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. 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). 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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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. 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. 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. 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.

**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’). 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 3. Cranial ultrasound of a four-month-old boy with a subdural collection due to BESS.](image)
Subdural hemorrhage is seen on CT in 77-89% of the cases with AHT. However, in autopsy studies SDHs have been described in approximately 83-90% of all cases. 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
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**APPROACH**

**Imaging strategy**

Kemp et al. performed a systematic review to determine the optimal imaging strategy to identify AHT. 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. These studies, however, were performed in adults suffered from conditions different from AHT and exact timing of the incident was not always known. 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. 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.
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.\textsuperscript{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.\textsuperscript{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.
REFERENCES