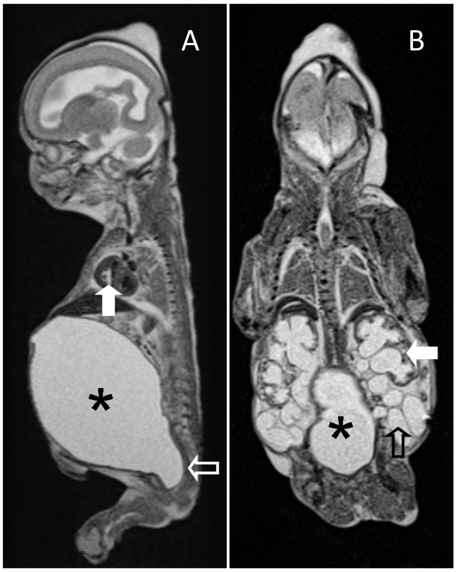

Figure 9a. *A neonate aborted at 20 weeks gestational age. a Antenatal US showed a massively dilated bladder and bilateral hydronephrosis. Sagittal T2-W MRI shows a distended bladder (asterisk) and a dilated posterior urethra (open arrow), consistent with posterior urethral valves (slice thickness: 1 mm, TR: 1500, TE: 161, FA: 150°). Note the fluid-fluid level in the heart (arrow) as a result of clotting blood.* ***Figure 9b.*** *Coronal T2-W MRI shows a distended bladder (asterisk) and dilated tortuous ureters (open arrow). There is a substantial bilateral pyelocaliceal dilatation (arrow). There is a relative hypoplasia of the lungs as a result of the oligohydramnion.*

The use of ultra-high-field MRI has been evaluated by Thayyil et al.[45], who concluded that “high-field MRI (and ancillary non-invasive post-mortem investigations) provided all the information that could be obtained with invasive autopsy for all internal organs in cases in which the intrauterine retention period was less than one week. Moreover, clinically useful information about the brain could be obtained, even in cases in which maceration and autolysis prevented formal neuropathological examination”.[45]

Combined CT and MRI

In a recent study, 30 adult study subjects underwent both minimally invasive autopsy (MIA) and conventional autopsy (CA).[46] Because of a wide variety of causes of death, it is difficult to draw conclusions in such a small group about the sensitivity and specificity for CA of different organ systems, but the overall agreement on cause of death between MIA and

CA was 77%. MIA correctly identified common causes of death, such as pneumonia and sepsis, but failed to demonstrate acute myocardial infarction (n=4). In this study MRI was superior to CT in detecting brain abnormalities and pulmonary embolus. Conversely, CT was superior to MRI for the detection of calcifications and pneumothorax. A head-to-head analysis for CT versus MRI was not presented.

Yen et al.[47] performed a retrospective study on postmortem neuroimaging (mostly in adults) as part of the Virtopsy® project, a Swiss research project that aims to eventually replace the standard autopsy by a virtual one combined with minimally invasive procedures. They found that imaging, compared with autopsy as the gold standard, correctly identified the cause of death in almost 80% of the cases where the brain was the primary atrium mortis. The overall agreement between CT and MRI was 69%. A closer look at different findings shows big differences between the accuracy of imaging and autopsy for different types of lesions. Autopsy was superior in detecting scalp lesions, intracranial blood layers and contusions less than three millimeters in thickness, plaque jaunes, dura mater ruptures and brain edema. Imaging, on the other hand, was better in visualizing gunshot injuries and complex skull fractures and in detecting pneumencephalon, ventricular hemorrhage and facial bone fractures. Furthermore, imaging was better in detecting lesions in a decomposed body. It has to be noted that the radiologists reviewing the CT and MRI data were not particularly trained in the forensic field, but that the outcome of the evaluation depends to a large degree on the previous forensic training of the radiologists.[47]

FORENSIC POSTMORTEM RADIOLOGY

The word "forensic" comes from the Latin adjective forensis, meaning"of or before the forum." Today "forensic" is interchangeably used with "forensic sciences" and implicitly means "related to the court" or "legal." The use of radiology in the legal system actually dates to 7 February 1896 when in Montreal, Canada, a radiograph (with an exposure time of 45 minutes) was obtained to locate a bullet lodged in the leg of a gunshot victim. Based on the radiograph the assailant could be convicted.[48]

With respect to forensic radiology, one aspect that needs to be addressed is patient confidentiality. Not only are the radiographs part of the evidence, and as such should be kept confidential in order not to compromise the chain of evidence, but there may also be interest from third parties not directly involved in the criminal procedure. It is good practice to store the data anonymously. In the last few decades radiology has been widely used in forensic sciences; however, in most cases radiologists have not been involved. In contrast to the clinical situation, forensic radiology will in most cases be done in children in whom the cause and manner of death are unclear and clinical information is not always available (e.g. in the case of the body of an unknown child). One of the aims of postmortem forensic radiology is to detect the presence of foreign bodies, such as fragments of glass and bullets, and to describe their position and, if applicable, the trajectory they followed. Radiology will

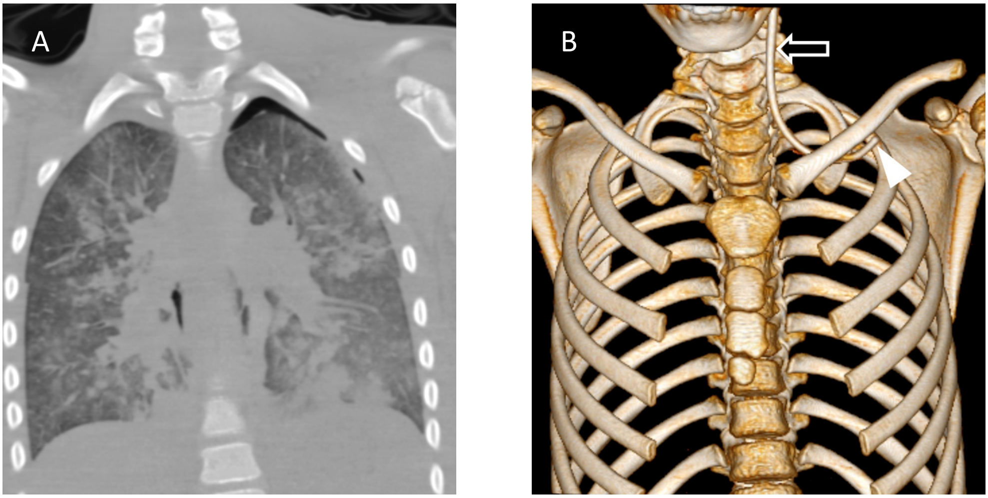

Figure 10a. *A 10-year-old boy who died in the hospital after a fall. a Postmortem CT shows a small pneumothorax, which was not found at autopsy. There is diffuse airway consolidation in keeping with postmortem pulmonary edema.* ***Figure 10b.*** *Surface-shaded rendering of the thorax shows an incorrectly positioned left subclavian line with the tip of the line in the jugular vein (arrow). The line was cut and the distal end (arrowhead) was buried subcutaneously.*

also be able to detect more subtle cases of pneumothorax or pneuperitoneum, for example, which can be missed in a conventional autopsy (Fig. 10). Furthermore, if radiology is used to describe the corpse prior to autopsy it makes revision possible even after the corpse has been buried. In legal proceedings this is an important advantage of postmortem radiology over the conventional autopsy. There are numerous forensic institutes in the world that have a radiological facility or are contemplating buying a CT and/or MR scanner.[49,50] In Europe one of the most well known is the Forensic Institute and the Centre for Forensic Imaging at the University of Bern, Switzerland.[39] The Virtopsy® project began at the institute, which is one of the leaders in scientific research and development in forensic radiology.[51] It is important to remember that in the end the aim of all forensic necroscopic examinations is to determine the cause (e.g. hypoxia) and manner (e.g. strangulation) of death in order to decide whether a crime has been committed (Fig. 11).

HISTORICAL PEDIATRIC SPECIMENS

Although slightly outside the scope of postmortem pediatric radiology, the use of radiological imaging of historical pediatric specimens is worth mentioning. There are many collections of human historical specimens that have been gathered over the centuries by both historians and clinicians. Some of these cases depict diseases and/or disorders that are now very rare and therefore of interest. Radiology can be an excellent tool used to investigate these delicate specimens without destroying them. In this article the use of radiology in this interesting scientific field is demonstrated with two pediatric cases.

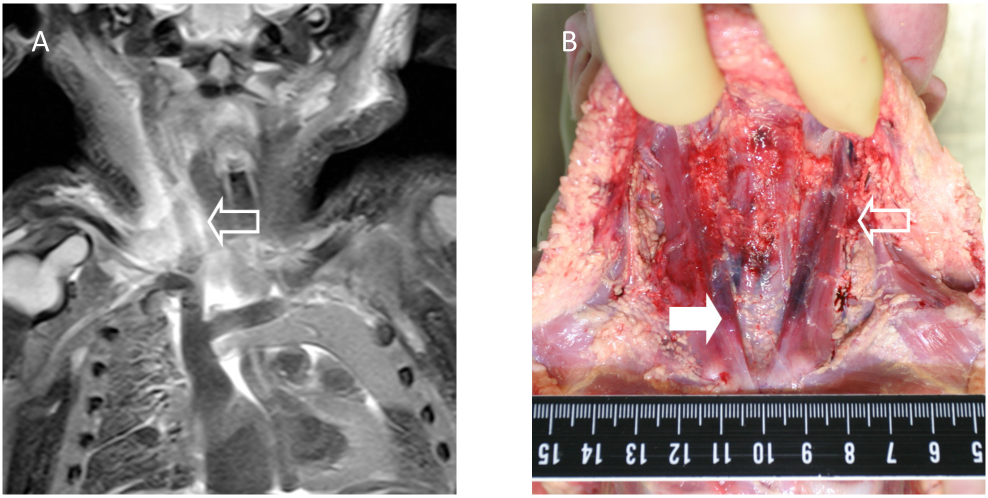

Figure 11a. *A neonate of unknown gestational age found in a garbage bin. a Coronal T2-W image shows edema around the right jugular vein (arrow) (slice thickness: 4 mm, TR: 5970, TE: 84, FA: 150°) (Reprinted with permission from Bilo RA, Robben SG, van Rijn RR [2009] Differentiating accidental trauma from child abuse. In: Forensic aspects of pediatric fractures. Springer-Verlag, in press).* **Figure 11b.** *Autopsy shows a bilateral haematoma (open arrow) around the jugular vein, the carotid artery and the sternocleidoid muscles (arrow). This finding is fitting with strangulation.*

The first case is a specimen owned by the Academic Medical Centre Amsterdam, which is home to one of the largest teratological collections in Europe (the Vrolik Museum). This collection of more than 2,000 specimens was founded by Gerardus Vrolik (1775–1859) and his son Willem Vrolik (1801–1863). It shows various aspects of human and animal anatomy, embryology, pathology, and congenital anomalies.[52] One of the specimens in this collection is a cephalothoracopagus, estimated to be 100–150 years old (Fig. 12). Conjoined twins are classified according to the site of union by using the suffix pagus (fixed), and therefore a cephalothoracopagus is joined by the head, thorax and (part of the) abdomen. The second case is from the National Museum of Antiquities in Leiden, the Netherlands. This particular mummy is of a boy, estimated to be 9.5–14.5 years of age, and has been dated to the third century A.D. (Fig. 13).[53] The mummy is one of eight (located in several museums worldwide), forming a homogeneous group based on similarities of both the exterior as well as the embalming techniques.[53]

CONCLUSION

In this review paper we have presented the current state of postmortem imaging in children. This exciting new field in pediatric radiology opens new areas in which close collaboration between radiologists and pathologists is essential. It is important that pediatric radiologists become involved in this field as pathologists are not trained in reading radiographs and may therefore miss essential clues.[54]

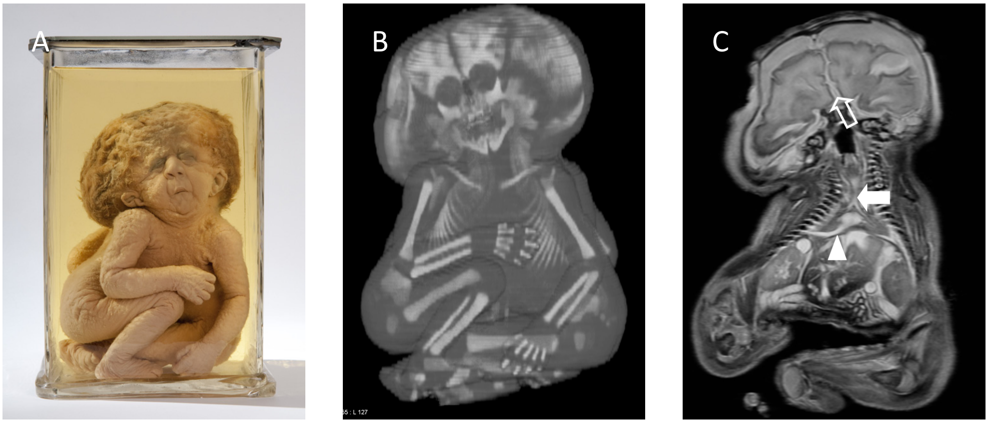

Figure 12a. *Historical pediatric specimen. a Image of cephalothoracopagus from the Vrolik Museum. Specimen is estimated to be 100– 150 years old.* ***Figure 12b.*** *Surface-shaded rendering shows a conjoined skull and chest; the spine, pelvis and extremities are separate.* ***Figure 12c.*** *Coronal T2-W MRI shows individual development of the brain with a clear separation between the right and left side of the craniothoracophagus (open arrow) (slice Thickness: 3 mm, TR: 2500, TE: 68, FA: 90°). The trachea is fused (arrow) and a single diaphragm is present (arrowhead). There is a compound liver (neoaxial orientation), which on further imaging shows two separate gallbladders. Normal renal development is present.*

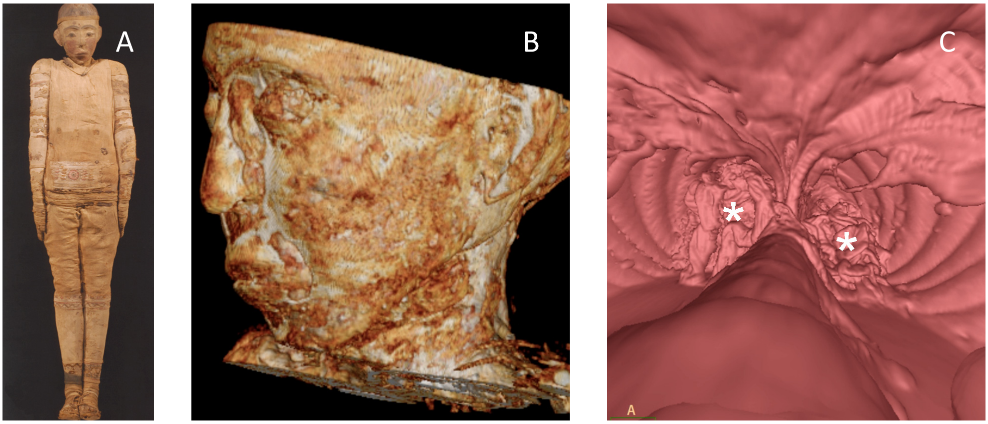

Figure 13a. *Second historical specimen. a Mummy of a boy, estimated age 9.5–14.5 years, dated to the third century A.D.* ***Figure 13b.*** *Shaded-surface rendering of the face shows facial features. The nose is slightly depressed, likely as a result of mummification. The ear is relatively large and stands off the skull.* ***Figure 13c.*** *Virtual endoscopy of the abdominal cavity shows absence of both abdominal and thoracic organs. The thorax is partially filled with gauzes (asterisk) (courtesy of the National Museum of Antiquities, Leiden, the Netherlands, reprinted with permission from Raven MJ, Taconis WK (eds) [2005] Egyptian mummies: radiological atlas of the collections in the national museum of antiquities in Leiden. Brepols, Turnhout, Belgium, pp 191–195).*

To date, nearly all radiological studies have looked at either general findings in a relatively small population or specific pathology in larger samples, and in almost all studies the set-up was descriptive. The lack of substantially large studies with statistical power and the wide variety of study designs makes it difficult to perform a meta-analysis of the published data. This is clearly illustrated by a recent systematic review by Scholing et al.[55] of the role of postmortem CT in trauma victims. They included 15 studies with a moderate sample size of 13 patients and a range of agreement between postmortem CT and autopsy of 46–100%. Sebire[56] adds that besides the lack of large-scale studies comparing imaging-based versus autopsy-based diagnoses, data on the accuracy of postmortem-obtained histopathological material has not been published. The combination of postmortem imaging with needle-core biopsy is something that deserves further attention, as most information at a conventional autopsy comes from microscopic histopathological examination. These publications in relation to the diminishing number of autopsies underscore the need for multi-institutional prospective studies in order to assess the full potential of this technique.

It is difficult to predict the future, but it seems certain that radiological techniques will play an important role in the future of both clinical and forensic pathology. For pediatric radiologists involved in this field, it completes the circle of life, making it one of the few medical specialties that cares for patients from the cradle to the grave. Perhaps in the future a new subspecialty of forensic radiology will emerge.[57]

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9

Chapter 10

Normal cranial postmortem CT findings in children

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Submitted for publication

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ABSTRACT

Postmortem imaging (both CT and MRI) has become a widely used tool the last few years, both for adults and children. If it would be known which findings are normal postmortem changes, interpretation of abnormal findings becomes less ambiguous. Our aim was to describe postmortem intracranial radiological findings on postmortem CT (PMCT) in children, which did not have a relationship with the cause of death, and to determine whether these findings have a relationship with the postmortem interval or with medical interventions.

We selected all consecutive pediatric autopsies that were performed at the Netherlands Forensic Institute in the period 1-1-2008 to 31-12-2011, whereby the subject underwent total body PMCT. We collected data on age at death, gender, cause of death determined by forensic autopsy and time between death and PMCT. Normal findings that were scored were: gray-white differentiation of the brain, collapse of the brain and/or ventricles, air in the orbit, fluid accumulation in the frontal and maxillary sinuses, and air in vessels of head and neck.

One-hundred-fifty-nine forensic pediatric autopsies were performed in the 4 year study period at the NFI; 77 underwent a total body PMCT, of which 68 were included in the analyses. Fluid accumulation in the sinuses was present 30-40% of the cases in which the sinuses were developed. In 22% of all children intravascular intracranial air, either arterial or venous, was detected. We did not find a relationship between the duration of the postmortem interval and the appearance of any of the findings. Intravenous infusion is significantly associated with the presence of intravascular air (B=1.9, p=0.04).

By demonstrating the intracranial abnormalities that appear postmortem, we have tried to provide more insight in the range of findings that can be seen with pediatric PMCT. As these findings resemble antemortem pathology, it is important that the radiologist who interprets PMCT has knowledge of these normal postmortem findings.

INTRODUCTION

Postmortem imaging (both CT and MRI) has become a widely used tool the last few years, both for adults and children. For children, especially in neonates, MRI is most commonly used in the clinical setting. As MRI is superior in visualizing soft-tissue and neuropathology it is especially useful in situations where congenital disorders with cardiac and brain anomalies are suspected.[1,2] Postmortem imaging is also frequently used in situations where parents/ guardians refuse conventional autopsy. In forensic departments postmortem CT (PMCT) scanning is becoming increasingly popular as well. Since the first publication in 2000 on the 'forensic digital autopsy', which was at that time named Virtopsy®[3], numerous articles have been published regarding the different applications of postmortem imaging. Postmortem imaging in adjunction to conventional autopsy has several advantages compared to conventional autopsy alone. A major advantage is that the radiological data can be stored indefinitely and, by virtue of the use of DICOM standards, shared across the world. This makes it possible to have access to the data by experts for a second opinion, without interfering the forensic evidence. Furthermore, data can be presented to non-medical trained people, e.g. in court, to visualize the injuries described. The use of 3-D reconstructions or other advanced imaging techniques make it possible to better visualize complex anatomical structures.

