Non-accidental Injury of the Pediatric Central Nervous System

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Introduction

Inflicted or non-accidental central nervous system (CNS) injury compromises a constellation of injuries to the pediatric brain and spine resulting from direct or indirect forces acting on the cranium and spine and the intracranial and intrathecal components. The recognition of inflicted injury has significantly improved over the past years. Imaging plays a major role in the early and specific detection and documentation of inflicted physical injury. Inflicted injuries can involve any body part and cover every type of injury (e.g., fractures, organ injuries, thermal injuries).

The pediatric skull, brain, and spine go through continuous anatomical and functional developmental phases. As a consequence, the type, pattern, extent, and distribution of traumatic CNS injuries differ depending on the age group of the affected child. Furthermore, the primary and secondary complications and the neurological and functional outcome are different for each age group.

The goals of this manuscript are to enlarge awareness of the epidemiology, mechanisms, and imaging features of inflicted injury of the pediatric CNS, to discuss the "accuracy" of dating of inflicted injury based on imaging findings, and to propose a diagnostic workup for suspected inflected neurotrauma.

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Historical Background

The French forensic physician Tardieu described a diverse range of physical and sexual injuries to children, including meningeal hemorrhage and brain injuries, as early as in the nineteenth century [1]. More than 80 years later, in 1946 the American pediatrician and radiologist Caffey first described the unusual association of chronic subdural hemorrhages and long-bone fractures [2]. In 1972, he published a description of the radiologic and clinical features attributed to shaking injuries [3]. Two pediatricians, Ludwig and Warman, introduced the term shaken baby syndrome in 1983 in the published review of infants and young toddlers injured by shaking. In 1987, Duhaime (neurosurgeon) reported that many victims of shaken baby syndrome showed evidence of blunt impact to the head at the time of diagnosis [4]. In the past decades, extensive efforts to progressively understand causations and mechanisms of inflicted injury have led to abundant objective research data regarding this specific type of injury.

Confusion of Definition

Diverse nomenclature has been used to describe the entity of inflicted CNS injury.

In 2009, the American Academy of Pediatrics (AAP) appealed for the introduction of more encompassing and less specific medical terminology covering the range of injuries to the skull and brain ("abusive head trauma") rather than implying a single injury mechanism ("shaken baby syndrome") by publishing a policy statement [5]. Inflicted or abusive injury is the more recent terminology applied to the outdated terms as battered child syndrome and shaken impact syndrome [5].

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Definition

The definition of child abuse according to the World Health Organization "includes all forms of physical and emotional ill-treatment, sexual abuse, neglect, and exploitation that results in actual or potential harm to the child's health, development or dignity." Inflicted neurotrauma focuses on the physical type of abuse to the CNS of infants and children by adults. Physical injury comprises approximately 20 % of all type of maltreatment injuries. Inflicted physical injury should be suspected in the context of an inappropriate or inconsistent history.

In terms of clinical, laboratory, and imaging findings, there is lack of consistent and reliable criteria for standardizing the diagnosis of inflicted injury. The pattern of abnormalities associated with inflicted injury does not follow circular logic to serve as diagnostic criteria to establish the diagnosis. Inflicted CNS injury remains a diagnostic and medicolegal challenge.

Epidemiology

The estimated incidence of inflicted injury to the brain and spine in the pediatric age group under the age of 1 is 14–40 per 100,000. Inflicted injury is the most common cause of neurotrauma in the age group younger than 2 years [6, 7]. Exact incidence numbers of inflicted CNS injury cannot be determined since there is no standardized definition; a portion of the involved infants and children is not in need of acute medical care and will not enter the medical system, and a subdivision of the medical presented cases are (initially) not recognized as inflicted injury cases. In general, the affected pediatric population consists of a higher proportion of boys (62–77 %), and the majority of cases manifests before 6 months of age (median age 2.2–5.9 months) [8].

Inflicted injury of the brain and spine is the most common cause of traumatic death in infancy [9, 10]. A substantial part of the survivors of inflicted CNS injury demonstrates impaired neurodevelopmental function, is moderately (14 %) to severely (50 %) disabled, and will have a lower life expectancy [10]. The poor outcome is predominantly due to the damage to an intensely developing CNS at this young age.

Perpetrators of inflicted injury are found across various socioeconomic demographics. Risk factors for mistreatment are being established and categorized into risk factors intrinsic to the child (e.g., male, young age), risk factors intrinsic to the perpetrator (e.g., young parent/caregiver, psychiatric problems), and risk factors intrinsic to family structure and socioeconomic situation (e.g., unmarried, minority group) [11].

Mechanisms and Pathophysiologic Processes of Inflicted Injury

Primary CNS injury occurs at the time of injury, whereas secondary injury to the brain and spine evolves over a certain time period (hours, days, months) after the initial trauma. Neurotrauma injury, accidental or inflicted, is initiated by either impulsive loading (movement of head by angular acceleration/deceleration forces to other part of body) or impact loading (direct linear forces to the head). Unique age-dependent anatomical and biomechanical features of the developing skull, brain, and spine cause these traumatic events to have different mechanisms and pathophysiologic injury patterns compared to adults.

