Fetal MRI: A pictorial essay

Sapna Rathee, Priscilla Joshi, Abhimanyu Kelkar, Nagesh Seth
Department of Radiodiagnosis, Bharati Hospital, Pune, Maharashtra, India

Correspondence: Dr. Sapna Rathee, C/O SR Century Public School, Delhi Rohtak Road, Bahadurgarh - 124 507, Haryana, India.
E-mail: dr.sapnarathee@gmail.com

Abstract
Ultrasonography (USG) is the primary method for antenatal fetal evaluation. However, fetal magnetic resonance imaging (MRI) has now become a valuable adjunct to USG in confirming/excluding suspected abnormalities and in the detection of additional abnormalities, thus changing the outcome of pregnancy and optimizing perinatal management. With the development of ultrafast sequences, fetal MRI has made remarkable progress in recent times. In this pictorial essay, we illustrate a spectrum of structural abnormalities affecting the central nervous system, thorax, genitourinary and gastrointestinal tract, as well as miscellaneous anomalies. Anomalies in twin gestations and placental abnormalities have also been included.

Key words: Anomalies; congenital; fetal magnetic resonance imaging; ultrasonography

Introduction
USG has routinely been used in the evaluation of obstetrical and gynecological conditions since the late 1950s. However, due to its limitations of a small field of view, operator dependence, a need for an additional imaging modality has emerged, especially in cases of oligohydramnios and obese patients. As MRI does not involve radiation, is safe for the fetus, and provides detailed structural anatomy, it has emerged as a suitable adjunct to USG.

MRI was first performed in 1983 for evaluation of the placenta and fetus.[1] The main drawback of MRI was motion which was overcome in the 1990s with the development of ultrafast sequences.[2] According to the Safety Committee of the Society for MRI, no known biological risks have so far been proven to be associated with MRI. Acoustic noise and biological effects are the main safety concerns for fetal MRI. The noise intensity produced by gradients in fetal MRI can reach 120 dB. Fetal hearing damage, which is a potential hazard, has still not been confirmed in practice.[3]

Fetal MRI is indicated in pregnant women when other non-ionizing diagnostic imaging methods are inadequate or when the examination provides important information that would otherwise require exposure to ionizing radiation.[4] The quality of fetal MRI is comparable to postnatal MRI, facilitating discussion of surgical treatment options. Relative advantages and disadvantages of antenatal USG and MRI are described in Table 1.

Fetal MRI should be performed in the second or third trimester. As the teratogenic effects of MRI in early pregnancy are not confirmed and the multilayer structure of the cerebral parenchyma is appreciable after 16 weeks of gestation on a 1.5 T MR, MRI is best performed after completion of organogenesis (16 weeks).[3] The patients are advised to fast for 4 h prior to the study, to reduce bowel peristalsis artifacts and to prevent postprandial fetal motion. Patients are asked to empty the urinary bladder prior to the study and positioned feet first supine or in left lateral decubitus position. A single-body matrix coil is often used over the abdomen and pelvis to improve the spatial resolution. No medication or sedation is required.

MR Protocol
MR studies are best performed on a MRI system with field strength of 1.5 T. Imaging is performed during free breathing with respiratory gating to avoid artifacts.

Initially, multiplanar T2-weighted (T2W) scout images are often obtained using 5-7-mm-thick slices with a 1- to 2-mm
Limited availability

250th Plane

3-plane Relatively operator independent

180 340×266 5
to echo

520/80

7.7/4.6

1

weeks with the 3-plane

Fetal MRI

0.5

3-plane 10

8000/900

FOV

375

Sagittal

0.4

4

450

Breath hold

400

20

2plane

IPI

TR/TE

T1WI

3plane

BTFE

1plane

2plane

SSh

MRCP

BFFE:

Balanced fast field echo, TSE:

Turbo spin echo, MRCP:

Magnetic resonance cholangiopancreatoscopy, RT:

Respiratory triggering, RLT:

Real time, TR/TE - Time to repeat/ tene}

MR: Magnetic resource imaging, FOV: Field of view

Table 2: Sequences for fetal MRI

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Plane</th>
<th>FOV (mm)</th>
<th>Slice thickness (mm)</th>
<th>Gap (mm)</th>
<th>TR/TE (ms)</th>
<th>Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>BFFE_Survey</td>
<td>3-plane</td>
<td>450</td>
<td>15</td>
<td>10</td>
<td>7.7/4.6</td>
<td>224×256</td>
</tr>
<tr>
<td>T2W_TSE</td>
<td>3-plane</td>
<td>180</td>
<td>4</td>
<td>0.4</td>
<td>520/80</td>
<td>340×266</td>
</tr>
<tr>
<td>SSh_MRCP</td>
<td>3-plane</td>
<td>250</td>
<td>40</td>
<td>0</td>
<td>8000/900</td>
<td>296×238</td>
</tr>
<tr>
<td>BTFE_RT</td>
<td>3-plane</td>
<td>375</td>
<td>5</td>
<td>0.5</td>
<td>4.6/2.3</td>
<td>312×247</td>
</tr>
<tr>
<td>T1_TSE</td>
<td>Sagittal, coronal</td>
<td>375</td>
<td>5</td>
<td>1</td>
<td>10/4.6</td>
<td>252×151</td>
</tr>
<tr>
<td>BTFE_RLT</td>
<td>Sagittal</td>
<td>320</td>
<td>5</td>
<td>5</td>
<td>2.2/1.10</td>
<td>192×190</td>
</tr>
</tbody>
</table>

MR: Magnetic resource imaging, BTE: Balanced turbo field echo, T2W: T2-weighted, BFFE: Balanced fast field echo, TSE: Turbo spin echo, MRCP: Magnetic resonance cholangiopancreatoscopy, RT: Respiratory triggering, RLT: Real time, TR/TE - Time to repeat/ tene}

MR: Magnetic resource imaging, BTE: Balanced turbo field echo, T2W: T2-weighted, BFFE: Balanced fast field echo, TSE: Turbo spin echo, MRCP: Magnetic resonance cholangiopancreatoscopy, RT: Respiratory triggering, RLT: Real time, TR/TE - Time to repeat/ tene}

For detailed neurological evaluation, multiplanar T2W and BTFE sequences can be obtained. Ventricular atrial measurements are typically in the axial plane. Cavum septum pellucidum and corpus callosum (CC) must be identified. Age-appropriate sulcation and gyration is evaluated next. The temento-vermian angle [Figure 1] is measured on the midline sagittal image of the fetal brain. It is the angle formed by lines along the anterior surface of the vermis and the dorsal surface of the brainstem. The angle should be near zero. Large angles indicate elevation of the vermis due to the developmental anomalies of vermis. The cerebellar transverse diameter and cisterna magna are measured in axial images.

Indications

The most important indications of fetal MRI are evaluation of the fetus in suspected chromosomal syndromes/familial genetic disorders where USG is normal, confirmation of anomalies/findings detected on USG, and detecting/excluding associated anomalies. Fetal MRI can also assist in planning prenatal/postnatal intervention where necessary [Table 3].

Spectrum of anomalies

CNS anomalies

The most common indication for CNS imaging was ventriculomegaly, followed by suspected CC abnormalities, cerebellar anomalies, congenital infections, malformations of cortical development, and posterior fossa anomalies. Ventriculomegaly is defined as atrial width equal to or more than 10 mm on the sonogram. Figure 1 shows normal CC and brain anatomy.

CC anomalies

The CC is a midline cerebral structure consisting of white matter tracts connecting two cerebral hemispheres. Its formation starts at the 10th week of gestation with genu formation and is completed by 18-20th weeks with the formation of rostrum. It is seen as a C-shaped, curved hypointense structure on T2W images in the midsagittal plane [Figure 1]. Cerebral ventriculomegaly raises the suspicion of CC agenesis. MRI is superior to prenatal USG for evaluation of CC at any gestational age as it actually shows the CC, whereas ultrasonography (USG) relies on indirect signs like absence of cavum septum pellucidum for diagnosing CC anomalies. MRI imaging features suggestive of CC agenesis are parallelization of lateral ventricles (Viking helmet sign), colpocephaly, and a high riding third ventricle [Figure 2].

Holoprosencephaly

It is characterized by lack of cleavage of prosencephalon. There is incomplete separation of two cerebral hemispheres. MRI is complementary to USG for confirmation and further evaluation of the subtypes of holoprosencephaly, i.e. alobar [Figure 3], semilobar, and lobar, in order of severity. The spectrum of findings in holoprosencephaly includes monoventricle, fusion of thalamus, and absence of falx, CC, and optic tracts.
Associated anomalies include cleft lip, hypertelorism, encephaloceles [Figure 4], adrenal and cardiac anomalies.

Neural tube defects
These are a group of anomalies due to incomplete closure of the neural tube in early pregnancy. They include spina bifida, meningocoele, meningomyelocele, and lipomyelomeningocele.

Anencephaly
It is a type of neural defect comprising absence of cranial vault and cortical tissue [Figure 5]. It can be associated with spina bifida, congenital heart anomalies, skeletal anomalies, gastrointestinal anomalies, and diaphragmatic hernias.

Iniencephaly
It is a neural tube defect, more common in females, with an incidence of 10 in 10,000. It is characterized by retroflexion of head, absence of occipital bones, spinal deformities, fusion of cervicothoracic vertebrae, and absence of neck causing upward turning of chin and face [Figure 6].