Until now, most studies focused on the detection of pathological changes or injuries with postmortem imaging. Several correlation studies have been performed in order to quantify the correlation between cause of death established with postmortem imaging and cause of death established with a conventional autopsy.[4-6] Furthermore, there is a focus of research on advanced imaging, e.g. postmortem ventilation and postmortem angiography.[7-10] An area of research that has been relatively unexplored is the field of 'normal' postmortem imaging findings. As a corpse undergoes significant postmortem changes, imaging the dead poses a challenge to radiologists.[11] Certain radiological findings that are pathological during life, e.g. intravascular air, are normal findings in the deceased.[12-14] Present studies have mainly focused on describing intra-abdominal air.[14-16] Furthermore, postmortem changes in vascular diameter have been described.[17,18] Recently, Smith et al. have described cranial postmortem CT observations that mimic antemortem pathology. They describe amongst others a loss of gray/white differentiation, callapse of the ventricles, a 'lumpy' falx and intravascular air.[19] If it would be known which findings are normal postmortem changes, interpretation of abnormal findings becomes less ambiguous. Moreover, the normal postmortem changes themselves can be used to classify decomposition changes and maybe even be useful in assessing the postmortem interval.[20] Therefore, our aim was to describe postmortem intracranial radiological findings, which did not have a relationship with the cause of death, in children and to determine whether these findings have a relationship with the postmortem interval or with medical interventions. First, we'll describe the type and number of abnormalities found. Second, we'll describe the relationship between the presence of these findings and postmortem interval and the relationship between the presence of (intravascular) air and medical interventions, namely intravenous access.

METHODS

Study population

We selected all consecutive pediatric autopsies that were performed at the Netherlands Forensic Institute (NFI, the Hague, the Netherlands) in the period 1-1-2008 to 31-12-2011, whereby the subject underwent total body PMCT. According to Dutch law, in all non-natural deaths in which a crime is suspected, a forensic autopsy should be performed at the NFI. As we were primarily interested in postmortem changes in the first days after the onset of death, we excluded cases with severe postmortem changes[21], scoring more than five points on the decomposition staging scale.[22] Furthermore we excluded cases in which normal anatomy was not assessable, e.g. victims of motor vehicle accidents or stabbing wounds, as these causes of death could have led to introduction of air into the vascular system. The study was not subject to institutional review board approval, as postmortem imaging was performed as part of the forensic work-up according to institutional NFI protocol.[23]

Postmortem imaging

Total body PMCT was performed shortly before conventional autopsy. As the NFI does not have CT facilities; scans were performed in the radiological departments in 2 centers: the Groene Hart Ziekenhuis (Gouda) and the Academic Medical Center (Amsterdam). These centers use clinical state-of-the-art scanners (respectively in Gouda Toshiba Aquilon, Toshiba Medical Systems Europe B.V., Zoetermeer, the Netherlands and in Amsterdam Philips Brilliance 64, Philips Healthcare, Best, the Netherlands or Siemens Sensation 64, Siemens, Erlangen, Germany). In all cases maximum slice thickness was 3.0 mm, with standard sagittal and coronal reconstructions. Field of view was adjusted to body size of the child. A PACS system (AGFA Impax 6.4, Mortsel, Belgium) was used to review the studies. All PMCT scans were blinded and evaluated by a pediatric radiologist (RR) with ten years of experience in forensic pediatric radiology and postmortem radiology.

Data evaluation

The radiologist did not have access to patient data. He did not have information regarding age, gender, cause of death or scene findings. He did not inspect the body, nor had he access to postmortem photos of the body. A case report form was designed in order to assess the scans in a structured way. We collected data on age at death, gender, cause of death determined by forensic autopsy and time between death and PMCT. If time of onset of death was unknown we set this at 0:00 hours on the day of PMCT. As prior studies on describing normal findings are scarce, no validated scoring system exists. We selected the items to score based on our own experiences and a recent article regarding postmortem CT observations involving the brain.[19] Normal findings that were scored were: gray-white differentiation of the brain, collapse of the brain and/or ventricles, air in the orbit, fluid accumulation in the frontal and maxillary sinuses, and air in vessels of head and neck.

Statistical analysis

Data were analyzed using BM SPSS Statistics for Windows (Version 19.0. Armonk, NY: IBM Corp) Medians with interquartile ranges (IQR) were calculated for numerical variables, as data were non-normally distributed. Normality was assessed using the Kolmogorov-Smirnov test. Differences between subgroups were tested with a Mann-Whitney U test for numerical variables and Chi-square for categorical variables. Relationship between postmortem interval, medical interventions and outcome was analyzed using logistic regression.

RESULTS

Study group

One-hundred-fifty-nine forensic pediatric autopsies were performed in the four year study period at the NFI. Fourteen of these were excluded because of severe decomposition; these were all neonates found after a long postmortem interval.[21] Of the remaining 144 autopsies with little postmortem changes, 77 (54%) underwent a total body PMCT. Scanned and non-scanned cases did not significantly differ in age, gender and cause of death (Table 1). Nine of the scanned cases were excluded because of severe injuries (due to (traffic) accidents n=5, multiple stabbing wounds n=4) making it impossible to assess normal postmortem findings. This resulted in 68 cases included in the analysis. Time interval between onset of death and scanning and medical interventions which could influence postmortem appearance are listed in table 2. Seventy-four percent of the cases were scanned within 24 hours after demise.

Table 1. *Characteristics of all children who underwent a forensic autopsy between 2008-2011*

Variable	PMCT n = 77	No PMCT n = 67	p
Age, median (IQR)	1 year, 4 months (2 months – 7.5 year)	1 year, 10 months (4 months- 14 year, 8 months)	0.05
Gender, n (%)			0.6
Male	39 (51)	37 (55)	
Female	38 (49)	30 (45)	
Conclusion based on autopsy (including scene findings), n (%)			0.7
Natural death	10 (13)	12 (18)	
Unnatural death	38 (49)	32 (48)	
No cause of death	29 (38)	32 (34)	

PMCT: postmortem CT; IQR: interquartile range

Figure 1. *Two-year-old boy, who was found death in prone position in his bed. No CPR was started and no attempts were done to get IV access. With neither PMCT nor autopsy, a cause of death was found. PMCT showed complete loss of gray-white matter differentiation and collapse of the ventricles (arrow), resulting from postmortem edema.*

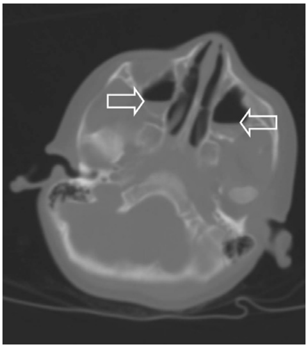

Figure 2. *Three-year-old boy, who was found in a fire in a caravan. CPR was started, an endotracheal tube was inserted, intra-osseous and IV infusion were administered. Despite these efforts he died on the same day. Cause of death established with autopsy was inhalation of smoke, fire and flames. With PMCT, no cause of death was established. Fluid accumulation in the maxillary sinuses is noted (arrows).*

Figure 3. *Ten-year-old girl who was killed by a relative by suffocation and strangulation. No CPR was started and no attempts were done to get IV access. There were no penetrating injuries in the body. PMCT was performed 2.5 days after demise. With PMCT no cause of death could be established, but extensive intracranial intravascular air was detected, e.g. bilateral in the middle cerebral artery (arrow).*

Table 2. *Characteristics of included children (n=68) who underwent PMCT (n=77 minus 9 excluded cases)*

Variable		
Postmortem interval, median (IQR)	Hours	20 (12-26)
CPR, n (%)	Yes No	43 (63) 25 (37)
Tube, n (%)	Yes No	38 (56) 30 (44)
IV fluids, n (%)	Yes No	33 (49) 35 (51)
Osseous puncture, n (%)	Yes No	30 (44) 38 (56)
Heart puncture, n (%)	Yes No	10 (15) 58 (85)
Lumbar puncture, n (%)	Yes No	3 (4) 65 (96)

PMCT: postmortem CT; IQR: interquartile range; CPR: cardiopulmonary resuscitation; IV: intravenous

Intracranial findings

Intracranial findings detected in this cohort are presented in table 3 (Fig. 1). The frontal sinus was developed in 17% (10/59) of all children. In 3 of these (30%) fluid accumulation was present. The maxillary sinuses were developed in 87-88% of all children (left 60/68, right 59/68). In 24/60 (40%) and 20/59 (34%) respectively, fluid accumulation was present (Fig. 2). None of the cases were drowning cases as verified by the clinical history and forensic investigation. Two children were found in a bathtub, with a bag around their head, but died as result of blunt trauma to the head. One of these had fluid accumulation of only the left maxillary sinus. The other had fluid accumulation of both left and right maxillary sinus, the frontal sinus was not developed. In 22% of all children intracranial intravascular air, either arterial or venous, was detected (Fig. 3).

Relationship between postmortem interval, IV access and intracranial findings

In table 4 the relationship between postmortem interval and intracranial findings (except for intravascular air) is presented. We did not find a relationship between the duration of the postmortem interval and the appearance of any of the findings. Table 5 shows the relationship between postmortem interval, intravenous access and the presence of intracranial intravascular air. We did not find a relationship between the duration of the postmortem interval and the appearance of intravascular air. Intravenous infusion is significantly associated with the presence of intravascular air (B=1.9, p=0.04). Intravenous infusion is significantly associated with air in 4 different vessels, namely left transverse sinus (B=3.0, p=0.04), left common carotid artery (B=3.1, p=0.03), right common carotid artery (B=3.1 , p=0.03) and right internal carotid artery (B=2.9, p=0.04).

DISCUSSION

We have described a variety of intracranial postmortem findings in children that are regularly seen as normal postmortem findings and do not seem to have a relationship with the cause of death. We found, amongst others, sedimentation of the frontal sinus in 30% and maxillary sinus in 34-40% of the cases. We did not find a relationship between postmortem interval and the appearance of any of the intracranial findings. We did find a significant relationship between intravenous access and intravascular air. This increased change of the appearance of intravascular air was only found after the presence of a peripheral venous cannula, not after osseous infusion or heart puncture.

We found a loss of gray-white differentiation in 72-85% of the cases. Others found this in 42% (14/33) of the cases.[19] We do not have an explanation for this difference, it is possible that the pediatric brain showes different postmortem changes compared to an adult brain. Another explanation might be the length of the resuscitation or the type of medication administered (both not investigated). The high number of cases in our cohort with fluid accumulation in the sinuses is notable, as this is considered by some authors as a sign of drowning.[24] As our cohort did not include drowning cases, fluid accumulation especially of

Table 3. *Postmortem intracranial abnormalities in children (n=68)*

Variable	
Brain	**n (%)**
Disturbed gray-white differentiation cortex	58 (85)
Disturbed gray-white differentiation basal nuclei	57 (84)
Disrupted gray-white differentiation fossa posterior	49 (72)
Collapse brain	1 (2)
Collapse ventricles	42 (62)
Orbit	
Intraconal air left	2 (3)
Extraconal air left	0 (0)
Intraconal air right	3 (4)
Extraconal air right	2 (3)
Sinus fluid accumulation (frontal sinus)	
Sinus not present	58
Sinus present	10
Fluid accumulation	3/10 (30)
Sinus fluid accumulation (left maxillary)	
Sinus not present	8
Sinus present	60
Fluid accumulation	24/60 (40)
Sinus fluid accumulation (right maxillary)	
Sinus not present	9
Sinus present	59
Fluid accumulation	20/59 (34)
Intravascular air	
Any air	15 (22)
Superior sagittal sinus	3 (4)
Left transverse sinus	4 (6)
Right transverse sinus	3 (4)
Sinus rectus	3 (4)
Left vertebral artery	4 (6)
Right vertebral artery	7 (10)
Basilar artery	2 (3)
Left posterior cerebral artery	1 (2)
Right posterior cerebral artery	0 (0)
Left medial cerebral artery	5 (7)
Right medial cerebral artery	5 (7)
Left anterior cerebral artery	6 (9)
Right anterior cerebral artery	6 (9)
Left common carotid artery	4 (6)
Right common carotid artery	4 (6)
Left internal carotid artery	2 (3)
Right internal carotid artery	4 (6)
Left external carotid artery	2 (3)
Right external carotid artery	2 (3)
Subarachnoid	3 (4)

Table 4. *Relationship between postmortem interval and presence of cranial abnormalities in children (n=68)*

Variable	n (%)	p
Disrupted gray-white differentiation basal nuclei	57 (84)	0.2
Disrupted gray-white differentiation posterior fossa	49 (72)	0.4
Collapse brain	1 (2)	-
Collapse ventricles	42 (62)	0.1
Intraconal air left	2 (3)	0.2
Extraconal air left	0 (0)	-
Intraconal air right	3 (4)	0.5
Extraconal air right	2 (3)	0.8
Fluid accumulation frontal sinus	3/10 (30)	0.2*
Fluid accumulation left maxillary sinus	24/60 (40)	0.1*
Fluid accumulation right maxillary sinus	20/59 (34)	0.1*

* Analyses are based on cases in which sinus was developed only: 10, 60 and 59 children respectively

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Table 5. *Relationship between postmortem interval, IV access and intravascular air in children (n=68)*

Variable		Postmortem interval	IV fluids	Osseous puncture	Heart puncture
	n (%)	p	p	p	p
Intravascular air					
Any air	15 (22)	0.4	0.04 (B = 1.9)	0.2	0.8
Superior sagittal sinus	3 (4)	0.9	0.2	0.3	0.4
Left transverse sinus	4 (6)	0.8	0.04 (B = 3.0)	0.2	0.7
Right transverse sinus	3 (4)	0.8	0.1	1	0.5
Sinus rectus	3 (4)	0.8	0.1	1	0.5
Left vertebral artery	4 (6)	0.7	0.3	0.3	0.8
Right vertebral artery	7 (10)	0.6	0.6	0.2	0.7
Basilar artery	2 (3)	0.2	1	1	1
Left posterior cerebral artery	1 (4)	-	-	-	-
Right posterior cerebral artery	1 (4)	-	-	-	-
Left medial cerebral artery	5 (7)	0.7	0.1	0.2	1
Right medial cerebral artery	5 (7)	0.7	0.1	0.2	1
Left anterior cerebral artery	6 (9)	0.7	0.1	0.2	0.7
Right anterior cerebral artery	6 (9)	0.5	0.2	0.6	0.2
Left common carotid artery	4 (6)	0.4	0.03 (B = 3.1)	0.3	0.8
Right common carotid artery	4 (6)	0.4	0.03 (B = 3.1)	0.3	0.8
Left internal carotid artery	3 (4)	0.3	0.9	0.7	1
Right internal carotid artery	5 (7)	0.2	0.04 (B = 2.9)	0.6	0.6
Left external carotid artery	2 (3)	0.3	1	1	1
Right external carotid artery	2 (3)	0.9	0.3	1	1
Subarachnoid	3 (4)	0.7	0.2	0.5	1

IV: intravenous

the maxillary sinus should be regarded as a normal postmortem finding in children, and thus not as pathognomonic for drowning. This number (34-40% of the cases) is comparable to studies in adults: Christe et al. found it in 36% (7/20) of their non-drowning cases and Kawasumi et al. in 65% (73/112) of their non-drowning cases.[25] It could either be a sign of sinusitis (not related to the cause of death), or it could be a postmortem alteration due to gravitation of bodily fluids.

The fact that we did not find a relationship between postmortem interval and appearance of the findings is remarkable, as we expected that more abnormalities appear over time. This is, amongst other, demonstrated by Egger et al, with the radiological alteration index.[20] They found that gas was present at more sites after a longer postmortem interval, with the longest postmortem interval being more than three days after death. However, as 74% of our cases were scanned within 24 hours, it might be possible that our postmortem interval is too short to detect a difference over time. On the other hand, in some cases it is already detectable after a few hours, so it is not possible to give a minimum postmortem interval after which it appears. Intrahepatic gas has been found to increase in amount within the first 24 hours, but only in 3 of 5 cases.[15] It is possible that, as we did not repeat scans over time in the same patients, small differences were not detected with our study design.

In studies in living patients, air embolism after insertion of a peripheral venous cannula has been described anywhere in the body in 5-15% of asymptomatic patients.[26] In our series, intracranial air occurred in 22%, although Smith et al found a rate of 42%.[19] Certainly the presence of putrefaction processes plays a role in this, as the presence of intravascular air is considered to be a normal postmortem finding due to putrefaction, if not caused by traumatic air embolisms.[13] However, we found a strong relation with the use of peripheral venous cannulas. It might be possible that in the acute setting, in which CPR is provided to a child and the child does not survive, infusion fluids are less accurate checked for air bubbles and therefore iatrogenic air embolisms occur more often. It is remarkable however, that the presence of intra-osseous infusion and heart puncture were not associated with intravascular air, as these are difficult procedures, not commonly applied by most doctors, and sometimes several attempts are necessary.

A limitation of our study is that the postmortem intervals were relatively homogenous distributed over the study population. It is possible that this is one of the reasons that we did not find a relationship between postmortem interval and intracranial abnormalities. Another limitation is that we did not have the possibility to scan the cases several moments over time. In order to study postmortem changes thoroughly, the best study design would be a design in which the same subjects are scanned at several moments in time, as was done by Fischer et al, who scanned their subjects every hour for 24 hours.[15] It might be difficult to obtain institutional review board approval for a design like this, but an animal study might be a start.

CONCLUSION

By demonstrating the intracranial abnormalities that appear postmortem, we have tried to provide more insight in the range of findings that can be seen with pediatric PMCT. As these findings resemble antemortem pathology, it is important that the radiologist who interprets PMCT has knowledge of these normal postmortem findings. Based on the present knowledge, a timetable for postmortem radiological alterations cannot be constructed yet.

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Chapter 11

Postmortem CT compared to autopsy in children: concordance in a forensic setting

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ABSTRACT

The aim of this study is to assess the accuracy of postmortem CT (PMCT) in determining the cause of death in children who underwent a forensic autopsy because of a suspected non-natural death.

We selected forensic pediatric autopsies at the Netherlands Forensic Institute, whereby the subject underwent PMCT between 1-1-2008 and 31-12-2012. Cause of death was independently scored by a radiologist and a pathologist. Cause of death was classified (1) in categories being natural, unnatural and unknown, (2) according to the ICD-10 and (3) according to institutional classification.

189 pediatric forensic autopsies were performed in the study period. Fifteen were excluded because of putrefaction. Of the remaining 174 autopsies, 98 (56%) underwent PMCT. PMCT and autopsy identified the same category in 69/98 cases (70%, kappa 0.49). They identified the same cause of death in 66/98 cases (67%, kappa 0.5) using ICD-10; in 71/98 (72%, kappa 0.62) using a forensic classification. PMCT performed better in unnatural deaths (59-67% agreement) than in natural deaths (0% agreement). If no cause of death was detected with autopsy, PMCT failed to identify a cause of death in 98% (39/40).

Pediatric PMCT does identify the majority of unnatural causes of death, but does not identify new diagnoses (true positives) if no cause of death is found during autopsy. Diagnostic accuracy in natural deaths is low.

INTRODUCTION

Postmortem imaging to determine the cause of death is becoming increasingly popular in both a clinical and forensic setting. A reason for this is that autopsy rates are declining and postmortem imaging seems to be an acceptable alternative. Although the number of publications on the subject is rapidly expanding, the diagnostic accuracy of postmortem imaging compared to conventional autopsy has not yet been validated for all settings. In earlier studies the majority of cases were fetuses and neonates[1,2] or adults who died of traumatic causes.[3-5] Recently, two major validation studies in clinical/community samples have been published; one in adults[6] and one in fetuses and children.[7] In the study in adults, both postmortem CT (PMCT) and postmortem MRI were performed; the study showed a concordance rate on cause of death (identifying the organ system involved) between postmortem imaging and autopsy of 70% (n=127/182). In the study concerning children, only postmortem MRI was performed. This study demonstrated a concordance rate of 50% in fetuses (n=137/272) and 69% in children (n=85/123, which was much higher if MRI was combined with minimally invasive autopsy (MIA). MIA enhanced the concordance rate to 97% in fetuses (n=263/272) and 76% in children (n=94/123). Both studies were performed under ideal circumstances, with every effort being made to obtain optimum scanning and reporting conditions. In the study in adults, both PMCT and postmortem MRI were assessed by four general radiologists, two neuroradiologists and two cardiac radiologists. Several consensus reports were written, resulting in 11 radiology reports per case. In the study in children, MRI was interpreted by four independent specialist pediatric radiologists. As mentioned by the authors, the results might therefore not reflect clinical practice.

Although in adults PMCT resulted in better concordance than postmortem MRI[6], little has been published on the use of PMCT in pediatric deaths. One PMCT study performed in children who died unexpectedly showed a concordance rate between PMCT and autopsy of 89% (n=42/47).[8] In order to determine the value of postmortem imaging, this technique needs to be validated in different settings. The aim of this study is to assess the accuracy of PMCT in determining the cause of death in children who underwent a forensic autopsy because of a suspected non-natural death.

