Imaging of Congenital Malformations of Brain: A Pictorial Essay
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Citation

Abstract
“A sad end to a happy dream” is what a newborn child with congenital brain anomalies can be to the parents. Nevertheless, diagnosing it correctly is of paramount importance. Imaging plays an important role in reaching the correct diagnosis. It is as important for every pediatrician to be familiar with basic imaging findings of common congenital anomalies, as it is for the radiologist. This pictorial essay attempts to concisely present the imaging features of common congenital anomalies. In this article we will first present a simplified classification of congenital anomalies affecting brain, followed by images and imaging findings of the common and certain uncommon but interesting or important congenital anomalies. Congenital anomalies can be broadly categorized into hindbrain herniations and miscellaneous malformations, hindbrain malformations (Posterior fossa malformations and cysts), disorders of diverticulation and cleavage and malformations of cortical development. In postnatal period, usually CT is the initial diagnostic tool. But MRI is superior to CT in most of the cases.

INTRODUCTION
Congenital anomalies of brain are commonly encountered in day to day practice. Although there is a very wide spectrum of anomalies with over 2000 different congenital cerebral malformations described, the number of anomalies routinely encountered is limited. It is essential for every medical practitioner to be aware of them and even more important for every pediatrician and radiologist to be familiar with them. Since imaging plays a significant role in reaching the correct diagnosis, a close association between the pediatrician and radiologist is necessary for optimum management of these unfortunate conditions.

DISCUSSION
Although some authors consider neurocutaneous syndromes to be a type of congenital malformations, we will not include these rather puzzling conditions in our discussion here.

HINDBRAIN HERNIATIONS AND MISCELLANEOUS MALFORMATIONS
This group of malformations includes the Chiari malformations, a group of mostly embryologically unrelated conditions in which cerebellar tissue is displaced into the cervical canal. We will also include in this section certain miscellaneous conditions such as callosal dysgenesis and lipoma.

CHIARI TYPE 1 MALFORMATION
Also known as cerebellar tonsil ectopia, this condition can be defined as a caudal protrusion of the cerebellar tonsils below the foramen magnum (Figure 1). Main imaging features include low-lying peg-shaped cerebellar tonsils, more vertical appearance of the tonsillar sulci, along with compression of cistern magna. Position of cerebellar tonsils is measured with respect to the “opisthion-basion line”, which is the line joining the anterior and posterior margins of the foramen magnum. Cerebellar tonsils protruding more than 6 mm below this line is abnormal in the first decade and 5 mm in 2nd/3rd decades [1]. It is most pronounced at 4 years. On radiography, features such as short clivus, atlas assimilation, craniovertebral segmentation/fusion anomalies...
or absence of cervical lordosis may be present. CT or MRI may reveal small posterior fossa. On MRI, one should look for presence of upper cervical cord edema and syrinx, which show correlation with the symptomatology and also for scoliosis.

Figure 1: Chiari Type 1 Malformation: A, Sagittal T1 weighted MR image showing caudal protrusion of the cerebellar tonsils below the foramen magnum (Black arrowhead). B, T1 weighted sagittal (Right) and FLAIR sagittal (Left) MR images, showing syrinx (Curved arrows) associated with Chiari 1 malformation in a different patient.

Figure 2
Figure 1b

CHIARI TYPE 2 MALFORMATION

This complex hindbrain malformation is characterized by small posterior fossa and herniation of cerebellar vermis, choroid plexus of fourth ventricle and part of medulla through foramen magnum (Figure 2). It is associated with lacunar skull (Luckenshadel). Neural tube closure defects such as myelomeningocele are present in almost all cases. Tentorium is hypoplastic and falx may be fenestrated. It is best appreciated on sagittal MRI image, which shows cascading protrusions of vermian nodulus and uvula, fourth ventricle, medulla, and cervical cord into the spinal canal. Cervicomedullary “kinking” is characteristic. Tectum appears inferiorly beaked. Axial images show cerebellar hemispheres extending anteriorly surrounding the brainstem. Cerebellum may also herniated upward through the tentorial incisura. Hydrocephalus is present in majority of the cases. Other associated malformations include callosal dysgenesis, heterotopias, polymicrogyria and diastematomyelia. Syrinx is associated in about 70-90% of cases. Most of the imaging features are result of very small posterior fossa.

