Imaging in Child Abuse

Einat Blumfield, M.D.

Department of Radiology, Jacobi Medical Center, Albert Einstein College of Medicine, Bronx, NY

Child abuse is a problem of particular concern to physicians and other professionals caring for children. Symptoms of physical abuse in children, especially infants, are often nonspecific and may overlap with numerous other clinical conditions. Therefore, radiologists play a key role in identifying imaging findings to make the diagnosis of physical child abuse.[1] While clinical clues to the diagnosis such as bruises and burns may exist, in many cases, there is absence of external signs of trauma, and imaging findings will be the first to raise suspicion of abusive injuries. Although many injury patterns may be seen with both accidental and nonaccidental trauma, there are some characteristic findings and injury patterns of abuse that should be recognized by radiologists who interpret pediatric imaging studies. This review covers the characteristic imaging manifestations of child abuse, as well as diagnostic pearls, pitfalls, and limitations associated with skeletal, intracranial, spinal, and abdominal injuries.

Skeletal Injuries

Aside from cutaneous findings, such as bruising and contusions, fractures are the next most common findings in abused children.[2] Therefore, when abuse is suspected in an infant, a complete skeletal survey is mandated. Skeletal surveys should include detailed radiographs of the entire skeleton. At least one frontal view of each long bone should be obtained. Radiographs of the spine, skull, hands and feet should be obtained as well.[2,3] Radiographs of the chest should include oblique views to improve visualization of rib fractures.[2] Ideally, the survey should be monitored by an experienced radiologist. In cases of equivocal findings, additional views, such as lateral or oblique views, should be obtained. In some ambiguous cases, radiographs may be repeated in 10-14 days to assess for healing of fractures. Fractures having the highest association with abuse include rib fractures, classic metaphyseal lesions (CMLs), scapular fractures, sternal fractures, and spinous process fractures.[1]

Bone scintigraphy may be added to the investigation for bony injuries. Bone scintigraphy has been shown to have higher sensitivity for rib fractures but lower sensitivity for long bone CMLs when compared to radiographs. Scintigraphy may be used in complicated cases that cannot otherwise be determined by radiographs.[2]

Rib fractures in infants younger than 1 year are highly specific for abuse. The proposed mechanism is tight encirclement of the rib cage by the person who shakes an infant, which leads to antero-posterior compression of the rib cage. The fractures typically occur in the posterior and lateral aspects of the ribs and less commonly anteriorly (**Figure 1**).

CMLs in infants are highly specific findings of abuse. The proposed mechanism is shearing with torsion and torque of the extremities that lead to metaphyseal fractures. The fracture line is nearly parallel to the physis and may appear as a corner fracture or a bucket handle fracture, depending on the part of the metaphysis involved and the radiographic projection (**Figure 2**). These fractures are most commonly seen at the knee (**Figure 3**), followed by the ankle and shoulder (proximal humerus).

Scapular and sternal fractures are reported to have high association with other imaging findings of abuse. Compression fractures of vertebral bodies have been reported in abused infants in high association with findings of abusive head trauma.[5]

Although the above described fracture patterns have a high specificity for abusive trauma, correlation must be made with the clinical history, as other processes may result in similar injury patterns on imaging. All of the described fractures may occur with accidental trauma when an appropriate mechanism is present. Rib fractures