MATERIALS AND METHODS

Study population

We selected all consecutive pediatric autopsies that were performed at the Netherlands Forensic Institute (NFI, the Hague) in the period 1-1-2008 to 31-12-2012, whereby the subject underwent PMCT. The NFI is the national center for forensic autopsies, and according to Dutch law all non-natural deaths in which a crime is suspected have to have an autopsy performed at the NFI. We excluded cases with severe postmortem changes, scoring more than five points on the decomposition staging scale.[9] The study was not subject to institutional review board approval, as postmortem imaging was performed as part of the forensic work-up according to institutional NFI protocol.[10]

Postmortem imaging

Total body PMCT was performed shortly before autopsy, using a clinical state-of-the-art scanner (Toshiba Aquilon, Toshiba Medical Systems Europe B.V, Zoetermeer, the Netherlands, Philips Brilliance 64, Philips Healthcare, Best, the Netherlands or Siemens Sensation 64, Siemens, Erlangen, Germany). In all cases maximum 3.0 mm thin slices, with sagittal and coronal reconstructions, were obtained. Field of view was adjusted to body size of the child. A PACS system (AGFA Impax 6.4, Mortsel, Belgium) was used to review the studies. The NFI does not have CT facilities; scans were therefore performed in the departments of radiology in the Groene Hart Ziekenhuis (Gouda) and the Academic Medical Center (Amsterdam). All PMCT scans were evaluated by a forensic pediatric radiologist (RR) with ten years of experience in forensic pediatric radiology.

Autopsy

Median time between time of death and autopsy was 1 day, range 0-7 days; in 90% of the cases an autopsy was performed within 2 days. Autopsies were performed according to the local protocol of the NFI.[10] The NFI autopsy includes external and internal examination of the body (both macroscopically and microscopically), including the internal organs of the three body cavities and dissection of the skull, neck and back. Additional investigations such as toxicology, microbiology, anthropology, DNA and metabolic investigations are performed when indicated, depending on the case at hand. All findings (both normal and abnormal) are reported; the cause, or possible cause, of death is a central aspect in the conclusion of the report. All autopsies were performed by a forensic pediatric pathologist (VS or AM) with respectively 8 and 15 years experience in the pediatric forensic field.

Data evaluation

Both the radiologist (RR) and pathologist (VS) determined the cause of death based on their findings. They had access to limited patient data, namely age, gender, medical problems before death and scene findings. The radiologist did not inspect the body, nor did he have access to postmortem photos of the victims. Cause of death was classified in three ways: (1) in three main groups comprising natural, unnatural and no cause of death, (2) according to the ICD-10[11] and (3) according to the forensic classification developed by the NFI.[10] For the concordance between radiologist and pathologist, cause of death was scored based on autopsy or PMCT findings only. In other words, a case could only be classified as unnatural cause of death if something abnormal was found during PMCT or autopsy. To describe the baseline characteristics of the group and to compare the scanned versus not-scanned cases, cause of death was scored based on autopsy findings in combination with scene findings. As an example, a cause of death could be unnatural if two children were found dead while the parent was committing suicide. Based on scene findings this was classified as an unnatural death, although no specific pathology was detected with PMCT or autopsy. To determine the correlation between radiologist and pathologist, only causes of death they were sure of were scored for this study. Concomitant disease was not classified, as these data were obtained in a forensic evaluation and we aimed to score undoubted causes of death. The reference standard was cause of death identified by the pathologist. Both radiologist and pathologist were blinded for the information by the other rater.

Analysis

Data were analyzed using IBM SPSS Statistics 19. Medians with interquartile ranges (IQR) were calculated for numerical variables, as data were non-normally distributed. Normality was assessed using the Kolmogorov-Smirnov test. Differences between subgroups were tested with a Mann-Whitney U test for numerical variables and Chi-square for categorical variables. Agreement was expressed as absolute concordance (number of cases correctly identified by radiologist divided by total numbers of autopsies). Furthermore, the kappa coefficient was calculated to describe the agreement between radiologist and pathologist, taking into account the agreement occurring by chance.

RESULTS

Study group

In the five-year study period, 189 pediatric forensic autopsies were performed at the NFI. Fifteen of these were excluded from this study because of severe putrefaction, these have been described in another paper.[12] Of the 174 autopsies with few postmortem changes, 98 (56%) underwent PMCT (Fig. 1). The number of PMCTs increased over time, from 34% in 2008 to 70% in 2012. In the group with a PMCT scan, median age was one year and one month, IQR three months to six years. There were 52 boys (53%) and 46 girls (47%).

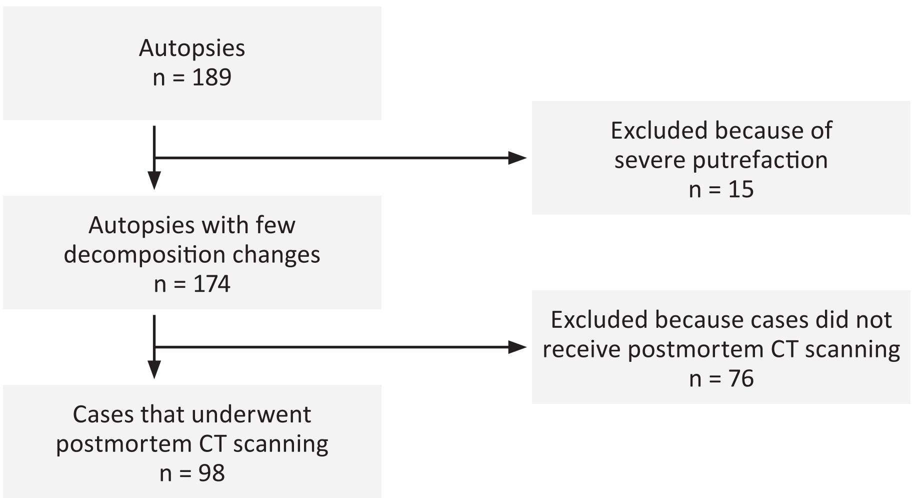

Figure 1. *Diagram of selected cases.*

Table 1. *Characteristics of children who underwent a forensic autopsy*

Variable	PMCT n = 98	No PMCT n = 76	p
Age, median (IQR)	1 year 1 month (3 months- 6 years)	2 years 6 months (5 months-15 years 9 months)	0.004
Gender, n (%)			0.95
Male	52 (53)	40 (53)	
Female	46 (47)	36 (47)	
Conclusion*, n (%)			0.67
Natural death	12 (12)	12 (16)	
Unnatural death	51 (52)	41 (54)	
No cause of death	35 (36)	23 (30)	
	PMCT n = 51	**No PMCT n = 41**	**p**
Child abuse in unnatural death, n (%)			0.073
Yes	42 (82)	30 (73)	
No	0 (0)	4 (10)	
Undetermined	9 (18)	7 (17)	

* Including scene findings

Table 2. *Agreement on cause of death using 3 main groups*

		Radiologist			
		Unnatural	No cause of death	Natural	Total
Pathologist	Unnatural	33	16	0	49
	No cause of death	1	39	0	40
	Natural	0	9	0	9
	Total	34	64	0	98

The case mix of the children who underwent PMCT was typical for the NFI[13]: based on both autopsy and scene findings, 51/98 (52%) died from unnatural causes, in 35/98 (36%) no cause of death was determined, i.e. classified as sudden infant death syndrome (SIDS) or sudden unexpected death in infancy (SUDI), and in 12/98 (12%) a natural cause of death was established. In the children who died of unnatural causes, the cause of death was child abuse in 42/51 (82%) of the cases; in 9/51 (18%) the difference between accidental trauma and child abuse could not be determined based on autopsy and scene information. Children who did and did not undergo PMCT differed in age: children who were not scanned were significantly older (median age two years and six months versus one year and one month, p=0.004) (Table 1).

Agreement on cause of death in three main groups

PMCT and autopsy identified the same category in 69/98 cases (70%) (Table 2). The kappa coefficient was 0.49. Of the 49 children identified from autopsy as an unnatural death, 33 of these (67%) were identified by PMCT as an unnatural death as well (Figs. 2, 3); in 16 no cause of death could be identified with PMCT (Figs. 4, 5). Of the 40 children in whom no cause of death was identified with autopsy, one was identified as unnatural and 39 as no cause of death by PMCT (Fig. 6). Of the nine children identified as natural death by autopsy, all were identified as no cause of death by PMCT (Fig. 7-10). Overall, PMCT was not able to identify the cause of death in 64/98 (65%) of the cases, 1.6 times more often compared to autopsy. PMCT identified one cause of death where autopsy classified the case as no cause of death. A small subdural hematoma (SDH) over the convexity was seen on PMCT, which was not found during autopsy (Fig. 6).

Agreement on cause of death using ICD-10

Chapters ICD-10

PMCT and autopsy identified the same organ system related to the cause of death in 66/98 cases (67%) (Table 3). The kappa coefficient was 0.50. Of the 49 cases identified with autopsy as unnatural death, 31 cases were classified as injury cases; 25/31 (81%) were classified with PMCT in the same category. Seventeen cases were identified with autopsy as external causes of death; 4/17 (24%) were identified with PMCT in the same category. There was one case of malnutrition due to neglect, which was classified as endocrine, but was considered an unnatural death by the pathologist. PMCT identified this case as no cause of death. Based on autopsy findings only, autopsy identified 40 children as unknown cause of death;

11

Table 3. *Agreement on cause of death using ICD 10 chapters*

			Radiologist									
			Injury	External	Endocrine	NOS	Perinatal	Infectious	Respiratory	Circulatory	Digestive	Total
Pathologist	Unnatural n = 49	Injury	25	0	0	5	0	0	0	0	1	**31**
		External	2	4	0	10	0	0	1	0	0	**17**
		Endocrine	0	0	0	1	0	0	0	0	0	**1**
	No cause of death n = 40	NOS	1	0	0	37	0	0	0	0	0	**38**
		Perinatal	0	0	0	2	0	0	0	0	0	**2**
	Natural n = 9	Infectious	0	0	0	1	0	0	0	0	0	**1**
		Respiratory	0	0	0	4	0	0	0	0	0	**4**
		Circulatory	0	0	0	4	0	0	0	0	0	**4**
		Total	**28**	**4**	**0**	**64**	**0**	**0**	**1**	**0**	**1**	**98**

* Both radiologist and pathologist could score the same categories. If one of the raters did not score any abnormalities in a category, this category is not shown in order to reduce the table size.

Table 4. *Agreement on cause of death using ICD 10 subgroups.*

				Radiologist					
				Crushing multiple body regions	Multiple injuries head	Intra-cranial NOS	SDH	Open wound neck	Multiple injuries thorax
Pathologist	Unnatural, n = 49	Injury n = 31	Crushing multiple body regions	3	0	0	0	0	0
			Multiple injuries head	0	12	0	2	0	0
			Intracranial unspecified	0	0	1	0	0	0
			SDH	0	0	0	1	0	0
			Multiple injuries of neck	0	0	0	0	0	0
			Open wound neck	0	0	0	0	2	0
			Multiple injuries thorax	0	0	0	0	0	2
			Multiple injuries abdomen	0	0	0	0	0	1
			Poisoning sedativa	0	0	0	0	0	0
		External n = 17	Smoke, fire, flames	0	0	0	0	0	0
			Foreign body airway	0	0	0	0	0	0
			Foreign body alimentary tract	0	0	0	0	0	0
			Hanging, strangulation, suffocation	0	0	0	0	0	0
		Endocrine n = 1	Malnutrition	0	0	0	0	0	0
	No cause of death, n = 40	NOS n = 38	SIDS	0	0	0	1	0	0
			Death NOS	0	0	0	0	0	0
			Gangrene	0	0	0	0	0	0
		Perinatal n = 2	Still birth	0	0	0	0	0	0
	Natural, n = 9	Infectious n = 1	Miliair TBC	0	0	0	0	0	0
		Respiratory n = 4	Pneumonia	0	0	0	0	0	0
			Bronchiolitis	0	0	0	0	0	0
		Circulatory n = 4	Myocarditis	0	0	0	0	0	0
		Total		**3**	**12**	**1**	**4**	**2**	**3**

* Both radiologist and pathologist could score the same categories. If one of the raters did not score any abnormalities in a category, this category is not shown in order to reduce the table size.

Smoke, fire, flames	Foreign body airway	Foreign body alimentary tract	Hanging, strangulation, suffocation	SIDS	Death NOS	Still birth	Pneumo-thorax	Peritonitis	Total
0	0	0	0	0	0	0	0	0	**3**
0	0	0	0	1	0	0	0	0	**15**
0	0	0	0	0	0	0	0	0	**1**
0	0	0	0	0	0	0	0	0	**1**
0	1	0	0	0	0	0	0	0	**1**
0	0	0	0	0	0	0	0	0	**2**
0	0	0	0	0	0	0	0	0	**2**
0	0	0	0	1	0	0	0	1	**3**
0	0	0	0	0	2	0	0	0	**2**
3	0	0	0	0	4	0	1	0	**8**
0	0	0	0	0	1	0	0	0	**1**
0	0	1	0	0	0	0	0	0	**1**
0	1	0	1	0	6	0	0	0	**8**
0	0	0	0	0	1	0	0	0	**1**
0	0	0	0	25	0	0	0	0	**26**
0	0	0	0	0	11	0	0	0	**11**
0	0	0	0	1	0	0	0	0	**1**
0	0	0	0	0	0	2	0	0	**2**
0	0	0	0	0	1	0	0	0	**1**
0	0	0	0	2	1	0	0	0	**3**
0	0	0	0	1	0	0	0	0	**1**
0	0	0	0	2	2	0	0	0	**4**
3	**2**	**1**	**1**	**33**	**29**	**2**	**1**	**1**	**98**

Table 5. *Agreement on cause of death using forensic classification*[9]

			Radiologist										
			Penetrating trauma	Blunt trauma	Acc. dec. Trauma*	Asphyxia	Thermal injury	Toxico-logical	Neglect	No cause of death	Suspected neonaticide	Perinatal	Illness	Total
Pathologist	Unnatural n = 49	Penetrating trauma	5	0	0	0	0	0	0	0	0	0	0	**5**
		Blunt trauma	0	7	1	0	0	0	0	1	0	0	0	**9**
		Acc. dec. trauma*	0	0	12	0	0	0	0	1	0	0	0	**13**
		Asphyxia	0	0	0	3	0	0	0	8	0	0	0	**11**
		Thermal injury	0	0	0	0	3	0	0	5	0	0	0	**8**
		Toxicological	0	0	0	0	0	2	0	0	0	0	0	**2**
		Neglect	0	0	0	0	0	0	0	1	0	0	0	**1**
	No cause of death n = 40	No cause of death	0	0	1	0	0	0	0	30	0	0	0	**31**
		Suspected neonaticide	0	0	0	0	0	0	0	0	6	0	0	**6**
		Perinatal	0	0	0	0	0	0	0	0	0	3	0	**3**
	Natural n = 9	Illness	0	0	0	0	0	0	0	8	1	0	0	**9**
		Total	**5**	**7**	**14**	**3**	**3**	**2**	**0**	**54**	**7**	**3**	**0**	**98**

* Acc. dec. trauma: Acceleration deceleration trauma

two perinatal deaths and 38 not otherwise specified (NOS). Of these 38 NOS cases, 37 (97%) were also identified by PMCT as unknown, and one was identified as injury. Both perinatal deaths were identified by PMCT. The nine children identified as a natural cause of death were classified with autopsy as infectious (n=1), respiratory (n=4) and circulatory (n=4). All of these were identified with PMCT as no cause of death.

Subgroups ICD-10

The pathologist used 22 different ICD-10 subgroups to classify the causes of death. Overall, in 64/98 cases (65%) PMCT classified in the same ICD-10 subgroup (Table 4). The kappa coefficient for the subgroups was 0.59. In 26/49 (53%) of the unnatural causes of death PMCT identified the same subgroup. In 38/40 (95%) of the unknown causes of death PMCT identified the same subgroup. In 0/9 (0%) of the natural causes of death PMCT identified the same subgroup.

Agreement on cause of death using NFI classification

The pathologist used 11 different codes from the forensic classification. In 71/98 (72%) PMCT identified the same forensic classification (Table 5). The kappa coefficient was 0.62. In 32/49 (65%) of the unnatural causes of death, PMCT identified the same diagnosis. In 39/40 (98%) of the unknown causes of death PMCT identified the same diagnosis. In 0/9 (0%) of the natural causes of death PMCT identified the same diagnosis.

DISCUSSION

We determined the concordance between PMCT and autopsy in cause of death in children. To our knowledge this is the first PMCT study performed in children in a forensic setting. The case mix of the patients seems to be an important predictor for the concordance between PMCT and autopsy. In unnatural deaths, concordance between PMCT and autopsy was 67%. A systematic review of this topic in adults showed a concordance in unnatural deaths between 46 and 100%.[14] In natural deaths, PMCT did not identify any cause of death in our study. Another study found a concordance rate of 88% for PMCT vs. autopsy (38/43) for natural pediatric deaths.[8] A pediatric MRI study, describing 88% natural and 12% unnatural deaths, found a concordance rate of 69% for MRI vs. autopsy (85/123).[7] We have no explanation for our poor results on natural deaths. Concordance rate on cases where autopsy did not identify a cause of death was 98%, which is comparable with other publications.[6-8]

False negatives

In the cases identified with autopsy as unnatural death (n=49), the number of false negatives was 39% (16/49). Unnatural deaths most commonly missed with PMCT were injuries caused by hanging, strangulation or suffocation (n=7) (Fig. 4), injuries caused by smoke and fire (n=5) (Fig. 7), head (n=3) and abdominal injuries (n=3). In the cases identified with autopsy as natural death (n=9), all PMCT reports were false negatives. These were all infectious diseases:

myocarditis (n=4) (Fig. 7, 8), pneumonia (n=3) (Fig. 9, 10), bronchiolitis (n=1) and miliair TB (n=1). However, other pediatric studies identified infectious diseases correctly: in the study by Proisy et al PMCT identified 79% (11/14) natural causes of death, including pneumonia (n=7), pneumonia and gastro-enteritis (n=1), pancarditis (n=1), metabolic disease (n=1) and bowel volvulus (n=1).[8] The only false negative causes of death were three cases of pneumonia. This low number of false negatives is surprising given that postmortem diagnosis of pulmonary disease is complex, since postmortem consolidation and livor mortis interfere with assessment of the lungs. Furthermore, radiological characteristics of pancarditis and metabolic disease are not described in the article, but in general these are not demonstrated with CT. An explanation for the different results between their study and this one, is the fact that we only scored causes of death if the radiologist was absolutely sure that these abnormalities had caused the death. Major or minor abnormalities were sometimes detected but not scored if it was not sure that these findings would have caused the death. We chose these strict criteria because all PMCTs were performed in a forensic setting; in Court a doubtful diagnosis is not acceptable. In the MRI study, 32/132 (26%) of the MRI reports were false negatives.[7] Diagnoses most commonly missed were sepsis (n=24) and placental abnormalities (n=3).

False positives

Of all cases where autopsy did not identify a cause of death (n= 40), PMCT identified a small SDH in one case (1%). As it is unlikely that an SDH would be missed during a forensic autopsy, this was regarded as a false positive finding. Based on this one extra case, it seems unlikely that PMCT in children will identify many diagnoses that will be missed during autopsy. PMCT identified two cases of pneumonia (2/47 or 4%) regarded to be false positives in another study.[8] In the MRI study, two false positive diagnoses (2%) were identified: ischaemic brain injury and drowning.[7]

Limitations

A limitation of our study is that not all autopsy cases underwent PMCT scanning, resulting in the inclusion of 59% of the autopsies. The reason for this is that the NFI does not own its own CT scanner and practicalities can impede routine transportation of the body. In children under the age of four a skeletal survey is always performed to identify occult fractures. These cases are transported to a hospital where they also undergo PMCT. Another reason is that the use of PMCT is a relatively new development and it takes time to implement new protocols. We do not expect that the selection of patients influenced our results, as distribution of causes of death was identical in the PMCT and the non-PMCT group.

Future perspective

Several adaptations to postmortem imaging are currently being developed. In adults, the results of postmortem angiography are promising.[15-17] As ischemic heart disease is uncommon in children, this will probably be of limited value in a pediatric setting. Postmortem ventilation, however, might improve the diagnostic value of postmortem imaging in children. Applying pressure to the lungs reduces livores, and small lung pathologies become more visible.[18] Minimally invasive autopsy increases the concordance rate between postmortem MRI and autopsy from 69 to 76% in children and shows even better results in fetuses.[7,19] The combination of PMCT and minimally invasive autopsy, or both PMCT and MRI with minimally invasive autopsy, is promising in adults[20,21], but has not yet been validated in children. In 2011, the first case was published in which a cause of death established by PMCT, in combination with postmortem MRI and tissue biopsy, was accepted by the Swiss Department of Public Prosecution, without confirmation by a forensic autopsy.[22] In this case, a pedestrian crossing the street had been hit by a car. On postmortem imaging, extensive blunt trauma was demonstrated; amongst others a vertebral fracture piercing the aorta and causing extensive internal hemorrhage. In many countries, e.g. the Netherlands, replacement of autopsy by postmortem imaging is currently not accepted in Court yet, as only validated and widely accepted methods can be submitted as evidence.

