

Educational paper

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. *Conclusion:* 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.

Keywords Abusive head trauma · Radiology · Child abuse · Head injury · Closed · Haematoma · Subdural

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 that can make the initial diagnosis more likely, e.g., when rib fractures are present, or it can make initial diagnosis less plausible, e.g., when underlying bone disease is detected. Furthermore, it can help in assessing a prognosis for the child, depending on the brain damage seen.

The aim of this educational paper is to give the paediatrician, 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 pathologies. We will describe the value of conventional radiology (CR), cranial ultrasonography (CUS), computed tomography (CT) and magnetic resonance imaging (MRI) in imaging abnormalities in

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AHT. Furthermore, the importance of interpreting, reporting and communicating radiological findings will be addressed in both a clinical and forensic perspectives.

Modalities

Conventional radiology

The role of conventional radiology (CR) in detecting child abuse and neglect (CAN) has recently been discussed in this journal [33]. A full skeletal survey should be performed in all children under the age of 2 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 [8] (Fig. 1). As linear fractures can occur after a short distance fall (e.g., fall from arm of caretaker or fall from stairs, 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 >3 mm of the fracture lines or occipital fractures are more commonly seen in child abuse [22, 24, 25]. 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 [8]. 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 [8]. As skull

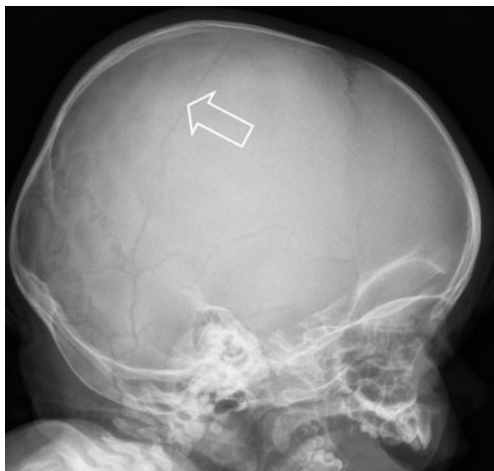


Fig. 1 A four-month-old boy with a linear skull fracture (arrow) after a 80 cm high fall on a hard surface

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 [8].

Secondly, the skull radiograph can be supportive in demonstrating or excluding underlying disease, e.g., wormian bones in osteogenesis imperfecta and Menke's disease [3, 19]. 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, b, c). For this purpose, it is of major importance that the skeletal survey is performed according to international guidelines [4, 31].

No specific type of skull fracture is pathognomonic for child abuse.

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 visualise the parts of the brain located just under the convexity of the skull. These places can harbour a subdural haematoma as a result of abuse but may be overlooked with CUS. With respect to sub-arachnoid haemorrhage, the sensitivity of CUS is inadequate for clinical use.

CUS is applied in children with an increased head circumference, where a diagnosis of benign enlargement of the sub-arachnoid space (BESS) is suspected. BESS is diagnosed in children with a rapidly growing head, enlarged sub-arachnoid spaces and normal or only slightly enlarged ventricles. BESS is a self-limiting condition that needs no intervention in most children. The aetiology 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 [35].

With the use of a high frequency linear transducer, the sub-arachnoid 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 4–5 mm is used as a cutoff level from normal. BESS is a known risk factor for SDH's after minimal or no head injury [35]. On colour Doppler CUS, a sign to look for are the crossing vessels, anchor veins in the sub-arachnoid space. This makes differentiation between BESS and a subdural haematoma possible [11, 23]. In children referred for an increase of head circumference, occasionally subdural haematomas can be diagnosed. In these cases, the crossing vessels will not be visible in the subdural