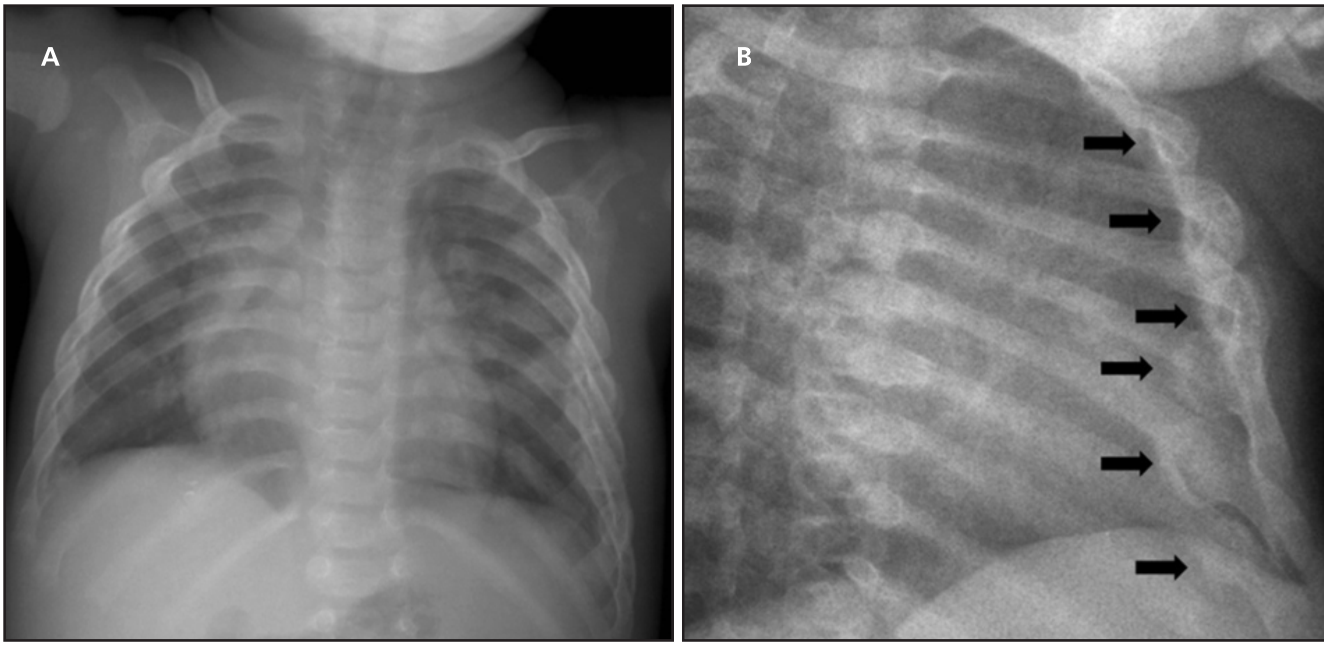


FIGURE 1. *Rib fractures. A 3-month-old twin with seizures and a skull fracture on CT with no reported history of trauma. The other twin had died and was found to have multiple rib fractures on postmortem examination. On the frontal view of the chest (A) performed as part of a skeletal survey, there are multiple rib fractures on the left. These fractures are better delineated on the oblique view (B, arrows).*

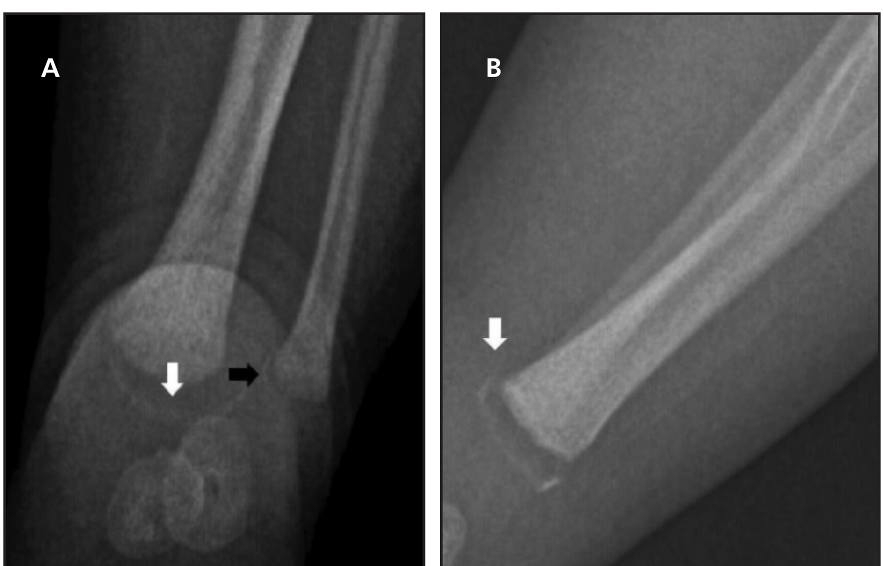
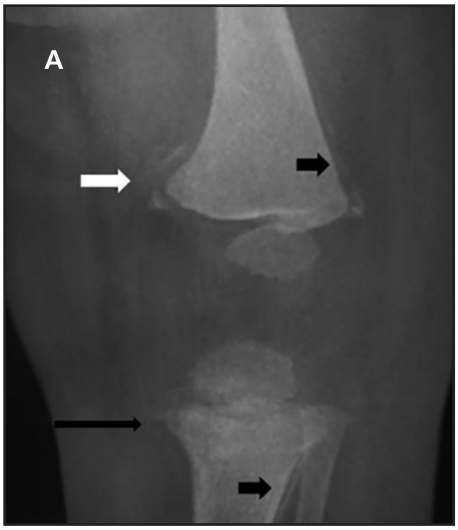


FIGURE 2. *Classic metaphyseal lesions (CMLs). A 1-month-old with a swollen leg. On the skeletal survey, the patient had 3 healing rib fractures, a healing clavicle fracture, and bilateral ankle fractures. Frontal (A) and lateral (B) views of the right ankle demonstrate a bucket handle fracture of the distal tibia (white arrows). A bucket handle fracture of the fibula is demonstrated as well (A, black arrow).*

and CMLs have been described with traumatic deliveries, metabolic disorders (eg, rickets, osteogenesis imperfecta), and skeletal dysplasias.[2,4] Rib and sternal fractures may occur with cardiopulmonary resuscitation (CPR).

