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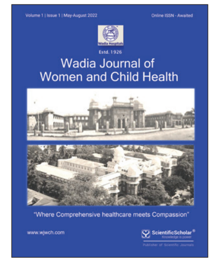

Pictorial Essay

Role of neuroimaging in pediatric head trauma

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Received : 03 August 2022
Accepted : 28 September 2022
Published : 17 November 2022

DOI
10.25259/WJWCH_15_2022

ABSTRACT

Pediatric head trauma is very common and accounts for most of the emergency hospital visits. It is also the most common cause for a pediatrician to refer a child for neuroimaging. Pediatric head injury causes lot of morbidity and mortality in children and can be due to accidental or abusive injury. Falls are most common in small children, whereas motor vehicle accident is more common in older children and adolescents. Pediatric brain injury differs from adult brain injury due to immature brain, mechanism of injury, and difficulty in neurological evaluation in children. The radiologist needs to be familiar with these to correctly interpret the scans and guide clinicians in appropriate patient care.

Keywords: Head trauma, Fractures, Extra-axial hemorrhages, Abusive head injury, Contusions

INTRODUCTION

Pediatric head injury is common and causes lot of morbidity and mortality in children and can be due to accidental or abusive injury. The role of radiologist is to identify the injury and grade the severity and guide clinician in appropriate patient care.[1]

IMAGING MODALITIES

Computed tomography (CT) scan is the modality of choice in imaging of acute head injury as it is readily available, less time consuming, and less expensive. It is indicated in severe head injury with altered sensorium or neurological deficits or in cases of suspected abusive head injury.[2] Furthermore, 3D CT scan can better visualize the calvarial fractures as compared to any other modality. However, CT scan utilizes ionizing radiation to which children are most sensitive and susceptible. Although the benefits of CT outweigh the risks, it is imperative to reduce the dosage of radiation as much as possible. Magnetic Resonance Imaging (MRI) is utilized in identification of additional or subtle injuries or for follow-up scans. In patients with minor head injury with no loss of consciousness or neurological deficits, imaging is not warranted and should be avoided.[3] Patients with subacute or delayed presentation require an MRI.

This pictorial essay discusses important CT and MRI findings and patterns of pediatric head injury. We have included:

i. Bony injuries, i.e., calvarial/orbital/skull base fractures
ii. Extra-axial hemorrhages, i.e., extradural/subdural and subarachnoid hemorrhages

How to cite this article: Gala F, Manek H, Bharati A. Role of neuroimaging in pediatric head trauma. Wadia J Women Child Health 2022;1(2):111-9.

iii. Parenchymal injuries, i.e., cortical contusions and diffuse axonal injury (DAI)
iv. Abusive head trauma (AHT), and
v. Birth-related injuries

Bony injuries

Calvarial fractures: There are multiple primary and accessory sutures in children; hence, diagnosis of calvarial fracture is challenging. Although the pediatric calvarium is resistant to fracture as compared to adults, fractures are not uncommon in children. The sutures have zig zag margins, occur at predictable location, and have sclerotic margins. The primary sutures are midline sagittal, paired coronal and lambdoid, and anteriorly single metopic suture between frontal bones [Figure 1]. The paired squamosal suture extends from pterion anteriorly to junction of lambdoid and occipitomastoid suture posteriorly. Both parietal and occipital bones have more accessory centers; so, accessory sutures are seen here. Sutures merge with each other whereas fracture lines may cross the suture to extend into another bone or can cause widening between sutures resulting in diastases [Figure 2]. Fractures appear as linear lucency and the scans have to be reviewed in at least two planes to avoid missing fracture which is oriented in plane of imaging.[1]

Depressed fractures [Figures 3 and 4] are characterized by inward displacement of calvarium at the impact site. More the depression, more chances of brain parenchymal injury. Often, in pediatric patients, there is depression of calvarium without fracture lucency called as ping pong fracture [Figure 5].

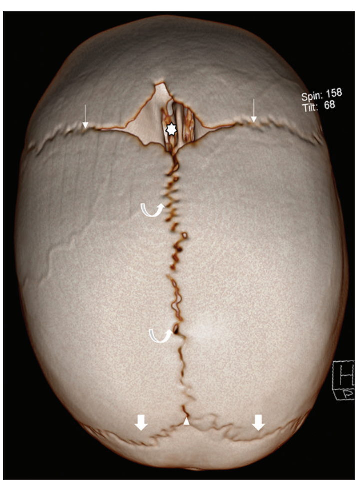

Figure 1: Normal sutures and fontanelles: Volume rendered (VR) image of the cranial vertex in a 1-year-old child depicts the anterior fontanelle (star) at the junction of the sagittal (curved arrows), coronal (straight thin arrows) sutures. The fused posterior fontanelle (triangle) at the junction of sagittal and lambdoid (thick arrows) sutures.

Fractures may involve paranasal sinuses/orbital walls/mastoids or skull base [Figures 6 and 7]. There may be associated hemosinus/hemotympanum and hemomastoid, and pneumocephalus.