Figure 2: A, Hypothalamus (long straight arrow) is elevated. There is massive enlargement of fourth ventricle (small arrowhead), apparently communicating superiorly with enlarged supracerebellar cistern. Tectum (large arrowhead) is displaced superiorly by fourth ventricle and is beaked. Inferior vermian peg is seen (open arrow). Inferiorly, dilated fourth ventricle extends through foramen magnum and is
associated with buckling of medulla (curved arrow). Cerebellar tissue is seen ventral to pons (short straight arrow). Note also thinning of posterior portion of body of corpus callosum (possibly from hydrocephalus) as well as absence of splenium. Supracerebellar cistern (s) and Interhemispheric cistern (0) are both enlarged. Choroid plexus of left lateral ventricle (c) extends medially toward midline. Note enlarged massa intermedia (M). B, Coronal view. Note medullary buckle (arrowhead) and enlarged supracerebellar cistern communicating with interhemispheric cistern (long white arrow). Part of medial occipital gyrus indents cistern (short white arrow). Midline cleft is seen on superior surface of cerebellum (black arrow). Choroid plexus in left lateral ventricle (c) is indicated. Note also that cerebellum, indented by low tentorium (open arrows), herniates superiorly. C, Axial view. Cerebellar migration is seen on each side of pons (arrows). Note enlarged fourth ventricle. [Figure and legend reproduced with kind permission from: Wolpert SM, Anderson M, Scott RM, Kwan ESK, Runge VM. Chiari II malformation: MR imaging evaluation. Am J Roentgenol. 1987; 149: 1033-42. © American Roentgen Ray Society.]

**Figure 3**

Figure 2a
CHIARI TYPE 3 MALFORMATION
This may be defined as Chiari 2 malformation with high cervical or occipital meningoencephalocele. The herniated sac may contain meninges, cerebellum, occipital lobe or brainstem [5]. Cisterns and dural sinuses may also be present. Features of Chiari 2 malformation are present.

CEPHALOCELES
Cephaloceles involve a skull defect associated with herniation of intracranial contents (Figure 3). Cephaloceles may be occipital, parietal, transsphenoidal, sincipital (frontoethmoidal) or nasal. Crista galli is important in differential diagnosis of congenital nasal masses. If it is present but split, the mass is dermoid. If it is absent or eroded and foramen cecum is enlarged, the lesion is a cephalocele [1].

Figure 3: Cephaloceles. A, Herniation of posterior fossa contents through occipital cephalocele is seen. B, Frontal cephalocele.

CORPUS CALLOSUM ANOMALIES
Corpus callosum forms from anterior to posterior except for the rostrum, which is formed last. Callosal agenesis may be complete or partial. In partial agenesis, splenium and rostrum are the missing parts. In complete agenesis the entire corpus callosum and the cingulate sulcus and gyrus are
absent.

Imaging of complete callosal agenesis (Figure 4) shows high riding third ventricle with spoke-like orientation of gyri around it. Lateral ventricles are widely separated, parallel and non-converging. Colpocephaly (dilated occipital horns) is commonly present and frontal horns may be small and pointed. Lateral ventricles are indented superomedially by the longitudinal white matter bundles (Probst bundles) [1].

Callosal anomalies are associated with other anomalies in 50 per cent of cases. These anomalies include Chiari malformations, heterotopias, lissencephaly, schizencephaly, Dandy-walker malformation, holoprosencephaly and lipomas [6]. Association with Aicardi syndrome is reported [7].

Figure 4: Corpus callosum agenesis: A, Axial CT scan of a patient with corpus callosum agenesis. Note the widely separated, parallel lateral ventricles with colpocephaly (Arrow). Left frontal horn is small and pointed (Curved arrow). Interdigitating gyri are seen (Arrowhead). B, T1 weighted axial MR image shows classical widely separated, parallel lateral ventricles with colpocephaly. High riding third ventricle open superiorly to interhemispheric fissure is present (Arrow). There is presence of focal nodular heterotopia along lateral wall of frontal horn of left lateral ventricle (Arrowhead). C, Axial true inversion recovery image of a different patient. Prominent occipital horns (Arrows), high riding third ventricle (White dot), irregular interhemispheric fissure and heterotopias (Arrowheads) are visualized. Note that presence of heterotopias is better appreciated on this inversion recovery image. D, Coronal T2 weighted image. Absence of corpus callosum is clearly visualized and third ventricle is open superior to interhemispheric fissure.
LIPOMA

Intracranial lipomas are thought to be brain malformations rather than a true neoplasm. Half of these occur with various degrees of callosal dysgenesis. About 80 to 90 per cent of lipomas are seen in the midline. Lipomas may be callosal or cisternal (Figure 5). Callosal lipomas may be anterior bulky tubulonodular which are usually associated with callosal dysgenesis, or they may be posterior ribbonlike curvilinear, which are seen with normal corpus callosum [1]. Lipomas have typical fat density (-50 to -100 Hounsefield Units) on CT. On MRI, lipoma appears hyperintense on T1 weighted image, intermediate signal on T2 weighted image and suppressed on fat-suppressed image.

