Fetal MRI: thoracic, abdominal and pelvic pathology

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Abstract
Fetal MRI: thoracic, abdominal and pelvic pathology. Ultrasonography (US) is the method of choice in fetal examination. However, magnetic resonance (MR) imaging is a complementary technique that contributes to the accurate diagnosis of fetal anomalies. The benefits of MR include excellent tissue contrast, large field of view and relative operator-independence. Most previous reports on fetal MR have focused on central nervous system (CNS). However, MR is a useful tool for the examination of fetal thoracic and abdominal anomalies. This article illustrates the different features of fetal thoracic and abdominal anomalies on MR, and further discusses the indications and benefits of fetal MR.

Keywords. Comparative studies. Fetal anomalies. Fetal MR. Fetal US. Magnetic resonance (MR) imaging. Pregnancy MR. Rapid imaging.

INTRODUCTION
Ultrasound (US) is the routine screening test for fetal anomalies but, even when performed by experienced personnel, it has technical limitations. Even if most ultrasound examinations are diagnostic, such limitations may require an alternative imaging method in more complex cases to confirm or complete ultrasound findings, to guide management of pregnancy and to plan intrauterine interventions, delivery, and postnatal care.

With the advent of ultrafast sequences in the 1990’s, magnetic resonance imaging (MRI) is becoming a non-invasive method complementary to ultrasound, useful in the detection of fetal anomalies, which is helpful in formulating prognosis and perinatal management. However, most published research has focused on brain pathology and only a few studies report the use of fetal MRI in thoracic, gastrointestinal or genitourinary abnormalities. This article reviews fetal thoracic anomalies (with an especial emphasis on congenital diaphragmatic hernia, where MRI plays the most important role) and describes the main indications for MRI in abdominal pathology, as well as the advantages and disadvantages of MRI as compared to ultrasound.

IMAGING PROTOCOL
Scans should be performed using high-field (1.5T) resonators with multi-channel coils of great spatial resolution. Three orthogonal planes with respect to the mother are identified to obtain sagittal, coronal and axial slices of the fetus, always taking as reference the last sequence used to plan the following sequence because of fetal movements. The main sequences used are (Fig. 1):

- T2-weighted images —such as Single Shot Fast Spin Echo T2 (SSFSE T2)— and balanced Steady-State Free Precession sequences—such as FIESTA sequence, with high tissue contrast, showing hypointense amniotic fluid. Both sequences are useful to study the airways, lung, urinary tract and gastrointestinal tract—from the esophagus to the loops of the proximal ileum. All these structures are hypointense on SSFSE T2- and T1-weighted images.

- T1-weighted images (3D gradient dual echo, 2D FSPGR or 3D LAVA): provide less tissue contrast than SS FSE T2 or FIESTA.

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assessments of the liver, the loops of the distal ileum and colon, which are visualized as hyperintense structures. 3D sequences offer the possibility of volume reconstructions of the entire colon. As in brain pathology, these sequences are useful to determine the presence of subacute bleeding, calcifications or lipomas (9).

- Diffusion-weighted imaging: its applications are evolving and it is currently being used in the assessment of lung parenchyma maturation (2) and in the study of renal pathology, such as renal venous thrombosis or the Twin-Twin Transfusion Syndrome (TTTS) (3).

THORACIC PATHOLOGY

Fetal lungs are filled with fluid, and are therefore hyperintense on T2-weighted imaging, easily differentiated from other organs. MRI will not replace US as a first-line screening technique, but is useful in cases of oligohydramnios, maternal obesity, and unfavorable fetal position. Levine et al. (4) examined by US 74 fetuses diagnosed with thoracic abnormalities. MRI yielded additional information in 38% of cases and affected care in 8%.

Congenital diaphragmatic hernia

Congenital diaphragmatic hernia (CDH) is the main indication for fetal MRI in thoracic pathology. The incidence of CDH is 1 in 2,500 to 1 in 5,000 live births (5), with 85% occurring on the left side (Bochdalek hernia), 15% on the right and 2% are bilateral (6). Approximately 40% of patients with CDH have other congenital malformations (mainly cardiac and of the central nervous system –CNS–), chromosomal anomalies (trisomy 21, trisomy 18 and trisomy 13) and genetic syndromes (Fryns syndrome, Lange syndrome or Marfan syndrome) (7). Associated anomalies are considered an independent survival factor (survival is less than 15%) (8).