Extra-axial hemorrhages may include

a. Extradural hemorrhage
b. Subdural hemorrhage
c. Subarachnoid hemorrhage

Acute hematomas are hyperdense on plain CT images, isodense in subacute stage, and appear hypodense in chronic stage.

a. Extradural hematoma or epidural hematoma: Is located between the dura mater and periosteum [Figures 8-10]. These appear biconvex in shape and can cross the midline but do not cross sutures as dura is firmly attached at sutures. The epidural hematoma occurs due to injury to epidural arteries most common middle meningeal artery or to dural venous sinuses when the epidural hematoma may cross the sagittal suture or tentorium. Epidural hematoma may cross the suture if there is injury to dura mater. Heterogeneous appearance of hematoma can occur due to clotted and unclotted blood and also in active bleeding when swirling pattern is seen. Surgical intervention is needed as these cause mass effect and neurological decline.
b. Subdural hematoma: It is located between dura and arachnoid mater. These are crescentic and can cross the sutures, however do not cross midline [Figure 11]. These occur due to injury to cortical bridging veins. Subdural hematomas can also occur in interhemispheric fissure or along tentorium. Treatment depends on the size and amount of mass effect and neurological status of child.
c. Subarachnoid hemorrhage: It is located between the arachnoid and pia mater. It is seen as hyperdensity in basal cisterns or sylvian fissures or cortical sulci [Figures 12 and 13]. Diffuse cerebral edema can also result in hyperdensity in basal cisterns due to vascular engorgement mimicking subarachnoid hemorrhage without actual bleed [Figure 14].[4]
d. Intraventricular hemorrhage: Very rarely post-traumatic isolated intraventricular hemorrhage may be seen [Figure 15].

Parenchymal injuries

a. Cortical contusions: The impact of brain parenchyma against calvarium or falx cerebri can result in cortical contusions which often extend deeper to involve subcortical white matter. These are uncommon in children as compared to adults as the calvarium is less rigid. Common locations include inferior frontal lobes and anteroinferior temporal lobes along anterior and middle cranial fossae, respectively, and parasagittal location adjacent to falx. These can be at site of impact (coup) or diagonally opposite (contra coup) [Figure 11].

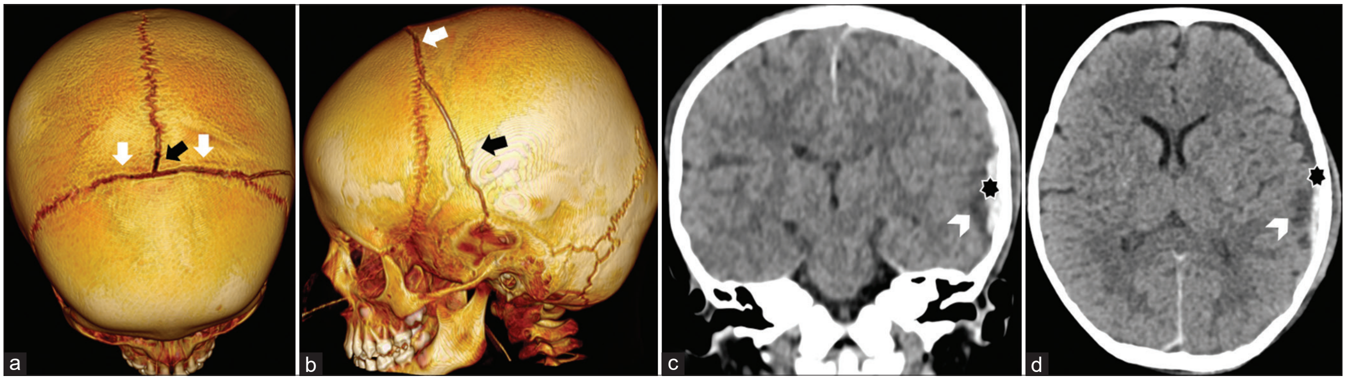

Figure 2: Sutural diastasis in a 3-year-old child: VR image at the cranial vertex (a and b) reveals abnormal widening of bilateral coronal sutures (white arrows) with small extension into sagittal suture and the left parietal bone (black arrow). Axial and coronal computed tomography (CT) image in brain window (c and d) show extradural hemorrhage (star) and parenchymal contusions (arrowhead) with overlying scalp hematoma.

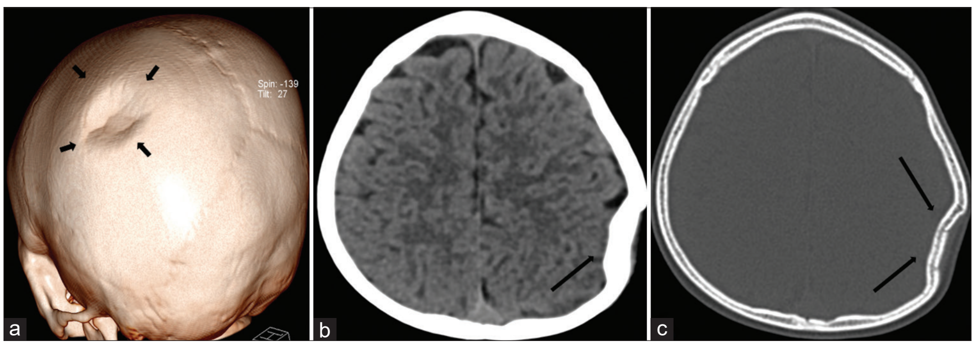

Figure 3: Depressed calvarial fracture without intracranial injuries in a 4-year-old child. VR image (a) and axial CT image in brain and bone windows (b and c) show a depressed comminuted left parietal bone fracture with inward angulation (black arrows).