CONCLUSION

In conclusion, PMCT in children does identify the majority of unnatural causes of death correctly (67%); it does not give new insight into the cause of death if this is unexplained according to the pathologist. Diagnostic accuracy in natural deaths in this study is low compared to other publications. At present, PMCT cannot replace conventional autopsy in children, but in combination with minimally invasive autopsy it might be suitable for determining those cases that require conventional autopsy.

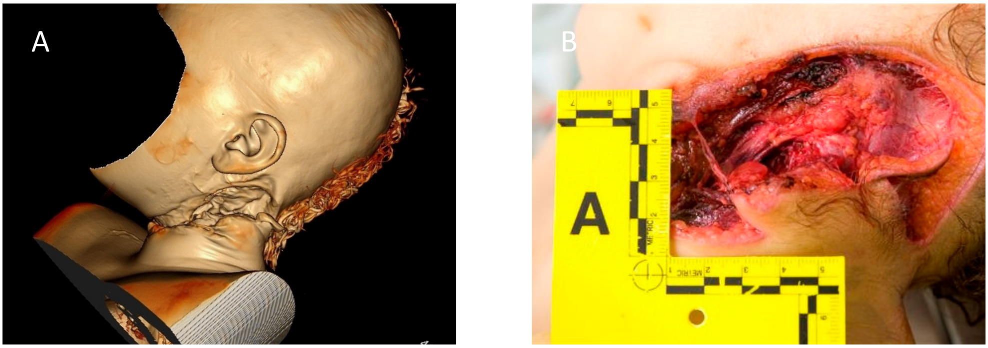

Figure 2. *Nine-year old girl found in bed, with a lot of blood nearby the body. The left side of the neck of the child was deeply cut, which was seen with both PMCT (A) and autopsy (B). The trachea was intact and the cause of death was exsanguination.*

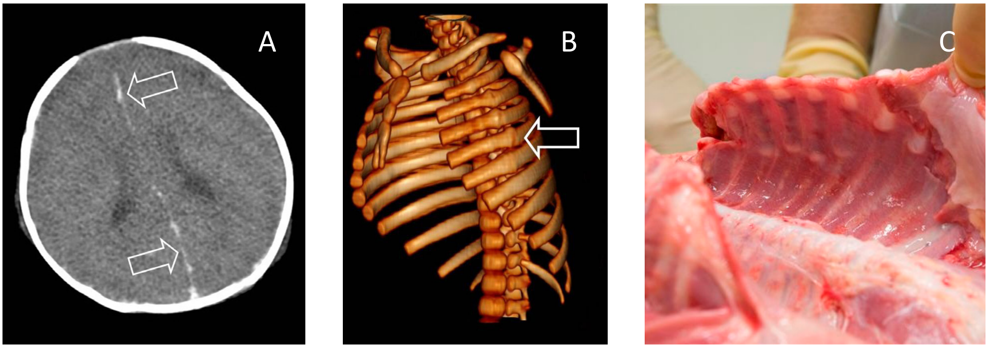

Figure 3. *Three-month-old girl, previously healthy, who according to caregivers suddenly collapsed and needed cardiopulmonary resuscitation. She was admitted to a pediatric intensive care unit, where she died on the day of the admission. PMCT scan shows a subdural hematoma along the falx cerebri (arrows) (A). The lack of gray-white matter differentiation is a normal postmortem finding. Chest CT of the same patient shows multiple healing rib fractures, second to sixth, along the left lateral side of the chest (arrow) (B). At autopsy, a subdural hematoma, subarachnoidal hematoma and contusion at the left frontal side of the cerebrum (no picture taken). There were healing rib fractures along the left lateral side, of the second to the sixth ribs (C). Underlying bone diseases were excluded microscopically. Based on the acute neurological deterioration and the older rib fractures, it was concluded that there were at least two (abusive) incidents separated in time.*

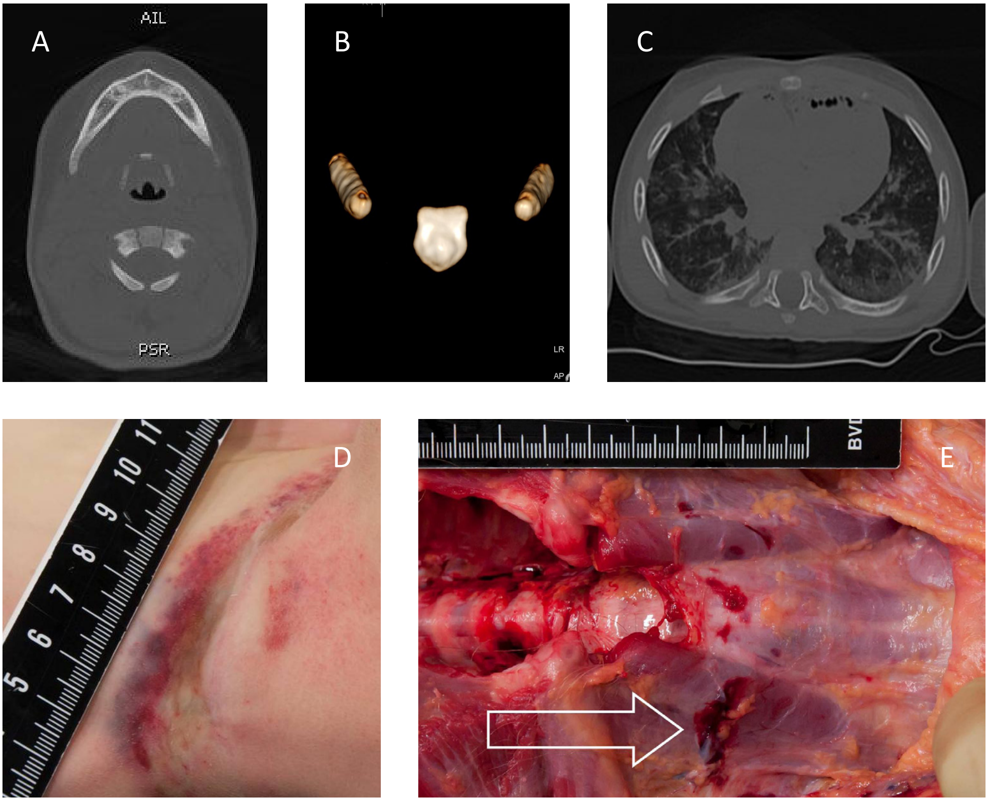

Figure 4. One-and-a-half year old boy, found hanging on a rope positioned around his neck. PMCT showed an intact hyoid larynx complex (A, B) and except for discrete signs of pulmonary edema (C), no other pathological findings were seen. Intra cardiac air in the right atrium and ventricle is noted; this is a normal postmortem finding. Autopsy demonstrated external and internal neck injuries; there was a circular skin abrasion (D) and some hemorrhages in the superficial soft tissues above the sternocleidomastoid muscle (arrow) (E). There were no fractures of the hyoid-larynx complex or the cervical spine. Cause of death was suffocation resulting from trauma on the neck.

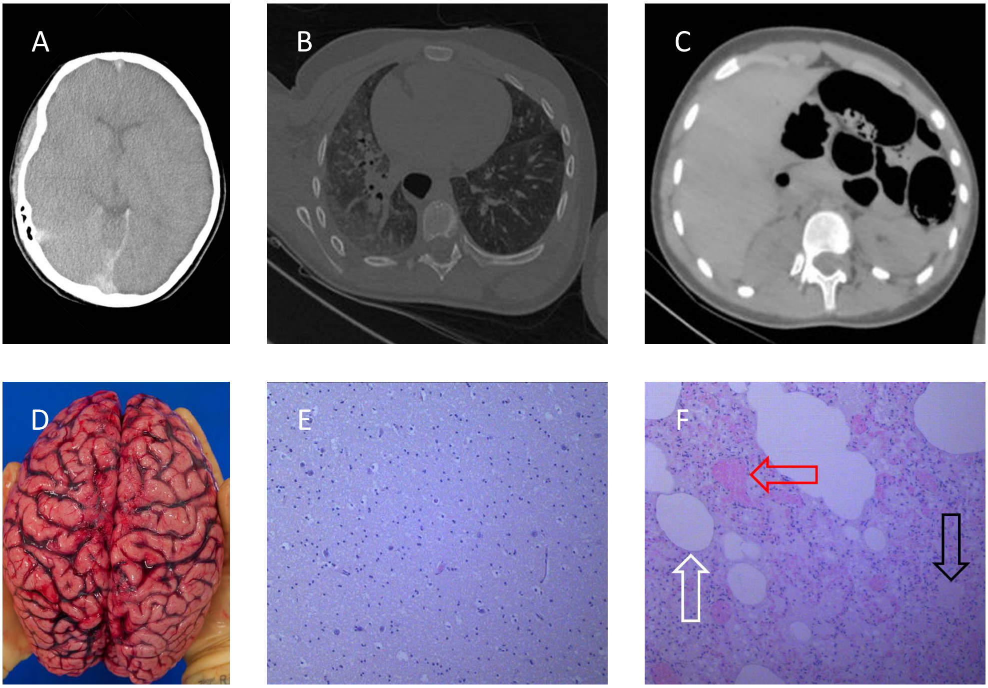

Figure 5. *Eleven-year-old girl found in a house, after a domestic fire. PMCT showed no signs of intracranial trauma (A), normal pulmonary postmortem findings, without signs of edema (B), and normal intra-abdominal organs (C). At autopsy the brain was slightly edematous; the weight was 1280 gram (compared to a reference standard of 1150 gram) and flattening of the gyri and sulci was seen (D). At microscopy edema was confirmed (E). In the lungs edema (black arrow), congestion (red arrow) and postmortem gas formation (white arrow) were seen (F). There were no signs of external trauma. Cause of death was carbon-monoxide intoxication, based on the combination of thermal damage to the airways and a carboxyhemoglobin level of 32% as measured in heart blood.*

Figure 6. *Six-month-old girl, found between the couch and the radiator. Her head was positioned downwards. According to clinical history the caregiver had been fallen asleep with the baby on the couch. On PMCT a thin layered subdural hematoma (arrow) was diagnosed (A). At autopsy, several bruises on the head were found. Furthermore, there was swelling of the brain; the dura was stretched and tense, the brain was bulging through the first incision in the dura; the gyri were pale and flattened (B,C). No definite cause of death was established. Autopsy did not confirm the radiological diagnosis of subdural hematoma. The radiological finding can be explained as a beam hardening artefact and constitutes a false positive finding.*

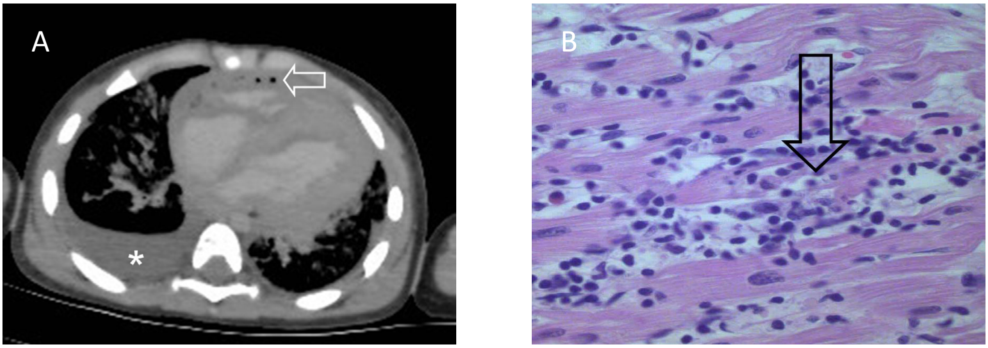

Figure 7. *One-year-and-three-month old boy found dead in an age appropriate car seat, after a two-hour car trip. PMCT showed a right-sided pleural effusion (asterisk) and a minute amount of air in coronary arteries (arrow) (A). There were no signs of trauma. Autopsy demonstrated a lymphocytic myocarditis, characterized by infiltration of lymphocytes between the cardiomyocytes of the heart, with cardiomyocytolysis (black arrow) (B). Cause of death was cardiac dysfunction based on lymphocytic myocarditis.*

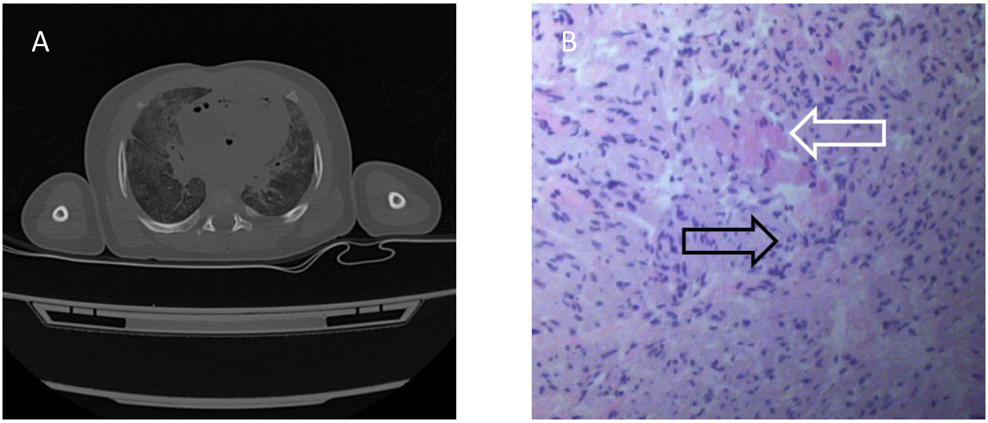

Figure 8. *Two-month-old boy found dead in prone position in his crib. PMCT showed no abnormalities, other than normal postmortem changes, such as a minor amount of postmortem gas formation in the right atrium and ventricle and left ventricle (A). At autopsy a bilateral pneumonia, with bronchial and alveolar leukocyte infiltrates, as well as a lymphocytic myocarditis, with lymphocyte-rich inflammatory infiltrate (black arrow) in combination with focal areas of cardiomyocytolysis with hypereosinofilia of the cardiomyocyte (white arrow) (B), were found. Microbiological throat swabs tested positive for Rhinovirus. Cause of death was tissue damage due to pulmonary and cardiac inflammations.*

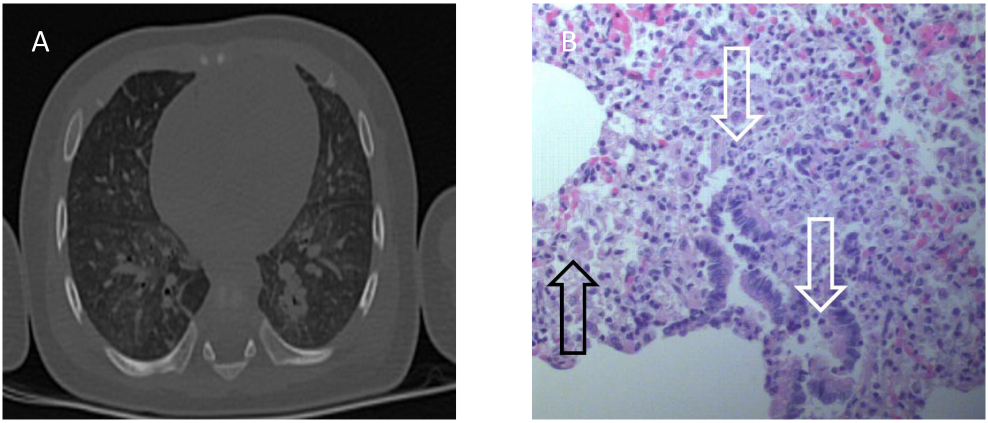

Figure 9. *Three-month-old boy found in a critical state in a baby chair at home. He was admitted to a pediatric intensive care unit, where on neuroimaging severe brain hypoxia was diagnosed. The patient died one week after admission, after medical support was withdrawn because of a poor neurological prognosis. PMCT showed infiltrative pulmonary lesions, differential diagnostically interpreted as edema or inflammation (A). Autopsy demonstrated severe pulmonary edema (black arrow) and bilateral bronchopneumonia with infiltration of neutrophilic granulocytes in alveoli and in bronchus lumen (white arrows) (B). In the brain hypoxic encephalopathy was detected. Microbial specimens were negative for viruses and bacteria. Cause of death was multi-organ failure.*

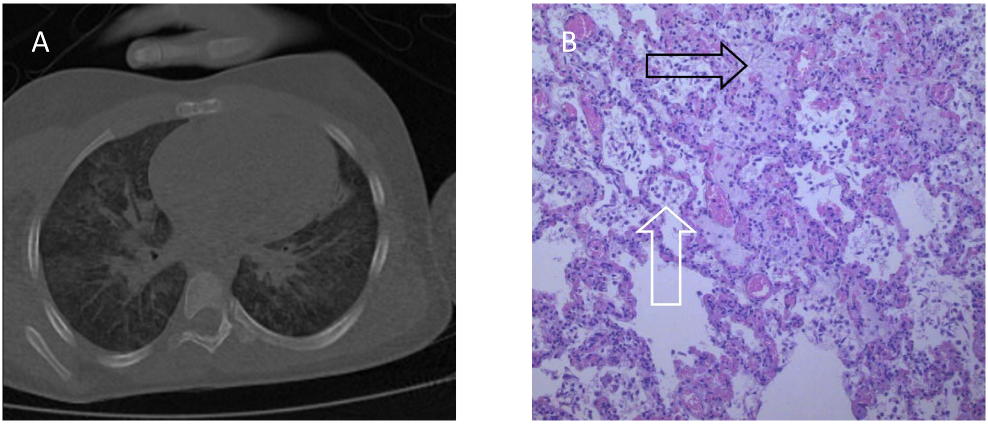

Figure 10. *Three-year-old girl found dead in her bed. PMCT showed diffuse patchy areas of ground glass (A). At autopsy bilateral pulmonary edema (black arrow) and pneumonia was observed, with neutrophile granulocytes in the alveoli (white arrow) (B). Microbiological specimen of the lung tissue was positive for B-hemolytic streptococci and in the throat specimen RS-virus was collected. Cause of death was organ dysfunction, especially of the lungs, on the basis of severe pneumonia.*

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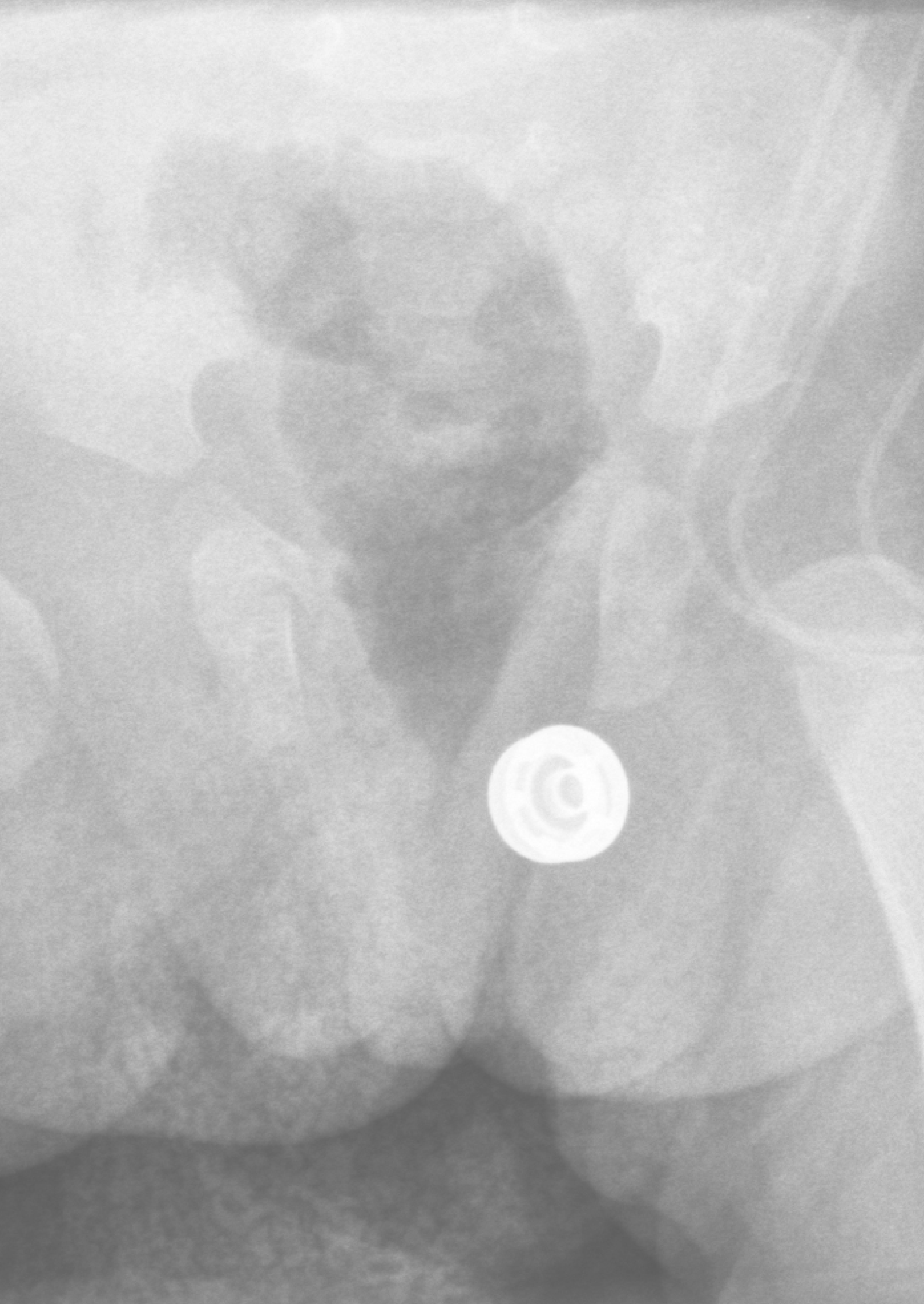

Chapter 12

The value of postmortem CT in neonaticide in case of severe decomposition: description of 12 cases

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ABSTRACT

In cases of neonaticide with delayed finding of the body, interpretation of autopsy results can be difficult because of decomposition. Postmortem computed tomography (PMCT) has become an increasingly popular tool in the (pediatric) forensic field. We performed a retrospective study to compare the outcome of PMCT with autopsy results in suspected neonaticide, in neonates found more than one week after their demise. We compared the performance of both methods on (1) determining gestational age, (2) differentiating between live birth and still birth and (3) determining cause of death. We selected all consecutive neonaticide cases with an estimated postmortem interval longer than one week, who underwent a forensic autopsy including a total body PMCT in the Netherlands Forensic Institute in the period 2008-2012. Both a pathologist and radiologist scored gestational age, signs of live birth and cause of death for each case. Twenty-two cases of neonaticide were identified in the study period, of which 15 cases were estimated to be found more than 1 week after death. In 12 of these a total body PMCT was performed. In all cases, late postmortem changes were present. Gestational age could be assessed with PMCT in 100% of the cases and with autopsy in 58% of the cases. In all cases neither PMCT nor autopsy was able to assess live birth and cause of death. PMCT is a better tool for estimating gestational age in case of suspected neonaticide with late postmortem changes compared to autopsy and should therefore be a standard part of the work-up. Signs of live birth and cause of death could not be determined with neither of the methods, an adjusted postmortem examination including limited autopsy for these cases might be developed.

