Recommendation and Guidelines for Perinatal Practice

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Fetal magnetic resonance imaging and ultrasound

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Abstract: Magnetic resonance imaging (MRI) has been increasingly adopted in obstetrics practice in the past three decades. MRI aids prenatal ultrasound and improves diagnostic accuracy for selected maternal and fetal conditions. However, it should be considered only when high-quality ultrasound cannot provide certain information that affects the counseling, prenatal intervention, pregnancy course, and delivery plan. Major indications of fetal MRI include, but are not restricted to, morbidly adherent placenta, selected cases of fetal brain anomalies, thoracic lesions (especially in severe congenital diaphragmatic hernia), and soft tissue tumors at head and neck regions of the fetus. For fetal anatomy assessment, a 1.5-Tesla machine with a fast T2-weighted single-shot technique is recommended for image requisition of common fetal abnormalities. Individual judgment needs to be applied when considering usage of a 3-Tesla machine. Gadolinium MRI contrast is not recommended during pregnancy. MRI should be avoided in the first half of pregnancy due to small fetal structures and motion artifacts. Assessment of fetal cerebral cortex can be achieved with MRI in the third trimester. MRI is a viable research tool for noninvasive interrogation of the fetus and the placenta.

Keywords: Fetal imaging; magnetic resonance imaging; safety.

Introduction

Ultrasound is the main, and often the only, imaging modality of choice for pregnant women. MRI has become more widely available and has become an accepted and a powerful complementary method for evaluation of the fetus in the past three decades [1]. According to a review of 13 published studies, MRI can aid prenatal ultrasound and improves diagnostic accuracy in selected maternal and fetal conditions [2]. Indications for fetal MRI are continuously evolving. Optimal application of MRI is fostered by manufacturing of MRI machines that have stronger field strengths. Improvement of MRI image acquisition is a result of ultrafast sequence protocols and better postacquisition image processing and rendering [3]. Fetal MRI technologies, in addition to rapid progressions in prenatal molecular genetics diagnosis and the availability of in utero intervention, have revolutionized obstetric practice. For appropriate clinical implementation of MRI, it is important that obstetricians are adequately informed of the basic principles, proper indications, potential additional benefits, limitations, and risks of MRI to the fetus. In this article, the Working Group...
on Ultrasound in Obstetrics of the World Association of Perinatal Medicine (WAPM) is aiming to outline an optimal application of fetal MRI for current practice from the fetal medicine specialist's point of view.

It is important to note that this article only provides basic principles of the conditions where MRI can significantly compliment high-quality fetal ultrasound. Common MRI sequences being applied to obtain the best characterization of various fetal tissue of interest will be briefly introduced. Deeper details on the interpretation of fetal MRI images, as well as the physics of novel MRI sequences, are of interest to MRI radiologists and scientists, and will not be covered in this article. Whenever fetal MRI is being considered, a fetal medicine specialist should be in close communication and working as a team with an MR radiologist according to the specific organ system that required additional information from MR, so that the MR radiologist can help in choosing the right sequence for the best image resolution. The consensus of when and how to use MRI to the maximum benefit to the mother and the fetus has not been reached by all international professional societies, therefore, this article cannot be viewed as an established legal standard of care.

History

Ultrasound remains the most important imaging modality for fetal assessment. High-quality prenatal ultrasound alone is adequate for fetal and maternal assessment in the majority of cases. In order to reach definitive diagnosis in complicated cases, it requires a skillful operator and a high-resolution ultrasound machine. MRI should be considered only when “high-quality ultrasound” cannot provide adequate information for prenatal counseling and management. A definition of optimal fetal anatomy survey by ultrasound has been offered in the guidelines from the International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) [4]. Even in the most experienced hands, certain factors, such as anhydramnios, fetal position, maternal adiposity, and fetal ossification may influence the diagnostic accuracy of ultrasound. In these selected cases, MRI may provide additional information due to its superb soft tissue characterization and large field of view. The image creation of MRI does not involve ionizing radiation, unlike a computerized tomography (CT) scan.