An important entity to keep in mind when considering the differential diagnosis of abuse is the metabolic bone disease of prematurity that results from nutritional deficiencies and may present with multiple fractures, including both metaphyseal and rib fractures in nonabused infants.[2,4] In these cases, it would be helpful to review prior radiographs, from the time the infant was admitted, for any fractures and to review the medical records for possible clinical manifestations of fractures during admission (eg, extremity swelling or tenderness, transient elevation of alkaline phosphatase level, etc.). In premature infants, gastrointestinal processes, such as necrotizing enterocolitis, may lead to prolonged periods of no oral feeding and reliance on parenteral nutrition, which can result in nutritional deficiencies and subsequent fractures.

Dating of fractures is important when abuse is suspected, as the healing stage of fracture(s) should be correlated with the timing of injury as reported by the infant's caregivers. Since different individuals may care for an infant at different times, accurate timing of the injury may help in suggesting the perpetrator of abuse. Unfortunately, dating of fractures by imaging is not an exact science.[2] Radiologists should be cognizant and cautious regarding attempting to provide accurate dates of injury. Nevertheless, experienced radiologists can determine the presence of multiple fractures in different stages of healing (**Figure 4**), in which case the probability of abuse is high. In most cases, fractures can be differentiated as acute, healing, and healed fractures. The first



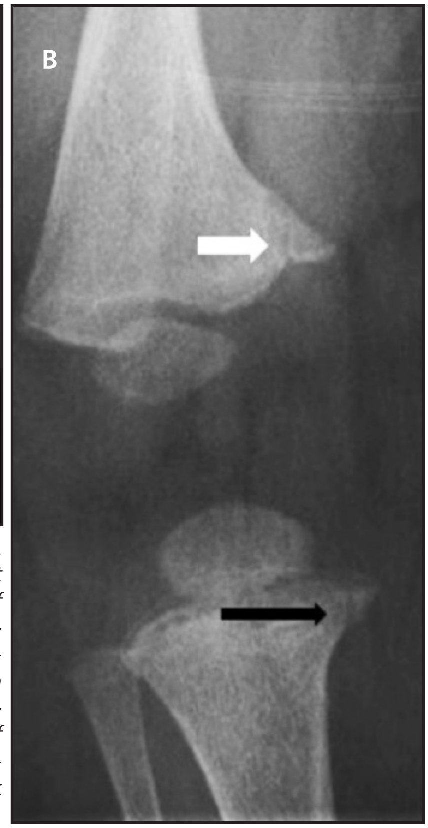


FIGURE 3. *Classic metaphyseal lesions (CMLs). A 5-month-old with swelling and redness of the left knee for several days and no reported history of trauma. Frontal view of the right knee (A) demonstrates healing metaphyseal fractures of the distal femur (white arrow) and of the proximal tibia (long black arrow arrow) with regions of periosteal reaction (short black arrows). Frontal view of the left knee (B) demonstrates fractures of the distal femur (white arrow) and proximal tibia (black arrow) with no evidence of healing.*

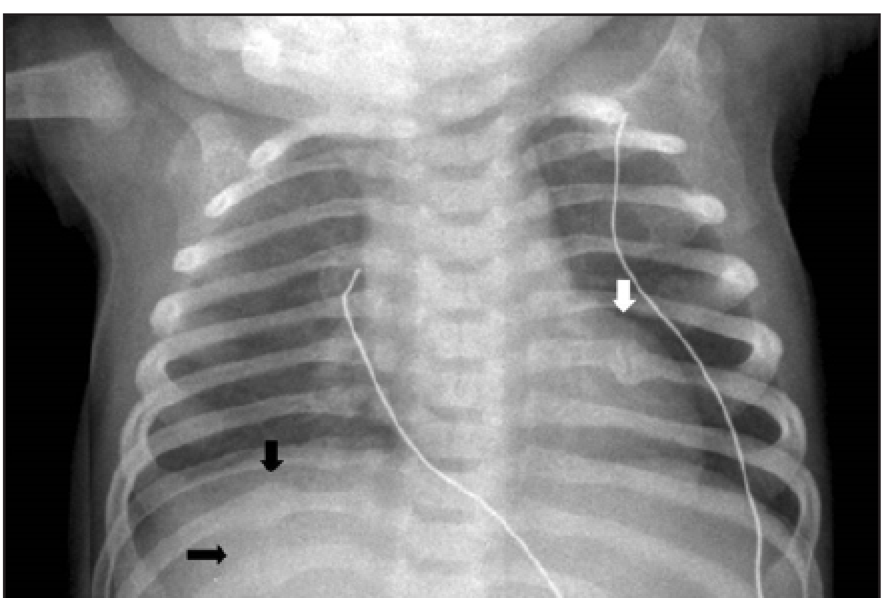


FIGURE 4. *Fractures in different stages of healing. A 2-month-old who presented with seizures. CT and MRI of the brain demonstrated SDH. Frontal view of the chest demonstrates rib fractures in different ages. In the fracture of the posterior left sixth rib (white arrow), the fracture line is still clearly identified. In the fractures of the right ninth and tenth posterior ribs (black arrows), there is evidence of callus formation with indistinct fracture lines.*