Figure 5: Sagittal T1 weighted MR image. A lipoma which is very bright on T1 weighted image, is seen along superior border of cerebellar vermis (Arrowhead).

HINDBRAIN MALFORMATIONS (POSTERIOR FOSSA MALFORMATIONS AND CYSTS)

DANDY WALKER COMPLEX

Dandy Walker complex includes a continuum of Dandy Walker malformation, Dandy Walker variant and mega cisterna magna [8].

DANDY WALKER MALFORMATION

Most important imaging features of Dandy Walker malformation are large posterior fossa with a large cerebrospinal fluid (CSF) cyst and absence of normal fourth ventricle (Figure 6). Occipital bone appears scalloped and remodeled. There is torcular-lambdoid inversion that is, transverse sinuses and the confluence of sinuses lie above the lambdoid suture [1, 8, 9].

Sagittal MRI (Figure 6B) reveals that the floor of fourth ventricle is normal, but dorsally fourth ventricle opens into a
large CSF filled cyst. Vermis is hypoplastic and is elevated over the cyst. Cerebellar hemispheres may be hypoplastic and anterolaterally displaced. Brainstem may be hypoplastic and compressed as well. Hydrocephalus is common, corpus callosum agenesis, heterotopias, schizencephaly, cerebellar dysplasias are also associated.

Main differential diagnosis of a posterior fossa cyst includes Dandy Walker continuum, posterior fossa arachnoid cyst, cystic neoplasms, dermoid, epidermoid and enterogenous cyst.

Figure 6: Dandy Walker Malformation: A, Axial CT image. Fourth ventricle (Arrow) dorsally opens into a large CSF filled cyst. Subtle remodeling of occipital bone is noted. Gross hydrocephalus is present (White dots). B, Sagittal T1 weighted image. The floor of fourth ventricle (Arrow) is normal, but dorsally fourth ventricle opens into a large CSF filled cyst (Arrowheads). Vermis (Curved arrow) is hypoplastic and is elevated over the cyst. Brainstem (Black dot) is hypoplastic and compressed. C, Axial T2 weighted MR image shows a large posterior fossa CSF intensity cyst with hypoplastic vermis and cerebellar hemispheres.
DANDY WALKER VARIANT

In this anomaly, there is mild vermian hypoplasia with communication of posteroinferior fourth ventricle and cisterna magna through enlarged vallecula, causing a variable size cystic space (Figure 7). Posterior fossa is of normal size.

Figure 7: Dandy Walker Variant. A, Axial CT image. B, Axial T1 weighted MR image (Different cases). There is communication (Arrows) between posteroinferior fourth ventricle and cisterna magna through enlarged vallecula, with a posterior fossa cyst. Severe hydrocephalus is present in Figure 7A.
MEGA CISTERNA MAGNA

In this variant, fourth ventricle, vermis and cerebellar hemispheres are normal. Large cisterna magna is present. Occasionally scalloping of occipital bone is seen (Figure 8).

Figure 8: Axial CT image showing mega cisterna magna (Arrows). Fourth ventricle, vermis and cerebellar hemispheres are normal. Scalloping of occipital bone is seen (Arrowheads).

JOUBERT BOLTSHAUSER SYNDROME (CONGENITAL VERMIAN HYPOPLASIA)

In this anomaly, there is inherited hypoplasia or aplasia of cerebellar vermis (Figure 9). Fourth ventricle is enlarged and has a typical “bat-wing” or “umbrella” appearance. Isthmus (area of pontomesencephalic junction) is narrow. Midbrain has the typical “molar tooth” appearance [10, 11, 12]. Associated abnormalities include holoprosencephaly, frontonasal dysplasia, pituitary hypoplasia. Abnormal signal may be noted in periventricular white matter. Renal cysts, hepatic fibrosis and cardiac anomalies may be associated, for which abdominal ultrasound may be advisable.