The degree of pulmonary hypoplasia and liver herniation are the main prognostic factors. To calculate lung volume on ultrasound, the lung-to-head ratio (LHR) (contralateral lung area / head circumference) is used, and it is measured in the second trimester. If LHR is >1.6, survival is ≥83%; if LHR is ≥1 and <1.6, survival is 66%; and with values ≥0.8 and <1, survival is 16% (9). Volumetric evaluation of the lung using 3D ultrasound for calculation of lung volume is not better than LHR (10).

With MRI, both the ipsilateral and contralateral lung volumes can be measured, thus obtaining the observed total fetal lung volume (TFLV).

Rypens et al. (11) conducted a multicenter (seven hospitals in France and Belgium) prospective study with MRI in 336 fetuses suspected of having CNS disorders, to establish the correlation between total lung volume and gestational age. Predicted or expected lung volume (ELV) is calculated by the equation: ELV = 0.0033g2.86 (where g is gestational age in weeks).

In their retrospective study of 46 fetuses from American women, Coakley et al. (12) found a strong correlation between total lung volume measured at MRI and liver volume measured at MRI, fetal weight estimated at US, head circumference measured at US and gestational age. The ELV is calculated by the equation: ELV = (0.47 ≥ liver volume in milliliters) + (0.76 ≥ biparietal diameter in millimeters) ≥ (0.39 ? femur length in millimeters) ≥ 18.9.

In addition, Cannie et al. (13) 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 ELV is calculated by the equation: ELV = (2.0 x 10-9 x FBV3) – (1.19 x 10-5 x FBV) + (0.0508 x FBV2) – 1.79.

The observed-expected (O/E) ratio for TFLV x 100 establishes the relative lung volume (RLV) and values below 80% are considered as hypoplasia (14). All fetuses with values <14.3% have a 100% mortality rate, those with values >32.8 have a 100% survival rate and those with values >44% do not need extracorporeal membrane oxygenation (ECMO) (15) (Figs. 2, 3 and 4).

MRI is also useful in the assessment of lung maturation by lung signal intensity: lung maturation has been correlated with a high signal intensity of the lung on T2-weighted images, calculating signal intensity ratios of lung/spinal fluid (16), lung/gastric fluid or lung/liver (17). Signal intensity increases with gestational age (18).

Moore et al. (19) have studied fetal lungs using diffusion-weighted imaging and have shown that the ADC increases with gestational age (as from week 18), probably reflecting the increase in alveolar fluid secretion and pulmonary vascularization (20-21).

Spectroscopy has theoretical potential for evaluation of lung maturation. Surfactant is composed of 90% phospholipids (basically 70% phosphatidylcholine—lecithin) and 10% protein. The amount of choline, the ratio of choline/creatinine, lecithin and lactate might be correlated with the amount of pulmonary surfactant (22-23). Unfortunately, this technique has several limitations (especially fetal motion artifacts).

Fetuses with liver herniation have 50% survival. The supradiaphragmatic liver position is difficult to visualize on US, while MRI allows identification of diaphragmatic defect (defect in the low-signal-intensity band on T2-weighted sequences), especially in sagittal and coronal planes, and the abnormal position of the liver (with hyperintense signal on T1-weighted images and hypointense signal on T2-weights images). The most commonly herniated structures in left-sided diaphragmatic hernias include omental fat, the small bowel, the left hepatic lobe and the stomach.
The kidney and pancreas are rarely herniated. In right-sided diaphragmatic hernias, the most commonly herniated organ is the liver with herniation of the right hepatic lobe.

Fetal endoluminal tracheal occlusion (FETO) is indicated for liver herniation (LHR <1, at week 26-29 and in the absence of chromosomal anomalies or associated abnormalities). FETO is a minimally invasive procedure in which an endotracheal balloon is inflated for 3 or 6 weeks. Retention of fluid within the lung accelerates lung maturation and reduces the risk of pulmonary hypertension. FETO should be performed prior to 29 weeks of gestation, and the balloon is then removed via fetoscopy —after being punctured at week 34— either by ex-utero intrapartum treatment (EXIT) or post-natal (either by tracheoscopy or percutaneous puncture). When FETO is performed before 29 weeks of gestation, a significant lung expansion occurs as a result of a marked production of fluids. When the balloon is removed, the RLV decreases by nearly 50%, but it is 40% higher than the RLV prior to balloon insertion. When FETO is performed after 29 weeks of gestation, the RLV does not increase after balloon removal.

In the study conducted by Jani et al, the main complications were: prelabor rupture of membrane (47%), chorioamnionitis and premature delivery. FETO increased survival in left-sided CDH from 24.1% to 49.1% and in right-sided CDH from 0% to 35.3%. Ninety-seven per cent of fetuses undergoing FETO were live born and 50% of those babies resisted surgery and were discharged from the hospital alive.