The first MRI performed during pregnancy was reported in 1983, to confirm placenta accreta suspected from clinical history and ultrasound findings [5]. The indications to perform MRI during pregnancy have been progressively extended to other fetal conditions. Even though the MRI technique is noninvasive, it should be offered only when ultrasound cannot provide adequate information for family counseling, in utero intervention, and delivery planning. Comparison between the advantages and disadvantages of fetal ultrasound and MRI is shown in Table 1. It is important to note that MRI is, in fact, operator-dependent. The radiologist or fetal MR specialist who can appropriately interpret the MR images has to be familiar with normal development of fetal anatomy. The MR images have to be read in correlation with those of ultrasound contexts.

Table 1: Comparison between the advantages and disadvantages of fetal ultrasound and MRI.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td><strong>Fetal ultrasound</strong></td>
<td>- Operator dependent &lt;br&gt;- Obstructed view &lt;br&gt;- Fetal position</td>
</tr>
<tr>
<td>- Convenient &lt;br&gt;- Widely available &lt;br&gt;- Affordable</td>
<td>- Fetal ossification, i.e. skull and thoracic rib cage &lt;br&gt;- Oligohydramnios</td>
</tr>
<tr>
<td>- Real-time interpretation by the operator &lt;br&gt;- Better for calcified lesion, i.e. brain, liver, and placenta &lt;br&gt;- Real-time guidance of invasive diagnostic and therapeutic procedures</td>
<td>- Maternal obesity and pelvic bone &lt;br&gt;- Limited field view &lt;br&gt;- Detects the more serious changes</td>
</tr>
<tr>
<td><strong>Fetal magnetic resonance imaging</strong></td>
<td>- Costly &lt;br&gt;- Not widely available &lt;br&gt;- High false positive &lt;br&gt;- Nonspecific findings</td>
</tr>
<tr>
<td>- Excellent tissue contrast for detection of subtle changes &lt;br&gt;- Large field of view for simultaneous evaluation of &lt;br&gt;- The whole fetal body &lt;br&gt;- Relationship with maternal structures &lt;br&gt;- Not limited by fetal position, ossification, oligohydramnios, or maternal obesity</td>
<td>- Not suitable for first-trimester fetus &lt;br&gt;- Gadolinium contrast should be avoided &lt;br&gt;- Operator-dependent: Interpretation of MR images with ultrasound contexts</td>
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</table>
Technical considerations for fetal MRI

The MRI machine operates at strong magnetic fields. The magnetism aligns tissue water protons along the direction of the field. An application of additional radio frequency pulse tips the magnetization. After the electromagnetic field is turned off, relaxation of protons releases radiofrequency signals that can be measured. Computerized interpretation of electromagnetic signal can accurately characterize types of soft tissue in the field. The soft tissue quality from MRI is defined as “increased” or “decreased” signaling. Standard MRI sequence for fetal assessment is a single-shot T2-weighted sequence; which provides excellent soft tissue characterization. There are several acronyms depending on the equipment manufacturer, including half Fourier rapid acceleration with relaxation enhancement (RARE), single-shot fast spin echo (SSFSE), single-shot turbo spin echo (single-shot TSE), extended-phase conjugate-symmetry rapid spin echo sequence (EXPRESS), half Fourier single-shot turbo spin echo (HASTE), and fast advanced spin echo (FASE) sequences [6].

The MRI’s diagnostic ability is highly operator-dependent and experts in this field are rare. T1-weighted MRI sequence protocol is more appropriate for lesions with fat, calcification, or hemorrhage. It is particularly useful for imaging of fetal brain. Slice images from three orthogonal planes are acquired. Generally, slice thickness of 3–4 mm provides optimal signal in the region of interest without significant partial volume averaging [7]. Image quality depends on the optimization of the sequence, hence MRI diagnostic ability is not operator-independent as it used to be said.

Different MR sequences are suitable for different kinds of fetal lesions. Choosing the right sequence for the best image resolution requires an effective communication between the fetal medicine specialist and the MR radiologist. Sequences that are considered to be “standard” for fetal assessment include T2, T1, echo planar imaging (EPI) (for fetal bone assessment), fluid attenuated inversion recovery (FLAIR) (to detect subarachnoid hemorrhage), diffusion weighted imaging (DWI) (to detect intracerebral hemorrhage), and MR spectrometry (for fetal lung assessment). More advanced MR imaging involves postscan processing, which will be good for functional study. These advanced MR sequences, including super-resolution 3D (three-dimensional) imaging, diffusion tensor imaging, and spectroscopy, is not a standard MR imaging for fetal assessment yet, and interpretation should be carefully made.