Brain Characteristics

Unmyelinated cerebral white matter in a neonate/infant consists of more water (and less myelin) and smaller axonal size if compared to completely myelinated white matter in an older child. As a consequence, the brain tissue is softer and more susceptible to diffuse acceleration-deceleration axonal injury in case of impulsive loading. Predilection sites for diffuse axonal injury are the dorsal brainstem, parasagittal white matter, corpus callosum, and gray-white matter junctions of the cerebral hemispheres (Fig. 1). Moreover, the programmed brain myelination pattern causes myelinated brain regions to absorb external forces distinct from unmyelinated brain regions resulting in cortical tear or cleft injuries rather than cortical contusions [12].

Skull Characteristics

The pediatric skull is thin and demonstrates a high degree of plasticity and deformity with transmission of impact forces to deeper brain structures compared to adults. Open sutures tolerate a small degree of motion of the bones of the cranial vault in relation to each other. Impulsive loading to an unsupported neck (shaking) causes the head to rotate/move along the fulcrum of the cervical spine. The younger the child, the more superior/cranial cervical spine or even the craniocervical junction will be injured. The relative large size and heavy weight of the pediatric head compared to the adult head causes altered dynamics of head acceleration due to external forces. The additional plasticity of the skull results in significant shear forces on the skull and dura versus the subdural vessels and brain with subsequent stretching and tearing injuries of the bridging vessels and the relative soft unmyelinated brain (e.g., subdural/subarachnoid hemorrhages, diffuse axonal injury) [12, 13]. The prominent

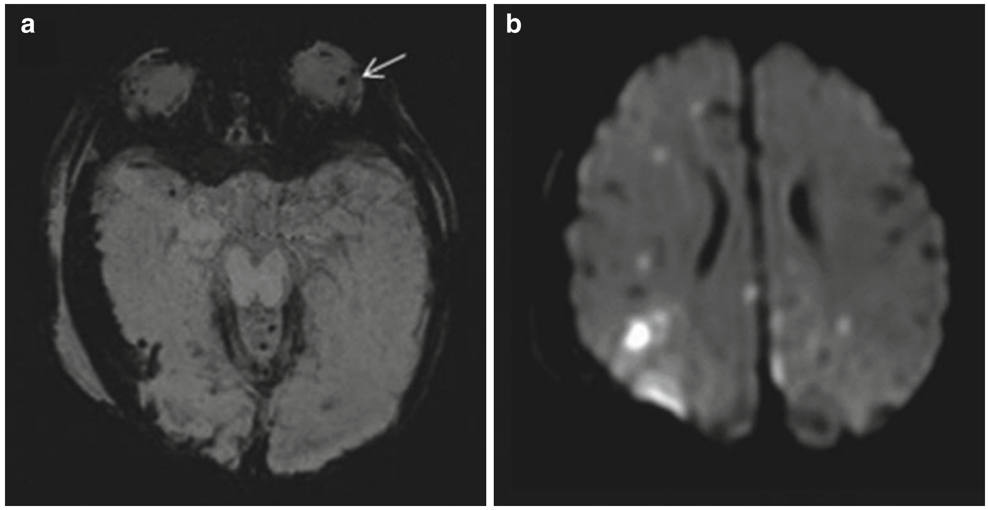

Fig. 1 Axial SWI MR image (**a**) reveals subdural hemorrhage over the right temporal region. Additional subarachnoid hemorrhage in this region is seen. Focal retinal hemorrhages are identified bilateral, left more than right (*white arrow*). Axial DWI MR image (**b**) demonstrates parenchymal shear injuries representing diffuse axonal injury in the subcortical and parasagittal white matter in the frontal and parietal regions

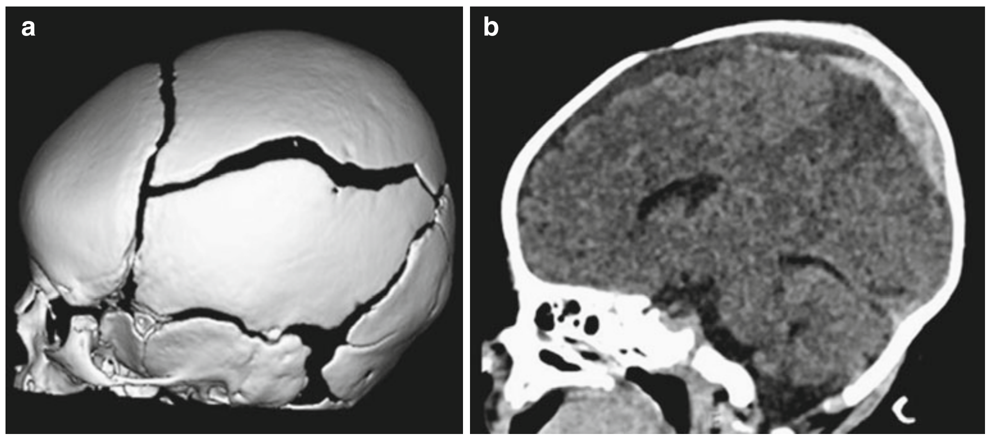

Fig. 2 3D CT image (**a**) shows a linear mild diastatic non-displaced fracture through the left parietal bone extending from the coronal suture to the lambdoid suture. Sagittal 2D CT image (**b**) reveals a hyperdense subdural hematoma in the left parietal region. Moreover, cortical contusion with subcortical edema is noted in the underlying left parietal lobe

extra-axial cerebrospinal fluid (CSF) spaces in the young age group even further increase the traction forces to the bridging veins with subsequent high risk of subdural hemorrhage (Fig. 2).