Cystic adenomatoid malformation (CAM) or congenital pulmonary airway malformation

CAM is the most commonly diagnosed fetal lung mass of the newborn period. It consists of lung hamartoma with proliferation of terminal bronchioles and lack of normal alveoli. They are solid or cystic masses, vascularized by the pulmonary artery and with drainage via the pulmonary veins. Most CAMs are unilateral and affect one entire lung lobe, although there are hybrid lesions associated with pulmonary sequestration with systemic vascularization. Stocker et al 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). CAMs are usually detected by ultrasound at 20 weeks of gestation and they appear as cystic or solid echogenic lung masses. They may be occasionally misdiagnosed on ultrasound as CDH or vice versa.

Isolated CAMs are associated with a good prognosis, with 97% survival (independent of histological type), excluding CAMs with associated abnormalities,
Fig. 2: (a), (b) and (c) Sagittal SS FSE T2. (d) Axial SS FSE. (e) VR of the right lung (5.311 cm³) and (f) VR of the left lung (1.425 cm³). Left-sided diaphragmatic hernia with herniated bowel loops (white arrow), stomach (white arrowhead) and left hepatic lobe (curved arrow). Right lung (broken arrow). Heart (black arrowhead). Hypoplasia of the left lung (black arrow) and contralateral cardiomesadiastinal shift. Expected total fetal lung volume: 18.2 cc; observed total fetal lung volume: 6.73 cc; relative lung volume: 36.9%. Gestational Age (GA): 20 weeks.

Fig. 3: (a) Coronal FIESTA and (b) Coronal T1-weighted dual echo gradient. (c) and (d) Sagittal SS FSE T2. Right-sided diaphragmatic hernia with herniated bowel loops (black arrow) and right hepatic lobe (white arrow). Hypoplasia of right lung (arrowhead). Contralateral cardiomesadiastinal shift. GA: 22.5 weeks. Right lung volume: 0.884 cc; left lung volume: 5.905 cc; observed total lung volume: 6.79 cc; expected total lung volume: 20.32 cc; relative lung volume: 33%.
which account for 3-12% (most of them corresponding to Stocker type II lesions). In over 50%, there is spontaneous resolution during pregnancy (29). Typically, CAMs with less than 57% of total lung volume regress completely, while those with a volume greater than 84% show partial regression.

The most important prognostic factor is the presence or absence of hydrops (31). CAM may cause compression of the heart and the inferior vena cava and, secondarily, impair cardiac contractility and venous return (32). If hydrops is left untreated, over 90% of fetuses will die before being born (30). To estimate the risk of developing hydrops, the CAM volume / head circumference ratio (CVR) is calculated at ultrasound. CAM volume is calculated based on ultrasound measurements obtained in three dimensions of the mass. The CAM volume is divided by the head circumference, which is assessed by ultrasound (occipital frontal diameter + biparietal diameter) x 1.57. If the CVR is > 1.6, the fetus will develop hydrops in 75% of cases; if the CVR is < 1.6, hydrops will occur in less than 3% of cases (33).

MRI findings vary according to the type of CAM: type I lesions manifest as hyperintense unilocular lesions on T2-weighted images; type II lesions appear as hyperintense multilocular lesions on T2-weighted images; type III lesions manifest as hyperintense solid masses with normal adjacent lung, which is more hypointense, on T2-weighted images. In addition, the volume of lesions and lung parenchyma can be calculated, thus allowing quantification and monitoring of the lesions growth or resolution (31) (Figs. 5 and 6).

CAMs require postnatal surgery, after one month of life, because of the risk of infection and the low risk of malignant transformation --annual rate of 3%-- into pleuropulmonary blastoma, rhabdomyosarcoma or myxosarcoma in infants and into bronchoalveolar carcinoma in children and adults (34).

**Bronchopulmonary sequestration**

Bronchopulmonary sequestration is the second most common lesion in prenatal diagnosis. Bronchopulmonary tissue is disconnected from the bronchial tree and pulmonary arteries and receives arterial blood from the systemic circulation, via the thoracic or abdominal aorta. The most common location is the left lower lobe (>2/3) (37), with 90% being supradiaphragmatic (Fig. 7) and less than 10% infra-diaphragmatic (30) (Fig. 8).