INTRODUCTION

Neonaticide is defined as the killing of an infant within 24 hours after birth.[1] The reported incidence of neonaticide in industrialized countries ranges between 2.4 per 100,000 and 7.0 per 100,000.[2] Neonaticide is the most common form of infanticide; the risk of being a victim is highest on the first day of life.[3,4] The aim of the forensic autopsy in suspected neonaticide is to address three questions; the first is to assess the gestational age of the child in order to determine whether the child was born at a potentially viable gestational age; the second is to assess whether the child was born alive or was a stillbirth in order to determine the severity of the criminal offense committed and the third is to determine the cause of death. In cases of neonaticide with delayed finding of the body, interpretation of autopsy results can be difficult because of late postmortem findings. Older children are more often found shortly after their demise, while victims of neonaticide tend to be found later, even years after their demise. Severe decomposition limiting the value of the autopsy has been described in 27% of neonaticide cases.[5]

Postmortem computed tomography (PMCT) has become an increasingly popular tool in the (pediatric) forensic field. It is being used to estimate gestational age, as well as to assess live birth and to determine the cause of death. The use of CT in order to assess gestational age has been described in several studies, which have shown that long bone measurements with CT correlate significantly with ultrasound estimates.[6,7] A recent study described the use of PMCT for differentiating between still birth and live birth.[8] In this study four cases are being described in which 'distinction between live birth and stillbirth signs using PMCT was easily achieved'. Although no large validation study on determining the cause of death in children with PMCT has been performed yet, a recent study concerning unexpected death in children found that PMCT findings corresponded to autopsy in 89% of the cases.[9] A validation study in adults showed a major discrepancy rate between postmortem radiology and autopsy findings of 32% in determining the cause of death.[10] These studies were all performed shortly after death, when little or no postmortem changes are to be expected; it is unclear how PMCT performs in determining the cause of death after a longer postmortem interval with signs of severe decomposition. Some case reports have been published describing the possibility of determining a cause of death with PMCT after long postmortem intervals.[11-13] Normal postmortem cadaveric decomposition changes can a.o. cause putrefaction gas, which can be possibly misdiagnosed as pathological processes.[14-17] If the possible additional value of PMCT in suspected neonaticide with late postmortem changes was quantified, this could improve current protocols for postmortem examinations. Therefore, we performed a retrospective study to compare non-contrast enhanced PMCT with autopsy in suspected neonaticide, in neonates found more than one week after their demise. We compared the performance of both methods on (1) determining gestational age, (2) differentiating between live birth and still birth and (3) determining cause of death.

MATERIAL AND METHODS

We selected all consecutive neonaticide cases with an estimated postmortem interval longer than one week, who underwent a forensic autopsy in the Netherlands Forensic Institute in the period 1-1-2008 to 31-12-2012.

External examination and autopsy

Autopsies were performed according to local protocol.[18] Gender was determined with visual inspection of outer and inner genitalia and DNA investigations. Postmortem changes were classified as: (PM 1) minor postmortem changes: rigor mortis (partially) present, red or red-purple livor mortis; (PM 2) moderate postmortem changes: rigor mortis dissolved, fixed livor mortis, possible green color of the skin, minor swelling due to postmortem formation of gas, minimal detachment of the skin; (PM 3) severe postmortem changes: rigor mortis dissolved, assessment of livor mortis not possible, green-grey to black discoloration of the skin, possible severe swelling due to postmortem formation of gas, detachment of epidermis, nails and hair, smoothing of tissues and partial skeletonization. Furthermore they were classified according to the decomposition staging scale.[19] This scale describes 10 different stages, with stage I-III being the putrid category, stage IV-VI being the bloating category, stage VII-VIII being the destruction category and groups IX-X being the skeleton category. If possible, foot length measurement was performed to determine gestational age. Reference values were obtained from 'Fetal and neonatal pathology'.[20] In the Netherlands, a fetus born at 24 weeks or later is considered potentially viable.[21] If a fetus is born before 24 weeks of gestation, no person can be prosecuted for neonaticide. If possible, live birth was assessed according to protocol, by performing hydrostatic flotation tests of the lungs and gastrointestinal tract, assessment of the functional closure of the Botallian duct and histology (the presence of air in the alveoli).[18,22] Histology, toxicology and DNA investigations were performed. Cause of death was classified according to the ICD-1023 and according to the forensic classification used by the Netherlands Forensic Institute.[18] All autopsies were performed by an experienced forensic pathologist (VS or AM) with extensive experience with pediatric forensic cases (8 and 15 years respectively).

PMCT

A total body non-contrast enhanced PMCT was performed shortly before autopsy, using a clinical state of art scanner (Toshiba Aquilon, Toshiba Medical Systems Europe B.V., Zoetermeer, the Netherlands or Philips Brilliance 64, Philips Healthcare, Best, the Netherlands). All studies were analyzed on a PACS system (Agfa Impax 6.4.0, Agfa Healthcare, Mortsel, Belgium). In all cases both MPR in the sagittal and coronal plane were performed. In order to measure the length of long bones, dedicated reconstructions were obtained along the long axis of the humerus, radius, femur and tibia. Additionally three dimensional surface shaded reconstructions were obtained. As this is a retrospective study, scan parameters were not identical in all cases, individual scan parameters are presented in table 1. In order to rule out the presence of rhizomelic or mesomelic shortening of

Table 1. Scan parameters

Case number	Slice thickness (mm)	kV	mAs	Scanner
1	0.9	80	157	Philips Brilliance 64
2	0.5	100	200	Toshiba Acquilon
3	0.5	100	50	Toshiba Acquilon
4	0.5	100	50	Toshiba Acquilon
5	0.5	100	50	Toshiba Acquilon
6	0.5	100	50	Toshiba Acquilon
7	1.0	140	179	Philips Brilliance 64
8	1.0	120	350	Toshiba Acquilon
9	1.0	140	179	Philips Brilliance 64
10	3.0	120	239	Philips Brilliance 64
11	0.5	100	50	Toshiba Acquilon
12	0.5	100	100	Toshiba Acquilon

the long bones, the diaphyseal lengths of the left, humerus, radius, femur and tibia were measured.[24,25] The median gestational age and 5th and 95th percentile were assessed for each individual bone, based on reference values reported in 'Fetal Radiology: a diagnostic atlas'.[26] Gestational age was calculated based on femoral length, using the regression formula as presented by Scheuer et al.[27] Aeration of the lungs and stomach, indicating live birth, was assessed and compared with gas localization elsewhere due to decomposition. Distribution of gas was assessed with the postmortem radiological alteration index (RAI).[28] Cause of death was classified according to the ICD-1023 and according to the forensic classification used by the Netherlands Forensic Institute.[18] All PMCT scans were assessed by an experienced forensic pediatric radiologist (RR) with 10 years of experience with forensic pediatric radiology.

RESULTS

Twenty-four autopsies on neonaticide cases have been performed in the Netherlands Forensic Institute in the period 2008-2012, of which 15 children (63%) were estimated to be found more than one week after their demise. In 12 of these (80%) cases a PMCT was performed and these were included in this study (Table 2). Eight of the children were found in a home, three were found nearby a home (e.g. garden or garden shed) and one was found in a meadow. The exact time between death and discovery of the body was unknown in most cases; based on testimonies during court proceedings it was estimated that this probably ranged between three weeks and seven years.

Table 2. *Characteristics of the cases*

Case	Estimated pm interval	Decomposition staging scales[19]	Location of discovery	Signs of violence	Siblings	Sex	Gestational age (in weeks) based on femur length[27] Mean (95% CI)	Gestational age (in weeks) based on foot length[20] Mean (Min–Max)
1	Months	VII	Home	-		M	40 (38–42)	39 (37–?)
2	Unknown	VII–VIII	Home	-		F	37 (35–39)	35 (33–36)
3	5 years	VII	Home	-	*	M	39 (37–41)	n.e.
4	7 years	VII	Home	-	*	F	39 (37–41)	34 (33–36)
5	3 years	VII	Home	Clothing in mouth	*	F	39 (37–41)	n.e.
6	1 year	VII	Home	Clothing in mouth	*	F	40 (38–42)	35 (33–36)
7	Months	VII–VIII	Garden shed	-	#	F	37 (35–39)	34 (33–36)
8	1–5 year	VII	Garden (flowerpot)	-	#	F	33 (31–35)	n.e.
9	1–5 year	VII	Garden (buried)	-	#	M	38 (36–40)	35 (33–36)
10	5 years	VII	Home	-		F	39 (37–41)	n.e.
11	Unknown	VII–VIII	Meadow	-		F	37 (35–39)	n.e.
12	3 weeks	VI	Home	Cloth around neck		F	39 (37–41)	37 (35–39)

95% CI, 95% confidence interval; Min, minimum; Max, maximum; M, male; F, female; n.e., not evaluable.
Children born to the same mother are marked with an * or an #.

External examination and autopsy

In all cases, late postmortem changes were present, defined as PM 3 (Fig. 1a, 2a). According to the decomposition staging scale the postmortem changes in all cases were classified between VI and VIII. Sex could be determined with visual inspection in 8/12 cases (67%); in the other cases DNA investigations were performed; there were 3 boys and 9 girls. In 7 of the 12 cases (58%) it was possible to measure foot length. This was 71 mm on average, range 68-80 mm. This matches a mean gestational age of 36 weeks. In none of the cases it was possible to determine whether the neonate had been alive after birth. Due to postmortem changes it was not possible to perform flotation tests to assess aeration of the lungs or gastrointestinal air or assess functional closure of the Botallian duct. Interpretation of histological data was not possible due to autolysis. Toxicology and DNA investigations did not provide information that was helpful in determining the cause of death. In none of the cases it was possible to determine a cause of death; all were classified as XVIII R99 (other ill-defined and unspecified causes of mortality) according to the ICD-10. In three of the cases there were indications of potential suffocation or strangulation; in two cases a balled-up piece of clothing was tightly

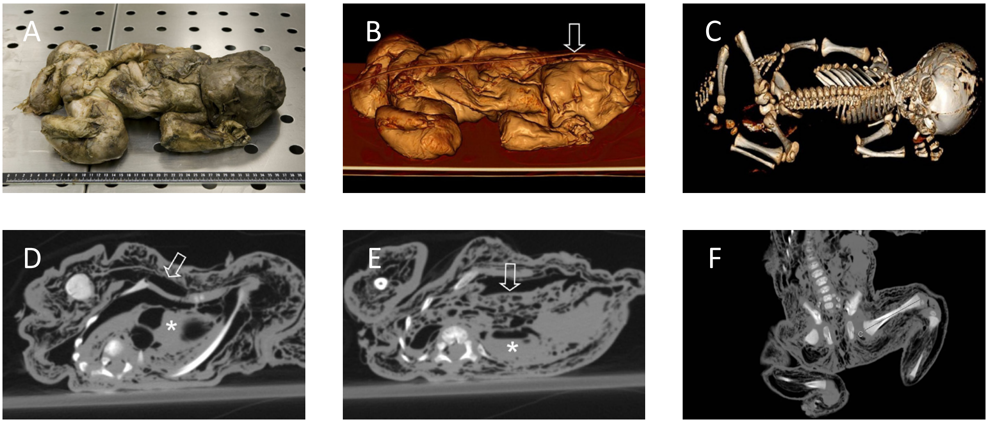

Figure 1a. *Neonate found several months after demise (case 1). Despite severe decomposition (scale VII) external features, such as the genitalia, are still present.* ***Figure 1b.*** *The neonate is scanned within the body bag (arrow points to the zipper), a surface shaded rendering of the soft tissue is routinely performed.* ***Figure 1c.*** *Also a 3D reconstruction of the complete neonatal skeleton is obtained. There is a normal fetal skeletal anatomy. The 'holes' in the skull are a result of the applied threshold and reflect the thin skull with a relatively low density on CT.* ***Figure 1d.*** *Axial slice at the level of the thorax shows extensive subcutaneous emphysema (arrow) and a massive amount of air in the right ventricle and atrium of the heart (RAI III, asterisk).* ***Figure 1e.*** *Axial slice at the level of the upper abdomen shows air in the liver (RAI III, arrow), the kidneys are not discernable (asterisk).* ***Figure 1f.*** *On a coronal-oblique reconstruction along the diaphysis of the left femur, the femoral length is measured.*

stuffed in the mouth and in one case a piece of cloth was wrapped around the neck. As it was not possible to assess whether the child was alive at the moment that this had happened, it was not possible to determine to what extent these findings contributed to the death of these children. Based on the circumstances in which the children were found, the cause of death was assumed to be (a form of) neonaticide in all cases, but stillbirth and abandonment could not be ruled out.

PMCT

In all cases, severe postmortem changes were present, defined as PM 3 (Fig. 1b-e). Gender could be determined in one case, in this case it matched the gender determined by the pathologist. In all cases it was possible to perform long bone measurements (Table 2, Fig. 1f, 2b). In one case the measurements were above the reference values provided in the literature. None of the children showed signs of rhizomelic or mesomelic shortening. All children were born at a potentially viable gestational age. In none of the cases it was possible to determine whether the neonate had been alive after birth due to late postmortem changes. The RAI is presented in table 3. In all cases, several sites (range 2-6) could not be assessed due to decomposition, therefore we did not calculate the index, as this method is only validated for 7 sites (Fig. 1d, e, 2b). For the same reason, in none of the cases neither a cause nor manner of death could be determined. The piece of cloth wrapped around the neck was recognized with PMCT, the t-shirt in the mouth of two children was not distinguishable from decomposing human remains with PMCT.

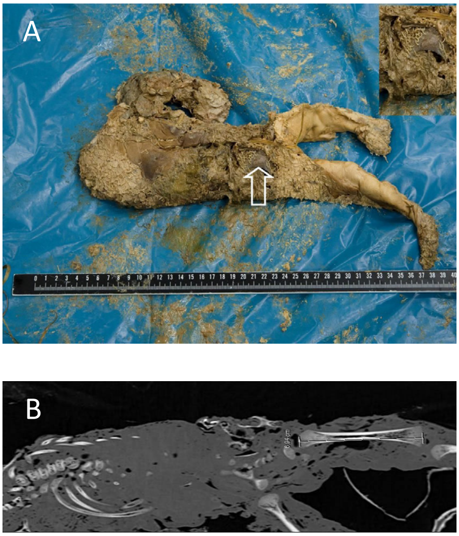

Figure 2a. Neonate found in a meadow (case 11). There is severe decomposition (scale VII-VIII), note the absence of the head. Although the neonate was wrapped in plastic bags, numerous worms were found on the body (insert). The soft tissue overlying the pelvis is largely decomposed (arrow). ***Figure 2b.*** Coronal-oblique reconstruction along the shaft of the left femur shows complete decomposition of the thoracic and abdominal organs (limiting the use of the RAI). The length of the left femur is measured to assess skeletal age.

DISCUSSION

The results of this study show that PMCT performs better in estimating gestational age compared to autopsy. Both PMCT and autopsy are unable to assess live birth and cause of death in case of late postmortem changes.

The major advantage of PMCT over autopsy in these cases is the rapid estimation of gestational age. In this study it was possible to estimate gestational age in 100% of the cases, compared to a 56% rate with autopsy. The only requisite is there should be identifiable and intact long bones. As decomposition of the skeleton occurs after a longer period of time than decomposition of the soft tissues, this method can be used in more cases than foot length measurement. After extraction and maceration, direct measurement of the long bones by an anthropologist is possible as well, but PMCT is faster, easier to perform and can be reassessed even after the neonate has been buried or cremated.

As decomposition hampers the assessment of signs of live birth and determination of cause of death in both PMCT and autopsy, none of the methods in this study was superior over the other to answer these questions. The fact that signs of live birth could not be determined by either method is understandable, as in both methods proof of life is demonstrated by the presence of air in lungs and/or digestive tract. Decomposition causes the presence of gas as well, and in many of our cases it was impossible to visualize the organs separately due to liquefaction, causing the distribution of air to be unreliable as well. Guddat et al. describe four cases with less severe postmortem changes, in which PMCT could assess the ratio between intrapulmonary air and air in other body parts and assist in the differentiating between live birth and stillbirth.[8] Distribution of air has been proven to be useful in distinguishing between putrefaction and air embolism in adults.[15] Our study did not include cases with little postmortem changes, and we did not find any studies describing the distribution of air in cases with severe decomposition changes.

The fact that no cause of death could be determined with autopsy because of late postmortem changes is to be expected and has been described by others as well.[5] It seems reasonable to assume and can be concluded from our results that the same holds true for determining the cause of death with PMCT. In autopsies with limited or no signs of decomposition, an advantage of autopsy above PMCT is the possibility of determining whether certain anomalies originated during life or after the demise. For example in injuries, bruising or hemorrhage around the injury indicates the incident must have happened while there was circulation. Differentiation between pre- and postmortem injuries is more difficult with PMCT. Although PMCT can detect hemorrhages around injuries depending on the size of those hemorrhages and the location of the injury and can therefore, in some cases, identify an injury as having been caused during life, the presence of a hemorrhage cannot be excluded with PMCT. Autopsy is a more sensitive method to detect this and therefore the method of choice to differentiate between pre- and postmortem injuries. In case of severe decomposition this advantage of autopsy is not applicable anymore, as late postmortem changes make it impossible to assess these aspects of injuries. In our study, two children had a t-shirt in their mouth. As signs of suffocation could not be assessed, it was not possible to conclude that the object in their mouth indeed contributed to their death. The same holds true for the child with a piece of cloth tied around the neck. Bruising, petechiae or other signs of strangulation could not be assessed; therefore interpretation of this finding was limited. Thus, in case of severe decomposition, the interpretation of PMCT and autopsy are more in keeping, compared to cases with a short postmortem interval, with respect to the assessment of live birth and determination of the cause of death.