Magnetic field strengths of 1.5 and 3 Tesla have been studied for imaging of the human fetus. Image construction using 3-Tesla magnetic field strength provides better anatomical delineation of the fetus, which is particularly useful for imaging of fetal brain, as well as functional MRI [8]. The 3-Tesla machine is very sensitive to fetal movement, which results in significant motion artifacts, especially if MRI is performed in the first half of a pregnancy [9]. Other factors that may increase motion artifact include postprandial MRI and polyhydramnios [10].

Safety of fetal MRI

The MRI is a noninvasive, nonionizing imaging system. With the conventional 1.5- and 3-Tesla machine, no clinically significant fetal effects have been reported [11]. The MRI should be avoided in the first half of pregnancy, particularly at <18 menstrual weeks’. The fetus at this early stage is small which limits anatomical assessment by MR. Excessive movement of a small fetus can create significant motion artifact that jeopardizes the MRI image quality [12]. However, MRI can be performed at any stage of pregnancy when the information requested from the study cannot be acquired by other imaging techniques. This may be the case in a suspected appendicitis.

There is an increasing usage of 3-Tesla MRI for fetal neuroimaging. It is considered to be safe for the human fetus, however, some concerns exist [13]. There are no reported harmful effects from MRI of the pregnant woman or fetus. Safety studies have been performed at or below 1.5-Tesla magnetic field strengths. With increasing field strengths, there may be higher tissue heating. Animal study shows that the use of 3-Tesla magnets for diagnostic MRI with normal specific absorption rate (SAR) regimens does not lead to temperature increases above 1°C, if imaging time is kept below 30 min. Increase in tissue temperature of 2.5°C was observed with longer imaging time, especially with high-SAR regimens [14]. Both the benefits and risks of 3-Tesla over the 1.5-Tesla machine in fetal imaging are still unclear. For the time being, it may be advisable to be more conservative by starting with magnetic field strength of 1.5 Tesla. If image quality is suboptimal, but not from motion artifacts, then stronger magnetic field strength of 3 Tesla may be offered based on individual cases [9]. With all these concerns, ultrasonography is still the primary method used in prenatal imaging for its safety, low cost, and availability. Fetal MRI should be offered only after a high-quality fetal ultrasound has been performed. The patient has to sign an informed consent stating the knowledge of risks and benefits of MRI examination during pregnancy.
Safety of MRI contrast media during pregnancy

Gadolinium-based contrast agents (GBCAs) have been widely used to enhance resolution of MRI. Examples of commercially available GBCAs include Magnevist (Bayer Schering Pharma, Leverkusen, North Rhine-Westphalia, Germany), MultiHance (Bracco Imaging, Milan, Italy), Omniscan (GE Healthcare, Little Chalfont, UK), OptiMARK (Liebel-Flarsheim, Cincinnati, OH, USA), and ProHance (Bracco Diagnostics Inc. Monroe Township, NJ, USA). Gadolinium is a paramagnetic ion that moves differently in a magnetic field. It can help in enhancing certain types of tissue, as well as aid in assessment of vascular structures (magnetic resonance angiography, MRA). Noncontrast MRI can readily detect most common fetal anomalies, therefore, GBCAs are not widely used in fetal MRI. The toxic effect of gadolinium to the fetus has been adequately tested in animals, but data in humans are still limited [15]. This makes gadolinium a category C medication (the safety in humans has not been proven and the impact of prolonged prenatal use remains unclear).

GBCAs should not be used during pregnancy. Gadolinium crosses the placenta into the fetal circulation. It is filtered through fetal kidneys and can remain in the amniotic fluid for an unknown period of time.

Experiments in animal models showed that prenatal exposure to gadolinium at high dosage and long duration can cause fetal malformations and growth restriction [16]. Data on the long-term consequences of in utero exposure of gadolinium are more limited. Experimental exposure of gadolinium may be related to mutagenesis and carcinogenesis in postnatal life [17]. Several small case series did not report any adverse neonatal outcomes after first-trimester exposure of gadolinium at clinical dose [18–20]. The information from these case series can be useful to counsel the pregnant women who unknowingly underwent MRI examination using GBCAs.