Extralobar sequestration occurs in the fetus, has its own pleural covering and venous drainage is through the azygos system or the inferior vena cava (in 25% of cases through the pulmonary veins) (35). Intralobar
Fig. 5 (a) Coronal SS FSE T2. (b) Sagittal SS FSE T2. (c) Axial SS FSE T2. (d) VR reconstruction of CAM. (e) VR reconstruction of the right lung. (f) VR reconstruction of the left lung. CAM type II in lower left lobe (curved arrow), upper left lobe (arrowhead) and right lung (white arrow). GA: 22.5 weeks. Right lung volume: 9.307 cc; left lung volume: 4.244 cc; total lung volume: 13.55 cc. CAM volume: 13.942 cc. CVR index: 0.75 (<1.6 good prognosis). As from 32 weeks of gestation, the heart occupied its place on the left side of the chest and follow-up ultrasound confirmed a reduction in the pulmonary area affected by CAM. Normal Full-term delivery, with newborn weighing 3200 g, not requiring respiratory assistance. Normal post-natal chest x-ray.

Fig. 6: (a) Sagittal SS FSE T2. (b) Coronal SS FSE T2. (c) Axial SS FSE T2 and (d) Coronal T1-weighted dual echo gradient. CAM type II in posterior segment of lower right lobe (white arrow). GA: 28 weeks. Normal liver (arrowhead) and colon’s hepatic flexure (broken arrow).
sequestration does not have its own pleura and drainage is through pulmonary veins (40). They are rarely diagnosed prenatally and are usually associated with type II-CAM (hybrid lesions) (41). They have an excellent prognosis when isolated and over 50% resolve in utero (29). Large lesions may compress the esophagus and thoracic veins, and subsequently cause hydrops (an indication for fetal intervention and early delivery) (42). Prenatal treatment with thoracoamniotic shunting is performed in cases of tension hydrothorax.

On MRI, pulmonary sequestration appears as a solid, hyperintense lesion on T2-weighted images, very similar to type III CAM. Identification of systemic blood supply helps in the diagnosis, mainly with balanced sequences. MRI can detect small lesions and associated anomalies.

Postnatally, most sequestrations are asymptomatic and may present with respiratory distress or cyanosis. Postnatal treatment consists of embolization of systemic blood supply or surgical resection, given the risk of infection, hemorrhage and questionable malignancy (mainly in hybrid lesions) (42).

**Bronchogenic cyst**

Bronchogenic cyst is the solitary cystic lesion most commonly found in the fetal chest. Most bronchogenic cysts appear as single lesions typically located in the mediastinum, in the carinal region, and less frequently, in the hilar region (43). On MRI, it appears as a well-defined cyst, hyperintense on T2-weighted images when compared to the surrounding lung tissue (Fig. 9). In addition, the MRI can detect bronchial obstruction due to mass effect of some cysts with hyperintensity on T2-weighted images of the obstructed lobe (44). The role of MRI is limited to the cases of bronchial obstruction, which will benefit from the EXIT-ECMO procedure with resection of the obstructive lesion, followed by reconstruction of the airway.

**Bronchial obstruction by mucous plug**

Obstruction by a mucous plug of a main or lobar bronchus produces an image similar to that of type-III CAM or a sequestration with intrathoracic mass, hyperintense on T2-weighted imaging, and which may cause mediastinal shift (Fig. 10). It may resolve spontaneously in utero or by postnatal bronchoaspiration (45).
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Fig. 9: (a) Sagittal FSE T2. (b) Sagittal FIEST A. (c) Axial SS FSE T2. (d) Coronal FIESTA. (e) Axial ultrasound and (f) sagittal ultrasound. Bronchogenic cyst in left lung (white arrow). GA: 22 weeks. Bichorial biamniotic twins.

Fig. 8: (a) and (b) Sagittal SS FSE T2. (c) Coronal SS FSE T2. (d) Axial SS FSE T2. Infradiaphragmatic sequestration (arrow) and systemic artery of abdominal artery (arrowhead). GA: 31.5 weeks.

Fig. 5: (a) Sagittal FSE T2. (b) Sagittal FIESTA. (c) Axial SS FSE T2. (d) Coronal FIESTA. (e) Axial ultrasound and (f) sagittal ultrasound. Bronchogenic cyst in left lung (white arrow). GA: 22 weeks. Bichorial biamniotic twins.
Fig. 11: (a) and (b) Sagittal SS FSE T2. (c) Coronal SS FSE T2. (d) oblique slice SS FSE T2. (e) Axial SS FSE T2 (f) T1 gradient echo. Omphalocele: herniated liver (white arrow), stomach (curved arrow), bowel loops without meconium (broken arrow) and bowel loops with meconium (arrowhead). GA: 20 weeks.