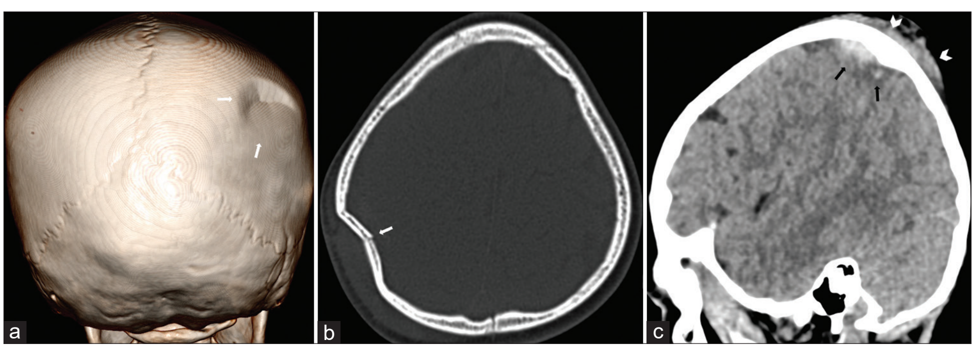

Figure 4: Depressed calvarial fracture with intracranial injuries in a 6-year-old child. VR image of skull (a), axial (b) image in bone, and sagittal image in brain window (c) show a depressed right parietal bone fracture with inward angulation (white arrows) associated epidural hematoma with parenchymal contusions (black arrow) and a superficial scalp hematoma (arrow heads).

On CT images, these are seen as hypodense edema or small foci of hyperdensities [Figures 2 and 4]. MRI with susceptibility-weighted imaging has much higher sensitivity in diagnosing these [Figure 16].[1]

b. Subpial hemorrhage: It occurs in the subpial space which is bounded by pia mater and external glial limiting membrane (outermost layer of neocortex). There is always an associated some amount of cortical injury as there is no absorption of blood from this space as compared to subarachnoid hemorrhage which can diffuse into CSF and subsequently be absorbed. Subpial hemorrhage can easily be mistaken for subarachnoid

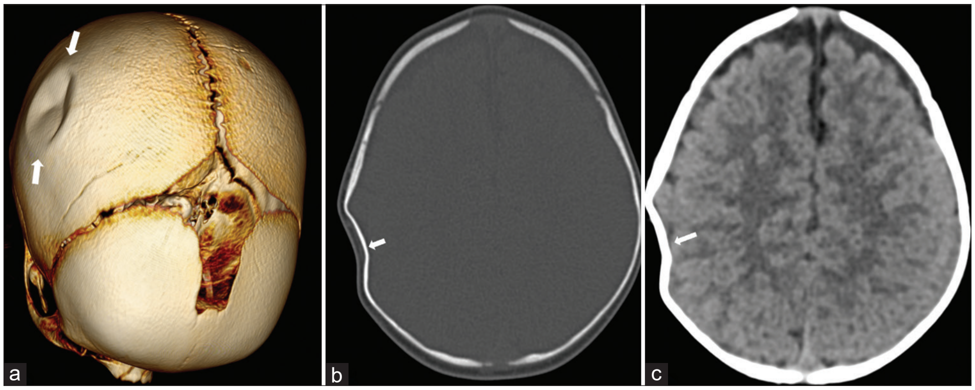

Figure 5: Ping pong fracture in 6-month-old girl: VR image of the skull (a) and axial image in bone (b) and brain window (c) show focal depression involving the right parietal bone without a discernible fracture lucency (white arrow).

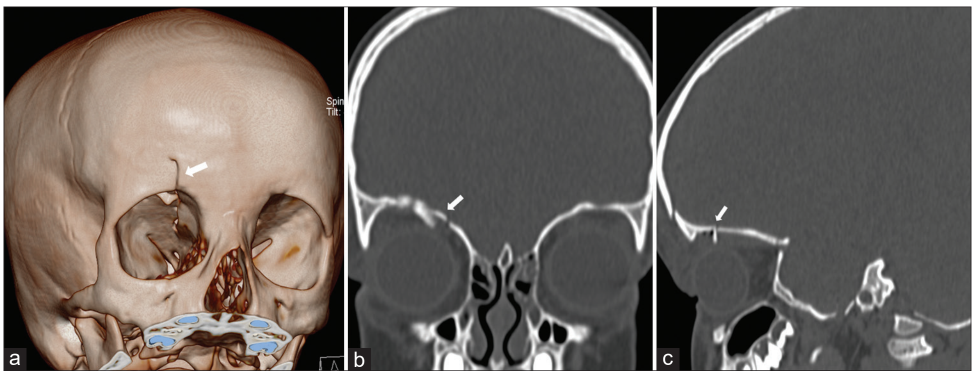

Figure 6: Orbital roof fracture in a 4-year-old boy: VR image (a) and coronal and sagittal sections brain window (b and c) show a displaced fracture of the roof of the right orbit (white arrows).

