Non-accidental trauma in children

Åsa Wiksell, MD and Håkan Caisander, MD

Department of Pediatric Radiology

Drottning Silvias Barn- och Ungdomssjukhus

Göteborg, Sweden

Introduction

The first known medical description of child abuse was published in 1860 by the French physician and forensic scientist Ambrose Tardieu. In modern times, the pediatrician and radiologist John Caffey in his famous 1946 paper showed a correlation between subdural hematomas and multiple fractures in young children and later coined the term “shaken baby syndrome” in 1974 (1). This term has in 2009 been replaced by abusive head trauma (AHT) to avoid implying a single mechanism of injury (2), although violent shaking is still one of the major causes (3, 4). In 1962 Kempe and Silverman (5) further described the clinical and radiological findings in physical child abuse and showed that it is much more common than earlier expected and that it occurs in all socioeconomic groups. They also expounded the usage of radiographs and drew the attention of journalists, politicians, and the public to broader issues of child maltreatment.

Despite laws against child abuse passing in more and more countries (Sweden was the first to do so in 1979), abuse still poses a challenge for society and the health care systems and is a major cause of morbidity and mortality.

Estimations of fatalities related to child abuse show approximately 1500 deaths in the USA (6) and 850 deaths in Europe (7) annually. Infants and small children are most prone to serious child abuse, especially infants around the age of 2-3 months, which coincides with the peak of normal crying in healthy infants (8). Seventy-five percent of deaths occur in children < 3 years of age and 50% in children < 1 year (9). The major cause of death is head injuries, but most of the deceased children have fractures, often at varying stages of healing (10).

Child abuse can occur in any family, but children are at greater risk if there is drug or alcohol abuse, mental illness, domestic violence or other socioeconomic and family stress in the family. Risk factors also include prematurity, developmental delay and disabilities of the child (8, 11).

The investigation of suspected child abuse is a delicate multidisciplinary task where radiology often plays a major role. High quality investigation is critical from a medical as well as a medico-legal perspective. A correct diagnosis of abuse can be crucial for the safety of the child since evidence from confessions shows that perpetrators tend to be repeat abusers (3). An incorrect diagnosis of abuse is also disastrous for the child and its caregivers. A study of missed AHT-cases (12) shows that about 1/3 had seen a medical professional after the AHT-event without being recognized as suspected AHT. A few missed cases were due to misinterpreted images.

As radiologists we need to be aware of possible symptoms, presentations and imaging findings in child abuse and to cooperate with clinicians in a thorough medical investigation.
Symptoms and signs

Victims of child abuse can present with many different symptoms and findings. Clinicians may find obvious signs such as bruises, burns, mouth injuries and soft tissue swellings. In AHT the symptoms may be subtle, such as “failure to thrive”, vomiting, increased head circumference and breathing disturbances or more dramatic, such as seizures, unconsciousness or even cardiorespiratory arrest. However there may not be any external signs of child abuse. In these cases imaging may be the only finding raising the suspicion of child abuse.

Imaging findings

Every injury must be evaluated considering the child’s age, developmental capabilities, the given history and medical status.

Skeletal injuries

All types of fractures may occur in child abuse. There is no kind of fracture that excludes inflicted injury. There are some fractures that are more specific for abuse (table 1) (13). It is of great importance to rule out mimics of child abuse such as osteogenesis imperfecta, rickets, Caffey’s disease and obstetric trauma to avoid an incorrect diagnosis with dire social and potential legal consequences for the family.

In infants the most common findings in inflicted trauma are fractures of the ribs, skull and metaphyses. In older children shaft fractures are the most common in both abusive and accidental trauma.

Table 1

<table>
<thead>
<tr>
<th>High specificity</th>
<th>Moderate specificity</th>
<th>Common but low specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMLs*</td>
<td>Multiple fx espec. bilateral</td>
<td>SPNBF**</td>
</tr>
<tr>
<td>Rib fx, espec. posteromedial</td>
<td>Fx of different ages</td>
<td>Clavicular fractures</td>
</tr>
<tr>
<td>Scapular fractures</td>
<td>Epiphyseal separations</td>
<td>Long bone shaft fractures</td>
</tr>
<tr>
<td>Spinal process fractures</td>
<td>Vertebral body fx &amp; sublux</td>
<td>Linear skull fractures</td>
</tr>
<tr>
<td>Sternal fractures</td>
<td>Digital fractures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complex skull fractures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pelvic fractures</td>
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</table>

* CML= classic metaphyseal lesion  **SPNBF= subperiosteal new bone formation

Classic metaphyseal lesions (CMLs) are fractures through the immature primary spongiosa at the end of the metaphysis, which is an area that is weaker than the overlying epiphyseal plate as well as the deeper structures of the metaphysis (fig. 1). This fracture is disc-like and centrally very thin, but cuts deeper in the periphery. If viewed tangentially it is seen as a thin radiodense band separated from the metaphysis by a radiolucent fracture line. If viewed on a cranially or caudally angled radiographs the fracture appears as a corner fracture (fig. 2) or as a bucket handle fracture (fig. 3). CMLs are most commonly found around the knee (distal femur and proximal tibia) and the ankle in infants. The mechanism can be acceleration and
deceleration forces, torsion or traction. There is often no soft tissue swelling or bruising associated with the injury.