Figure 9: Joubert syndrome. A. Axial T1 weighted MR image. Fourth ventricle is enlarged and has a typical “umbrella” appearance (Arrow). B. Note the typical “molar tooth” appearance of midbrain (Black arrows), small vermis (Arrowhead) and narrow isthmus (White long arrow) on this T1 weighted image. C, Sagittal T1 image. Fourth ventricle is enlarged with vermian hypoplasia and abnormal folial pattern. Note that isthmus is abnormally narrow (Arrow).
Rhombencephalosynapsis consists of congenital fusion of cerebellar hemispheres, dentate nucleus and superior cerebellar peduncles (Figure 10). This is associated with vermian agenesis or hypogenesis [13, 14]. Rhombencephalosynapsis differs from Dandy-Walker malformation in that the anterior vermis is absent and posterior vermis is deficient in this [15]. Transverse diameter of cerebellum is reduced. This may be accompanied by corpus callosal dysgenesis, aqueductal stenosis leading to hydrocephalus, septo-optic dysplasia or holoprosencephaly.

Figure 10: Rhombencephalosynapsis. A, Sagittal T1 spin-echo image shows abnormal cerebellar vermis. B, Axial T2 spin-echo image shows continuity of the cerebral hemispheres across the midline without a midline cerebellar vermis. The cerebral hemispheres are abnormal, with reduced white matter and inward folding of the cortex as a result of ventriculoperitoneal shunting. (Figure and legend reproduced with kind permission from: Patel S, Barkovich J. Analysis and Classification of Cerebellar Malformations. Am J Neuroradiol. 23: 1074-87. August 2002. © by American Society of Neuroradiology.)
Regarding holoprosencephaly, the phrase “Face predicts brain” is apt. It is a spectrum of congenital structural forebrain anomalies and is the commonest malformation involving face and brain together. Its hallmark is monoventricle with non-cleaved frontal lobes. Also there is non-cleavage of diencephalon, and at times basal ganglia and thalami [16, 17]. Sylvian fissures are displaced anteriorly, resulting in increased sylvian angle (angle formed by lines drawn tangentially through the sylvian fissures). Radiography reveals hypotelorism and fused metopic suture.

It is a spectrum with three forms, alobar, semilobar and lobar [15, 17, 18]. Alobar variety (Figure 11A), which is the most severe form, is characterized by monoventricle with “horseshoe” brain, fused thalami and basal ganglia, and absence of septum pellucidum, corpus callosum, falx cerebri and interhemispheric fissure, in association with severe craniofacial anomalies. In semilobar holoprosencephaly (Figure 11B) facial anomalies are variable, rudimentary occipital horns of lateral ventricles are present and falx is partially present. Lobar form, which is the least severe form, has squared-off frontal horns, well formed falx, separated thalami and only some anteroinferior fusion of hemispheres. Septum pellucidum is absent in all three forms. Holoprosencephaly may be associated with cyclops with ethmocephaly, dorsal brain cyst or olfactory nerve hypoplasia. Extracranial anomalies such as polydactyly, renal dysplasia, omphalocele and hydrops may be associated. Myelination may be delayed.

Figure 11: Holoprosencephaly. A, Axial CT image showing alobar holoprosencephaly. Note the fused thalami (Arrows), monoventricle with absence of septum pellucidum and absence of interhemispheric fissure and falx. B, Axial CT of semilobar holoprosencephaly. Note single large ventricle, absence of septum pellucidum and rudimentary interhemispheric fissure (Arrow).
SEPTO-OPTIC DYSPLASIA (DE MORSIER SYNDROME)

Septo-optic Dysplasia (Figure 12) is characterized by hypoplastic optic nerves/tract, absence of septum pellucidum and hypothalamic-pituitary dysfunction [19, 20, 21]. Frontal horns of lateral ventricle have flat roof and they are pointed inferiorly. Pituitary stalk may be thin with ectopic posterior pituitary. Schizencephaly and heterotopias may be associated [19, 20]. Many of the features overlap with lobar holoprosencephaly and some authors consider these two to be the same disorder.

Figure 12: Septo-optic Dysplasia. Axial CT images. A, Note absence of septum pellucidum. B, Non-visualization of bilateral optic nerves.