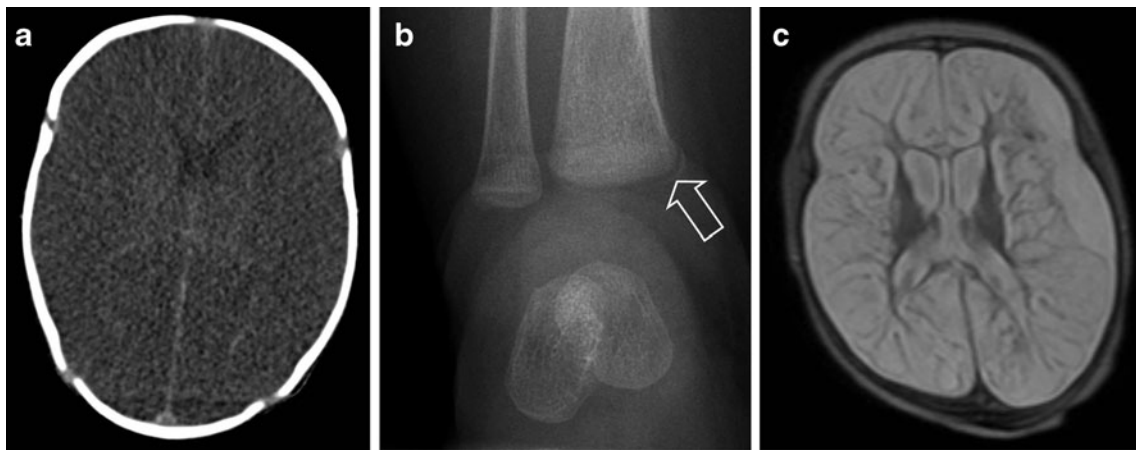


Fig. 2 **a** A two-month-old girl admitted because of abusive head trauma. The CT obtained at admission shows an overall decrease in density of brain tissue and a lack of grey–white matter differentiation. This is a sign of severe hypoxia of the brain and has a poor prognosis. **b** The skeletal

survey shows a metaphyseal corner fracture of the distal tibia. This, in combination with the intracranial trauma, is highly indicative of abusive head trauma. **c** Five weeks after the initial CT scan, the girl has developed extensive diffuse multicystic encephalomalacia

collection, in many cases the border between the subdural and sub-arachnoid space will be visible (Fig. 3).

Once diagnosed, a SDH can be evaluated over time with CUS.

The use of cranial ultrasonography (CUS) is not primarily indicated in establishing the diagnosis of AHT.

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.

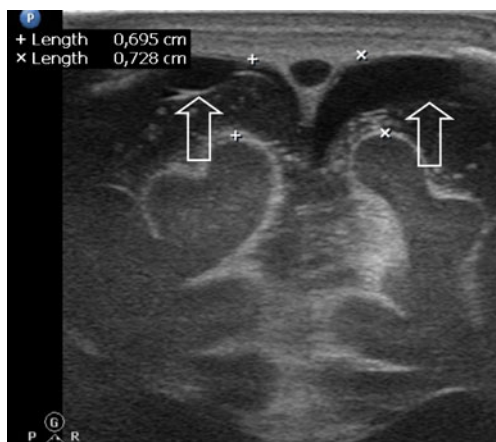


Fig. 3 Cranial ultrasound of a four-month-old boy with a subdural collection due to BESS

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 in the website of the ‘Image Gently campaign’ [30]). 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 nonmedical personnel (Fig. 4a). Non-contrast-enhanced CT has a high sensitivity for detecting acute haemorrhage and midline shift (Fig. 5). It is less sensitive for the detection of non-haemorrhagic injuries, especially in the acute phase. In the setting of cranial trauma or AHT, there is no need for contrast-enhanced studies.

Subdural haemorrhage is seen on CT in 77–89% of the cases with AHT [15, 29]. However, in autopsy studies, SDH’s have been described in approximately 83–90% of all cases [10, 14]. Subdural haemorrhage as well as sub-arachnoidal and epidural haemorrhage are seen in both AHT and after accidental trauma and are therefore not discriminating factors. Epidural haemorrhage 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 haemorrhages. 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 the 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’ [31]. 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

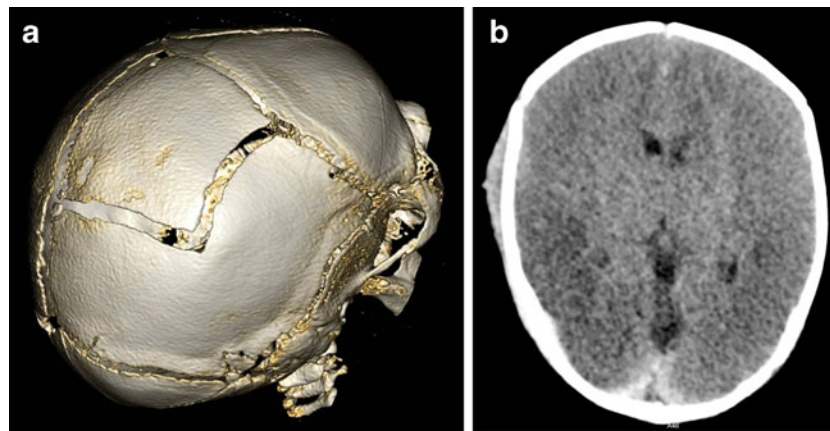


Fig. 4 **a** A three-dimensional shaded surface display (3D-SSD) of a skull fracture in a six-week-old boy with no history of trauma. The 3D-SSD images can be used to display the lesions to lay persons, e.g., parents or in court. These images should always be interpreted in combination with the original axial source data in order not to miss small lesions,