Rib fractures in healthy infants and young children are unusual and should be regarded with suspicion. In abused children they are common and usually occult, either identified on a chest radiograph or on a skeletal survey. They are often multiple and seldom associated with intrathoracic injuries.

Especially posteromedial rib fractures in infants are strongly correlated to abuse. They are proposed to arise from anteroposterior thoracic compression as when adult hands squeeze the chest of the small child (fig 4) (10, 13, 14). Acute rib fractures can be very hard to identify and are more easily seen on follow-up radiographs when callus has been formed (fig 5). In doubtful cases CT can be of great help in classifying rib anomalies and injuries.
Dating fractures is very difficult and an estimation of the age of fractures should only be given in intervals (table 2) (15). The rate of healing depends on which bone is injured as well as on the age of the child.

\textit{Table 2}

<table>
<thead>
<tr>
<th>Feature</th>
<th>Age of fracture (maximum)</th>
</tr>
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<tbody>
<tr>
<td>Soft tissue swelling</td>
<td>1 to 10 days (2 weeks)</td>
</tr>
<tr>
<td>Periosteal reaction</td>
<td>4 to 10 days (2 weeks)</td>
</tr>
<tr>
<td>Blurring of fracture lines</td>
<td>7 to 10 days (2 weeks)</td>
</tr>
<tr>
<td>Soft callus</td>
<td>2 to 4 weeks (6 weeks)</td>
</tr>
<tr>
<td>Hard callus</td>
<td>3 to 8 weeks (3 months)</td>
</tr>
<tr>
<td>Remodelling</td>
<td>&gt;8 weeks</td>
</tr>
</tbody>
</table>
Head injuries

Skull fractures are seen in both accidental and inflicted trauma. A simple (linear) fracture of the parietal bone is the most common type in both instances (13). More complex fractures can be encountered in accidental as well as inflicted trauma. The combination of alleged very mild trauma and a complex fracture should raise the suspicion of abuse. There is poor correlation between the presence of a skull fracture and the extent of intracranial damage. For example, a fall from a changing table can result in a skull fracture without any neurological symptoms or intracranial findings. On the other hand, abused patients can present with extensive intracranial injuries without any fracture. Dating skull fractures is not possible in the absence of soft tissue swelling. The presence of soft tissue swelling indicates that the fracture is less than two weeks old (15).

The most common intracranial finding in AHT is subdural hematoma (SDH), a venous bleeding where the accepted mechanism of injury is tearing of bridging veins. They can be quite small, but are sometimes large and demanding intervention. The SDH can be recognized over the convexities, interhemispherically, along the tentorium, as well as infratentorially (fig 6).

Fig. 6. Four different patients with SDH (and other injuries supporting the diagnosis of non-accidental trauma)
Dating SDH from imaging is debatable and influenced by many factors as hematocrit, coagulation status, mix with cerebrospinal fluid in cases of tearing of arachnoid membranes, repetitive injuries, re-bleeds etc. (16). The most recent recommendation is not to date SDH based on imaging (17). Time of onset of the child’s symptoms appears to be the best clue for dating the incident according to Adamsbaum’s studies from 2010 and 2014, where perpetrators describe often immediate behavioral changes of the child after the abusive event.

Causes of SDH other than abuse include accidental trauma, birth-related trauma, metabolic disease, coagulopathy and over-shunting. Subdural collections may be found in infectious disease (empyema, effusion). Increased extra-axial fluid is seen in the so-called BESS (benign enlargement of the subarachnoid spaces). Differentiating between subdural and subarachnoidal fluid is sometimes difficult on CT images (if attenuation is like to CSF).

Retinal hemorrhages (RH) are a common finding in patients suffering from AHT. Although it is primarily a task for the ophthalmologist to provide a thorough examination of the retina as a part of the work-up, hemorrhages can be visualized on MRI, especially on SWI-sequences (fig. 7). A study by Vinchon et al (18) where confessed abuse cases were compared with witnessed accidents showed that extensive RH in the absence of impact were only seen in the abused group. They concluded that the combination of RH, absence of impact and SDH had a very high specificity for abuse, but a low sensitivity.