Fig. 10: (a) and (b) Coronal SS FSE T2. (c) and (d) Sagittal SS FSE T2. Affected LLL (white arrow), healthy LUL (arrowhead) and healthy right lung (broken arrow) with normal x-ray at birth, corresponding to transient atelectasis due to mucus plug. GA: 20.5 weeks.
Other less common indications

Thoracic abnormalities less commonly assessed by MRI include: congenital airway obstruction (by extrinsic factors or tracheal and bronchial stenotic or atresic malformations), congenital lobar emphysema, pleural effusion, pericardial effusion, pericardial tumors (teratoma), mediastinal tumors (teratoma, lymphangioma) and cardiac tumors (rhabdomyoma).

ABDOMINAL PATHOLOGY

Published studies on the usefulness of MRI in abdominal pathology are much less than those on thoracic MRI. Even if most ultrasounds are diagnostic, they have limitations that create a need for an alternative imaging method.

Anterior abdominal wall defects

The incidence of anterior abdominal wall defects is 1 in 2000 live births. The commonest abdominal wall defects are gastroschisis and omphalocele and the less common are the pentalogy of Cantrell (midline abdominal wall defect, anterior diaphragmatic hernia, diaphragmatic pericardial defect, lower sternal defect and cardiac abnormalities) and the cloacal and bladder extrophy.

Omphalocele

An omphalocele is a midline supraumbilical abdominal wall defect with herniation of abdominal content, covered by the peritoneum and amnion, with umbilical cord insertion in the apex of the omphalocele. The most commonly herniated organs are the liver, stomach and loops of the small bowel, which are easily identified on MRI. Omphalocele is associated with other malformations in 40 to 70% of cases and the incidence of chromosomal anomalies is 10 to 40%, including trisomy 13, 14, 15, 18 and 21.

The presence of liver in herniated organs has been considered as the element that differentiates between large and small omphalocele. Large omphaloceles have a high mortality rate, as several surgical procedures are required to obtain closure of the defect, with their main limitation being a small thoracic cavity, associated pulmonary hypoplasia and the need for prolonged mechanical ventilation (Fig. 11). On MRI, the presence of the liver in herniated organs is easily identified and the degree of pulmonary hypoplasia can be established. Small omphaloceles (Fig. 12) show higher association with chromosomal abnormalities.

Gastroschisis

Gastroschisis is a typically right-sided paraumbilical anterior abdominal wall defect. The loops of the small bowel are most frequently prolapsed and float in
Fig. 13: (a) and (b) Coronal SS FSE T2. (c) and (d) Sagittal SS FSE T2. Single umbilical artery (white arrow). Esophageal atresia with small-sized stomach (arrowhead) and small esophageal pouch (broken arrow). Trachea (curved arrow). GA: 31.5 weeks.

Fig. 14: (a) and (b) Sagittal FIESTA. (c) Coronal FIESTA. (d) and (e) SS FSE T2-weighted urography images. (f) Coronal T1-weighted dual echo gradient. Left renal agenesis. Hypertrophic right kidney (white arrow). Bladder (white arrowhead). Loops of small bowel (broken arrow) and colon’s splenic flexure (curved arrow) in the left renal fossa. GA: 32 weeks.
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Fig. 15: (a) Coronal SS FSE T2. (b) Axial SS FSE T2. (c) Sagittal SS FSE T2. Multicystic right kidney (arrow). Normal left kidney (arrowhead). GA: 20 weeks.

Fig. 16: Bichorial biamniotic twin pregnancy. Cloacal malformation. (a) Ultrasound at 15 weeks of gestation: rectal-sigmoid dilation (white arrow) and fecal impaction (white arrowhead) in one twin, without ascites. (b) Ultrasound at 20 weeks of gestation: cystic structure with incomplete septum (broken arrow), anterior to rectosigmoid and posterior to the bladder (black arrow), with ambiguous genitalia. MRI was performed at 26.5 weeks of gestation. (c) Sagittal SS FSE T2 and (d) Sagittal SS FSE T2 (URO-MRI). Ascites (black arrowhead) of the twin in longitudinal position and left breech presentation. Cystic structure (broken arrow) anterior to the rectum-sigmoid. (e) and (f) Coronal FIESTA. Ascites (black arrowhead) and cystic structure with incomplete septum (broken arrow) with content inside (curved arrow), suggesting detritus from fistula of the rectosigmoid (white arrow). Bladder cannot be identified. G SS FSE T2 (URO-RM). Grade III/IV hydronephrosis on the right side (1) grade II/IV hydronephrosis on the left side (2), suggesting urinary ascites. Postnatal follow-up by x-ray: retrograde filling of contrast material through single perineal opening (3). Filling of bladder (4), vagina and partial septate uterus (5) containing hydrometrocolpos and gas because of rectosigmoid fistula. The rectosigmoid is not filled with contrast (6).

