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ORIGINAL ARTICLE

Neuroimaging in Pediatric Age - An Overview.

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Abstract

Neuroimaging in pediatric age-group has multiple indications ranging from antenatal to postnatal causes. It includes brain and spine imaging, utilising primarily high-resolution ultrasonography to magnetic resonance imaging. This field is developing as a subspecialty in the field of imaging. This article not only discusses multiple imaging modalities but also their role in variety of pathological conditions related to central nervous system.

Introduction

Paediatric Neuroimaging is progressively developing subspecialty in the field of Radiodiagnosis & Imaging; focussing on the role of Imaging in getting a clue into day to day clinical as well as emergency conditions and on their management. There is a whole series of imaging based investigations targeting the neurogenic, brain & spine oriented, conditions with advances in the field towards targeted diagnostic imaging. Choice of imaging modality depends on the presenting complaint/ disease under consideration, age of the child (newborn/ infant/ early childhood) as well as severity of the disease.

Cranial Ultrasonography/ Neurosonography

It is the first line of investigation in selected condition and will remain as the most convenient and non invasive diagnostic tool in imaging. Translation of brain anatomy into the sonographic examination of the neonatal brain remains an invaluable tool in initial assessment and applies normal sonographic principles. Many specific clinical questions can be resolved by optimally utilizing this simple informative tool. The primary advantages of the Neurosonography rely on its portability, lack of need to transport baby and the ease of availability. The amount and quality of the information acquired from the study can be immensely useful for diagnosis, outcome and prognosis [1]. The use of ultrasound has grown leaps and bounds, in every aspect of neuroimaging with improvement in the transducer frequency and targeted machine presets. Advances like Color Doppler, have greatly facilitated the diagnosis and imaging quality, particularly in vascular disorders & cerebral ischemia.

Neurosonography starts with gray-scale imaging through the widened anterior fontanelle in both coronal and sagittal planes [24] . Generally, six to eight coronal images are obtained, beginning at the anterior frontal lobes (supraorbital regions) and extending to the occipital lobes; posterior to the lateral ventricle trigone [5]. Sagittal planes are obtained at the same window with 90^0 rotation of the transducer, including a midline and two parasagittal views of right and left hemispheres [4,5]. Accessory windows (Mastoid & posterior fontanelle) and high resolution imaging using high frequency linear array transducer completes the examination, with better assessment of the brainstem, posterior fossa structures, and gray-white matter differentiation, respectively [6]. Doppler imaging for arterial and venous structures (like vein of Galen malformation) are useful for supporting the diagnosis in cases of vascular occlusion & ischemic changes with application of routine spectral tracing [2].

Hypoxic Ischemic Encephalopathy (HIE) – Figure 1

Neonatal encephalopathy as a sequel to birth asphyxia is referred to as Hypoxic ischemic encephalopathy/ injury (HIE). Hypoxic-ischemic injury (HIE) to the brain is a devastating occurrence that frequently results in death or profound long-term neurologic disability in both children and adults. Neuroimaging with ultrasonography (US), computed tomography (CT) and magnetic resonance (MR) imaging has become increasingly valuable in the work-up of patients with HIE. Imaging findings in HIE are variable and depends upon the brain maturity at the

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time of insult and the duration/ severity of the insult [7]. Hence, due to widespread availability, painless and not requiring sedation, sonography is an ideal imaging modality.

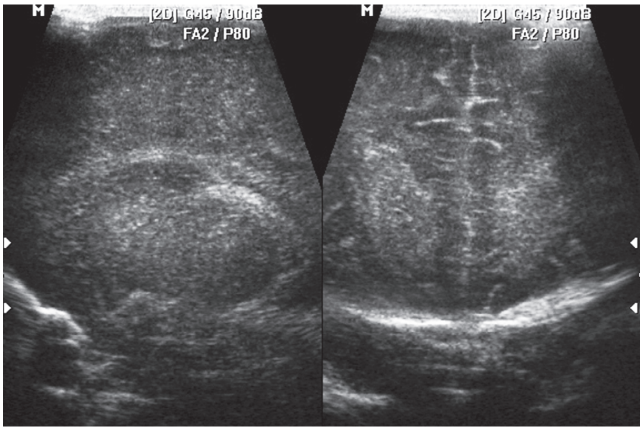

Figure 1: HRUS image of neonatal cranium showing diffusely echogenic bilateral basal ganglia in a case of HIE

Imaging manifestations in HIE are based on the pathophysiological events which are variable and are based on two broad groups i.e. gestational age (with 36 weeks of gestation as cut-off) & secondly on the clinical severity of asphyxia.