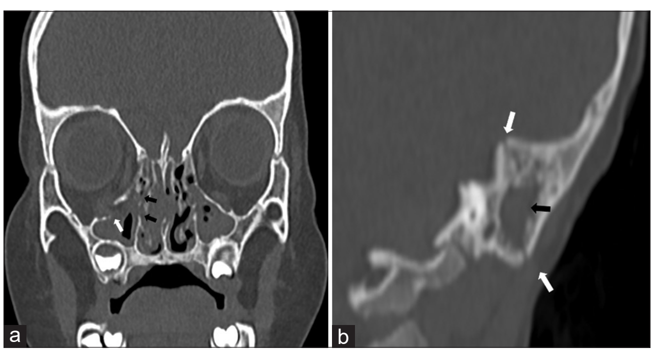

Figure 7: A 2-year-old with orbital and temporal bone fractures: Coronal image in bone window (a) shows fracture of the right orbital floor (white arrow) and medial wall of the right maxillary sinus (black arrows) with hemosinus. Coronal section of the left temporal bone in bone window (b) shows vertical fracture line through mastoid (white arrows) with hemomastoid (black arrow).

hemorrhage [Figure 12]. It is commonly seen in neonatal period and can occur in birth injury, perinatal asphyxia, fetal head molding, clotting disorders, or in abusive head injury. On imaging, subpial hemorrhages appear ellipsoid or semi-elliptical in shape, and displace the underlying cortex. These hemorrhages are opposed to gyral and sulcal edges and cause mass effect on the cortex.[5]

c. Diffuse Axonal Injury (DAI): DAI is the most severe type of the primary brain injury occurring in high-speed motor vehicle accidents due to sudden rotational accelerating and decelerating motion resulting in shearing of nerve fibers. These occur at gray-white matter junction as cortex and white matter have different densities and rotate at different speeds leading to stretching of axons. It may present with unconsciousness and result in neurological deficit.[6] MRI with susceptibility weighted imaging (SWI) and diffusion weighted imaging (DWI) sequences is extremely useful in grading DAI. Grade 1 is characterized by involvement of lobar white matter near gray-white matter junction. Grade 2 is lobar white matter plus corpus callosum with preferential involvement of body and splenium, whereas Grade 3 is lobar white matter, corpus callosum, and brainstem/superior cerebellar peduncles.[7] DAI can be hemorrhagic or non-hemorrhagic [Figures 16 and 17].

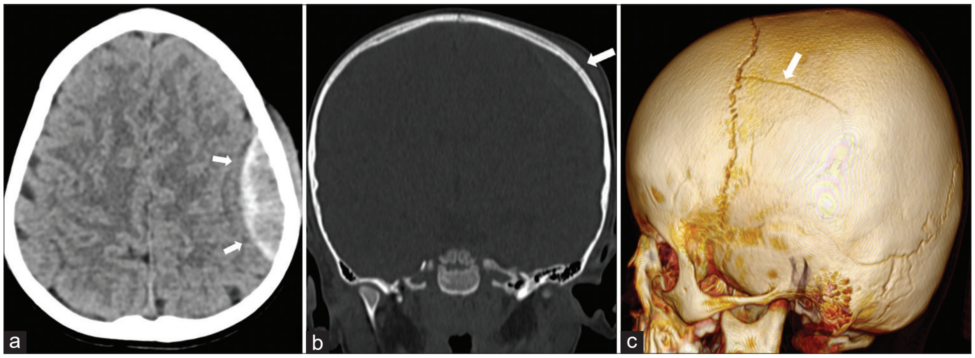

Figure 8: A 3-year-old boy with extradural hematoma and fracture: Axial non-contrast CT image in brain window (a) reveals lenticular/biconvex hyperdense epidural hemorrhage (white arrows) overlying the left parietal lobe. Coronal image in bone window (b) and VR image of skull (c) shows an undisplaced left parietal bone fracture (white arrows).

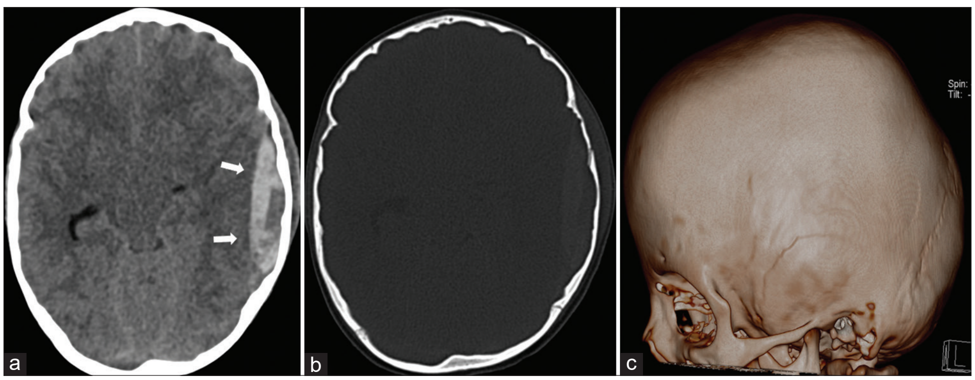

Figure 9: An 8-year-old girl with epidural hematoma without fracture: Axial non-contract image in brain (a), bone (b) windows reveal a lenticular/biconvex hyperdense epidural hemorrhage (white arrows) overlying the left temporal lobe. VR image of skull (c) shows no fracture line.