the amniotic fluid without covering membrane. Extracorporeal colon may be present in gastroschisis, but not sigmoid or rectum. Prolapse of the liver less frequently occurs. A higher incidence is found in mothers using vasoactive substance (cocaine, nicotine, decongestants or aspirins) and in mothers younger than 25 years old. These defects are not generally associated with other malformations, although they may affect the gastrointestinal tract by 10-15% (atresia, stenosis, short bowel syndrome) probably due to ischemic damage by loop obstruction. They are associated with oligohydramnios and intrauterine growth retardation (IUGR). When associated with polyhydramnios, bowel atresia or obstruction should be ruled out. MRI allows visualization in cases of oligohydramnios or maternal obesity, or associated bowel complications. In 4-5% of cases, gastroschisis is associated with cardiac malformations. The incidence of chromosomal anomalies in gastroschisis is below 3%.
GASTROINTESTINAL ABNORMALITIES

Fetal scan of the gastrointestinal tract is based on the presence of “natural” contrast media: swallowed amniotic fluid passed to the intestines and meconium. Swallowing of amniotic fluid begins by 9-10 gestational weeks; however, except for the stomach, it is not until 25 gestational weeks that significant amount of fluid enters the fetal intestines to serve as a natural contrast medium. The full-term fetus swallows as much as 750 ml/day. Meconium starts to accumulate in the rectum by 18-20 gestational weeks, with retrograde filling of the colon and distal ileal loops.

Most abnormalities are diagnosed by ultrasound and do not require a complementary diagnostic method.

The main indications for MRI in gastrointestinal assessment are: identifying the site of bowel obstruction (bowel atresias, meconium ileus and bowel volvulus) and ruling out bowel ischemia (wall thickening, meconium peritonitis) and malrotation.

Esophageal atresia

The most common is type A with proximal atresia and distal tracheoesophageal fistula. Diagnosis is established by the presence of polyhydramnios, small stomach, proximal esophageal pouch and IUGR in the 2nd or 3rd trimester (Fig. 13). The tracheoesophageal fistula cannot be detected by MRI. It is associated with trisomy 18 and, in the absence of fistula, it is more common in trisomy 21.

Duodenal atresia or stenosis

Duodenal atresia or stenosis is diagnosed by means of the double bubble sign of the stomach and duodenum (hypointense on T1-weighted images and hyperintense on T2-weighted sequences), which includes duodenal stenosis, annular pancreas, Ladd bands and volvulus. Duodenal atresia is associated with other abnormalities and trisomy 21.

Small bowel atresia or stenosis

Small bowel atresia is seen as dilated bowel loops proximal to the obstructed segment. MRI provides additional information since in the case of jejunal stenosis or atresia, dilated loops are hypointense on T1-weighted images and hyperintense on T2-weighted images (with triple bubble sign and polyhydramnios, if proximal jejunum is affected) while in ileal atresia or...
Fig. 18: Retroperitoneal teratoma. (a) and (b) Axial SS FSE T2. (c) and (d) Coronal SS FSE T2. (e) Sagittal Fiesta. (f) Sagittal T1-weighted echo gradient. Cystic mass on right adrenal location, with solid poles (white arrow), crossing the midline (arrowhead) anterior to the aorta. The mass inferiorly displaces the right kidney with horizontalization of the kidney (curved arrow). GA: 35.5 weeks.

stenosis, dilated loops resemble a “string of sausages” with meconium, being hyperintense on T1-weighted images and iso-hypointense on T2-weighted images (57). Distal atresias have a higher risk of perforation and meconium peritonitis.

Meconium peritonitis

Meconium peritonitis is a chemical peritonitis secondary to the perforation of a bowel loop, diagnosed on US with the finding of peritoneal calcification, ascites and pseudocysts (54). MRI cannot identify calcifications but allows easy recognition of dilated loops, ascites, polyhydramnios and cystic masses (meconium pseudocysts). Pseudocysts may contain internal septations with a variable T1 signal and a high T2 signal (58), hyperintense on T1-weighted images and intermediate on T2-weighted images (59) or hyperintense on T1- and very low on T2-weighted images (60).

Colon malrotations

Malrotations can be diagnosed on MRI as from 25 weeks of gestation. MRI shows the abnormal position of the colon, using T1-weighted sequences, given meconium content (55).

Megacystis-Microcolon-Intestinal Hypoperistalsis Syndrome

Enlarged bladder (the most typical finding) is easily diagnosed on ultrasound and MRI. On MRI, this finding can be visualized as from 25 weeks of gestation given the very small amounts of meconium present in the rectum. At the end of gestation, more meconium accumulates and the microcolon can be seen (55).