The inner table of the skull of an infant is not as irregular and uneven as in older children, resulting in less cortical contusions in the young age group. Furthermore, the groove of the middle meningeal artery is shallow (more mobility of the artery), and the pediatric dura is more firmly adherent to the inner table of the skull, decreasing the risk of epidural hemorrhages in infants and young children and causing epidural hemorrhages to be more often from venous rather than arterial quality.

Facial Characteristics

The relative small surface of the pediatric facial bones and the undeveloped and unaerated paranasal sinuses result in considerable more direct transmission of external forces to the skull and brain (potentially resulting in brain injury) and substantial less absorption of applied external forces by the paranasal sinuses [12].

Spinal Characteristics

The mechanisms of injury to the spine consist of hyperflexion, hyperextension, axial loading, axial rotation, and distraction. The younger the child, the weaker the neck muscles and relatively the bigger and heavier is the head in relation to the torso. The immature osseous structures of the cervical spine in infants and younger children are reflected by an anterior wedge-shaped morphology of the vertebral bodies, horizontal-oriented facet joints, and flat morphology of uncinate processes [14, 15]. The stability of the craniocervical junction and cervical spine in the pediatric population is more dependent on the ligaments compared to the osseous elements of the spine [12, 15]. This causes relative ease of vertebral subluxation with complete recovery of the bony elements to normal anatomical alignment. As a consequence, acceleration/deceleration and rotational

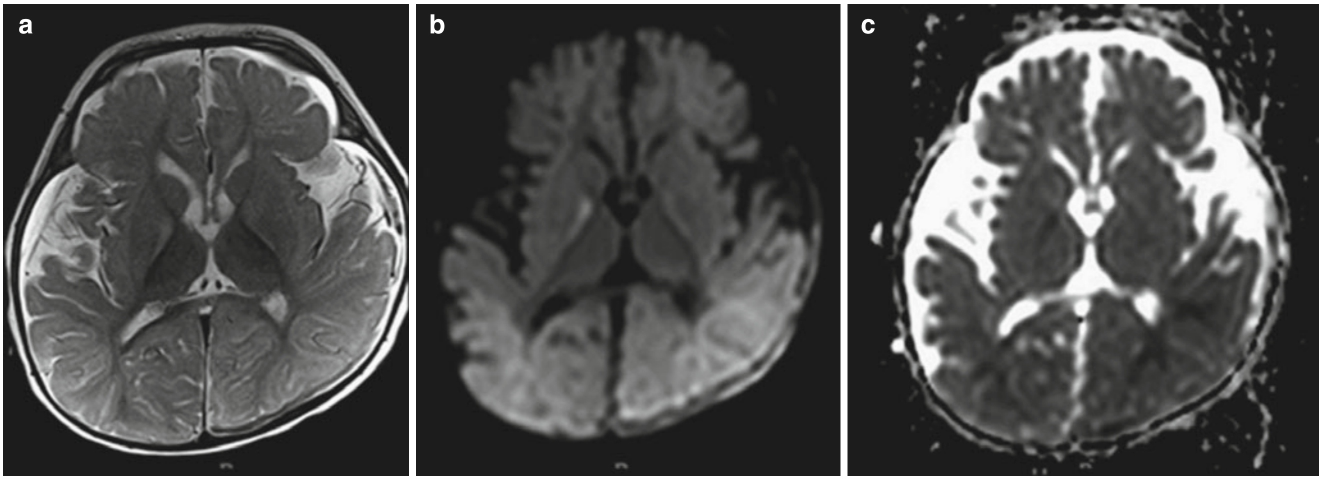

Fig. 3 Axial magnetic resonance images of a young infant exposed to inflicted injury with resultant concomitant hypoxic-ischemic injury. Axial T2-weighted MR image (**a**) shows bilateral hemorrhages along the convexities and focal shear injury of the splenium. Additional T2 hyperintense signal in the bilateral medial segment of the globus pallidus and diffuse T2 hyperintensity in the bilateral parieto-occipital brain parenchyma and adjacent cortex in conjunction with reduced gray-white matter differentiation are noted. Trace of diffusion MR image (**b**) and corresponding apparent diffusion coefficient (ADC) map (**c**) reveal acute hypoxic-ischemic injury with restricted diffusion in the bilateral medial segment of the globus pallidus, bilateral parieto-occipital white matter regions, and less pronounced in the bilateral frontal white matter regions

trauma (impulsive loading) of the spine in neonates and young infants have a potential to cause stretch injury particular to the cervical spine/spinal cord. Cervicomedullary cord damage (e.g., axonal injury) or vascular injury (e.g., epidural hemorrhage) potentially results in apnea or respiratory arrest ultimately leading to hypoxic-ischemic brain and spinal cord injury.