Other findings in neuroimaging include cortical or bridging veins thrombosis (fig. 8), brain swelling and ischemia (fig. 9). Parenchymal contusions/lacerations (fig. 10) and DAI may be encountered, but are less common. The introduction of MRI of the spine in suspected abuse during the last decade has increased the awareness of spinal injuries. Examples of findings include ligamentous injuries, soft tissue edema, cord injuries and blood in the spinal canal (fig. 11).
Fig. 9. Ischemic injuries in two different patients. (a) DWI (b) CT in acute setting

Fig. 10. Lacerations/contusions (arrows) and also supra- and infratentorial SDH in same patient. (a) T1-image (b) T2-image
Fig 11. Soft tissue edema and focal bleeding (a), cord edema (b), hemorrhage in spinal canal (c).
Radiological investigation

A proper investigation requires good cooperation and communication between clinicians and radiologists. The following recommendations are based on the 2017 guidelines of the Royal College of Radiologists (19). They are soon to be approved as Swedish national recommendations by the Swedish Society for Pediatric Radiology (SFPR). The final version (in Swedish) will soon be found at their website http://www.sfmr.se/sidor/sfpr---riktlinjer/

We would like to stress the importance of the follow-up skeletal survey and the inclusion of the spine when performing MRI of the brain. In the new guidelines the follow-up study has a reduced number of images.

Initial imaging

For all children under the age of two years the radiological investigation should always include a full skeletal survey (see appendix A for views to be obtained). In children under the age of one, unenhanced computed tomography (CT) of the brain should be performed in addition to the skeletal survey regardless of clinical symptoms.

In children above the age of one showing external signs of head injury or neurological symptoms, or when injuries with high specificity for child abuse are present, a CT-scan should also be performed.

Skeletal surveys may also be appropriate in older children in some cases, for example, when a child is not able to communicate or when there is clinical suspicion of fractures.

In older children that can communicate properly and where physical abuse is suspected primarily the injured body part is imaged in accordance with clinical findings.

When injuries to the thoracic organs or abdomen are suspected the investigation is conducted in the same way as in accidental trauma using body CT. CT can be also be considered when there is doubt regarding the nature of rib anomalies.

Further imaging

MRI of the brain and the whole spine (see appendix C) should be performed within the first few days in all cases where cranial CT has detected intracranial hemorrhage and/or parenchymal injury and/or skull fracture, or when the child has ongoing neurological symptoms or signs irrespective of an apparently normal initial CT scan.

Follow up imaging

In all children where a skeletal survey has been conducted a follow-up skeletal survey (see appendix B for views to be obtained) should be performed 11-14 days (no later than 28 days) after the initial survey, even if the initial examination is normal. This is because follow-up imaging can detect new injuries and fractures that only become visible when healing. The follow-up will sometimes also assist with dating of injuries.
References:

11. Nspcc.org.uk
APPENDIX A.

Initial skeletal survey standard views

The skeletal survey should be acquired as soon as possible, preferably during office hours within 24 hours from the request being made. Imaging should be made by two radiographers with appropriate training and expertise. A pediatric nurse should assist the child and radiographers during the procedure.

It is of great importance that the images carry anatomical side markers that is not overlying any body parts, the child’s clothes are removed, and that no objects such as for example ID-tags or diapers obscure the images.

The radiologist in charge should approve the images before the child leaves the radiology department in case repeat or additional views are needed.

Head, chest, spine and pelvis

- Skull anterior-posterior (AP) and lateral
- Chest AP (to include the shoulders) and both obliques (including all ribs)
- Pelvis and abdomen AP
- Spine lateral (in small children this may be possible with one view, for larger children separate views will be required)

Upper limbs

Infants*  
- Whole arm AP (centered at the elbow)
- Elbow coned lateral
- Wrist coned lateral
- Hand including wrist PA

Larger children  
- Humerus AP including joints
- Forearm AP including joints
- Elbow coned lateral
- Wrist coned lateral
- Hand including wrist PA

Lower limbs

Infants*  
- Whole lower limb (centered at the knee)
- Knee coned lateral
- Ankle coned lateral
- Foot PA

Larger children  
- Femur AP
- Tibia and fibula AP
- Knee AP
- Ankle AP
- Knee coned lateral
- Ankle coned lateral
- Foot PA

* whole arm or leg fits in one single good quality view
APPENDIX B.

Follow up skeletal survey standard views

The follow up skeletal survey should be acquired 11-14 days after the initial imaging. This examination includes fewer images.

The radiologist in charge should be asked before the examination if there are additional images required other than the standard views stated below, for example laterals of an injured or suspicious area.

The same standards as for the initial imaging regarding personnel, side markers, obscuring objects and image approval by the radiologist in charge apply to the follow-up survey.

Injured or suspicious areas

- Areas that were abnormal or suspicious on initial skeletal survey should be closely examined after discussions with the radiologist.

Head, chest, spine and pelvis

- Chest AP (to include the shoulders) and both obliques (including all ribs)

Upper limbs

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<thead>
<tr>
<th>Infants</th>
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<td>Whole arm AP (centered at the elbow) including joints</td>
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<td>Knee AP</td>
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APPENDIX C.

MRI of the brain and the whole spine

MRI protocols must be adapted to local routines and technical resources. The examination should include images in all three planes and in addition to morphological sequences also diffusion weighted imaging and sequences susceptible to blood.

MRI imaging of the brain and spine in suspected child abuse should include:

**Brain**
- T1 sagittal and axial (or volume)
- T2 axial
- T2 Flair coronal
- SWI
- DWI

**Spine**
- T1 sagittal (axial as needed)
- T2 sagittal (axial as needed)
- STIR sagittal