Although generally seen as a valuable addition, replacement of autopsy by postmortem imaging does, at present, not seem feasible for the majority of (forensic) cases. In 2011 the first case report has been published in which postmortem imaging replaced a forensic autopsy, as both cause and manner of death were accepted by the authorities.[29] In most countries this is not acceptable yet, but as postmortem radiology is a field that develops rapidly, this might be possible for certain cases in the future. Taking in regard the aim of a forensic autopsy in suspected neonaticide, an adjusted autopsy protocol might be considered in case of late postmortem changes. If PMCT is performed to estimate gestational age, an external autopsy or visual inspection of the body might be sufficient to gather all relevant information. This could be complemented with DNA investigations to determine kinship and sex (if the latter was not possible with CT/external inspection) and toxicological investigations to determine the presence of toxicological substances. In the 12 cases we describe this would have provided the same amount of information as a full autopsy.

CONCLUSION

In case of late postmortem changes, PMCT is superior in estimation of gestational age compared to foot length measurement. There is no difference between PMCT and autopsy regarding the assessment of live birth or cause of death; both modalities were unable to determine these 2 parameters in any of the 12 cases in our sample. These results might influence protocols for postmortem examination for suspected neonaticide in case of severe putrefaction. PMCT is indispensable and should be performed compulsory; a full autopsy might not always be necessary. We propose a new protocol for postmortem examination, consisting of a PMCT, visual inspection and sampling for DNA, toxicological and other forensic investigations.

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Chapter 13

Pneumomediastinum and soft tissue emphysema in pediatric hanging

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ABSTRACT

Postmortem computed tomography (CT) is increasingly being used as a tool in forensic pathology. The exact value of postmortem imaging in detecting specific conditions has not yet been established, but in specific cases, it can be used as a diagnostic tool demonstrating findings that remain undetected during autopsy, as in this case. Pneumomediastinum and soft tissue emphysema were detected with postmortem CT in a 3-year-old girl after hanging. It was not found during autopsy. This radiological finding matches three adult cases previously described. It is assumed that in this case, the first reported in a child, hanging was the most likely cause as well. In the adult cases, it was interpreted as a vital sign; the person must have been alive to create a pressure gradient causing rupture of the alveoli. This case demonstrates one of the added values of postmortem imaging, the possibility of demonstrating findings that remain undetected during autopsy.

INTRODUCTION

Postmortem imaging, as an addition to the conventional judicial autopsy, is increasingly being used as a tool in forensic pathology. The advantages of postmortem radiological imaging are that it is a noninvasive modality and yields a result that can be kept and shared unaltered over time. This makes it possible to reassess the data in future if needed, in contrast to an autopsy in which the quality of reassessment will decline in time because of postmortem changes. In recent years, numerous publications on the use of postmortem imaging, especially computed tomography (CT), have appeared in radiological as well as forensic journals. Based on their research, Bolliger et al. conclude that the use of CT has proven “to be an invaluable tool in three areas of forensic pathology, namely in the detection and demonstration of fractures, the detection of foreign bodies, and the detection of gas”.[1] The first validation study on postmortem imaging in adults revealed a major discrepancy rate between imaging and autopsy in establishing the cause of death of 30%.[2] The exact value of postmortem imaging in detecting specific conditions has not yet been established, and no reliable positive and negative predictive values for different conditions have been determined. It is known, however, that on a case by case basis, it can be used as a diagnostic tool demonstrating findings that remain undetected during autopsy, as is demonstrated in this case. A child in which postmortem imaging demonstrates the presence of pneumomediastinum and soft tissue emphysema is presented. These findings are interpreted as a result of compression of the neck by hanging.

CASE

A 3-year-old girl was found by a neighboring child hanging in the stairwell at home. The child alarmed his parents who called the general practitioner (GP). The GP found the girl with a rope around her neck in full suspension, cut the rope, and called emergency services. Although the body was already cold when they arrived, resuscitation was started. Resuscitation was stopped according to protocol when no signs of life were detected. The girl was previously in good health. Because of privacy considerations, no details about the family can be presented. The mother and siblings were at home when the girl was found. One of the siblings, walking around in the house, had a piece of rope tied around his neck. Two pieces of rope were hanging in the stairwell, one was cut (by the GP), and one was tied in a slip knot. More rope was found elsewhere in the house. The knots in the ropes could not have been tied by a young child. The mother was mentally confused at the moment the GP and emergency services arrived and not able to clarify what happened. She was arrested, and in the police interrogations during the investigations, it became clear that she intended to kill her four children and subsequently commit suicide. The sibling with the rope around his neck had also briefly been hung by the mother, but she untied him when the doorbell rang. According to the mother, the children were alive when she hung them. The mother was diagnosed with a psychiatric disorder by two forensic psychiatrists and was convicted to imprisonment and subsequent detention in hospital.

Radiological Findings

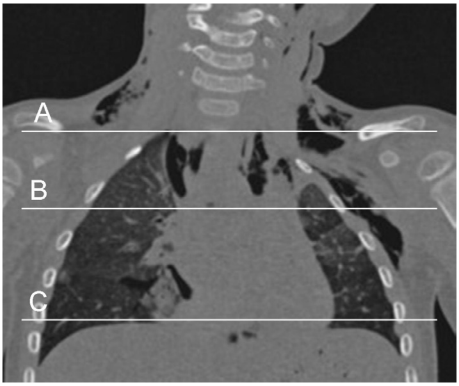

Figure 1. *Coronal reconstruction displaying the axial levels as shown in Figure 2a–c.*

As part of the standard protocol of the Netherlands Forensic Institute, a skeletal survey and postmortem total body CT were performed before forensic autopsy.[3] The scan was performed several hours after death on a Philips Brilliance 64-slice CT scanner (Philips Medical Systems, Best, the Netherlands). Scan parameters were as follows: 210 mAs, 300 kV, and slice thickness 0.9 mm, and coronal and sagittal reconstructions were obtained. The radiological studies were evaluated by a board-licensed pediatric radiologist without prior knowledge of the autopsy findings. Skeletal survey showed no abnormalities, especially no rib fractures. Computed tomography revealed extensive cervical and thoracic soft tissue emphysema and a pneumomediastinum (Figs 1 and 2a-c). No fractures, especially no fractures of the cervical spine or hyoid bone, were detected on CT imaging. It should be noted that only dislocated fractures of the hyoid can be seen on CT. Advanced visualization, adapted from Aghayev et al.[4], consisted of 3-D rendering of gas structures (Fig. 3).

Autopsy Findings

An autopsy was performed according to the pediatric forensic autopsy protocol by the Netherlands Forensic Institute.[3] During autopsy, a full circular hanging mark around the neck was detected, with a constant width of five millimeter, with redness on the edges due to subcutaneous bleeding. There were no abrasions and no bruises. The mark was situated higher just under the left ear, where a vague point of suspension was observed (Fig. 4). Petechial hemorrhages were observed in the eyelids, facial skin, and conjunctivae (Fig. 5) and

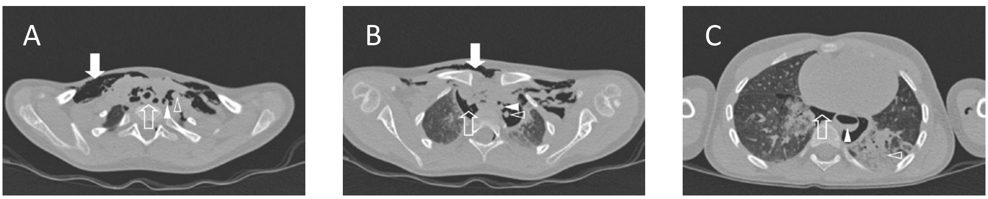

Figure 2a. *Axial computed tomography (CT) scan in lung setting. This shows subcutaneous emphysema (solid arrow), air in the trachea (open arrow) with air in the adjacent esophagus, and air surrounding the left common carotid artery (solid arrowhead) and left jugular vein (open arrowhead).* ***Figure 2b.*** *Axial CT scan in lung setting. This shows subcutaneous emphysema (solid arrow), pneumomediastinum (open arrow), and air surrounding the left common carotid artery (solid arrowhead) and left subclavian artery (open arrowhead).* ***Figure 2c.*** *Axial CT scan in lung setting. This shows pneumomediastinum (open arrow), air fluid level in the esophagus (solid arrowhead), and postmortem consolidation of lung parenchyma (open arrowhead).*

internally on the surface of the heart. At autopsy, no subcutaneous or mediastinal emphysema was observed. It should be noted that palpation of the body is not a standard procedure during autopsy. If this had been performed, the emphysema probably would have been detected. The pneumothorax was not diagnosed. There were no injuries internally in the neck (no hemorrhages, no fractures of the hyoid and laryngeal structures). There were no hemorrhages at the attachment points of the anterior neck muscles. Trachea and oral cavity were intact; both showed no signs of a traumatic intubation. Organ weights of the brain and lungs were higher than normal as a sign of edema, which was confirmed later microscopically. There were no signs of disease macroscopically and microscopically. Toxicology investigation demonstrated no alcohol or drugs. A small amount of atropine was detected, which was given during resuscitation. Cause of death was explained by cerebral ischemia due to carotid occlusion and/or airway occlusion by direct compression of the larynx or trachea. Injury of the neck showed subcutaneous bleeding, indicating that this injury was caused, while the victim was alive. Whether there had been other forms of violence, for example, airway obstruction caused by compression of the nose and mouth or other forms of violence on the neck, cannot be excluded based on autopsy results. A possible contribution to the cause of death by a cardioinhibitory reflex cardiac arrest cannot be excluded.[5]

Figure 3. 3-D reconstruction of gas collections shows a pneumomediastinum and extensive emphysema of the thorax and the neck.

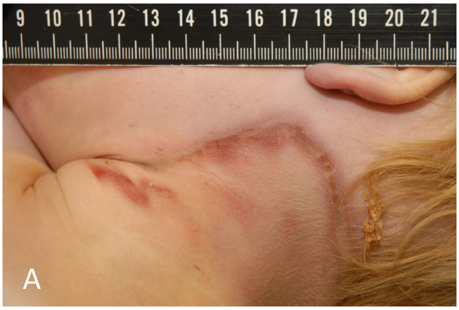

Figure 4. *Circular hanging mark with abrasions, impression, and hemorrhage in the edges.*

Figure 5. *Petechial hemorrhages in the eyelids, facial skin, and conjunctivae.*

13

DISCUSSION

Findings of soft tissue emphysema and pneumomediastinum after hanging, as reported in this case, have previously been described by Aghayev et al.[4] in an adult population. They described the presence of pneumomediastinum and soft tissue emphysema of the neck in three of five adults who died as a result of hanging. This is the first pediatric case in the literature. Pediatric hanging is extremely rare, in contrast to adults where this is a commonly encountered suicide mechanism. Most of the pediatric hanging cases are accidental, while this case illustrates a nonaccidental form, which is exceptional. Accidental hanging in children is mostly related to curtain and blind cords, key cords, and child restrainers, and in children playing “the choking game”.[6–14] In older children, autoerotic asphyxiation as an accidental form of hanging and suicide by hanging are, although rare, also encountered.[15,16] The mechanism of the development of pneumomediastinum was first presented by Macklin and is known as the “Macklin effect”.[17,18] The basic mechanism is explained by the presence of a pressure gradient, between the air-filled alveoli and the surrounding interstitial tissue. This pressure gradient causes alveolar rupture with air leaking into the pericapillary interstitial pulmonary tissue. The interstitial space is connected with the periarterial, peribronchial, and perivenous sheaths. Leakage from these spaces will allow air to enter into the mediastinum, leading to a pneumomediastinum. If the air leaks from the mediastinum, through the fascia it can leak into the cervical and subcutaneous soft tissues. The similarity with the cases described by Aghayev et al. suggests that these radiological findings probably result from the trauma described, hanging. Although putrefaction can cause pneumomediastinum in combination with emphysema as well, in this case the time between death and imaging is too short to explain this finding. The absence of other signs of putrefaction, for example, the absence of intravascular gas on postmortem CT and the absence of alcohol by toxicological investigation, supports this theory. Another mechanism that might cause pneumomediastinum and subcutaneous emphysema is cardiopulmonary resuscitation (CPR). It can be caused by injury of the trachea due to traumatic intubation, rib fractures due to chest compressions causing pneumothorax, or rupture of the alveoli due to high intrathoracic pressure.[19–23] The adult cases described by Aghayev were not resuscitated, as they were found hours after death. The girl described in this case report had been resuscitated, although the forensic report suggests that this started after her demise. The complication rate of CPR is very low. Matshes et al. found one case of emphysema in 383 children who received CPR. Other studies did not find any emphysema or pneumomediastinum in children after CPR[25,26], although in the study by Bush et al., in 1 of 211 children, a pneumothorax was found.[25] There were no signs of traumatic intubation or rib fractures in our case. However, the possibility of rupturing of the alveoli by CPR cannot be excluded. Between 2008 and 2011, 99 pediatric postmortem CTs were performed in our forensic institute. In only two of them, the cause of death was hanging. Only in one of these cases, pneumomediastinum and subcutaneous emphysema were detected. This is in line with the findings by Aghayev et al., who performed postmortem CT in 95 cases. Pneumomediastinum and soft tissue emphysema were only present in three cases, which all died because of hanging. Therefore, hanging is considered to be a more probable cause of these findings than CPR. Furthermore, the localization of the air in neck and head suggests that it developed while the body was in vertical position. In many forensic cases, the origin of soft tissue emphysema in combination with pneumomediastinum may not be clear, and a differential diagnosis should be considered. Pneumomediastinum in children can be caused by several medical conditions. The most common causes are cited to be asthma exacerbation and pulmonary infection.[27,28] Spontaneous pneumomediastinum (also known as Hamman's syndrome) is seen in combination with and without subcutaneous emphysema. It is a well-known phenomenon with a bimodal peak incidence in children below the age of 4 years and children aged 15–18 years.[29–31] It is caused by alveolar rupture due to a sudden increase in intrathoracic pressure. It can develop after events that trigger a Valsalva maneuver. Other rare causes described in the literature are measles infection[32–35], temporomandibular joint surgery[36], dental extraction (most likely as a result of the use of air- powered tools)[37–42], foreign body aspiration[43–48], ketoacidosis in diabetic patients[49], and playing wind instruments.[50] If hanging is the cause of pneumomediastinum and soft tissue emphysema, this can be interpreted as a vital sign, as the person must have been alive to create a pressure gradient. In a forensic setting, this can be important as it demonstrates that the person must have been alive at the time the trauma occurred. In this case, however, vitality of the hanging mark was already confirmed as there was subcutaneous bleeding around the edges, indicating that the victim was alive at the time of the trauma. The preferable imaging tool for the detection of pneumomediastinum and soft tissue emphysema is computed tomography.[4] The detection of gas within soft tissues is difficult at autopsy, and the findings of pneumomediastinum or soft tissue emphysema are frequently missed[4], like in our case. This is the first case in the literature demonstrating cervical and thoracic soft tissue emphysema and a pneumomediastinum in a child after hanging. Although CPR cannot be excluded as a cause of the radiological findings in this case, the resemblance with the cases described in adults suggests a common pathway. Furthermore, this case illustrates the efficacy of postmortem imaging in detecting gas formation, which in some cases is not detected during autopsy.

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Summary, conclusion and future perspectives

SUMMARY

In this thesis we have brought together our studies describing the possibilities and impossibilities of establishing a diagnosis of child abuse in both living and deceased children, focusing on (forensic) pediatric radiology.

The thesis is divided into two parts, with the first part describing aspects of imaging in living children, suspected of being victims of child abuse, and the second part describing imaging in deceased children in a forensic setting.

In **part I**, **chapter 1**, we have given an overview of imaging techniques in suspected physical abuse, and the specificity of different types of fractures.[1] Fractures are common in childhood; the likelihood of sustaining a fracture is 2.1% per year in children.[2] Conventional radiography is the usual method for diagnosing fractures. A skeletal survey, according to international guidelines consisting of at least 20 radiographs, is the best way to detect fractures.[3,4] The survey should be repeated 14 days after the initial trauma, to detect fractures that have formed callus over the period and were not visible at first examination. There is no consensus about the role of bone scintigraphy. Although it has a higher diagnostic yield in more anatomical complex locations, it is less sensitive for classic metaphyseal lesions (CMLs).[5] CT should not be used as a replacement for conventional radiography to detect fractures, firstly because of the high radiation dose, and secondly because CMLs will go undetected. Whole-body short tau inverse recovery MRI (WB-STIR) has a low sensitivity for CMLs and rib fractures and should not be performed routinely. Certain fractures have a high specificity for abuse, but no fracture in itself is pathognomonic for child abuse. The injury should therefore always be related to the clinical history presented by the caregiver. Types of fractures most specific for abuse are rib fractures (especially posterior rib fractures) and CMLs. Dating fractures is not an exact science, but there is evidence that recent and old (healing) fractures can be distinguished.

In **chapters 2 and 3** we reviewed the social-pediatric and radiological aspects of abusive head trauma (AHT).[6,7] AHT is a relatively common cause of neurotrauma in young children, with an incidence of 14–40 cases per 100,000 children under the age of one year.[8-12] About 15–23% of these children die shortly after the incident.[8-10,12] One-third of the AHT survivors are severely disabled, one-third of them are moderately disabled and one-third have no or only mild symptoms.[8,13,14] However, neurological problems can occur after a symptom-free interval and half of the AHT survivors have IQs below the tenth percentile.[15,16] Clinical findings in AHT are dependent on the definitions used, but AHT should be considered in all young children with neurological signs and symptoms, especially if no or only mild trauma is described. Subdural hematomas (SDHs) are the most frequently reported finding. The only clinical feature that has been identified as discriminating AHT from accidental injury is apnea, with a positive predictive value (PPV) of 93%.[17] A differential diagnosis of SDH exists, but the differential diagnosis of SDH in combination with fractures or other signs

of trauma is very limited. Detailed history-taking is the key to the diagnosis and should consist of a detailed history of the event that led to the clinical situation, medical history, growth curve, medical history of siblings, prior involvement of child welfare services and assessment of risk factors. In **chapter 3** we reviewed the role of radiology in establishing the diagnosis of AHT.[7] It is an important tool in describing the location and severity of the injury. Furthermore, it can help in the detection of abnormalities that can make the diagnosis more likely, such as rib fractures, or it can make the initial diagnosis less plausible, for example, if underlying bone disease is detected. Finally, it can help in assessing a prognosis, depending on the brain damage identified. In the acute phase, computed tomography (CT) is the best tool for neuroimaging. If CT is abnormal, early magnetic resonance imaging (MRI) including diffusion-weighted imaging (DWI) should be performed. The role of MRI, if initial CT is normal, is unclear as is the role of repeat CT if early MRI is performed. There is no evidence-based approach for the follow-up of AHT; both repeat CT and MRI are currently being used. A full skeletal survey, according to international guidelines, should always be performed to obtain information on possible underlying bone diseases, or injuries indicative of child abuse. Cranial ultrasonography is not indicated as a diagnostic modality for the evaluation of AHT. The final diagnosis of AHT can never be based on radiological findings only; it should always be made in a multidisciplinary team assessment, where all clinical and psychosocial information is combined and the diagnosis is established by a group of experts in the field.

In **chapters 4 and 5** we studied all Dutch cases of AHT for which forensic medical expertise was requested by the Courts. The Courts request forensic medical expertise for 7.4 per 100,000 children per year in the Netherlands.[18] Based on these forensic reports, risk factors for child abuse identified in other studies were found in this sample as well: prematurity, dysmaturity and twins/triplets were found in 27%, 23% and 10% of cases respectively, maternal age under 20 years in 17%. Of the parents, 60% had completed only primary or secondary education, and 38% of the families were known to child welfare authorities. It was striking that in 81% of families there was evidence of prior episodes of abuse. These results underline the need to improve the recognition of AHT by both child welfare authorities and the health care system. We also found that in 48% of the cases there was evidence of impact trauma. This resulted in **chapter 5**, where we tried to differentiate between impact and non-impact trauma based on radiological findings.[19] We did not find any statistically significant differences in the distribution of radiological findings between the two groups, neither on neuroimaging nor on skeletal surveys. This indicates that, except in the case of a skull fracture, radiological findings cannot be used to determine the trauma mechanism leading to the injuries in AHT.

As SDHs are the most common manifestation of AHT, we performed a systematic review to identify the evidence for dating of SDHs on imaging findings, described in **chapter 6**.[20] Age determination can be used to check whether there is a consistent history and can relate the injuries to possible perpetrators. We included 25 studies describing densities/ intensities

of SDHs on CT and/or MRI. Pooled time intervals showed a wide range and did overlap. Concluding, we did not find evidence that SDHs can be accurately dated on neuroimaging findings. In **chapter 7** we described the knowledge and practice of Dutch radiologists regarding dating SDHs.[21] We performed an online survey among neuroradiologists and pediatric radiologists. The results demonstrated that there is a considerable practice variation among Dutch radiologists regarding the age determination of SDHs. None of the participants was ‘very certain’ of their age determination. This implicates that dating of SDHs is not suitable for use in Court, as no uniformity among experts exists.
The first part of the thesis ends with **chapter 8**, a case report of a neonate with a CML of the distal right femur; a fracture of the long bones with a high specificity for child abuse.[22] In this case it was detected after vaginal breech delivery, which we determined to be the cause of the fracture. With this case report we want to underline the need for a differential diagnosis, especially in children with fractures in whom abuse is suspected.