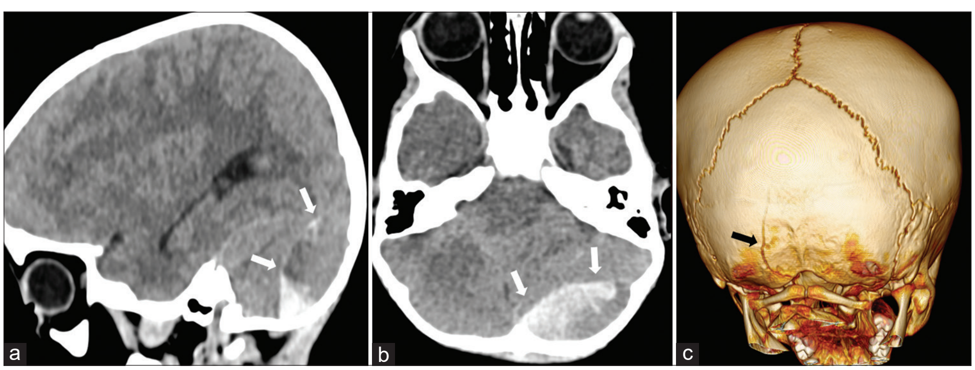

Figure 10: Active epidural hemorrhage with a swirling pattern in a 2-year-old boy. Sagittal (a) and axial (b) CT images of brain show heterogeneous density biconvex epidural hematoma in posterior fossa indenting the left cerebellar hemisphere with a swirling pattern, worrisome for active hemorrhage. VR image of the skull (c) shows undisplaced fracture of overlying occipital bone (black arrow).

Abusive Head Trauma (AHT)

AHT or shaken baby syndrome have been synonymously used to describe the non-accidental injuries in children. The mechanism of injury can be shaking and/or shaking with impact or blunt impact alone, hence, term AHT has been recommended by Committee on Child Abuse and Neglect of American Academy of Pediatrics in 2009. AHT causes lot of morbidity and mortality in children and diagnosis of these cases needs a high degree of suspicion. The characteristic triad of AHT includes subdural hematoma, retinal hemorrhage and hypoxic ischemic encephalopathy. Both CT and MRI are useful in evaluation of AHT. CT scan will show skull fractures with focal scalp swelling and underlying hematoma due to direct impact, subdural hemorrhages of varying duration and at atypical locations – along interhemispheric fissures/posterior fossa, occurring due to tear of bridging veins in children subjected to rotational and acceleration-deceleration forces. Subarachnoid hemorrhages are the second most common after subdural hemorrhages. Axonal injuries also occur in these kids. Subdural hemorrhages may show membranes or internal septations suggesting chronicity. There may also be thrombosis of bridging veins. Fractures seen with AHT may be multiple, stellate, and bilateral fractures that extend across sutures, and without an appropriate history. Retinal hemorrhages are also common and need fundoscopy for diagnosis.[8] MRI is useful in assessing these injuries due to better soft-tissue resolution. With more severe AHT, hypoxic ischemic injury may be seen which is characterized by restriction on DWI images [Figure 12]. Other injuries include fractures in cervical

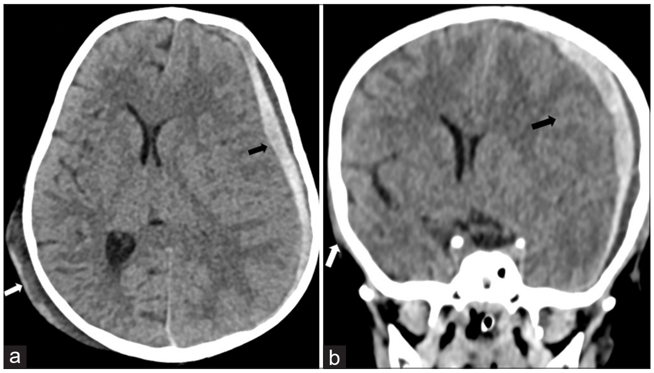

Figure 11: A 3-year-old child with acute on chronic subdural hematoma and scalp hematoma on opposite side suggestive contrecoup injury. Axial and coronal CT images in brain window show a hyperdense crescent-shaped subdural hemorrhage overlying the left cerebral hemisphere (black arrows) and scalp hematoma on the opposite side (white arrows).