Chiari malformations
These are a group of disorders associated with congenital downward displacement of the cerebellum and brainstem, showing peg-like tonsillar herniation into the upper cervical canal on T2W images with a small posterior fossa. Four types are known. Chiari I is the commonest type with tonsillar herniation. Type II is associated with lumbosacral spinal myelomeningocele [Figure 7]. Type III is associated with a cervical/occipital encephalocele, and type IV is a variation of cerebellar hypoplasia. The limitation of USG...
in visualizing the posterior fossa and detecting tonsillar herniation has been overcome by fetal MRI.

**Genitourinary tract anomalies**

MRI scores over USG as fetal kidneys are well visualized and can be evaluated in the early gestational period as well as in the presence of scanty liquor. Oligohydramnios limits the assessment of genitourinary anomalies on US due to the poor sonic window, thus making MRI a useful adjunct. Fetal ureters are not visualized on USG unless dilated. Hydronephrosis is the most common genitourinary abnormality detected on prenatal USG.[11] Commonest causes of hydronephrosis are pelviureteric junction obstruction, vesicoureteral reflux, megaureter, and posterior urethral valves (PUVs).

**Posterior urethral valves**

It is the commonest cause of hydronephrosis and obstructive uropathy in male infants. On antenatal USG, the urethra shows a “keyhole” appearance with a distended urinary bladder and urethra proximal to valve [Figure 8]. Three types of PUVs were described in the past; however, at present, only one type is accepted (type I).[12] Fetal MRI
helps in diagnosing PUVs with associated hydronephrosis or renal dysplasia.

**Congenital megaureter**
An infantile ureter measuring more than 7 mm, visualized as a hyperintense tubular structure posterior to the bladder on T2W sequences is termed as a megaureter.[13] It can be further classified as obstructed primary megaureter, refluxing primary megaureter (vesicoureteric reflux), and non-refluxing obstructed primary megaureter.[13]

Antenatally, this is seen as a dilated collecting system and ureter [Figure 9], as was seen in a 25-week pregnancy in our series. Reflux maybe excluded postnataally.

**Multicystic dysplastic kidney**
In multicystic dysplastic kidneys [Figure 10], multiple small non-communicating cysts are seen dispersed throughout the renal parenchyma. It usually affects one kidney with associated renal abnormalities like vesicoureteric reflux, pelviureteric junction obstruction, ureteral ectopia, and ureterocele in the contralateral kidney.[14] The non-communication of the cysts helps differentiating it from hydronephrosis.

**Chest anomalies**
Fetal lungs appear hyperintense on T2W and BTFE images. Common fetal thoracic anomalies are congenital diaphragmatic hernia (CDH), congenital pulmonary airway malformations (CPAM), and bronchopulmonary sequestration (BPS).[15]

Lung volume is calculated on USG by lung to head ratio (LHR); if it is >1.6, survival is >83%. In MRI, total fetal lung volumes (TFLV) can be calculated. Cannie et al.[16] conducted a study in 200 fetuses without abnormalities at University Hospital Gasthuisberg (Belgium). Total lung volume correlated best with fetal body volume (FBV) than with all other biometric variables. The estimated lung volume ELV is calculated by the equation: $ELV = [(2.0 \times 10^{-9}) \times FBV^{3}] - [(1.19 \times 10^{-5}) \times FBV^{2}] + (0.0508 \times FBV) - 1.79$. All fetuses with values < 14.3% have a 100% mortality rate and those with values >32.8 have a 100% survival rate.[16] Thus, MRI scores over USG in calculating the lung volume.
Congenital diaphragmatic hernia
In CDH, the diaphragm is incompletely formed resulting in a defect through which the contents of the abdomen can enter the thoracic cavity [Figure 11]. Left-sided diaphragmatic hernias are more common than right-sided ones, with omental fat, stomach, and small bowel loops being the commonest structures to herniate. In addition to more accurate evaluation of residual lung volume, MRI assesses the contents of the hernia more accurately than USG, hence determining the outcome.

Congenital pulmonary airway malformations
They are abnormal pulmonary solid/cystic masses vascularized by the pulmonary artery and drained via pulmonary veins. Stocker et al.[17] classified them as: Type I (one or more cysts >2 cm), type II (multiple cysts 2-0.5 cm), and type III (large microcystic lesion <0.5 cm). CPAMs appear hyperintense on T2WI than the normal lung parenchyma.