In the second part of the thesis, we describe imaging studies in deceased children. In **chapter 9**, we reviewed the current techniques used in postmortem imaging.[23] As autopsy rates are declining, postmortem imaging could be an alternative. Postmortem radiology can be used in the clinical setting, in a forensic setting and to depict historical specimens, for example mummies. Conventional radiology has been in use for a long time, as the skeletal survey can be used to detect both fractures (in case of suspected non-natural death) and underlying bone disease or metabolic disorders. It is being used for fetuses and children up to four years of age; above this age it is not likely that additional information can be found with a skeletal survey. Furthermore it can be used to obtain detailed radiographs of specimens collected by the pathologist. Conventional angiography is upcoming; at the time of writing the review article, publications on the subject were scarce, but several papers have been published in the meantime. Information on ultrasonography is limited, but it can be used to guide biopsies in case of minimal invasive autopsy. Both CT and MRI are the most important modalities in current postmortem imaging.

In **chapter 10** we described 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.[24] We found that, although intravascular air is a normal postmortem finding, it appears more often in children in whom IV fluids have been administered.

In **chapter 11** we described 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.[25] PMCT and autopsy identified the same cause of death in 67% of the cases (kappa 0.5) using ICD-10 classification. PMCT did identify the majority of unnatural causes of death in children correctly (67%), but diagnostic accuracy in natural deaths in our study was low (0% agreement) compared to other publications. It does not give new insight into the cause of death, if this is unexplained according to the pathologist, because PMCT failed to identify a cause of death in 98% of these cases; in the one case in which it did identify a cause of death which was not found with autopsy, this was considered to be a false positive finding. Our agreement of 67% is comparable with the agreement of 69% found in a MRI study, performed in the same age group.[26] We conclude that, at present, PMCT cannot replace conventional autopsy in children.

In the ideal situation, PMCT is performed shortly after demise, to minimize the number of postmortem changes that can hinder interpretation of the images. In forensic practice, however, not all bodies are found shortly after their demise. Therefore, in **chapter 12**, we described the value of PMCT in neonaticide with delayed finding of the body, causing severe decomposition changes.[27] In neonaticide, besides establishing a cause of death, an autopsy is also needed to determine gestational age and to assess possible live birth. In the case of late postmortem changes, PMCT is superior for estimating gestational age compared to foot length measurement with autopsy. There is no difference between PMCT and autopsy regarding the assessment of live birth or cause of death; both modalities were unable to determine these two parameters in any of the 12 cases in our sample. This might influence protocols for postmortem examination for suspected neonaticide in case of severe decomposition. PMCT is indispensable and should be performed compulsorily. In contrast to cases with little or no decomposition changes, described in chapter 11, a full autopsy might not always be necessary. We propose a new protocol for postmortem examination in the case of severe decomposition changes, consisting of a PMCT, visual inspection and sampling for DNA, toxicological and other forensic investigations.

The second part of the thesis ends with **chapter 13**, a case report describing pneumomediastinum and soft tissue emphysema after pediatric hanging.[28] It illustrates one of the additional values of PMCT compared to autopsy, by demonstrating that the child was alive at the moment of hanging. Although cause of death was established with autopsy, these PMCT findings were not detected. Since they can be interpreted as vital signs at the moment of death, as the child must have been breathing to cause a pressure gradient that made the air escape, this information is of additional value to the other vital signs that were detected with autopsy.

CONCLUSION

Forensic pediatric radiology is a field that is developing rapidly. As establishing or missing a diagnosis of child abuse can have severe consequences, it is a field in which research should always be directed towards the diagnostic value of a test, and the amount of certainty that can be ascribed to each radiological report. In imaging in living children, many of these certainties have already been established. For the skeletal survey, for instance, the additional value of each of the radiographs is well known, as is the additional value of a repeat skeletal survey. But in forensic science, information on methods that are not effective are also valued. For example, we found that the difference in injuries between impact and non-impact (presumed shaking) in AHT cannot be based on imaging findings. Furthermore, we did not find sufficient data to accurately date SDHs based on imaging findings, although in another study we found that dating SDHs is commonly practiced by radiologists. These results underline the need for evidence based reporting guidelines in forensic pediatric radiology.

Postmortem imaging is a new field; it is even referred to in some quarters as a new subspecialty[29], with many developments having taken place in the past few years. Although many advantages of postmortem imaging compared to autopsy are obvious, for example, the possibility of different observers reassessing the data over time, in our validation study the diagnostic accuracy is still low. The case mix seems to be an important predictor for the probability of agreement between PMCT and autopsy. In our study it performs better in non-natural deaths. In a prospective validation study on postmortem MRI in children, overall agreement was 56%, but this was raised to 89% if MRI was followed by minimal invasive autopsy.[26] Here, age was an important predictor, as agreement for MRI and autopsy was 43% in fetuses aged 24 weeks or younger, 63% in fetuses older than 24 weeks and 69% in children. It is possible that the combination of CT, MRI and minimal invasive autopsy will enhance rates of agreement in the future, but at present PMCT cannot yet be seen as a replacement for a conventional autopsy. This is different in the subgroup of neonates with severe postmortem changes, because PMCT and autopsy are equally impeded by decomposition changes and the diagnostic accuracy of both modalities in determining the cause of death is low. In these cases, PMCT performs better in age determination of the neonates, making it an indispensable tool in the evaluation of neonaticide.

FUTURE PERSPECTIVES

During this PhD project, several developments have contributed and still are contributing to the professionalization of the field of forensic pediatric radiology. In 2012, the International Society of Forensic Radiology and Imaging (ISFRI) was founded in Switzerland.[30] Its aim is to strengthen and develop the field of forensic radiology and imaging worldwide, including promoting best practice and developing international quality standards and guidelines in this field of imaging. A yearly congress is organized and since 2013 a scientific journal, aimed at forensic and postmortem imaging in particular, has been published: the Journal of Forensic Radiology and Imaging (JOFRI).[31]

In the Netherlands, several national developments with opportunities to improve the forensic sciences are also in progress. In 2013, the Dutch Health Council published a report regarding the position of the forensic (health) sciences in the Netherlands.[32] It was recommended that the forensic health sciences should acquire a more academic character and that an academic chair and accompanying research group should be established in order to develop a more evidence-based approach. Our radiological projects could contribute to academic development within the forensic sciences. The Co van Ledden Hulsebosch Center, established in 2013, is an interdisciplinary center of expertise for forensic scientific and medical research.[33] It is a collaboration between the faculties of physical sciences, mathematics and informatics, the Academic Medical Center and the Netherlands Forensic Institute. By collaboration with other disciplines, forensic questions that cannot be answered with forensic radiology, e.g. dating of SDHs, might be investigated with other techniques. For example, spectrometry, currently being used for the age determination of bruises[34], might also be a valid method of age determination of SDHs. In June 2012, a subsection on postmortem and forensic radiology was founded within the Dutch Radiological Society. Its aim is to bring together radiologists with an interest in post-mortem and forensic radiology in order to exchange experiences, develop imaging guidelines, and generate collaborative research.

From the side of pediatrics, the professionals with whom the radiologist works most closely in case of suspected abuse, several initiatives have been initiated. In the USA, child abuse pediatrics has been a new pediatric subspecialty since 2006.[35] In the Netherlands this subspecialty does not exist, but several centers have acquired a great deal of expertise in diagnosing and managing child abuse cases. Currently, the Erasmus Medical Center Rotterdam, University Medical Center Utrecht and Academic Medical Center Amsterdam are working on a national center of expertise for child abuse (LECK), where colleagues can receive advice regarding diagnostics in and managing of child abuse cases. Furthermore, national guidelines and multicenter research projects will be developed by the LECK. Moreover, since 2011 a two-day course recognizing and responding to child maltreatment (the WOKK) is mandatory for residents in pediatrics.

An important theme in future forensic radiological child abuse research in living children is the dating of injuries. The more accurately injuries can be dated, the more precisely the history described by parents/caregivers can be verified. This question is valid not only for SDHs, but for fractures as well. In a meta-analysis, based on 82 fractures, a schedule with three age groups was constructed, but detailed fracture dating is still not possible.[36] Other research fields might include the possibilities of advanced MRI sequences in neurotrauma (including spinal injuries)[37,38] and the possibilities of whole-body MRI for the detection of fractures, potentially in combination with conventional radiographs of the joints to detect CMLs.[39] Furthermore, in order to improve the detection of rib fractures, which are very specific for abuse but, especially if no callus is present, are easily missed on conventional radiographs, the value of ultra low-dose CT for the detection of rib fractures could be investigated.[40-42]

Non-radiological topics in child abuse research are dictated by the fact that in many families child abuse is recurrent. As we, and others, found that a large proportion of AHT victims or their siblings were either known to social services, or had presented in a hospital with complaints due to abuse, the major challenges in child abuse research are those in the field of early detection and effective interventions to stop abuse. Although these themes are not radiological, they can possibly reduce the number of children with 'fractures in different stages of healing'. As the first (neurological) signs of AHT can be vague and do not always lead to neuroimaging, the studies of Berger et al. regarding serum biomarkers for pediatric brain injury are promising.[43-48] If brain injury could be diagnosed with a routine laboratory test, this could be used as a simple screening instrument in the emergency department. Studies on effective interventions to prevent or stop abuse focus primarily on parenting programs. They mainly use derived outcome measures, such as parent-child interaction or mental health, and find variable results.[49] A systematic review of behavioral interventions to stop child abuse found that risk assessment and behavioral interventions reduced child abuse in young children. Home visitation programs also reduced child abuse, but results were inconsistent.[50]

Future research on postmortem imaging in children should be aimed at determining the diagnostic and economic value of the combination of different techniques. Although neither PMCT nor postmortem MRI alone, are currently sufficient to determine the cause of death in children, the addition of minimal invasive autopsy with tissue sampling, postmortem ventilation and angiography could be promising.[26,51,52] However, the combination of these techniques will probably be introduced at a very high cost. Efficiency should be taken into account when introducing a new method. Furthermore, knowledge regarding normal postmortem findings is needed, both to understand pathological changes and to develop a timescale for postmortem radiological alterations. It is possible that the question will arise of who will interpret the postmortem imaging studies. As it requires specific knowledge of both postmortem changes and the interpretation of imaging findings, either a pathologist with an interest in radiology or a radiologist with an interest in pathology could be suitable candidates.[29] Different methods are practiced in different centers. Regardless of the direction in which postmortem imaging evolves; forensic pediatric radiology will continue to play an important role in the diagnosis of child abuse, in both living and deceased children.

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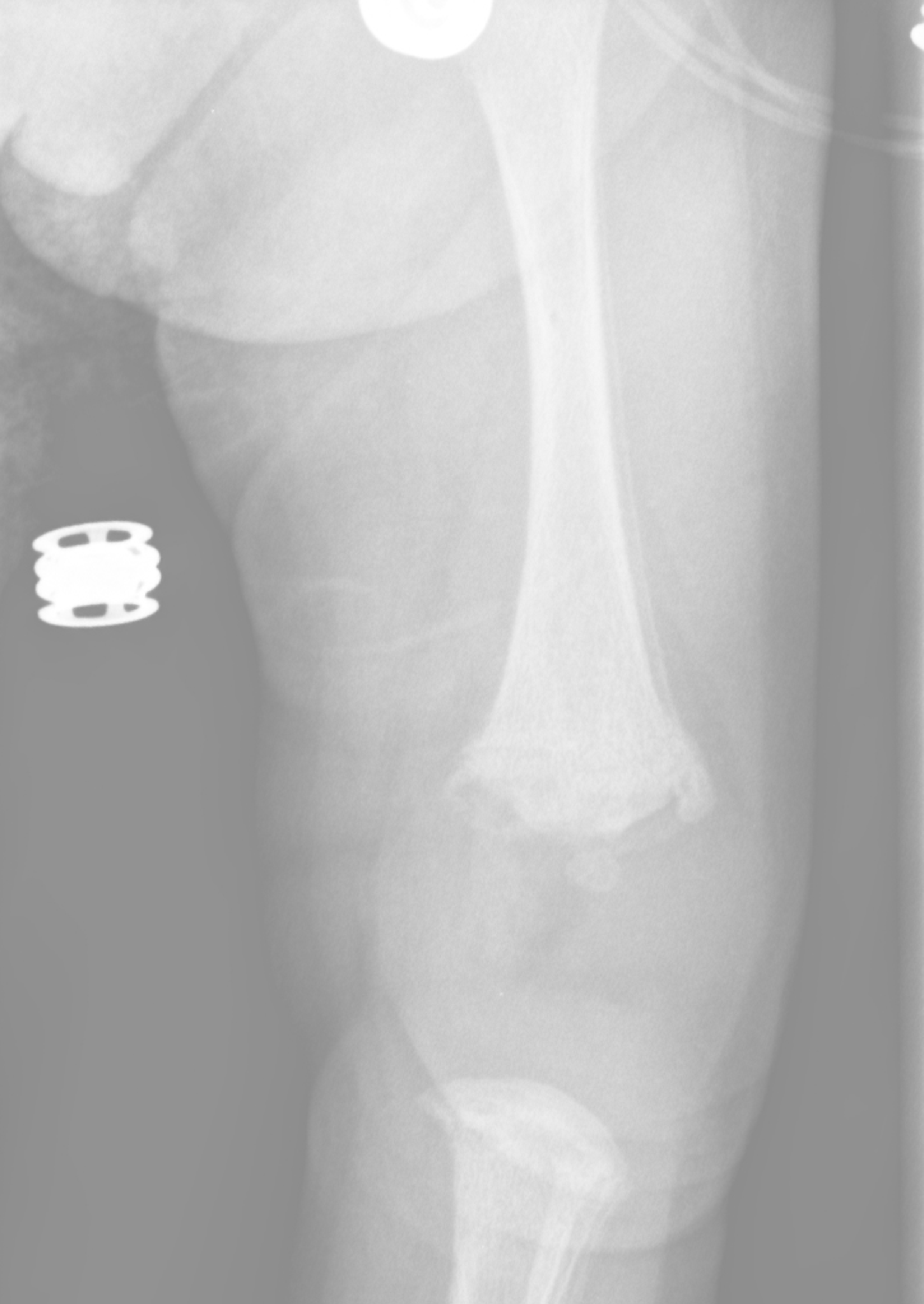

Nederlandstalige samenvatting

INTRODUCTIE

Kindermishandeling is wereldwijd een groot probleem met ernstige gevolgen. De definitie van kindermishandeling volgens de Wet op de Jeugdzorg is “elke vorm van voor een minderjarige bedreigende of gewelddadige interactie van fysieke, psychische of seksuele aard, die de ouders of andere personen ten opzichte van wie de minderjarige in een relatie van afhankelijkheid staat, actief of passief opdringen, waardoor ernstige schade wordt berokkend of dreigt te worden berokkend in de vorm van fysiek of psychisch letsel.” Lichamelijke kindermishandeling is de meest bekende vorm. Andere vormen zijn emotionele mishandeling, seksueel misbruik en verwaarlozing.

Kindermishandeling komt veel voor. In Nederland hebben betrokken professionals (o.a. leraren, dokters, wijkagenten) bij 2,7% van alle kinderen een vermoeden van kindermishandeling. In 10% van deze gevallen gaat het om fysieke kindermishandeling. Wanneer het aan jongeren zelf gevraagd wordt, vindt men veel hogere getallen. Bijna 14% van de jongeren rapporteert een vorm van lichamelijke kindermishandeling. In deze 14% zijn alleen de zwaardere gevallen van mishandeling meegeteld, de ‘pedagogische tik’ valt hier niet onder. De Nederlandse cijfers zijn vergelijkbaar met de internationale literatuur. Behalve korte termijn gevolgen (afwezigheid van school, doktersbezoek), zijn er ook veel lange termijn gevolgen van kindermishandeling beschreven. Er lijkt een relatie te bestaan tussen kindermishandeling en verminderde schoolprestaties, gedragsproblemen waaronder crimineel gedrag, diverse psychiatrische problemen en alcohol- en drugsafhankelijkheid. Er is een sterke relatie tussen kindermishandeling en overgewicht. De relatie tussen kindermishandeling en lichamelijke aandoeningen op volwassen leeftijd is niet heel duidelijk vastgesteld, maar er lijkt een verband te bestaan tussen mishandeling en de mate waarin gebruik wordt gemaakt van de gezondheidszorg.

De diagnose kindermishandeling kan moeilijk zijn om te stellen. Voor lichamelijke mishandeling is radiologie een belangrijk diagnostisch instrument, omdat hiermee botbreuken en inwendige letsels afgebeeld kunnen worden. Hierbij is het heel belangrijk deze letsels te kunnen relateren aan de verklaring die wordt gegeven door ouders/verzorgers en zo mogelijk de kinderen zelf. Wetenschappelijk onderzoek naar kindermishandeling is relatief nieuw. De eerste publicatie over radiologische aspecten van kindermishandeling was in 1946 van Caffey. Hij beschrijft zes jonge kinderen met botbreuken en bloedingen in het hoofd zonder verklaring voor deze letsels, maar noemt de mogelijkheid van mishandeling niet. De eerste publicatie waarin kindermishandeling expliciet genoemd wordt is die van Kempe, in 1962. De laatste decennia is de aandacht voor kindermishandeling in wetenschappelijk onderzoek enorm toegenomen, sinds 1994 zijn er meer dan 1000 publicaties per jaar over het onderwerp. Aangezien radiologie een beslissende stap kan zijn om de diagnose lichamelijke mishandeling te stellen, wilden we met dit proefschrift enkele openstaande vragen in de forensische kinderradiologie onderzoeken.

SAMENVATTING

In dit proefschrift hebben we onze studies gebundeld die betrekking hebben op de mogelijkheden en onmogelijkheden om de diagnose kindermishandeling te stellen met behulp van (forensische) kinderradiologie. Het proefschrift is verdeeld in twee delen. Het eerste deel beschrijft studies bij levende kinderen, het tweede deel beschrijft studies bij overleden kinderen.

In **hoofdstuk 1** geven we een overzicht van de verschillende beeldvormende technieken die gebruikt worden bij een vermoeden van kindermishandeling, en de specificiteit van bepaalde botbreuken. Een skeletstatus –een serie röntgenfoto's bestaande uit tenminste 20 opnames– is de beste manier om botbreuken vast te stellen. Breuken die vaak bij kindermishandeling voorkomen, vaker dan bij ongelukken, zijn ribbreuken en metafysaire hoekfracturen. In **hoofdstuk 2 en 3** beschrijven we de symptomen en radiologische aspecten van toegebracht schedelhersenletsel, ook bekend als het shaken baby syndroom. Een groot gedeelte van deze kinderen overlijdt of is blijvend gehandicapt. Afhankelijk van de ernst van de letsels kunnen kinderen zich met verschillende neurologische symptomen presenteren. Bij radiologisch onderzoek wordt vaak een subduraal hematoom, een bloeding onder het harde hersenvlies, gevonden. Alhoewel een subduraal hematoom meerdere oorzaken kan hebben, past de combinatie van dit type hersenbloeding met botbreuken of andere verwondingen het meest bij toegebracht letsel, zeker wanneer ouders zich geen of alleen een relatief klein ongeluk kunnen herinneren. Een CT scan van het hoofd is de beste manier om hersenletsel vast te stellen vlak na het voorval. Als deze afwijkend is, is een MRI nuttig om de letsels nauwkeuriger in beeld te brengen. Naast beeldvorming van het hoofd dient altijd een skeletstatus gemaakt te worden om botbreuken af te beelden. In **hoofdstuk 4** beschrijven we een groep kinderen met toegebracht schedelhersenletsel. We vonden dat er veel risicofactoren voor mishandeling in deze groep aanwezig waren, zoals vroeggeboorte, minderjarige ouders en ouders met een zeer laag opleidingsniveau. Ook bleek dat 38% van de gezinnen al bekend was bij hulpverleningsinstanties in verband met eerder gepleegde kindermishandeling. In 81% van de gezinnen waren er sterke aanwijzingen dat dit kind of broertjes/zusjes al eerder mishandeld waren. Bij 48% van de kinderen waren er aanwijzingen voor botsend geweld op het hoofd. Daarom hebben we in **hoofdstuk 5** onderzocht of er een onderscheid gemaakt kan worden tussen botsend geweld en een andere oorzaak voor de hersenletsels, bijvoorbeeld schudden, op basis van radiologische gegevens. Dit blijkt niet het geval. Behalve een breuk in de schedel, die per definitie ontstaan is door botsend geweld, zijn er geen radiologische verschillen tussen deze groepen gevonden. In **hoofdstuk 6** hebben we onderzocht of de leeftijd van een subdurale hematoom, een bloeding onder het harde hersenvlies, vastgesteld kan worden met behulp van CT en MRI scans. We hebben in een systematisch literatuuronderzoek alle beschikbare studies (25 artikelen) op een rij gezet en vonden dat dit niet met grote precisie mogelijk is. In **hoofdstuk 7** beschrijven we de resultaten van een enquête over het dateren van subdurale hematomen, afgenomen bij Nederlandse radiologen. Uit deze enquête blijkt dat er een grote praktijkvariatie is onder radiologen met betrekking tot het dateren van hematomen. Geen van de radiologen was erg zeker over de door hem of haar vastgestelde leeftijd van een hematoom. Hieruit concluderen wij dat het dateren van subdurale hematomen niet nauwkeurig genoeg is om te gebruiken in een rechtszaak, aangezien de literatuur niet eenduidig is en experts niet op één lijn zitten. **Hoofdstuk 8** is een case report waarin we een kind beschrijven met een metafysaire hoekfractuur van het rechter been. Deze breuk wordt gezien als zeer specifiek voor kindermishandeling. In dit geval constateerden we dat deze ontstaan moet zijn tijdens een vaginale stuitbevalling. Met deze casus willen we het belang van een brede blik onderstrepen; ook als er een hoge verdenking op kindermishandeling is kan er een ander probleem spelen.