which can be obscured in the rendering process, giving false negative results. **b** CT shows a relative high density of the basal ganglia known as the reversal sign. This finding is a sign of diffuse, anoxic/ischaemic cerebral injury and carries a poor prognosis

from AHT, e.g., children with rib fractures, multiple fractures, facial injury or children younger than 6 months of age [26].

The long-term effects of ionizing radiation cannot be used as a counterargument for performing a cranial CT because missing the diagnosis of AHT can have severe, even lethal, consequences.

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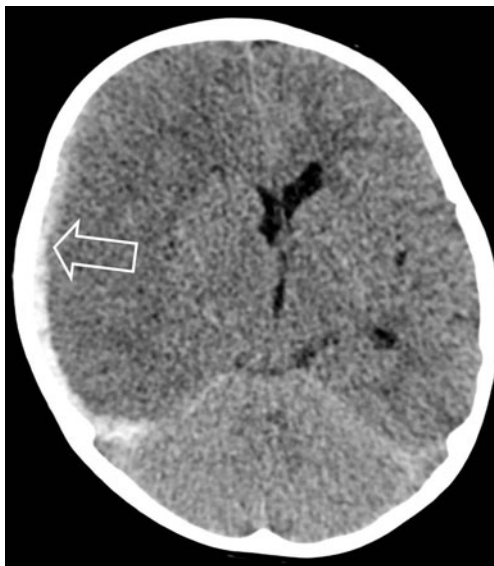


Fig. 5 A three-year-old boy with a right-sided subdural haematoma (*arrow*) and a shift of the midline as a result of this subdural haematoma. Note the decrease in density of the white matter on the right side and the asymmetry of the ventricles

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 haemorrhage compared to CT. Secondly, the long scan time makes it more difficult to perform successfully in children, unless general anaesthesia is used. This requires MR-compatible anaesthesia equipment, transferring a sometimes instable patient for a longer time from a paediatric ward to the radiology department and the presence of a doctor responsible for the anaesthesia. The last mentioned demands strict arrangements between paediatricians 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) [31].

SWI is a technique originally developed for the analysis of small vessels and the detection of small brain tumours. 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, haemorrhage and iron deposits [2, 27]. The high sensitivity for small haemorrhages 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 haemorrhagic brain lesions, such as can be seen in diffuse axonal injury [32]. The extent and number of the micro-haemorrhages detected with SWI has been shown to correlate with a poor long-term outcome in children with AHT [5, 6, 12].

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 the case of cytotoxic oedema resulting from an ischaemic 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 [7, 17, 28] (Fig. 4b, c). In cases of suspected AHT, DWI, as SWI, should always be performed [21].

Approach

Imaging strategy

Kemp et al. performed a systematic review to determine the optimal imaging strategy to identify AHT [21]. 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 SDH's, sub-arachnoid haemorrhages, cranial shearing, ischaemia, infarction, parenchymal haemorrhages 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 six 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 haemorrhages

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 basis for unconditional statements on dating intracranial pathology based on radiological findings only is not validated. Current knowledge on dating SDH's is primarily based on two studies [34]. These studies, however, were performed in adults suffering from conditions different from AHT and exact timing of the incident was not always known [16, 18]. In a clinical setting, the generally accepted theory that acute haemorrhage SDH is hyperdense and that older haemorrhage 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 analysed, 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 [1]. Vinchon et al. tried to develop a time scale model for SDH's 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 [34].

In a clinical setting, dating SDH on CT and/or MRI is common practice. In the setting of AHT, where a legal procedure is likely to occur, this practice has not been validated sufficiently.

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 arising 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.

Interpretation of imaging in case of suspected AHT cannot be done without access to complete clinical information.