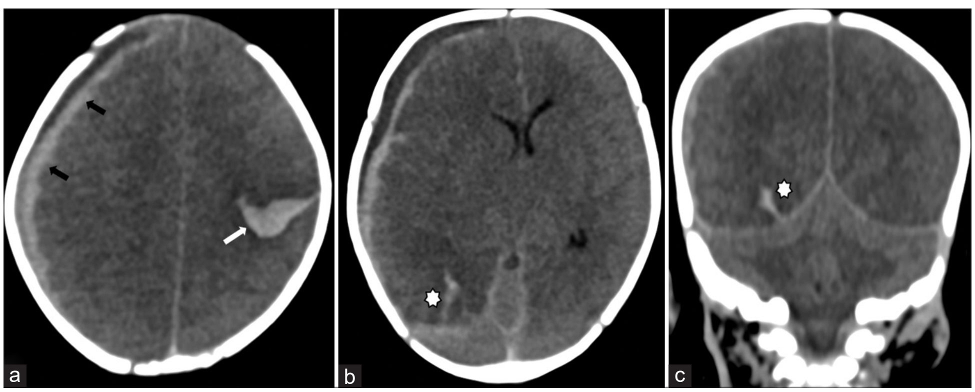

Figure 12: Abusive head injury: axial (a and b) and coronal CT (c) images in a 3-month-old girl child showing right frontoparietal (white arrow) convexity acute on chronic subdural hematoma (black arrow), left parietal subpial hemorrhage, subarachnoid hemorrhage (asterisk) with diffuse cerebral edema. White cerebellar sign on coronal image is seen. These findings are suspicious for abusive head injury.

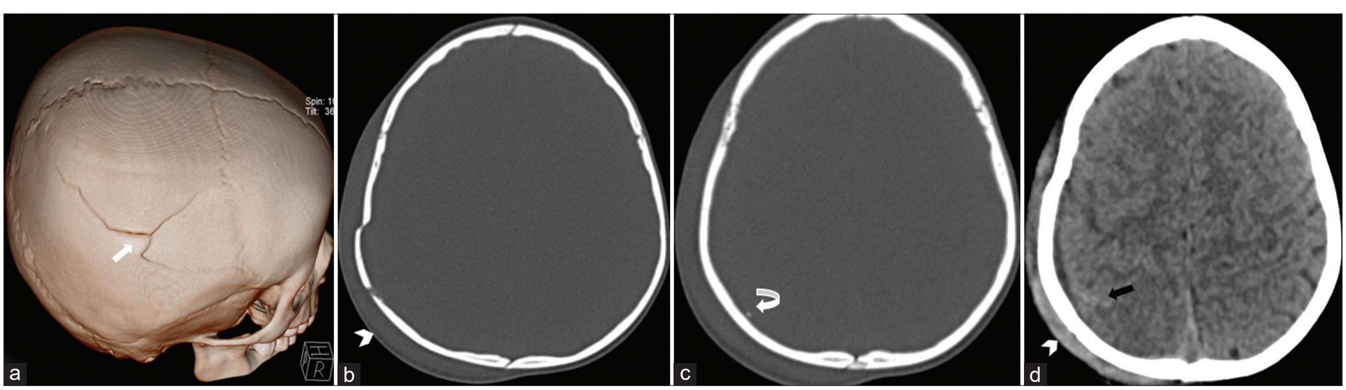

Figure 13: Post-traumatic subarachnoid hemorrhage in a 3-year-old girl: VR (a) and axial section of skull in bone (b-c) and brain (d) window show comminuted mildly displaced fracture of the right parietal bone (white arrows) with underlying subarachnoid hemorrhage (black arrow) in the right post central gyrus and overlying scalp hematoma (arrow head). Small fracture chip is seen in extradural fluid (curved arrow).

spine and cervicovertebral junction, metaphyseal lesions, and posterior rib fractures.

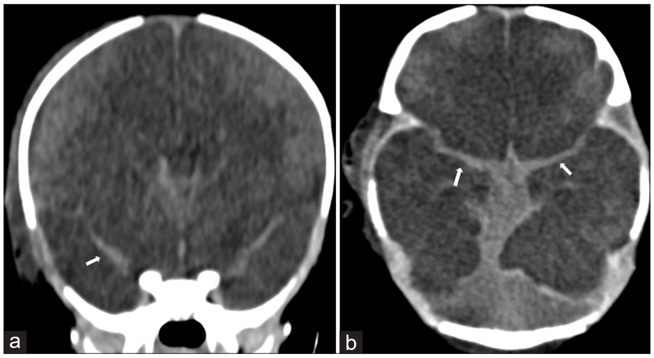

Figure 14: A 2-day-old boy with perinatal hypoxic ischemic injury. Pseudo subarachnoid hemorrhage in neonate showing extra-axial hyperdensity (white arrow) mimicking subarachnoid hemorrhage due to vascular engorgement, CSF effacement, and adjacent parenchymal hypodensity.

Birth related injuries

These injuries occur due to birth process and are mostly seen with assisted vaginal deliveries than with cesarean section. These are better evaluated with USG; however, cross-sectional imaging may show these when neonate is imaged for some other cause. These can be extracranial or intracranial [Figures 18-20].

Extracranial hemorrhages can be of three types:

a. Caput succedaneum: This is scalp hemorrhage superficial to galeal aponeurosis. It occurs due to local venous congestion caused by pressure of presenting part of scalp against dilated cervix during delivery. It may cross the midline and is self-limiting.
b. Subgaleal hemorrhage: This type of scalp hemorrhage occurs deep to galeal aponeurosis and superficial to the periosteum. It can also cross the midline and may extend into soft tissues of neck/orbit when large. These result from injury to emissary veins during instrumentation and assisted delivery (vacuum/forceps