Large bowel atresia

Large bowel atresia mainly affects the rectum. Atresia of the transverse colon produces dilation of the proximal colon, small amount of distal meconium and dilation of small bowel loops with absence of peristalsis. Cecal atresia causes dilation of the cecum and ileum with abundant meconium (61).

Hirschsprung disease

In Hirschsprung’s disease, there is rectal dilation with hypointense inverted signal on T1-weighted images and intermediate signal on T2-weighted images (62).
Anal atresia

Small and isolated forms of anal atresia may go undetected by MRI. V-shaped or U-shaped loops in the pelvis suggest a diagnosis of anal atresia. They are frequently associated with urinary tract fistula producing enteroliths (which are better identified on ultrasound) or they may be part of the VACTERL syndrome (vertebral anomalies, anal atresia, cardiac anomalies, tracheoesophageal fistula, renal and limb defect).

GENITOURINARY ABNORMALITIES

Fetal urine is the main source of amniotic fluid. As from 10 weeks’ gestation, fetal kidneys produce urine and during the second half of pregnancy, they produce 90% of amniotic fluid.

MRI is indicated only when ultrasound findings are inconclusive, especially in the cases of oligohydramnios or anhydramnios. 2D and 3D T2-weighted sequences with long repetition time (RT) are useful to obtain urography images of the excretory system without intravenous contrast (which is contraindicated). Diffusion-weighted sequence would be useful in cases of suspected renal infarction due to venous thrombosis with a decrease in the apparent diffusion coefficient (ADC) and in the twin-twin transfusion syndrome, where the ADC of the donor twin is higher than that of the recipient twin and is related to the severity of the syndrome. Diffusion-weighted imaging helps in the diagnosis of (unilateral or bilateral) renal agenesis because this technique is very sensitive in detection of the renal parenchyma.

Hydronephrosis

Hydronephrosis is clearly visualized on T2-weighted images. In the coronal plane, urography images can be obtained, with visualization of the whole ureteral course.

Pyeloureteral junction stenosis

The pyeloureteral junction stenosis is the most frequent cause of hydronephrosis detected prenatally and it may progress to a displastic kidney with multiple cortical and medullary cysts.

Duplicated renal collecting system

A duplicated renal collecting system is the most common anomaly. MRI can be helpful in the diagnosis of complete or incomplete duplex system, and ectopic drain of an ureterocele associated with the upper ureter.

Bilateral renal agenesis

MRI allows diagnosis of bilateral renal agenesis, as severe oligohydramnios or anhydramnios impairs assessment by US. It is associated with congenital heart disease and Potter’s syndrome due to oligohydramnios (typical facies, joint contractures and pulmonary hypoplasia).

Unilateral renal agenesis

Unilateral renal agenesis (Fig. 14) generally occurs in isolation, and has a normal life expectancy, although it may be occasionally associated with VACTERL syndrome. When a kidney is not located within the renal fossa, MRI helps in identification of the ectopic kidney location.

Autosomal polycystic kidney disease

Autosomal recessive polycystic kidney disease is characterized by large kidneys with high uniform intensity on T2-weighted images and loss of cortico-medullary differentiation; the pyelocaliceal system is not identified.

Multicystic dysplastic kidney

Multicystic dysplastic kidneys (Fig. 15) are enlarged, with multiple cysts of different size peripherally and centrally located, with little renal parenchyma. These cysts demonstrate high signal intensity on T2-weighted sequences and are separated from the pyelocaliceal system.

Bladder extrophy

Bladder extrophy is a rare malformation in which the anterior wall of the bladder is absent, and the posterior wall is exposed externally. MRI identifies an extruded solid mass below the umbilical cord insertion, with normal kidneys and amniotic fluid.

Cloacal malformation

Cloacal malformation is a rare cause of obstructive uropathy secondary to failure of the division of the primitive cloaca, with communication between the gastrointestinal, urinary, and genital structures, resulting in a single perineal opening. Cloacal malformation is more common in women, with bilateral hydronephrosis, cystic lesion in the pelvis and difficulty in visualizing the bladder because of its small size (Fig. 16). It is associated with meconium calcification in the...
Fig. 19: (a) Coronal FIESTA (b), (c), (d), (e) and (f) Axial FIESTA. (1) Supradiaphragmatic inferior vena cava; (2) Middle hepatic vein; (3) left hepatic vein; (4) right atrium; (5) descending thoracic aorta; (6) azygos vein; (7) abdominal aorta; (8) hemiazygos vein; (9) right hepatic vein; (10) left ascending lumbar vein. Agenesis of inferior vena cava secondary to thrombosis, with collateral flow through paravertebral veins, azygos and hemiazygos ascending lumbar veins. Bilateral adrenal hemorrhagic pseudocysts. Kidneys with cortical thickening (white arrows), mainly on the left kidney. (g) Sagittal SS FSE T2. Left adrenal hemorrhagic pseudocyst and high signal intensity in the upper pole of kidney, suggesting renal infarction (broken arrow). (h) Diffusion-weighted image. High intensity signal of left kidney suggesting probably venous infarction (white arrowhead). GA: 36 weeks.