Secondary CNS injury is the consequence of various complex biochemical and physiological events in response to or as a complication of the primary CNS injury. The initiating traumatic event leads more frequent to hyperemic cerebral edema in the pediatric age group compared to adults, likely resulting from immature or impaired autoregulation of the pediatric brain perfusion, increased (immature) permeability of the blood-brain barrier, and an enhanced inflammatory response of the injured developing brain. Decreased cerebral arterial blood flow occurs more rapidly in children, because of a relative low baseline mean arterial blood pressure. Hypoxic-ischemic brain injury (Fig. 3) can result from global cerebral edema, focal compression of vascular structures due to herniation or mass effect of intracranial hemorrhages or from primary vascular injury. In addition, spinal injury with consequent asphyxia and compression of major cervical arterial vessels as well as chest compression (while the child is forcefully shaken) leading to hypoventilation or cardiac arrest can potentially result in hypoxic-ischemic brain injury (Fig. 4) [12]. Diastasis of remaining open sutures can prevent sudden and rapid rise of intracranial pressure to a certain degree.

The chronic sequelae of inflicted traumatic brain injury include, e.g., hydrocephalus, encephalomalacia, and CSF leak.

Age-Specific Patterns of Inflicted Injury

The traditional classical triad of inflicted brain injury due to impulsive loading includes subdural hematomas, associated brain abnormalities (encephalopathy), and retinal hemorrhages (Fig. 1). Additional related spinal, skeletal, and skin abnormalities are potentially present. The presence of the characteristic triad is no definite evidence of inflicted CNS injury in the absence of other corroborative findings. At present, apnea is considered the single critical distinctive feature for inflicted CNS injury compared to accidental neurotrauma. Retinal hemorrhages (severe grade) and rib fractures are considered as significant risk factors for inflicted brain injury [16]. The presence of a subdural hematoma in neonates and infants is more suggestive for inflicted brain injury compared to accidental injury [17].

Inflicted brain injury patterns depend on the type of loading mechanism and the impact of the specific mechanism related to the age of the affected child. Impulsive loading (e.g., "shaken baby phenomenon") with consequent diffuse axonal injury, white matter tear, or cleft and subdural hemorrhages are more frequent in neonates and infants. Occult damage to the brain due to inflicted injury is more frequently observed in children under the age of 1 year [18]. Impact loading (e.g., "beating up") causes more focal injury, e.g., skull fracture, cortical contusions, and epidural hematoma, in older children [12]. In addition, midface fractures are less prevalent in the young group.

Inflicted spinal injury demonstrates two distinct patterns of injury depending on the age of the affected child. Infants less than 1 year of age show a higher incidence of cervical