Figure 24
Figure 11a

Figure 25
Figure 11b

Figure 26
Figure 12a
MALFORMATIONS OF CORTICAL DEVELOPMENT
HETEROTOPIC GRAY MATTER

Heterotopic gray matter \cite{22,23} is caused by arrested migration of neurons from periventricular germinal zone to cortex. It can be inherited or acquired (maternal trauma, infection or toxin). It can be band-like (laminar) (Figure 13A) or nodular (Figure 13B). Nodular heterotopias can be focal or diffuse. Subependymal heterotopias are the most common, seen as nodules indenting the ventricles.

Heterotopic gray matter is isodense with gray matter on CT and isointense with gray matter on MRI. Band heterotopias resemble double cortex, the inner heterotopic band may be thick or thin and continuous or discontinuous. Overlying cortex may be dysplastic or it may be normal, depending on the amount of heterotopic gray matter. Calcification is very rarely seen in the heterotopic gray matter.

Figure 13: Heterotopic Gray Matter. A, Axial MR image showing a band of heterotopic gray matter bilaterally (Arrows) with thin overlying cortex, giving an appearance of double cortex. B, Axial MR image showing subependymal nodular heterotopic gray matter (Arrows) lining both lateral ventricles.
SCHIZENCEPHALY

Schizencephaly is a cerebrospinal fluid-filled cleft extending from the ependymal surface of the brain to the pia. It is lined by gray matter. Schizencephaly may be closed-lip (Figure 14A) or open-lip (Figure 14B) and it can be unilateral or bilateral (Figure 14C). Closed-lip (type 1) schizencephaly is a thin, gray matter lined cleft in parenchyma. Usually the ventricular margin shows an outpouching at the site of closed-lip schizencephaly, acting as an important clue. Open-lip schizencephaly is a larger, gray matter lined cleft with obvious defect in ventricular margin. Closest differential of open-lip schizencephaly is porencephaly. But porencephalic cysts are lined by gliotic white matter in contrast to the gray matter lined schizencephaly. Associated findings may include heterotopias, absence of septum pellucidum, hippocampal abnormality, pituitary hypoplasia, callosal dysgenesis.

Figure 14: Schizencephaly. A, Unilateral closed-lip schizencephaly. Note the gray matter lining (Arrowhead) and a small outpouching (nipple) of the ventricular margin (Arrow). B, Large open-lip schizencephaly. The gray matter lining (Arrows) differentiates it from porencephalic cyst. C, Bilateral closed-lip schizencephaly.

LISSENCEPHALY

Developing fetal brain normally appears smooth or “agyric” until 16th to 17th week of intrauterine life. Lissencephaly refers to absent or poor sulcation (Figure 15). It can be complete (agyria) or incomplete (agyria-pachygyria). Type I lissencephaly shows the typical figure eight configuration of brain with colpocephaly, thickened cortex, smooth gray-white matter interface, flat broad gyri and shallow sylvian fissures. Type II lissencephaly on MR shows thickened cortex having polymicrogyric appearance. Type I lissencephaly is associated with Miller-Dieker syndrome while type II lissencephaly is associated with Walker-Warburg syndrome.

Figure 15: Lissencephaly. A, Type 1 lissencephaly showing shallow sylvian fissures, absence of gyri and thickened cortex (Arrow). B, Pachygyria. Note the thick cortex, sparse flat gyri and figure of eight appearance. C, This spin echo MR image shows pachygyric brain. Note the paucity of gyri.
affecting mainly the occipital regions (Arrows). Gyri are also sparse in right fronto-parietal region. Sylvian fissures are shallow.

HEMIMEGALENCEPHALY

This is a hamartomatous overgrowth of a part or all of a cerebral hemisphere [1, 25, 26]. There is an enlarged hemisphere with enlarged lateral ventricle (Figure 16). Posterior falx and occipital lobes are usually displaced to the opposite side. Cortex may be thick, dysplastic or pachygyric. Heterotopias may be present. T2 images may show abnormal signal due to abnormalities of myelination, gliosis or calcification. It may be associated with hemimaylolar or hemimandibular overgrowth. It needs to be differentiated from hemiatrophy involving the contralateral side and hemimegalencephaly associated with tuberous sclerosis. In tuberous sclerosis, the other clinical and radiological findings of tuberous sclerosis are easily identifiable.

Figure 16: Hemimegalencephaly. A, T1 weighted axial spin echo image. B, Coronal FLAIR image. Note the enlarged right hemisphere with enlarged right lateral ventricle.

References

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