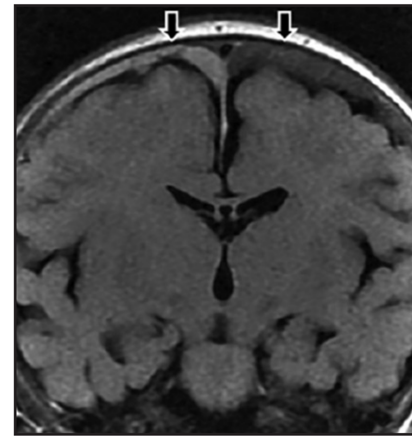


FIGURE 5. *Abusive head injury – SDH. A 2-month-old who presented with a seizure. Coronal fluid attenuated inversion recovery (FLAIR) MR image demonstrates thin bilateral SDHs of differing signal intensities (black arrows) with extension into the interhemispheric fissure on the right. The patient also had parietal bone fractures, rib fractures, and a fracture of the right proximal tibia.*

radiographic finding of healing is periosteal reaction (**Figure 3A**), which appears in most cases 10-14 days following the injury. However, it may appear as early as 4 days and as late as 21 days from the initial injury. Later findings include loss of the fracture line definition, soft callus formation, and hard callus formation. As there is high variability in the timing of the appearance regarding these findings, they are less helpful in the dating process.[2]

Fractures are commonly identified in association with findings of abusive head trauma. Since findings of abusive head trauma are frequently nonspecific, detection of fractures in these patients has important implications in identifying abusive injuries.[5]

Abusive Head Trauma

While any type of cranial injury may be caused by abuse, there are some characteristic findings of abuse that commonly manifest in shaken baby syndrome. In cases of abusive shaking, there is commonly no direct impact to the head; therefore, external signs of trauma such as scalp hematomas and bruises, are often absent. The classical findings described in association with shaking are subdural hematomas (SDHs) (**Figure 5**). Usually, these hematomas are thin, diffuse, and layer along the convexities with extension along the falx cerebri. They may be unilateral but are commonly bilateral.[6] These hematomas are thought to result from rupture of bridging veins due to the shear forces with rapid acceleration and deceleration

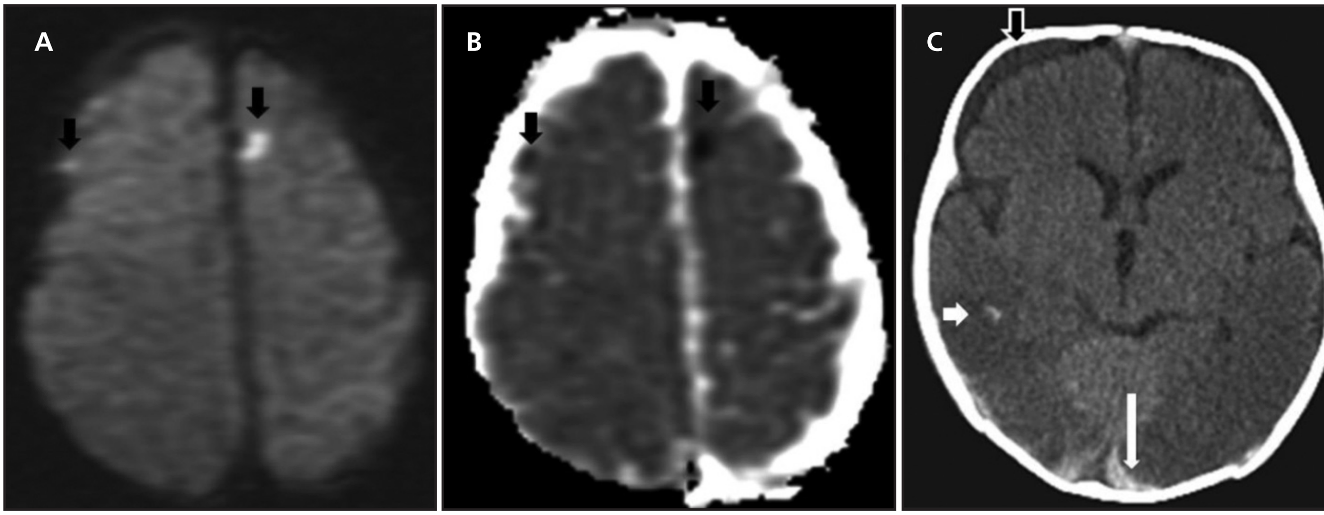


FIGURE 6. *Abusive head injury – multiple findings. Axial DWI (A) and ADC map (B) images in the same patient as in Figure 5 demonstrate 2 focal areas of restricted diffusion in the frontal lobes (black arrows), consistent with acute infarcts. Axial unenhanced CT image (C) in a different patient who presented with unresponsiveness and bilateral retinal hemorrhages demonstrates diffuse hypodensity of the cerebrum with loss of gray-white matter differentiation, consistent with global hypoxic ischemic injury. There is a focal area of hemorrhage in the right temporal lobe (short white arrow), as well as acute (long white arrow) and chronic (black arrow) SDHs.*