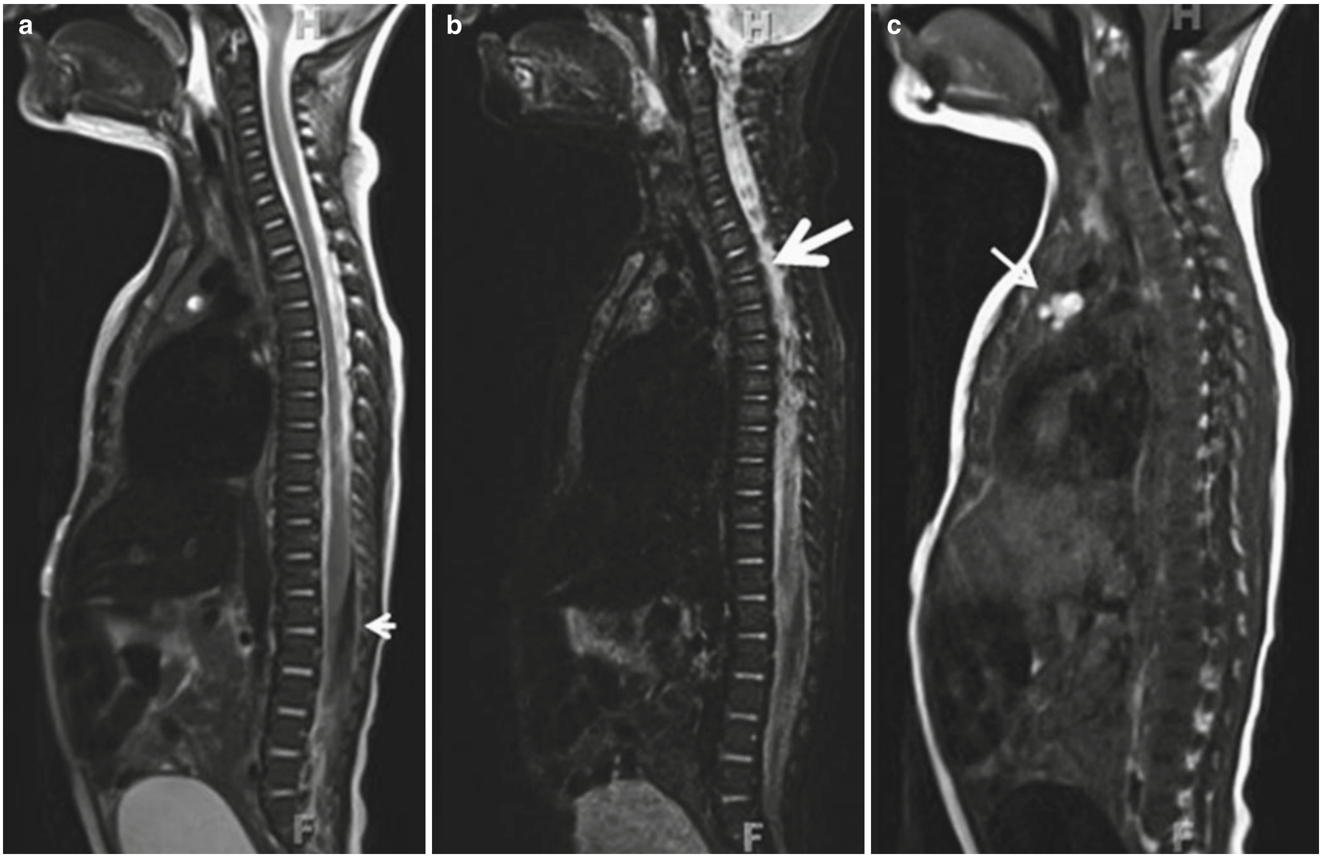

Fig 4 Sagittal midline T2-weighted MR image (**a**) shows an epidural hematoma in the posterior lumbar spinal canal (*white arrow head*). The sagittal STIR image (**b**) reveals a compression fracture at the level T2 (*white arrow*). In the sagittal T1-weighted image (**c**), a hyperintense mediastinal hematoma is demonstrated (*small white arrow*)

spinal cord injuries without osseous abnormalities (SCIWORA), potentially leading to instantaneous damage to the respiratory centers at the cervicomedullary junction, respiratory distress, and subsequent hypoxic-ischemic brain and spinal cord injury. The infants over 1 year of age present more common with thoracolumbar injury with visible spinal deformity and/or focal neurological signs (Fig. 4) [15, 19].

Imaging Findings of Inflicted Injury in the Brain

There is not one single radiologic finding pathognomonic or specific for inflicted brain injury.

The morphology of a skull fracture is not a discriminative factor to differentiate inflicted brain injury from accidental brain injury. Multiple or complex skull fractures are more frequently diagnosed in case of inflicted neurotrauma. Non-visualization of scalp or skull abnormalities on imaging studies should not be interpreted as absence of impact injury.

Subdural hemorrhage is the most frequent neuroradiological finding in the setting of inflicted brain injury as subdural hemorrhage is identified in about 80 % of the cases (Fig. 2) [8, 20]. The typical distribution in the pediatric age group is bilateral over the cerebral convexities, extending into the posterior interhemispheric fissure and into the posterior fossa. The interhemispheric subdural hematoma is not considered characteristic of inflicted injury. The typical characteristics of the different types of extracerebral hemorrhages (subarachnoid, subdural, epidural) can be obscured because of membrane layer disruption with subsequent merging of the features of various types of hemorrhage [13, 21].

Various other types of intracranial injuries are associated with inflicted neurotrauma, in descending order: diffuse axonal injuries, tear or cleft injuries, subarachnoid hemorrhages, intracerebral hemorrhages, and epidural hemorrhages [8].

Diffuse axonal injury demonstrates focal MR susceptibility artifacts and/or focal restricted diffusion (Fig. 1). If the lesions encountered on diffusion-weighted imaging are arranged within a vascular distribution rather than at the predilection sites of DAI, a vascular injury should be suspected. The severity grade of diffuse axonal injury, quantified by the number and volume of microhemorrhages on susceptibility-weighted imaging (SWI), correlates with the long-term neurologic outcome of the affected child [22, 23].

Diffuse cerebral edema, focal compression of vascular structures due to herniation or mass effect of intracranial hemorrhages, or primary vascular injury can result in hypoxic-ischemic brain injury.

The subacute to chronic sequelae of inflicted injury of the brain comprise hydrocephalus, atrophy, encephalomalacia, gliosis, mineralization, and chronic extracerebral fluid collections. Radiological imaging studies are an important tool in assessing a short-term and long-term prognosis for the affected child based on the severity of brain abnormalities.

Imaging Findings of Inflicted Injury in the Spine

The spectrum of injuries differs with degree of spinal development and therefore differs with age. Overall, the spine is not considered to be a common site of trauma due to inflicted injury. However, in the age group under the age of 2 years, inflicted injury is a relative frequent cause of spinal trauma [14]. The cervical spine, in particular the craniocervical junction and upper cervical spine, are predilection sites of inflicted injury to the spine in neonates, infants, and young children. The majority of inflicted spinal injury is associated with simultaneous injury to the brain [14, 15, 19].

Due to the immaturity of the spine and the consequent morphology and position of the vertebrae and laxity of the surrounding ligamentous structures, the pediatric cervical spine is at risk for spinal cord injuries without demonstrating osseous abnormalities, known as spinal cord injury without radiographic abnormality (SCIWORA). In addition, ligamentous injury of the cervical spine with lack of osseous involvement is a relative common inflicted injury. Furthermore, craniocervical subdural and epidural hemorrhage is reported in inflicted spinal injury in infants [15, 19]. Spinal fracture types associated with inflicted injury include vertebral body compression fractures (Fig. 4).