Preterm Neonate with Asphyxia

HIE is more common in preterm neonates than in term neonates. At least 5% of infants born before 32 weeks and up to 19% of infants born before 28 weeks develop cerebral palsy [8]. *Mild to moderate asphyxia* is a common pattern of brain injury with two of the major pathologies being *germinal matrix haemorrhage & Periventricular Leukomalacia (PVL).* Intracranial haemorrhage is divided into four grades according to Papile et al with increasing severity from germinal matrix to intraventricular and intraparenchymal hemorrhage[9]. Sonographic appearance of early PVL (Periventricular flares) is visualized in 15 to 35 % cases with progression into cysts; from periventricular to subcortical regions [10,11]. Late stage of PVL is very difficult with best assessed on CT/ MRI. *Severe asphyxia* involves metabolically most active areas like deep gray matter, posterior fossa and brainstem. Cranial sonography may show increased echoes in thalami & basal ganglia in first 2 days or may be normal[12].

Term Neonate with Asphyxia

HIE continues to be a major cause of death and neurodevelopment disability in term neonates, although its prevalence appears to be declining which was described as 2-4 per 1000 live term births [13]. 15-20% of the neonates die during the neonatal period while nearly 25% develop permanent neurological deficiency [14]. Clinical signs and symptoms of hypoxic encephalopathy are usually nonspecific at birth and evolve over a period of days [15] and identified on the basis of a constellation of clinical findings. These findings include fetal heart rate abnormality, severe functional impairment (indicated by a low 5-minute APGAR score), need for resuscitation, severe fetal acidemia, abnormal neurologic examination and an abnormal electroencephalogram (EEG) [16].

Cranial sonography in the 1st week of life in term neonates has a fairly low sensitivity (50%) for detecting abnormalities [15,16], but its sensitivity increases when it is performed after 7 days [17,18]. Similar to severe asphyxia in preterm, term neonates also show increased echogenicity in deep gray matter nuclei with diffuse cerebral edema as early finding. Partial asphyxia spares the deep gray matter with involvement of the cortical & subcortical watershed zones.

Neurosonography ceases to be a practical imaging option in infants once the anterior fontanelle has closed, usually before 4 months of age [19]. Hence, CT becomes the initial imaging study of choice which is being discussed later. With an advent of growing improvement in diagnostic techniques and patient awareness, the radiologists and paediatricians should be well acquainted with the imaging modalities, particularly USG because of its wider availability.

Congenital CNS Anomalies – Figure 2

Figure 2: HRUS image of neonatal cranium showing hypoplastic cerebellar vermis in a case of Dandy-Walker Variant

Neonatal head enlargement is one of the most common indication/ clinical presentation for which neurosonography is advised and plays a reasonably efficient role in describing the deviation from the normal anatomy. Severity of hydrocephalus, extent and level of obstruction can be commented on sonography. Similar described entities like aqueductal stenosis, hydranencephaly & agenesis of the corpus callosum can also be inferred on the basis of Cranial US. Other anomalies which can be assessed on USG include holoprosencephaly, Dandy-Walker Malformation, Arnold-Chiari Malformation & sometimes cortical dysplasia. Vascular malformation like Vein of Galen malformation can assessed in retrospect of cross sectional imaging like CT/MRI. Cephalhematoma and cephalocele can be evaluated on cranial USG.

Sonographic examination can be useful in follow up of vascular malformations like calcifications and for superior sagittal sinus thrombosis in cases. Retrospectively, cranial USG also helpful in assessment of hemispheric masses like teratoma, lipoma, cysts like arachnoid and choroid plexus cysts [20].

Computed Tomography

Computed tomography is mainstay of paediatric neuroimaging which maintains a balance between USG and MRI due to its wider availability than MRI and enhanced diagnostic ability than USG. The modality is useful in cases where there is suspicion on sonography and in cases which cannot be subjected to sonography i.e. infants with closed fontanelle. Recent advances in fast scanning techniques, isosmolar contrast agents and low radiation protocols have made CT as gold standard imaging modality for all the major neurological brain disorders.