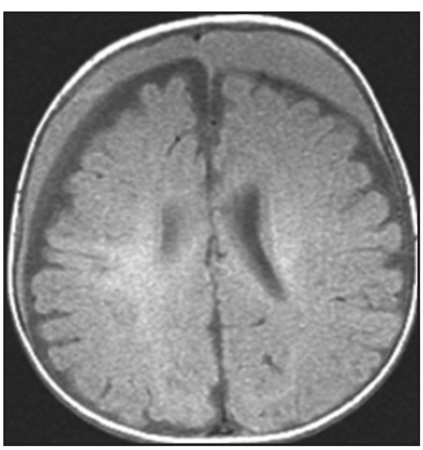


FIGURE 7. *SDH associated with benign prominence of the subarachnoid spaces. A 4-month-old with increasing head circumference and no other clinical findings. Axial T1 MRI demonstrates bilateral SDHs, as well as prominence of the subarachnoid spaces. No evidence of abuse was found in this patient, and the SDHs are presumably the result of benign prominence of the subarachnoid spaces.*

associated with vigorous shaking. These veins drain the cerebral parenchyma and course through the subarachnoid and subdural space enroute to the dural venous sinuses.[6]

Other intracranial findings described in shaken babies include parenchymal contusions, typically caused by the impact of the brain against the calvarium, diffuse axonal injury due to the shear strain and rotational forces, and

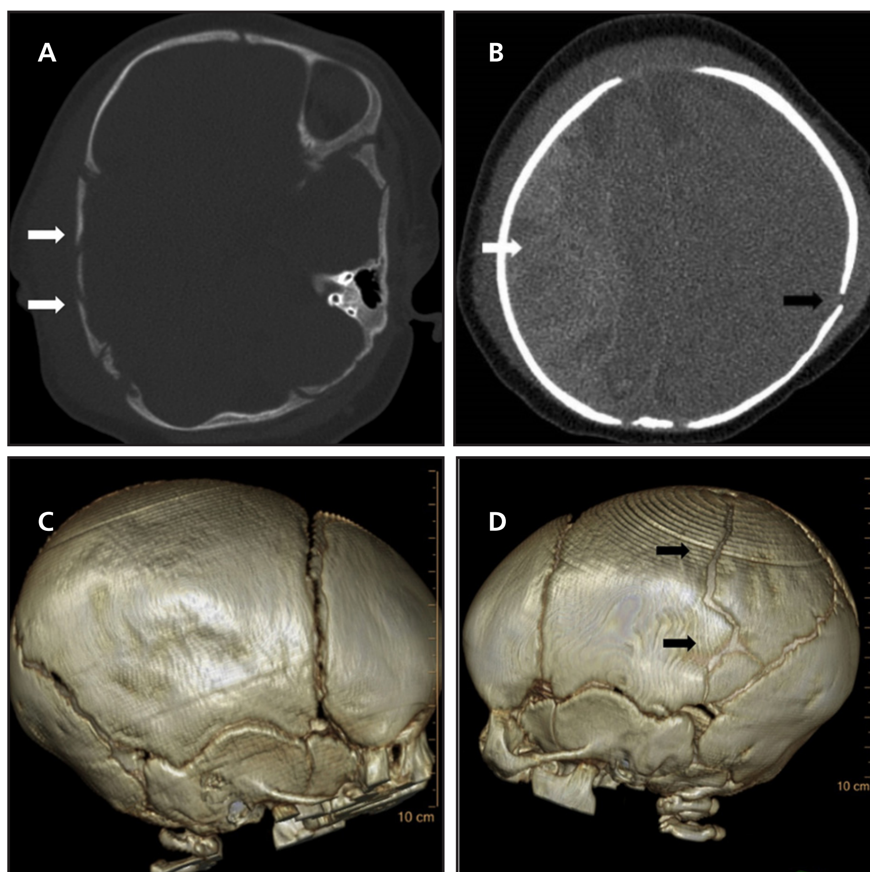


FIGURE 8. *Skull fracture vs. sutures. A 2-month-old who fell out of a stroller. Axial image from a CT scan in bone window (A) demonstrates right scalp soft-tissue swelling overlying the right temporal bone with linear calvarial lucencies (white arrows). An axial CT image in soft-tissue window at the level of the parietal lobes (B) demonstrates a large right epidural hematoma with significant mass effect (white arrow), as well as an additional linear lucency in the left parietal bone (black arrow). 3-D reconstructions of the calvarium (C, D) demonstrate normal sutures and no fractures on the right (C) and a linear parietal fracture on the left (D, black arrows).*