Imaging Findings of Inflicted Injury in the Rest of the Body

The most common findings concerning inflected injury are skin lesions (bruises, contusions). The second most frequent type of injury is fractures. The fractures potentially involve multiple sites and typically appear in diverse healing stages [24]. In particular, posterior and lateral rib fractures, spiral long-bone fractures, and metaphyseal fracture lesions are strongly associated with inflicted injury. Fractures inconsistent with the nature of the reported trauma or inappropriate for the age of the child are suggestive for inflicted injury. In neonate and infants, the fractures often coexist without any external physical findings or skin lesions. Therefore, the absence of external findings can at no time exclude inflicted injury.

Nonskeletal injuries to the chest, abdomen, and pelvis can occur in the setting of inflicted injury. Potential thoracic imaging findings are pleural effusion, lung contusion, chylothorax, hemopericardium, and cardiac contusion/laceration. Abdominal injuries detected on imaging include contusion/laceration of solid organs, injury to or rupture of bowel/bladder, mesenteric root injury, and (sequela of) pancreatitis [25].

Dating of the Imaging Findings of Inflicted Injury

There is a general impression that radiological imaging is able to date the demonstrated abnormalities to a certain accuracy. In medical decision-making, criminal investigations, and legal proceedings, dating of the imaging findings is a recurring issue.

The temporal evolution of intraparenchymal hemorrhages in general is reasonable consistent; however, the evolution of subdural hemorrhages is reported to be variable or not consistent [13, 17]. Recent literature reveals a wide range and broad overlap of the time intervals reported for the different appearances of subdural hemorrhages on CT and MR imaging studies. Hemorrhage with both CT hyperdense and hypodense features can indicate hyperacute hemorrhage or chronic hemorrhage with sign of rebleed. Intracranial hemorrhagic material may intermix with cerebrospinal fluid. In addition, the hemoglobin concentration of the blood affects the density of the acute hemorrhage. Particularly in the pediatric age group, no significant differences are established between the time intervals for the different CT densities of subdural hemorrhages [17]. A hypothesis for the distinct temporal evolution of parenchymal and subdural hemorrhages in children is the high oxygen tension in the subdural space caused by the vascularized dura [26]. As a consequence, CT or MR imaging appearances of subdural hemorrhages are inappropriate to accurately date the subdural hemorrhages.

The exact dating of fractures based on the presence of periosteal reaction, hard callus formation, or signs of remodeling is not sufficiently consistent to rely on. Therefore, dating of fractures is limited to differentiate recent from old fractures [24]. In addition, due to the membranous origin of the calvarial bones, skull fractures demonstrate lack of periosteal reaction in the healing process. The healing time of a simple linear skull fracture mandates up to 6 months in an infant and as long as 1 year in an older child [21]. Consequently, dating of a skull fracture is even less consistent and lacks the possibility of distinguishing recent from old fractures.

Differential Diagnosis of Inflicted Injury of the Central Nervous System

In regard of the fact that inflicted injury of the brain and spine is the most common cause of neurotrauma in the pediatric age group under the age of 2, the diagnosis of inflicted injury has to be considered in all children presenting to the medical care system with features of neurotrauma. Furthermore, in various non-neurologic and vague clinical settings, inflicted neurotrauma should always be in the differential diagnosis. Alternative hypotheses for the pattern of injury or clinical presentation have to be considered at all times. Follow-up or additional diagnostic workup may be necessary for differential diagnosis. Radiological imaging studies are important to demonstrate abnormalities associated with inflicted neurotrauma; on the other hand, these studies can reveal features of underlying disease clarifying the clinical presentation and imaging findings.

The differential diagnosis for intracranial hemorrhage and/or related brain abnormalities is extensive and comprises of congenital as well as acquired medical conditions. Birth trauma is a plausible differential diagnosis in the neonatal age group. Birth trauma is frequently causative for the development of subdural hemorrhages. These types of neonatal hemorrhages tend to involute completely within 4 weeks of age [24]. Another relative common condition to consider in the young age group is benign enlargement of the subarachnoid spaces. Furthermore, conditions causing hypoxic-ischemic injury (e.g., apnea, cardiac arrest, seizure), vascular abnormalities (e.g., arterial or venous thrombosis, AVM), infectious diseases, coagulation disorders (e.g., vitamin K deficiency), and metabolic disorders (e.g., glutaric acidosis type 1, Menkes disease) are appropriate differential diagnoses in all pediatric age groups. Connective tissue disorders (e.g., osteogenesis imperfecta) must be considered in case of multiple fracture sites. Alternative diagnoses have to be ruled out by knowledge of the medical history, complete clinical examination, or laboratory tests before trauma is considered as the possible diagnosis. To distinguish accidental trauma from inflicted trauma, detailed evaluation of the constellation of clinical and imaging findings in the context of the provided history is essential (Fig. 5).