A multidisciplinary child abuse and neglect team (CAT) should collect these data and advice the clinician. It is of

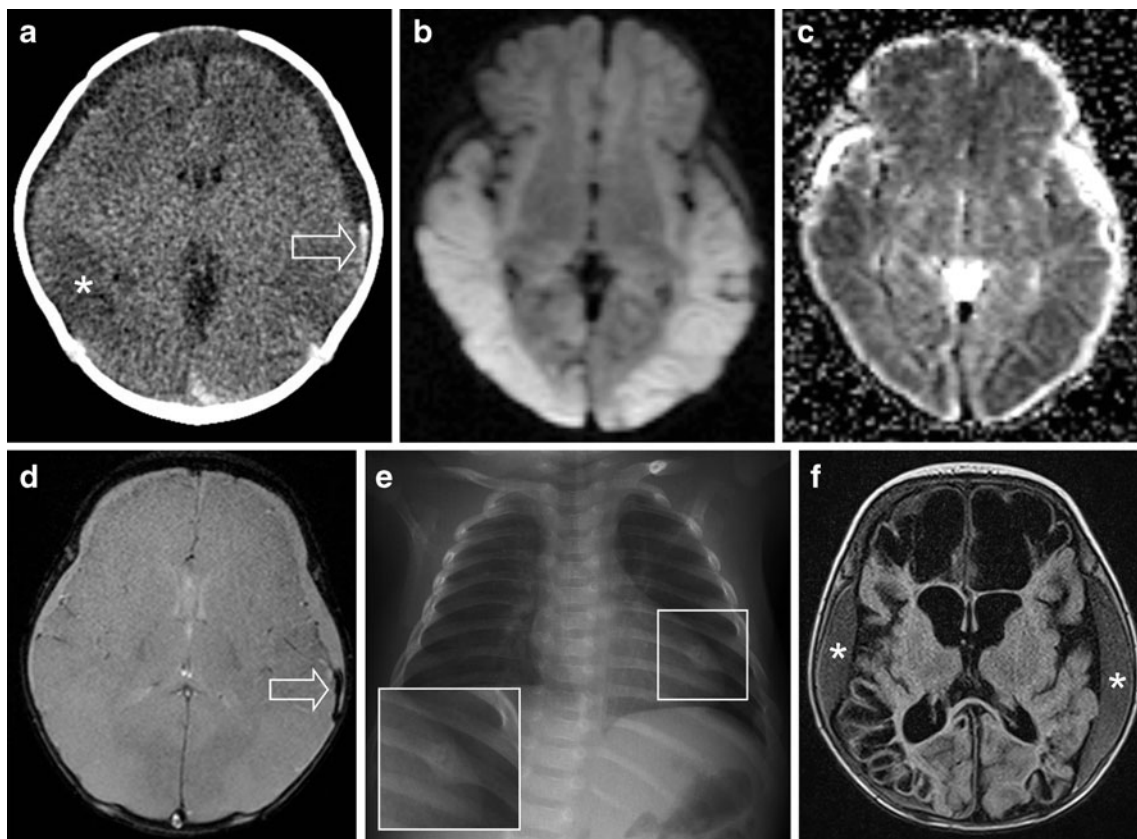


Fig. 6 **a** A two-year-old girl with a subdural haematoma along the left convexity (*arrow*) and diffuse ischaemia (*asterisk*) as a result of abusive head trauma. **b** Diffusion-weighted MRI, obtained on the same day as the MRI, shows extensive temporoparietal cytotoxic oedema as a result of disturbed perfusion (restricted diffusion). **c** Diffusion-weighted MRI (apparent diffusion coefficient) shows a corresponding decrease in signal intensity. **d** Blood clot in the subdural haematoma shown on the FLuid Attenuation Inversion Recovery (FLAIR) image. This sequence

uses a long TI 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. **e** Chest radiographs obtained 3 weeks after the incident shows a consolidating posterior ribfracture (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. **f** MRI obtained after 2 months of the incident shows extensive diffuse multicystic encephalomalacia and bilateral subdural hygromas (*asterisk*)

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 [13, 20]. 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 [9]. 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 paediatric radiology and child abuse. In case of doubt, an expert in child abuse should be consulted.

A multidisciplinary child abuse and neglect team (CAT) should collect all patient data and advise the clinician. It is of great value if a (paediatric) radiologist is part of the CAT.

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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