Fig. 20: Portosystemic shunt with aneurysm or venous lake in 30-gestational-week-old fetus. (a), (b), (c), (d) and (e) MRI. Axial FIESTA; (f) Sagittal FIESTA. Umbilical cord (curved arrow). Absence of venous conduit, with umbilical vein (black arrow) draining into the portal vein (arrowhead) at the level of the hepatic hilum. Venous lake or aneurysm (white arrow) in segment VIII. Anterior drainage vein (1). Posterior drainage vein (2). Vessel collecting blood from (1) and (2) and draining into the inferior vena cava (3). Inferior vena cava (broken arrow). Left hepatic vein (black arrowhead).
urinary tract and colon, which are better identified on ultrasound (72,74). There is a minor variant: the urogenital sinus, with communication between the vagina and the urinary tract (which normally occurs during embryological development). Such communication may occur at any point from the urethral meatus to the bladder, but the majority occur within the mid to distal portion of the urethra. The two structures join and exit on the perineum as a single common urogenital sinus channel (79).

Prune-Belly or Eagle-Barrett Syndrome

The Prune-Belly or Eagle-Barrett Syndrome is a rare congenital malformation with severe hydronephrosis, abdominal muscle deficiency and chytrorchidism. MRI identifies hydronephrosis, bilateral ureteral dilatation and dilation of the entire urethra, unlike posterior valves, which cause proximal urethral dilatation. Genitalia are absent and it is associated with oligohydramnios (76).

ABDOMINAL MASSES

Most abdominal masses are benign cystic lesions: Intestinal duplication cyst: unilocular cyst, with double-layered wall of muscle and mucous membrane. The most common location is in the distal ileum.

Mesenteric cyst: considered as a lymphatic malformation. It may be unilocular or most commonly multilocular with multiple septa (Fig. 17). It may occasionally extend into the retroperitoneum and lower limbs.

Ovarian cyst: this is the most common female abdominal mass in the third trimester. Ovarian ligaments are lax and the ovarian cyst may be found in any location. It may be simple or complicated, with torsion and bleeding.

Urachal cyst: unilocular cyst that occurs in the midline between the bladder and the umbilical cord insertion.

Cholecystic cyst: unilocular cyst that occurs in the right upper quadrant. Bile ducts may be seen entering into the cyst.

TUMORS

MRI can detect, localize and characterize benign cystic lesions, differentiating them from bowel loops (77,78). The experience with MRI in the diagnosis of congenital hepatic masses is very limited. Most are large and solid masses (hemangioendothelioma, hepatoblastoma or metastatic neuroblastoma), with cystic lesions (mesenchymal hamartoma) being less common (79).

Mesoblastic nephroma is the most common renal solid mass. It is a benign tumor with excellent prognosis associated in 70% of cases with polyhydramnios (80).

VASCULAR PATHOLOGY IMAGING

The use of intravenous contrast (gadolinium) is not accepted. Gadolinium chelates cross the placenta (86) and there is potential risk of gadolinium-induced nephrotoxicity (nephrogenic systemic fibrosis) (87).

Balanced sequences (FIESTA) are useful in assessing thoracic and abdominal vascular anatomy without contrast (80), mainly in cases of intra- or extra-lobar sequestration, developmental abnormalities of the inferior vena cava (Fig. 19) or vascular malformations such as hepatic portosystemic shunts (Fig. 20).

CONCLUSIONS

MRI plays an important role as complementary method to ultrasound due to its multiplanar capability and tissue differentiation. Its main indication is the assessment of diaphragmatic hernia, where MRI provides diagnostic information, establishes a prognosis and helps in planning delivery and postnatal surgery. In gastrointestinal pathology, MRI is useful in the assessment of bowel obstruction, perforation and malrotation. In genitourinary imaging, MRI does not have the limitations of ultrasound (oligohydramnios or maternal obesity) and it is used in the assessment of renal agenesis, obstructive pathology and cystic kidney disease. Furthermore, it allows characterization of congenital cystic lesions. With balanced sequences, MRI angiographies can be performed without intravenous contrast; this is useful in the assessment of congenital vascular pathology of large vessels and pulmonary sequestration.

References


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