Bronchogenic cysts
These are congenital malformations of the bronchial tree (type of bronchopulmonary foregut malformation) appearing as large solitary cystic lesions. Most bronchogenic cysts appear as single lesions typically located in the mediastinum [Figure 12], in the carinal region, but can also be found in the lung parenchyma or extend below the diaphragm as dumbbell-shaped cysts.[18]

Cystic hygromas
They are known as vasculolympathic origin anomalies.[19] They can arise anywhere along the lymphatic system; however,
Figure 8 (A-D): Bilateral hydronephrosis due to posterior urethral valves at 23 weeks gestation. Sagittal T2W, (A) coronal T2W, (B) single shot T2W, (C) and T2W coronal (D) images show grossly distended urinary bladder causing elevation of the diaphragm, occupying the whole abdomen. Dilated posterior urethra and bilateral hydronephrosis is seen.

Figure 10 (A-C): Left multicystic dysplastic kidney with right hydronephrosis and hydroureter in a fetus at 22 weeks. USG suggestive of bulky left multicystic dysplastic kidney, non-visualized right kidney, and urinary bladder with severe oligohydramnios. T2W coronal, (A) BTFE coronal (B) and BTFE coronal images, (C) detected the presence of right kidney with hydronephrosis, hydroureter, and normal urinary bladder, and confirmed dysplastic left kidney.

in most cases, they are located in the head and neck region. Cystic hygromas are multilobulated, thin-walled, lymph-containing sacs [Figure 13].

Other anomalies
Amniotic band syndrome
These are a group of congenital anomalies affecting the limbs and internal organs due to early rupture of amnion leading to fibrous bands with entrapment and herniation of the fetal parts [20] [Figure 14]. Multiple amniotic bands maybe associated with colpocephaly due to CC dysgenesis.
**Congenital vascular malformations**

These are a group of congenital dysplasias affecting the arterial, capillary, or venous system, presenting at birth. Sturge Weber, Klippel–Trenaunay, Maffucci, and Proteus syndromes are a few of these complex malformations.

Klippel–Trenaunay syndrome [Figure 15] comprises bony or soft tissue hypertrophy (localized gigantism), venous malformations, and port wine hemangiomas.[21]

**Twin pregnancies**

Miscellaneous conditions were seen in twin pregnancies including conjoined twins, genitourinary anomalies (renal agenesis) involving one twin [Figure 16], dilated PUVs [Figure 17], and twin reversed arterial perfusion sequence (TRAP) syndrome.

**TRAP sequence**

It is seen in multifetal monochorionic pregnancies. It consists of abnormalities resulting from entrapment of various fetal parts from a disrupted amnion. The condition results in one normal (pump) twin and abnormal (acardiac) co-twin[22] [Figure 18]. The acardiac twin is further classified as acardiusanceps (when the head is poorly formed), acardiusacephalus (if the head...
is absent), acardiusacormus (presence of head only), and acardiusamorphous (unrecognizable amorphous mass).\[^{[23]}\]

**Placental anomalies**
Placenta previa, accreta, increta, and hydatiform molar pregnancy with live fetus [Figure 19] were few of the placental indications for performing fetal MRI.

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**Figure 14 (A-G):** Amniotic band syndrome in a fetus at 18 weeks. Maternal T2WI sagittal, axial and oblique coronal images (A-D and E-G) show multiple amniotic bands with fetus trapped in persistent hyperflexion. Herniation of abdominal contents limited by amniotic membrane. Additional MRI findings: Dilated lateral ventricles (cerebral hydramnios), absent corpus callosum. (H) Autopsy specimen

**Figure 15 (A-F):** Venous/lymphatic malformation and Klippel-Trenaunay-Weber syndrome at 28 weeks gestation. T2W coronal, (A and B) Coronal USG, (C) T2W sagittal (D) images show hyperintense subcutaneous soft tissues in right lower limb with extension into the gluteal region and T2W coronal (F) image shows bulky kidneys

**Figure 16 (A and B):** Diamniondichorionic twin pregnancy with renal agenesis in presenting twin. T2W sagittal (A and B) images show presence of kidneys with distended bladder in the more cranial twin B. Distended bladder/both kidneys could not be demonstrated in the “presenting” more caudally placed fetus, twin A

**Conclusion**

The main role of MRI was to confirm/exclude lesions suspected on USG, as well as to define their extent and demonstrate associated abnormalities.

Fetal MRI scored over USG due to its higher spatial resolution, larger field of view, and ability to visualize fetal anatomy well, despite scanty liquor. Maternal factors such as echogenic abdominal wall and obesity are also not deterrents.
Fetal MRI is increasingly used in clinical practice, partly because of the increasing interest in fetal surgery and fetal medicine. It allows simultaneous imaging of different organ systems with reproducibility of images, producing images akin to postnatal scans, thus facilitating surgical planning and intervention. It helps predict postnatal management and in genetic counseling.

Sequences such as DWI, Apparent Diffusion Coefficient, MRI spectroscopy, functional imaging, and volumetric data acquisition are still under research and show future promise.

Declaration of patient consent
The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

References
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