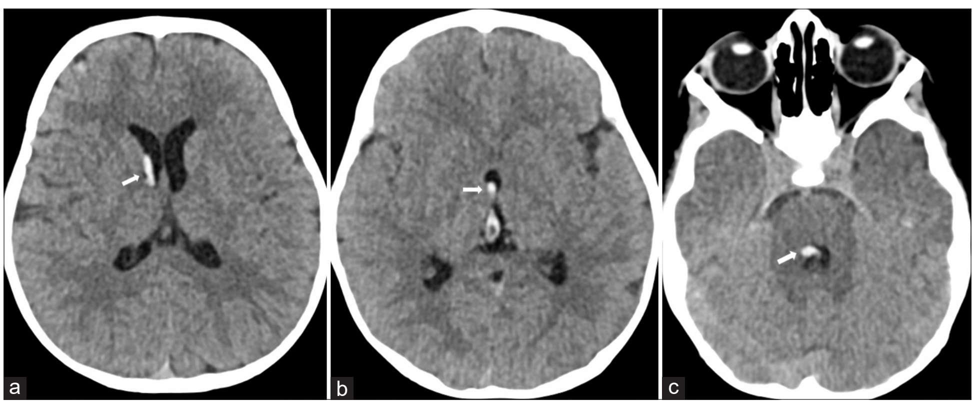

Figure 15: A 1-year-old child with post-traumatic intraventricular bleed. Axial images (a-c) of the CT brain show multiple foci of hyperdensity (white arrows) within the lateral, third, and fourth ventricles without hydrocephalus suggestive of intraventricular bleed.

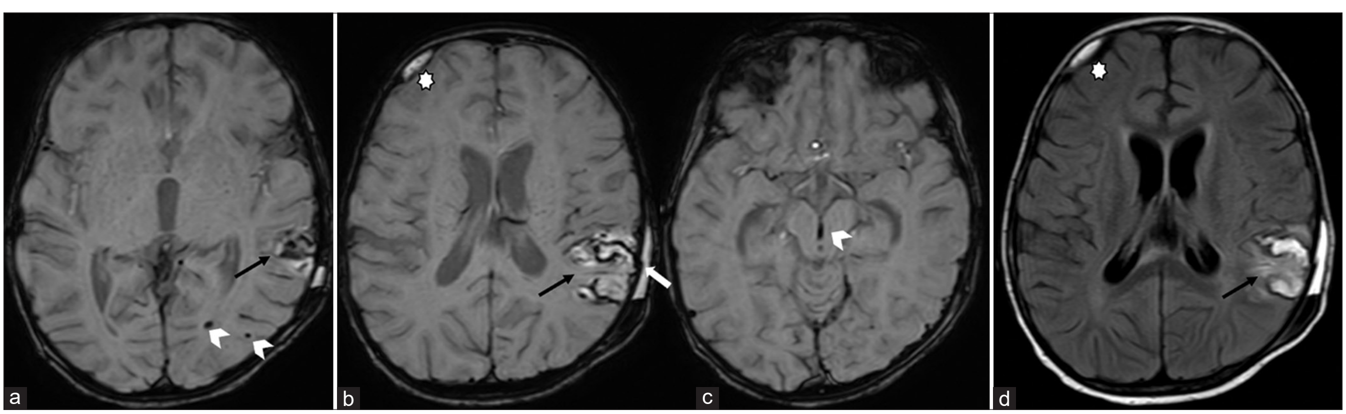

Figure 16: SWI (a-c) and Flair (d) axial images in 1-year-old boy who had trauma show parenchymal contusion in the left parietal lobe (black arrow) with overlying fracture and scalp hematoma (white arrow). Tiny microhemorrhages are seen in the left posterior periventricular white matter, midbrain (arrowhead) suggestive of DAI. Small right frontal extra-dural hematoma (star) is seen due to contrecoup injury.

delivery). These are also self-limiting and usually resolve within weeks.

c. Cephalohematoma: These are subperiosteal hemorrhages which are limited by bones and do not cross sutures. These also occur due to prolonged labor and instrumental delivery. These hematomas occur as a result of rupture of blood vessels traversing from skull to periosteum. They usually resolve spontaneously within 3 months. In case these however can persist for a long time calcification may occur resulting in contoural deformity.[9]

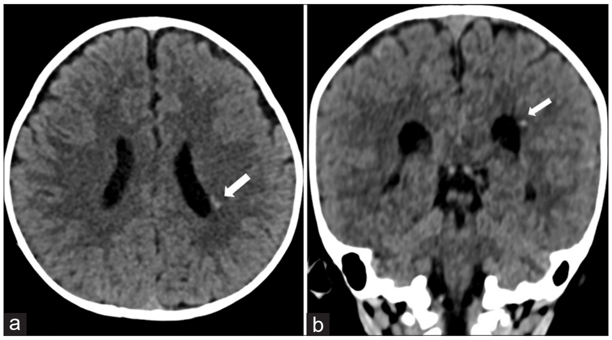

Figure 17: Hemorrhagic diffuse axonal injury on CT. Axial (a) and coronal (b) CT image demonstrates multiple tiny hemorrhagic foci in the left periventricular white matter (arrow).

d. Skull fractures may occur as a result of instrumented vaginal deliveries. The fractures can be linear or depressed and are asymptomatic unless associated with intracranial injury.