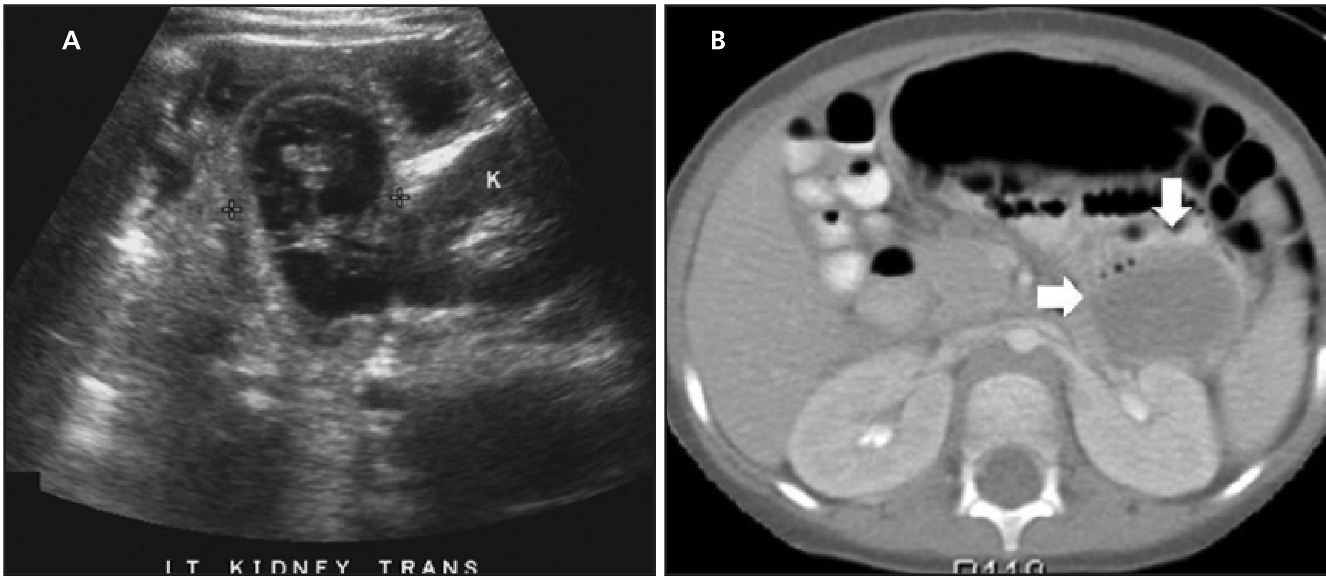


FIGURE 9. *Duodenal injury. A 2-year-old with bilious vomiting. Transverse image from an ultrasound of the left upper abdomen (A) demonstrates a thick-walled bowel loop (marked by calipers) just medial and anterior to the left kidney (K). Enhanced axial CT image (B) confirms the diagnosis of a duodenal hematoma, involving the fourth segment of the duodenum (white arrows).*

infarcts or hypoxic ischemic encephalopathy (HIE) (**Figure 6**). HIE may result from central apnea secondary to injury to the brainstem or upper cervical spinal cord, prolonged seizure activity, or aspiration.[6,7]

In many cases, retinal hemorrhages will be present in association with SDHs.[8,9] These are usually depicted on clinical ophthalmological examination. The retinal hemorrhages described with abusive head trauma are extensive, multilayered hemorrhages. Such retinal hemorrhages have also been described in the absence of abusive head injury, to include patients with bleeding disorders, sepsis and leukemia. Other causes of retinal hemorrhage include high altitude exposure, elevated blood pressure, and some metabolic disorders, which typically cause small focal retinal hemorrhages.[10]

The diagnosis of abusive head trauma can be challenging,[9] and it should not rely solely on the presence of SDH and retinal hemorrhages, as there are other conditions associated with these findings. In the setting of a traumatic birth, the presence of SDH is common. These bleeds are typically small and most often resolve within 4 weeks of life.[10] SDH has also been reported in infants following hypoxic ischemic injury; however, these reports have been questioned and the matter remains controversial. This presents a significant challenge to the diagnosis, as many abused infants present following seizures and apneic episodes.[10]

Another problematic entity is the "benign prominence of subarachnoid spaces." This is a common condition of expansion of the subarachnoid spaces in infancy, typically presenting with an enlarged head. It is thought to be the result of imbalance between production and absorption of cerebrospinal fluid and usually resolves within 1-2 years with no neurological consequences. Nevertheless, there are several reports of cases of SDH occurring spontaneously in patients with this entity (**Figure 7**).[10,11] This could be explained by increased motion of the brain within the skull due to the prominence of the extra-axial spaces, which may lead to stretching and rupture of bridging veins with otherwise trivial movements or trauma. In such patients, cross-sectional imaging studies may show the prominent subarachnoid spaces in association with the SDH. It may be helpful to evaluate the infant's head circumference and inquire about a family history of macrocephaly, as there is familial predisposition of this entity.