Workup of Inflicted Injury of the Central Nervous System

The diagnosis of inflected CNS injury has to be approached with careful consideration of every available detail of current clinical symptoms and mode of presentation, complete medical and family history (including siblings), growth curve, physical examination, laboratory testing, radiologic

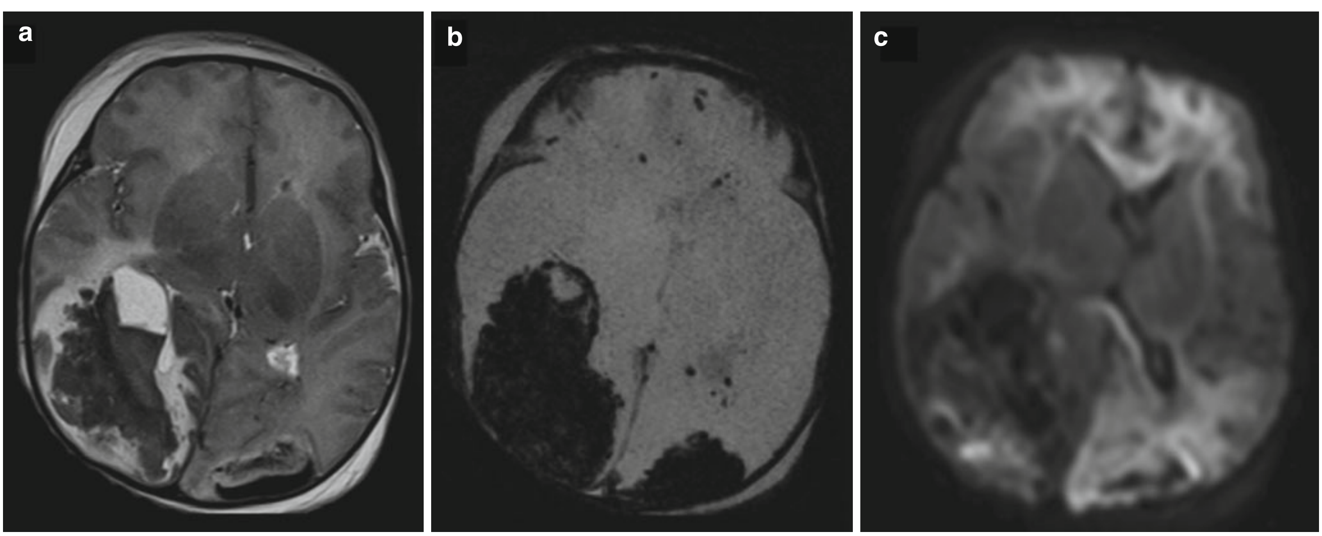

Fig. 5 Axial T2-weighted MR image (**a**), axial SWI MR image (**b**), and axial trace of diffusion MR image (**c**) in a child with liver failure and consequent coagulopathy. In addition, the patient was resuscitated from cardiac arrest. The axial T2-weighted image and SWI image (**a**) show extensive intraparenchymal hemorrhages in the right parieto-occipital region and to a lesser extent in the left parieto-occipital region. Subdural and subarachnoid hemorrhages are noted. The axial SWI image (**b**) reveals additional microhemorrhages scattered in the bilateral frontoparietal regions. On the axial trace of diffusion MR image (**c**), the extensive concomitant diffuse hypoxic-ischemic injury is best appreciated

evaluation, and assessment of possible risk factors. The workup is focused on identifying related injuries, evaluation of the pattern of injuries, detecting injuries of differing age, and exclusion of entities mimicking inflicted injury. One important issue is to determine if the described trauma or situation is considered adequate to cause and/or explain the presenting injury pattern.

Conventional radiography, CT, and MRI are complimentary imaging techniques in the context of suggested inflicted injury. The only available guideline for standardized overall use of different imaging modalities in inflicted neurotrauma is published by the Royal College of Radiologists (RCR) and the Royal College of Paediatrics and Child Health (RCPCH) in 2008 [6]. The time interval between the inflicted injury and the moment of presentation (acute or delayed) and the timing of the specific imaging modality are taken into account. The combined use of CT and MR imaging techniques enables more accurate detection, localization, and characterization of intracranial injury. The role of repeated CT or MR imaging studies is controversial and is completely dependent on the clinical situation of the affected child. The decision to image thoracoabdominal structures is based on the clinical presentation or concerning features on conventional radiographs. Depending on the anatomical region of concern and the age of the affected child, potential useful imaging studies include abdominal ultrasound and CT scan of chest and/or abdomen with intravenous contrast administration.

Computed Tomography

In the setting of (accidental or inflicted) traumatic injury to the CNS, CT is the first-line imaging modality of choice. Cranial CT offers reliable identification of skull fractures as well as intracranial pathology. The standard use of 3D reconstructions improves the detection of fractures even further (Fig. 2). Evaluation of the images in multiple window-level settings is essential to depict subtle hyperdense hemorrhages adjacent to the skull. Multiplanar reconstructions are recommended to include the craniocervical junction for evaluation of fractures, (sub)luxations, and hemorrhages. In any event of a child presenting with signs of abuse combined with signs of possible neurotrauma or retinal hemorrhages, a cranial CT imaging study has to be performed [6, 7, 20]. Due to the possibility of occult brain injury in young children, the ACR appropriateness criteria advise CT evaluation in "any child younger than 24 months of age and suspected physical abuse with or without focal neurologic signs or symptoms" [7]. The RCPCH/RCR guidelines recommend a CT study in "any child under the age of one where there is evidence of physical abuse" [6].

Spinal CT of the cervical or thoracolumbar spine is recommended if there is clinical or radiographical suspicion for vertebral fracture or dislocation.