Hypoxic Ischemic Encephalopathy

As described in the neurosonography, computed tomography is next or sometimes first imaging modality of choice, usually in cases of strong clinical suspicion & inconclusive or normal USG findings. Diffuse cerebral edema with loss of gray white matter differentiation is the feature of severe form of hypoxic encephalopathy, although CT is much less sensitive and specific than MRI. Periventricular leukomalacia is confidently diagnosed on CT imaging with clinical manifestation of delayed milestone and cerebral palsy [12,21]. Hypoxic ischemic encephalopathy in post natal period is usually trauma, choking, drowning/ asphyxiation which shows basal ganglia involvement with reversal sign (sparing of posterior fossa & thalami) & white cerebellum sign [22,23].

Congenital Anomalies

There is a whole gamut of congenital brain anomalies, ranging from the level of organization disorder to histogenesis [24]. Many of these can be confidently diagnosed on computed tomography. Schizencephaly, microgyria, Holoprosencephaly, septo-optic dysplasia, corpus callosum dysgenesis and hydranencephaly are supratentorial brain anomalies while Dandy-Walker & Chiari Malformations are infratentorial anomalies, which are diagnosed on CT[25-27]. Some of the disorders of histogenesis like tuberous sclerosis, Sturge-Weber syndrome can be confirmed on CT imaging with ancillary supportive findings on MRI [28-29].

Inflammatory Brain Diseases

CT is predominantly the first investigation of choice in suspected cases of neonatal/ childhood infections which usually manifests with non specific signs and symptoms. Specificity comes in evaluation of congenital infections like TORCH which shows parenchymal calcifications. However, some times the imaging features are difficult to recognize and non specific in the form of meningeal and cisternal based lesions.

The most common form of infection is meningitis which can gave variable imaging manifestations ranging from normal to meningeal enhancement, hydrocephalus, subdural effusion and even sequel to vascular complications (vasculitis infarcts)[30]. Other inflammatory conditions can be cerebral abscess, tubercular brain disease (meningeal, parenchymal), neurocysticercosis & viral encephalitis (figure 3). Microcephaly, hydrocephalus and periventricular calcifications are some of the specific signs of congenital neonatal infections [31]. HIV and Fungal infections are uncommonly seen in pediatric age group; however manifestation like diffuse cerebral atrophy and basal ganglia calcifications can be seen in congenital HIV infection. Calcifications are never seen below 1 year of age [32].

Figure 3: Transaxial CECT brain image shows degenerating cyst of cysticercus in right frontal lobe anteriorly

Brain Tumors

Brain tumours are uncommon in neonates and may be of congenital in origin that are more in supratentorial location like embryonal tumours, teratoma and congenital glioblastoma multiforme. 1-2% of all the brain tumors occur in children under 2 years of age group [33]. Tumours of the age group 2-10 years are more benign and 3/4th of them being in infratentorial location [34]. Common pediatric brain tumors are pilocytic astrocytoma, medulloblastoma, ependymoma and brainstem glioma.

CT is primarily required in most of the brain tumours because of non specific presentation, wider availability of the diagnostic technique and faster scan procedure; the most crucial factor for the pediatric group. Most of the pediatric brain tumors are showing areas of calcifications and are pertaining to specific locations; hence MRI is only complimentary in the diagnosis. Supratentorial tumours like Primitive Neuo-Ectodermal Tumor (PNET), Dysembryoplastic Neuroepithelial Tumor (DNET), ganglioma and Craniopharyngioma can be diagnosed on CT images convincingly. Pineal Tumors and Choroid plexus papilloma are some of the other commonly described pediatric brain tumors (figure 4). Neuroradiologist must appreciate the consequences of brain tumors like edema, hemorrhage, hydrocephalus and herniations which can be potentially life threatening.

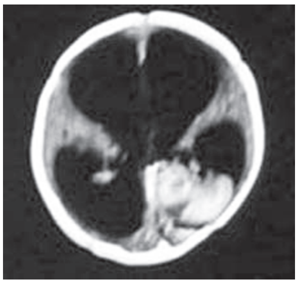

Figure 4: Transaxial CECT brain image shows choroid plexus papilloma in left ventricle associated with severe hydrocephalus

Magnetic Resonance Imaging (MRI) & its Advances

MRI has been a major breakthrough in neuroimaging, from the neonatal to adults and geriatric age-groups. The modality is equally good in diagnosing intracranial as well as spinal disorders of pediatric age group. Excellent soft tissue contrast differentiation, tissue/ pathological characterization, non involvement of ionizing radiation are few of the characteristics of MRI, making it the best 2nd line investigation in almost all the cases which remain undiagnosed and in cases with strong clinical/ imaging suspicion.