e. Intracranial hemorrhages: Epidural hematoma is rare and may be associated with calvarial fracture. Subdural hematoma is the most common type of intracranial hemorrhage due to birth injury. These occur, most commonly, along cerebral convexities posteriorly, along interhemispheric fissure and tentorium and also along posterior fossa.[10]

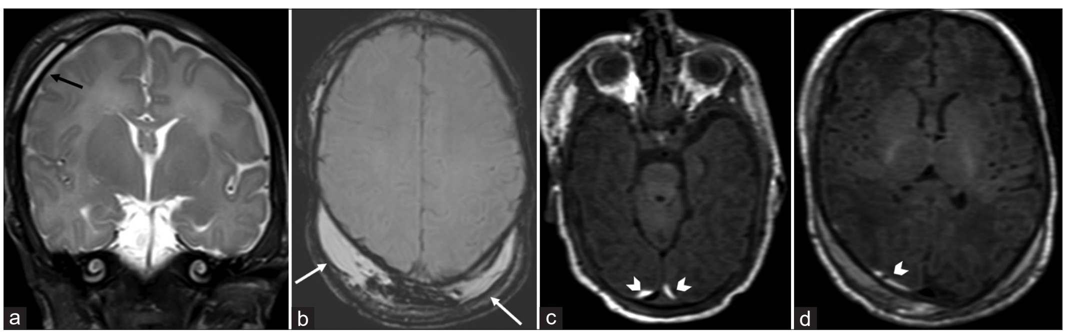

Figure 18: Birth injuries: Vacuum delivery: Coronal T2W (a), axial SWI (b), and T1W (c and d) MRI images in a 7-day-old with cephalohematoma along right frontoparietal region (black arrow) and large caput succedaneum in bilateral parieto-occipital region (white arrow). Extradural hemorrhages along posterior parieto-occipital convexities (arrowhead).

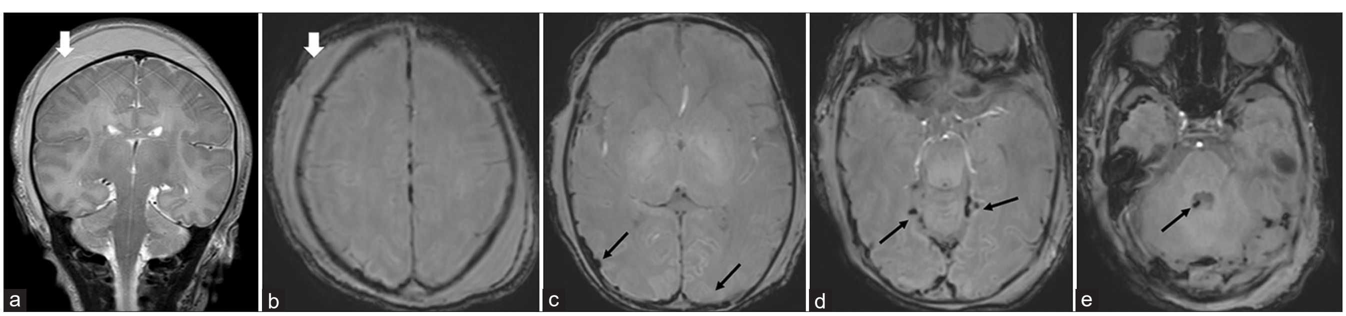

Figure 19: Coronal T2w (a) and axial SWI (b-e) images in 2-day-old show large subgaleal collection with extension into neck (white arrow) post forceps delivery. Also note hemosiderin staining along bilateral parieto-occipital dura mater, tentorial cerebelli, and around wall of 4th ventricle (black arrow).

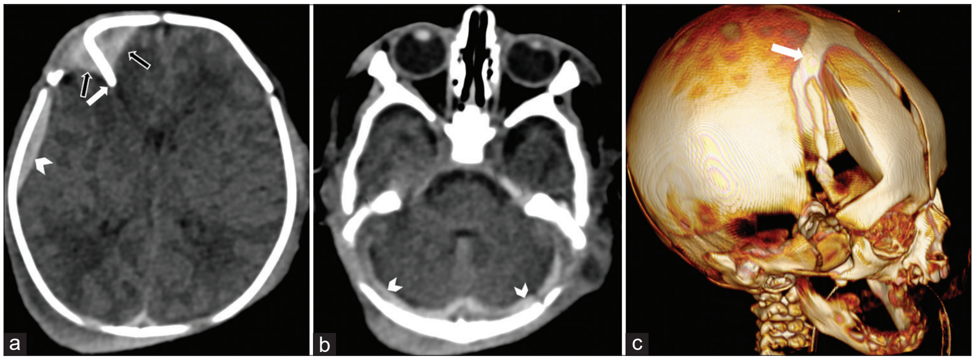

Figure 20: Comminuted depressed fracture in post forceps delivery in 1-day-old child: Axial (a and b) and VR CT images (c) of brain showing comminuted depressed fracture (white arrows) of the right frontal bone with underlying epidural hematoma with parenchymal injury (black arrow) and subdural hemorrhages in posterior fossa (arrowhead).

CONCLUSION

Imaging plays an important role in diagnosis of pediatric head trauma. An emergent CT head is useful in the diagnosis of skull fractures and intracranial bleed. MRI brain is preferred in patients with DAI and in suspected cases of AHT.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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