Magnetic Resonance Imaging

MR imaging of the brain is less sensitive for detection of acute hemorrhage in comparison with CT [20]. Additional long scan times, limited availability, and the potential need for general anesthesia or sedation in the pediatric population result in the use of MR imaging as second-line imaging tool in the setting of inflicted injury of the brain and spine. The importance of complementary MR imaging of the brain is highlighted by detection of additional imaging findings in 25–30 % of inflicted injury cases [20, 23] due to the superior contrast resolution of MRI versus CT. MRI gives a detailed picture of potential parenchymal injury (e.g., diffuse axonal injury) and offers valuable information about the character and time evolution of intracranial hemorrhages. Furthermore, MRI demonstrates more detailed visualization of the posterior fossa structures. The published standard of the RCPCH/RCR for MR imaging of the brain and spine in case of suspected inflicted CNS injury offers different imaging protocols depending on the acute or non-acute presentation of the affected child [6]. The American College of Radiology and Society of Pediatric Radiology (ACR/SPR) and the RCPH/RCR recommend T1- and T2-weighted sequences, gradient echo or susceptibility-weighted sequences, and diffusion-weighted sequences as minimal imaging protocol. MRI has superior ability in monitoring the pattern of cascade of secondary brain injury compared to CT. If the abnormalities demonstrated with conventional imaging techniques do not adequately explain the neurological deficits, the added value of advanced functional imaging techniques, like DTI and fMRI, is emphasized.

In neonates and infants, MR imaging of the cervical spine is advisable to add to the standard MR imaging of the brain, because of the relative high risk of inflicted spinal cord injury of the cervical spine without radiographic abnormality (SCIWORA). The low threshold for MR imaging of the cervical spine is all the more important because upper cervical injuries typically demonstrate lack of external signs in this young age group.

MR imaging of the thoracolumbar spine is recommended if there are clinical features or findings on conventional radiographs suggesting thoracolumbar spinal injury.

Conventional Radiography

The role of conventional radiography in inflicted CNS injury is focused on the skeletal survey to confirm clinical evident conditions, detect potential occult trauma, and reveal and identification of underlying disease processes. Because of the importance of the detected skeletal abnormalities in supporting or rejecting the diagnosis of inflicted injury or potential alternative diagnoses, it is of major concern to perform the skeletal survey according to international guidelines. The most recent guidelines (2014) of the ACR/SPR and the 2008 guidelines of the RCPCH/RCR have reached consensus about the skeletal survey protocol [6, 7]. The skull radiograph is a consistent and obligatory part of the skeletal survey in both guidelines (regardless of performing a CT scan of the skull and brain). In case of equivocal imaging findings or persistent clinical suspicion, a repeat skeletal survey after 14 days is recommended. The follow-up skeletal survey excludes the skull radiograph due to the absence of periosteal reaction in the healing process of skull fractures. The use of whole-body MR imaging instead of standard skeletal survey is discouraged as a consequence of to the low sensitivity in detecting inflicted injury-related skeletal abnormalities. In particular situations, site-specific MR imaging proves to be useful for further evaluation and characterization of abnormalities [24].

Ultrasound

Ultrasound of the pediatric skull and brain is not routinely used in the diagnostic workup of inflicted brain injury. The structures located in the periphery of the brain and in the extra-axial spaces, under the convexity of the skull, being exact the areas of major concern in the workup of inflicted CNS injury, are difficult or impossible to visualize by means of cranial ultrasonography. In specific cases, ultrasound of the brain is useful for establishing a suspected alternative diagnosis (e.g., benign enlargement of the subarachnoid spaces) or for follow-up of already identified intracranial pathology.

Making the diagnosis of inflicted injury has major social, psychosocial, and legal consequences. Therefore, the used medical terminology must accurately reflect the medical diagnosis. The radiology report should include a detailed factual and objective description of the imaging abnormalities, as well as the pattern, distribution, and severity of the abnormalities. The relevant differential diagnoses have to be included in the report. A remark regarding the quality of the study and the adherence of the study to international guidelines has to be incorporated. In case of suspected inflicted injury based on radiological imaging findings, immediate communication with the responsible clinician is essential for the safety of the affected child and the siblings [20].

The consequential ethical and legal mandates to report suspected inflicted injury to authoritative institutions for further investigation and intervention in the form of child protection procedures are of particular importance. Non-diagnosis or delayed diagnosis in the case of child abuse potentially has severe consequences for the involved child as well as the siblings.

A multidisciplinary approach to child abuse is essential in order to deal with and resolve this specific medical entity in the best possible way.

Conclusion

Timely recognition and early identification of features suggestive for inflicted injury are essential to minimize the consequences of primary injury to the brain and spine and limit or prevent the occurrence of secondary CNS injury. A multidisciplinary approach to child abuse is essential. Radiological imaging plays a crucial role in the detection of physical child abuse. The imaging studies can provide confirmatory evidence of inflicted injury or, on the other hand, contribute by narrowing down a differential diagnosis. If the diagnosis of inflicted injury is not considered or delayed, involved children and siblings are at high risk of repeated abuse. In case inflicted injury is suspected, an appropriate referral to child protection programs should be made as soon as possible.

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