Skull fractures may be seen in both accidental and nonaccidental trauma. The probability of abuse in infants with skull fractures is estimated at approximately 30%.[6] Some patterns of fractures have a higher association with abuse compared to accidental trauma, to include depressed, diastatic, and compressed fractures.[5] Skull fractures may be diagnosed on radiographs or computed tomography (CT) scans. When diagnosing fractures on CT, it is important to obtain reconstructions, since fractures may be missed if they are oriented in the same plane as the axial slices. Three-dimensional (3-D) reconstructions are helpful in differentiating fractures from sutures, including accessory sutures and variants that are commonly present in children (**Figure 8**).[12] Epidural hematomas are commonly seen in association with skull fractures.

Establishing the timing of abusive head trauma is complicated and controversial, as perpetrators rarely admit their actions.[13] Dating based upon imaging findings alone is often inaccurate. On CT, an acute SDH may be homogenously hyperdense or may demonstrate mixed density. Subacute hematomas will generally be isodense to brain parenchyma. Chronic hematomas are typically hypodense. It is

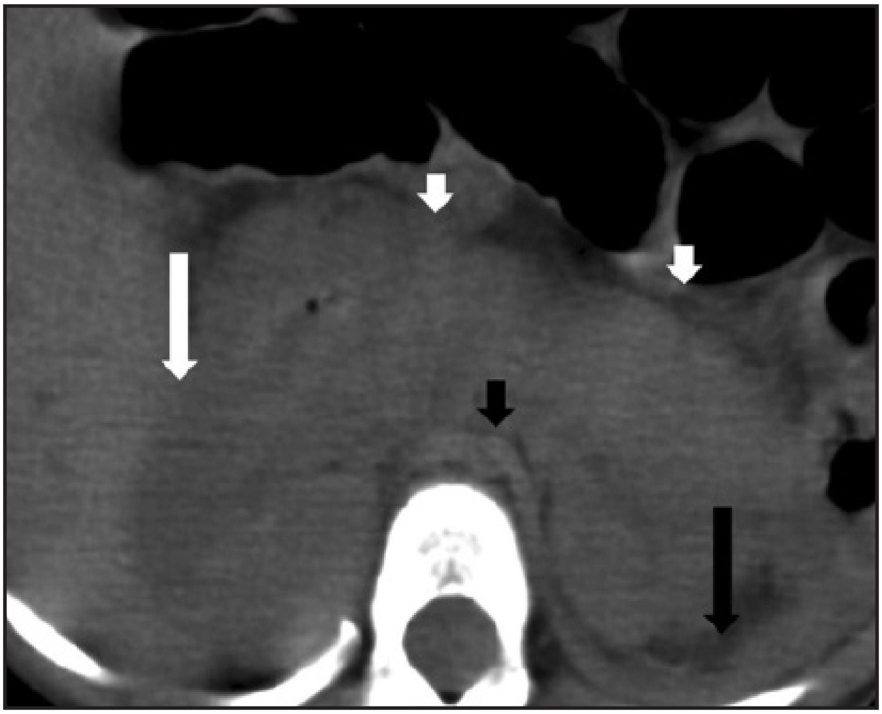


FIGURE 10. Pancreatic injury with adjacent hemorrhage. A 4-year-old who died following injuries inflicted by a caretaker. Axial unenhanced CT image through the upper abdomen demonstrates diffuse swelling of the pancreas (short white arrows), retroperitoneal hemorrhage (long black arrow), intraperitoneal fluid/hemorrhage (long white arrow), and marked narrowing of the aorta (short black arrow) due to hemodynamic shock.

important to realize that a pattern of heterogeneous or multilayered densities within a SDH does not in and of itself imply repeated injury, as there is clear evidence that SDHs may rebleed spontaneously due to the presence of inflammatory membranes with newly formed capillaries.[13]

Dating of SDH on MRI is even more complicated, as there is significant overlap of the signal intensities between different stages of hematomas, and the evolution of SDH is less predictable than intraparenchymal hematomas. The potential influx of cerebrospinal fluid (CSF) into the subdural space can also complicate the imaging findings of SDH on MRI. Dating of parenchymal injuries is more accurate, particularly when there are ischemic changes with areas of cytotoxic edema that will present with restricted diffusion, which peaks within the first few days but may persist for up to 7-14 days. Evaluation with both CT and MRI is complementary and may improve the accuracy of dating injuries.

Spinal Injuries

Spinal injuries have been described in association with abusive head trauma. However, the literature on this topic is scarce, likely because these injuries are typically diagnosed on MRI, which is not routinely performed as part of a child abuse work-up. Also, the clinical presentation of spinal injuries may be vague with additional distracting injuries. There is clear evidence that shaken babies suffer injuries to their upper cervical spinal cord or brainstem due to the increased proportion of head to body size, laxity of spinous ligaments, low muscle tone, and incomplete ossification of the vertebrae. This may lead to apnea, which is a common presentation in abusive head trauma.[14]

Abdominal Visceral Injuries

Injuries to the abdominal viscera have been reported in abused children. They usually occur in toddlers, in contrast to the findings of abusive head trauma and characteristic fractures that are typically seen in infants. Based on a recently published meta-analysis,[15] injuries to the solid organs and hollow viscera of the abdomen have been reported in abused children with similar frequencies. Injuries to the hollow viscera are more common with abuse than in accidental trauma with the duodenum most often involved. The duodenum may sustain a transmural hematoma, perforation or transection; the third and fourth portions of the duodenum are most often involved (**Figure 9**).