Het tweede deel van het proefschrift beschrijft radiologische studies bij overleden kinderen. In **hoofdstuk 9** beschrijven we de meest gebruikte technieken bij postmortale radiologie, het vervaardigen van beelden na het overlijden. De skeletstatus, CT en MRI scans worden momenteel het meest gebruikt. In **hoofdstuk 10** beschrijven we normale postmortale veranderingen in het hoofd bij kinderen die na het overlijden een CT scan gehad hebben. Alhoewel lucht in de bloedvaten bij alle kinderen gezien kan worden, wordt dit vaker gezien bij kinderen die een infuus gehad hebben. In **hoofdstuk 11** beschrijven we de waarde van een postmortale CT scan, een CT scan verricht na het overlijden, met betrekking tot het vaststellen van een doodsoorzaak bij 98 kinderen. We vergeleken de doodsoorzaak vastgesteld door de radioloog op basis van de CT scan met de doodsoorzaak vastgesteld door de forensisch patholoog op basis van de obductie. Dezelfde doodsoorzaak werd vastgesteld in 67% van de kinderen. Er werden met een postmortale CT scan geen doodsoorzaken gevonden die met een obductie niet gevonden werden. De overeenstemming tussen postmortale CT en obductie was hoger bij kinderen die aan een niet-natuurlijk overlijden waren overleden dan bij kinderen die aan een ziekte waren overleden. We concluderen dat een postmortale CT scan op dit moment niet geschikt is om een obductie bij kinderen te vervangen. In **hoofdstuk 12** beschrijven we de waarde van een postmortale CT scan bij 12 zuigelingen die lange tijd na het overlijden gevonden zijn. We vonden dat de zwangerschapsduur van de gevonden zuigeling nauwkeuriger bepaald kan worden met een meting van het bot in het bovenbeen met een CT scan, dan met een voetlengtemeting tijdens obductie. Met geen van beide methoden kon vastgesteld worden of de baby na de geboorte geleefd had, of wat de doodsoorzaak was. Hieruit concluderen wij dat een postmortale CT bij zuigelingen, die lange tijd na het overlijden gevonden zijn, van toegevoegde waarde is en altijd verricht moet worden. **Hoofdstuk 13** is een case report, waarin we de radiologische bevindingen beschrijven bij een kind dat overleden is doordat het verhangen is aan een touw. Met een postmortale CT scan werd lucht vastgesteld in de borstkas en onder de huid. Dit betekent dat het kind nog geleefd heeft toen het opgehangen werd. Lucht op deze plaatsen werd niet tijdens de obductie gevonden. Hiermee tonen we aan dat, alhoewel een CT scan niet gebruikt kan worden om de doodsoorzaak met zekerheid vast te stellen, een CT scan wel waardevolle informatie kan geven die bijdraagt aan inzicht in de omstandigheden waaronder een kind overleden is.

TOEKOMSTIGE ONTWIKKELINGEN

Het doel van dit proefschrift is om een bijdrage te leveren aan de ontwikkeling van de forensische kinderradiologie. De afgelopen periode zijn er meer ontwikkelingen geweest die hebben gezorgd voor een professionalisering van het vakgebied. Zo is er een internationale organisatie opgericht die zich bezig houdt met onderzoek en het ontwikkelen van richtlijnen binnen de forensische radiologie, the International Society of Forensic Radiology and Imaging. Deze organisatie is ook een wetenschappelijk tijdschrift begonnen, the Journal of Forensic Radiology and Imaging. In Nederland is het Co van Ledden Hulsebosch Centrum opgericht, dat bezig houdt met forensisch wetenschappelijk onderzoek. De Nederlandse Vereniging voor Radiologie is gestart met een sectie postmortale radiologie. Ook zijn er drie academische ziekenhuizen bezig met het opzetten van een landelijk expertisecentrum kindermishandeling, het LECK.

Toekomstig onderzoek binnen de forensische kinderradiologie bij levende kinderen zou zich kunnen richten op het dateren van letsels. Informatie over het ontstaan van een letsel kan gebruikt worden om te bepalen wie er op dat moment contact had met het kind en de dader zou kunnen zijn. Wij vonden dat het dateren van subdurale hematomen, een veel voorkomende bevinding bij toegebracht schedelhersenletsel, momenteel niet goed mogelijk is. Ook botbreuken kunnen niet nauwkeurig gedateerd worden. Een ander onderzoeksonderwerp is het valideren van technieken waarmee hele kleine breuken vastgesteld kunnen worden. Een grote uitdaging binnen niet-radiologisch onderzoek naar kindermishandeling is het voorkomen van (herhaalde) kindermishandeling. Aangezien wij, net als vele anderen, gevonden hebben dat kindermishandeling vaak meerdere keren binnen één gezin plaats vindt, is het belangrijk te weten hoe kindermishandeling vroegtijdig herkend en gestopt kan worden. Een veelbelovend onderzoek in deze richting is het onderzoek van Berger naar een bloedwaarde die gebruikt kan worden om te screenen op hersenletsel. Op deze manier zouden kinderen die gezien worden door een arts met vage klachten zoals huilen, onderzocht kunnen worden op hersenletsel zonder dat zij daarvoor een CT scan krijgen. Onderzoek naar effectieve methoden om kindermishandeling te voorkomen richt zich met name op ouderschapsprogramma's. Er zijn onderzoeken die laten zien dat bijvoorbeeld huisbezoeken bij risicogezinnen de kans op kindermishandeling verkleinen, maar de resultaten zijn niet eenduidig. Onderzoek binnen de postmortale radiologie zou zich kunnen richten op kosteneffectiviteitstudies. Het is momenteel niet mogelijk om met alleen een CT scan op betrouwbare wijze een doodsoorzaak vast te stellen, maar in sommige studies is de combinatie van verschillende methoden veelbelovend. Het is niet bekend wat de kosten zijn van dergelijke invasieve postmortale onderzoeken, en de kosten dienen wel meegenomen te worden bij de beoordeling van nieuwe technieken. Ook kennis over normale postmortale veranderingen is nodig, enerzijds om pathologische afwijkingen te herkennen, anderzijds om een tijdslijn te ontwikkelen waarmee het postmortale interval vastgesteld kan worden. Postmortale radiologie is een vakgebied in ontwikkeling. Onafhankelijk van hoe het zich zal ontwikkelen, zal forensische kinderradiologie een belangrijke rol spelen bij het stellen van de diagnose kindermishandeling, bij zowel levende als overleden kinderen.


L

Dankwoord

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Portfolio

PhD student: Tessa Sieswerda-Hoogendoorn
PhD period: February 2009 – March 2013
PhD supervisor: R.R. van Rijn, MD, PhD

PhD Training	Year	Workload (ECTS)
General courses		
AMC World of Science	2009	0.7
Biostatistics	2010	2
Cochrane systematic review	2010	0.3
Oral presentation in English	2012	0.3
Scientific writing in English	2012	0.8
Specific courses		
Wokk; child abuse for pediatricians	2009	0.8
Virtopsy Course; post-mortem imaging	2010	1
Master Evidence Based Practice, University of Amsterdam	2010-2012	97
Seminars, workshops and masterclasses		
Seminar impact of violence Diane Benoit	2010	0.2
Expert meeting 'education about sexual abuse' organised by Kinderpostzegels	2010	0.2
Expert meeting 'neglect' organised by Ministry of Health, Welfare and Sport	2011	0.2
Expert meeting 'child abuse in medical education' organised by Ministry of Health, Welfare and Sport and KNMG	2012	0.2
Oral presentations		
Communication about child abuse at the emergency department - Congres Kindermishandeling aanpakken, Amsterdam	 2010	 0.5
Child abuse detection at the emergency department based on parental characteristics - European Conference on Child Abuse and Neglect, Amsterdam	 2012	 0.5
Abusive head trauma in the Netherlands, evidence for multiple incidents of abuse - International Conference on Shaken Baby Syndrome, Boston - International Society for the Prevention of Child Abuse and Neglect, Istanbul - International Conference on Child and Family Maltreatment, San Diego	 2012 2012 2013	 0.5 0.5 0.5
Poster presentations		
Abusive head trauma in the Netherlands, evidence for multiple incidents of abuse - Amsterdam Kindersymposium, Amsterdam	 2013	 0.5
Interdisciplinary hospital-based child abuse and neglect team - EUCCAN, Amsterdam - Amsterdam Kindersymposium, Amsterdam - ESSOP, Maastricht	 2012 2012 2011	 0.5 0.5 0.5
Child abuse detection at the emergency department based on parental characteristics - ISPCAN, Honolulu	 2010	 0.5

PhD Training	Year	Workload (ECTS)
Poster co-authored, not presented		
Child abuse detection at the emergency department based on parental characteristics		
- IPA, Johannesburg	2010	0.2
Prevalence of child sexual abuse in children with chronic abdominal pain: a systematic review		
- EUCCAN, Amsterdam	2012	0.2
- Amsterdam Kindersymposium, Amsterdam	2012	0.2
- 5th European Pediatric Motility Meeting, Amsterdam	2011	0.2
aftERcare: Amsterdam follow-up of troubling ER visitors' children; assessment and referral to external help		
- ISPCAN, Istanbul	2012	0.2
- Amsterdam Kindersymposium	2012	0.2
Dating of subdural haemorrhages on CT and MRI findings		
- Helfer society, San Francisco	2013	0.2
- ESPR, Budapest	2013	0.2
Conferences		
Kindermishandeling aanpakken, Amsterdam, the Netherlands	2009	0.25
Kindermishandeling aanpakken, Amsterdam, the Netherlands	2010	0.25
ISPCAN, Honolulu, USA	2010	0.75
ISPCAN, Tampere, Finland	2011	0.75
ISFRI, Basel, Switzerland	2012	0.5
EUCCAN, Amsterdam, the Netherlands	2012	0.5
ISPCAN, Istanbul, Turkey	2012	0.75
ICSBS, Boston, USA	2012	0.5

Parameters of esteem	Year
Grants	
Nationaal congres Kindermishandeling	
- Ministerie van Jeugd en Gezin	2010
- Stichting Kinderpostzegels	2010
Multicenter study 'aftERcare'	
- Stichting Kinderpostzegels	2010
- Gemeente Amsterdam	2010
EUCCAN (European Conference on Child Abuse and Neglect)	
- Stichting Kinderpostzegels	2012
- Verwelius	2012
Evaluatie multidisciplinaire initiatieven kindermishandeling	
- ZonMW	2012
Awards and prizes	
Multicenter study 'aftERcare'	
- Nationale Jeugdzorg Prijs	2010

Teaching	Year	Workload (ECTS)
Guest lecturing		
General practitioners AMC-UVA, child abuse reporting code	2009	0.1
Medical students AMC-UVA, child abuse	2009-2011	0.6
Social workers AMC, child abuse	2009	0.1
Department pediatric radiology AMC, postmortem radiology	2009, 2011	0.3
Netherlands Forensic Institute, radiology in child abuse	2010-2013	0.3
Physicians assistants pediatric OPD AMC, child abuse	2011	0.1
Child psychiatrists Bascule, physical examination to detect child abuse	2012	0.1
Haamstede course for GPs, child abuse	2011	0.1
Symposium Rijnland hospital, child abuse	2012	0.1
GPs in training AMC-UVA, recognizing child abuse	2011, 2012	0.4
Junior interns AMC-UVA, child abuse	2012-2013	0.6
Interns AMC-UVA, physical examination to detect child abuse	2012-2013	0.5
Pediatricians in training AMC-UVA, child abuse	2011-2012	0.7
Advances in Forensic Medicine UVA, dating hematomas	2013	0.1
Focus group child abuse Dutch Pediatric Association (NVK), forensic radiology	2012	0.1
Supervising		
E. Nadort. Signalling and tackling child abuse.	2009	1
E. Sneekes and F. Moesker. Abusive head trauma in the Netherlands.	2010	1
S. de Milliano and D. Bakkenist. New hospital-based policy for children whose parents present at the ER due to domestic violence, substance abuse and/or a suicide attempt.	2011	1
D. Aaftink. A multidisciplinary child abuse team in a hospital setting; overview of diagnoses and interventions.	2011	1
A. Strik and N. Hilgersom. Pneumomediastinum and soft tissue emphysema in pediatric hanging.	2011	1
J. Baart, A. Roos en P. Hudepohl. A retrospective study of all children presenting with fractures at the accident and emergency department of the AMC.	2011	1
G. Eggenhuizen and R. Detering. Differential diagnosis of subdural hematoma.	2012	1
F. Postema. Age determination of subdural hematomas.	2012	1
Other		
Organisation of 2 Dutch conferences on child maltreatment	2009, 2010	4
Organisation of an international 3-day conference on child maltreatment (EUCCAN)	2012	4
Reviewer European Journal of Radiology	2012	1

List of publications

Published

Sieswerda-Hoogendoorn T, Postema FAM, Verbaan D, Majoie CBLM, van Rijn RR. Age determination of subdural hematomas with CT and MRI: a systematic review. Eur J Rad. 2014. Accepted for publication.*

Sieswerda-Hoogendoorn T, Soerdjbalie-Maikoe V, Bakker H, van Rijn RR. Postmortem CT compared to autopsy in children; concordance in a forensic setting. Int J Legal Med. 2014. Accepted for publication.*

Postema FAM, Sieswerda-Hoogendoorn T, Majoie CBLM, van Rijn RR. Age determination of subdural hematomas: survey among radiologists. Emerg Radiol. 2014. Accepted for publication.*

Sieswerda-Hoogendoorn T, Robben S, Karst WA, Moesker F, van Aalderen WM, Laméris JS, van Rijn RR. Abusive head trauma; differentiation between impact and non-impact cases based on neuroimaging findings and skeletal surveys. Eur J Radiol. 2014;83(3):584-8*

Sieswerda-Hoogendoorn T, Strik A, Hilgersom N, Soerdjbalie-Maikoe V, van Rijn RR. Pneumomediastinum and soft tissue emphysema in paediatric hanging; a case report. J Forensic Sci. 2014;59(2):559-63*

Sieswerda-Hoogendoorn T, Soerdjbalie-Maikoe V, Maes A, van Rijn RR. The value of post-mortem CT in neonaticide in case of severe decomposition; description of 12 cases. Forensic Sci Int. 2013;233(1-3):298-303*

Hoytema van Konijnenburg EMM, Teeuw AH, Sieswerda-Hoogendoorn T, Leenders AGE, van der Lee JH. Insufficient evidence for the use of a physical examination to detect maltreatment in children without a prior suspicion: a systematic review. Syst Rev. 2013;2(1):109

Sieswerda-Hoogendoorn T, van Rijn RR, Robben SGF. Classic metaphyseal lesion following breech birth, a rare birth trauma. Journal of Forensic Radiology and Imaging. 2014;2(1):2-4*

Sieswerda-Hoogendoorn T, Bilo RAC, van Duurling LBCM, Karst WA, Maaskant JM, van Aalderen WMC, van Rijn RR. Abusive head trauma in the Netherlands, evidence for multiple incidents of abuse. Acta Paediatr. 2013;102(11):e497-501*

Sonneveld LP, Brilleslijper-Kater SN, Benninga MA, Hoytema van Konijnenburg EMM, Sieswerda-Hoogendoorn T, Teeuw AH. Prevalence of child sexual abuse in pediatric patients with chronic abdominal pain: a systematic review. J Pediatr Gastroenterol Nutr. 2013;56(5):475-80

Hoytema van Konijnenburg EM, Sieswerda-Hoogendoorn T, Brilleslijper-Kater SN, van der Lee JH, Teeuw AH. New hospital-based policy for children whose parents present at the ER due to domestic violence, substance abuse and/or a suicide attempt. Eur J Pediatr. 2013;172(2):207-14

Soerdjbalie-Maikoe V, de Wijs-Heijlaerts KJ, Meijerman L, Verheugt AJ, Sieswerda-Hoogendoorn T, Maes A. Neonaticide in Nederland: vaak vermoed, zelden bewezen. Ned Tijdschr Geneeskd. 2013;157(49):A6546

Sieswerda-Hoogendoorn T, Bakx R, Teeuw AH. Een meisje van één jaar met perineumletsel. Tijdschr voor Kindergeneesk. 2013;4

Sieswerda-Hoogendoorn T, Brilleslijper-Kater SN. Hoofdstuk ‘kinderen als getuige van huiselijk geweld’ voor het boek ‘Medisch handboek kindermishandeling’, Bohn, Stafleu van Loghum, 2013

Sieswerda-Hoogendoorn T. Several neuroradiological features can help distinguish abusive and non-abusive head trauma. J Pediatr. 2012;160(5):880-1

Sieswerda-Hoogendoorn T, Boos S, Spivack B, Bilo RA, van Rijn RR. Abusive head trauma Part II: radiological aspects. Eur J Pediatr. 2012;171(4):617-23*

Sieswerda-Hoogendoorn T, Boos S, Spivack B, Bilo RA, van Rijn RR. Educational paper: Abusive Head Trauma part I. Clinical aspects. Eur J Pediatr. 2012;171(3):415-23*

van Rijn RR, Sieswerda-Hoogendoorn T. Educational paper: imaging child abuse: the bare bones. Eur J Pediatr. 2012;171(2):215-24*

Sieswerda-Hoogendoorn T, Wilde JC. Een jongen met een zwelling in de buik. Ned Tijdschr Geneeskd. 2012;156(23):A2814

Sieswerda-Hoogendoorn T, van Rijn RR. Current techniques in postmortem imaging with specific attention to paediatric applications. Pediatr Radiol. 2010;40(2):141-52*

Submitted

Sieswerda-Hoogendoorn T, Beenen LFM, van Rijn RR. Normal cranial postmortem CT findings in children.*

Teeuw AH, Sieswerda-Hoogendoorn T, Aaftink D, Brilleslijper-Kater SN, van Rijn RR. A multidisciplinary child abuse team in a hospital setting; overview of diagnoses and interventions.

Publications marked with an asterisk (*) are part of this thesis

Biography

Tessa Sieswerda-Hoogendoorn was born in The Hague in 1983. After graduating from secondary school, the Stedelijk Gymnasium Arnhem, she started to study medicine at the University of Amsterdam (UvA) in 2000. She carried out research projects in Nepal and Suriname and did an internship in Tanzania. She graduated from medical school in 2008 and worked with great enthusiasm as a senior house officer in pediatrics in the Zaans Medisch Centrum, Zaandam. In 2009 she started work as coordinator of the child maltreatment team in the Emma Children's Hospital AMC, under the supervision of A.H. Teeuw, MD. In this position she was responsible for patient care, education and several research projects dealing with child maltreatment. She was the initiator of a multicenter study relating to parents visiting the emergency department due to domestic violence, intoxication or attempted suicide. In this period she also obtained her Masters degree in Evidence-Based Practice at the UvA. She combined the position as coordinator of the child maltreatment team with a PhD research project at the Netherlands Forensic Institute, under the supervision of R.R. van Rijn, MD, PhD, resulting in this thesis. Since 2014 Tessa Sieswerda-Hoogendoorn has been a resident in pediatrics at the Emma Children's Hospital AMC. She is married and has 2 daughters.