Extensive literature is available providing information about the MRI features in cases of Hypoxic Ischemic Encephalolopathy (HIE), Congenital Brain anomalies, Inflammatory Brain diseases as well as Pediatric Brain tumors (figure 5). Additional advantage of MRI in Brain imaging is regarding the assessment of normal myelination as well as **Metabolic and white matter** disorders which remain undiagnosed on routine CT imaging. The diagnosis of these disorders is often a challenge due to their non specific presenting features like ataxia, spasticity, delayed development and seizures. Biochemical tests are often negative as a consequence of these at least 60% of children with inborn errors of metabolism remain undiagnosed [35].

Figure 5: Transaxial CEMR brain image shows tuberculoma in pontocerebellar region causing mass effect on fourth ventricle

Metabolic brain diseases are further classified into major categories according to the site of involvement like gray matter or white matter or both; lobe predominance like Alexander Disease in frontal lobe & Canavan disease with diffuse pattern; pattern of enhancement; associated anomalies like macrocephaly and cystic changes like in Van der Knapp disease. There are multiple diseases with specific imaging features like Metachromatic leukodystrophy and Adrenoleukodystrophy [36-38].

Recent advances in the field of MRI have been in practice nowadays because of their supportive role in diagnoses; however they never overrule the preliminary diagnoses made on routine MR imaging. These accessory technical advances are MR Spectroscopy (throwing light on the chemical milieu of the concerned pathology), MR diffusion imaging (free movement of the protons in the chemical environment), Perfusion study (vascularity and blood brain barrier) and diffusion tractography (about the direction and changes in the normal neurological tracts in brain).

Imaging in Pediatric Spine Disorders

The most common and almost exclusive spinal disorder of the pediatric age group is Spinal dysraphism, which is defined as abnormal and incomplete fusion of the mesenchymal and neural elements during the spinal cord development. Incidence of spinal dysraphism is approximately 0.05 to 0.25 per 1000 births [39]. The disease is broadly classified into open and closed type and initial evaluation is done through clinical assessment. There are many cutaneous manifestations of closed dysraphic states which may remain asymptomatic. Prenatal diagnosis can be made during ultrasound or fetal MRI. Post natal imaging is usually done with MRI, which is the imaging modality of choice [40,41]. There can be associated anomalies like hydrocephalus and Chiari malformations, along with spinal dysraphism.

Other modalities can play a supplemental role in making diagnosis. Scout films or plain radiographs can be used for the assessment of the vertebral column revealing scoliosis, spina bifida and vertebral segmentation anomalies [41,42]. Bony spur can be seen in cases of diastematomyelia. Similarly, ultrasonography can be used in neonates and infants; usually before the ossification of the posterior elements. The modality can provide adequate information regarding the type of malformation, status of the central canal, hydromyelia and neural placode. Flaring of the posterior elements and herniation of the neural elements are well appreciated on USG; however, the level of dysraphic spine is best defined on CT or MRI imaging. Osseous elements can be better delineated on Computed tomography with assessment of bony spur in split cord malformations.

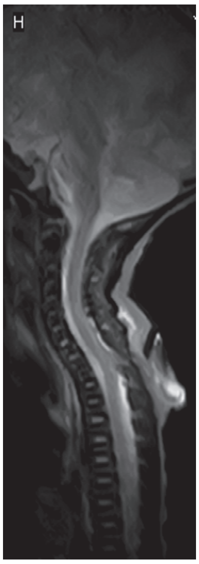

Figure 6: Sagittal T2W GRE images shows mid-dorsal meningocele with tethered cord in a case of spinal dysraphism

MRI has always been a gold standard & single stop shop imaging modality for evaluation of the spinal dysraphism and the most accurate, non invasive method (figure 6). There are benefits of entire spine and brain evaluation, cord tethering, hydromyelia and other associations. The application of variable sequences is useful for characterization of any associated pathology like Dermoid, lipomatous component and epidermoid cyst. However, the clinic-radiological classification by Torotti et al and embryologic development of the spine is important for radiologists and clinicians to reach a diagnosis [41-43].

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