The pancreas may also be injured in abusive abdominal trauma (**Figure 10**), as reported in association with duodenal injuries. Pancreatitis is the typical early presentation, while psueodcyst formation is a delayed manifestation.[15] Radiologists need a high index of suspicion of abuse in these clinical settings, since these entities are otherwise uncommon in young children. The possibility of abuse should especially be raised in young children with these findings and no clear history of significant abdominal trauma. Injuries to other solid abdominal organs, including the liver, spleen, and kidneys have been reported in cases of abuse. However, these are also very common in the setting of significant accidental trauma (eg, motor vehicle accidents).

The clinical implications of visceral injuries are significant and should not be overlooked. It is estimated that they contribute to up to about 50% of child-abuse-related fatalities.[15] As in many cases of abuse, the symptoms are often nonspecific, and a history of trauma is often not elicited initially. Children may present with vomiting; abdominal pain and bruises are not always present. Therefore, a high index of suspicion is required on both the part of the clinician and the radiologist.

Conclusion

Imaging plays an important role in the diagnosis and investigation of child abuse. Due to the nonspecific clinical presentation of physical abuse, radiologists may be the first to raise suspicion of abuse based upon characteristic imaging findings. Characteristic findings include patterns of skeletal injuries (eg, rib fractures and CMLs), abusive head trauma, and blunt abdominal injuries (eg, duodenal and pancreatic injuries). Since these injuries may be fatal, or abuse may continue if not promptly recognized, it is imperative that these findings not be overlooked or underestimated. It is also important for radiologists to acknowledge that dating of abusive trauma is often limited and inaccurate. The primary role of the radiologist is to identify the patterns of abusive injury and identify findings suggesting various ages of injury, which is specific for abuse.

Acknowledgement

The author thanks Isaak Manaster, B.S., for help with image editing.

References

1. Adamsbaum C, Méjean N, Merzoug V, Rey-Salmon C. How to explore and report children with suspected non-accidental trauma. Pediatr Radiol 2010;40:932-938.
2. Offiah A, van Rijn RR, Perez-Rossello JM, Kleinman PK. Skeletal imaging of child abuse (non-accidental injury). Pediatr Radiol 2009;39:461-470.
3. ACR–SPR Practice parameter for skeletal surveys in children, Amended 2014 (Resolution 39). http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/Skeletal_Surveys.pdf. Accessed April 2, 2015.
4. Kleinman PK. Problems in the diagnosis of metaphyseal fractures. Pediatr Radiol 2008;38(suppl 3):S388-394.
5. Barber I, Kleinman PK. Imaging of skeletal injuries associated with abusive head trauma. Pediatr Radiol 2014 Dec;44(suppl 4):S613-620.
6. Vázquez E, Delgado I, Sánchez-Montañez A, et al. Imaging abusive head trauma: why use both computed tomography and magnetic resonance imaging? Pediatr Radiol 2014;44(suppl 4):S589-603.
7. Ichord RN, Naim M, Pollock AN. Hypoxic-ischemic injury complicates inflicted and accidental traumatic brain injury in young children: the role of diffusion-weighted imaging. J Neurotrauma 2007;24:106-118.
8. Nadarasa J, Deck C, Meyer F, et al. Update on injury mechanisms in abusive head trauma--shaken baby syndrome. Pediatr Radiol 2014;44(suppl 4):S565-570.
9. Leventhal JM, Asnes AG, Pavlovic L, Moles RL. Diagnosing abusive head trauma: the challenges faced by clinicians. Pediatr Radiol 2014;44(suppl 4):S537-542.
10. Jenny C. Alternate theories of causation in abusive head trauma: what the science tells us. Pediatr Radiol 2014;44(suppl 4):S543-547.
11. Ghosh PS, Ghosh D. Subdural hematoma in infants without accidental or nonaccidental injury: benign external hydrocephalus, a risk factor. Clin Pediatr 2011;50:897-903.
12. Medina LS. Three-dimensional CT maximum intensity projections of the calvaria: a new approach for diagnosis of craniosynostosis and fractures. Am J Neuroradiol 2000;21:1951-1954.
13. Adamsbaum C, Morel B, Ducot B, et al. Dating the abusive head trauma episode and perpetrator statements: key points for imaging. Pediatr Radiol 2014;44(suppl 4):S578-588.
14. Kemp A, Cowley L, Maguire S. Spinal injuries in abusive head trauma: patterns and recommendations. Pediatr Radiol 2014;44(suppl 4):S604-612.
15. Maguire SA, Upadhyaya M, Evans A, et al. A systematic review of abusive visceral injuries in childhood—their range and recognition. Child Abuse Negl 2013;37:430-445.