Indications of fetal MRI

Ultrasound remains the primary tool of fetal imaging. In experienced hands, good quality ultrasound can diagnose most fetal and placental abnormalities. Suboptimal ultrasound resolution can be encountered in maternal adiposity and ossified fetal bony structures. The MRI is proven to be superior to ultrasound with regard to differentiation of soft tissue characteristics and volumetric measurement. There is no single optimal time to perform fetal MRI. The most common indications for fetal MRI are neurological (suspicion of CNS anomalies). Rossi and Prefumo recently published a review article showing that MRI confirmed ultrasound-positive findings in 65.4% of fetuses, and provided additional information in 22.1%. In 30% of fetuses, the discordant MRI findings from ultrasound were significant enough to change the clinical management. Disagreement was noted mainly for midline anomalies (48.6%) [21]. In another study of 92 patients, MRI diagnosed more anomalies in fetal brain, thorax, abdomen, and skeletal systems [22]. Some studies have confirmed this superiority of MRI [2, 22]. These studies were, however, criticized for their inherent biases, such as their retrospective nature, skill of ultrasound examiners, and time lapse between ultrasound and MRI that may allow for some in utero evolution of the lesions. Prospective studies were designed to overcome these limitations, and the results still suggested that MRI can provide additional information that lead to changes in clinical management for fetuses with either intra or extracranial anomalies [23, 24]. Obstetric conditions where MRI may provide additional information of clinical significance are summarized in Table 2. More details for the most common indications of obstetric MRI will be discussed. These include morbidly adherent placenta, anomalies in the central nervous system, thorax and lung, and head and neck regions of the fetus.

Morbidly adherent placenta

Abnormal invasion of the placenta into the myometrial wall could cause catastrophic bleeding at the time of delivery. Women with the placenta implanted on a previous uterine surgical scar should receive a good quality ultrasound to exclude the possibility of morbidly adherent placenta (MAP). Accurate diagnosis can lead to optimal counseling, preoperative preparation, and coordinated postpartum care. Sonographic appearances of MAP include loss of the retroplacental hypoechoic line, multiple vascular lacunae, and thin myometrial thickness (<1 mm) at the implantation site. Ultrasound examination alone has a low sensitivity to identify MAP, as shown in Table 3 [25]. Doppler studies, showing bridging vessels across the tissue planes and chaotic vascular pattern demonstrated by 3D power Doppler, can improve the sensitivity in detection of MAP. However, ultrasound and Doppler studies are occasionally nondiagnostic. These sonographic and Doppler findings are, however, not specific to MAP. Additional challenges for sonographic diagnosis of MAP also include posterior placenta and maternal obesity.
Table 2: Potential indications of fetal MRI.

<table>
<thead>
<tr>
<th>Indications</th>
<th>Specific conditions</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morbidly adherent placenta</td>
<td>– Only when ultrasound is inconclusive</td>
<td>Conflicting evidence: if routine MRI in cases that MAP is suspected from ultrasound examination can significantly reduce maternal morbidity</td>
</tr>
<tr>
<td>(MAP)</td>
<td>– Demonstration of abdomino-pelvic adhesions can be helpful in planning the surgery</td>
<td>Conflicting evidence: agreement rate of findings from ultrasound, MRI, and postnatal imagings</td>
</tr>
<tr>
<td>Central nervous system</td>
<td>– Ventriculomegaly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Posterior fossa anomalies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Migrational defects/cerebral cortical dysfunction</td>
<td></td>
</tr>
<tr>
<td>Thorax and lungs</td>
<td>– Congenital pulmonary airway malformations</td>
<td>Available evidence: total fetal lung volume measured from MRI can predict neonatal survival of fetuses affected with severe CDH</td>
</tr>
<tr>
<td></td>
<td>– Congenital diaphragmatic hernia</td>
<td></td>
</tr>
<tr>
<td>Head and neck region</td>
<td>– Venolymphatic malformations</td>
<td>Limited data. Individual judgment</td>
</tr>
<tr>
<td>Abdomen and pelvis</td>
<td>– Retropertoneal malformations</td>
<td>Limited data. Individual judgment</td>
</tr>
<tr>
<td></td>
<td>– Cloacal anomalies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Dysplastic kidneys</td>
<td></td>
</tr>
<tr>
<td>Complicated monochorionic</td>
<td>– Prediction of cerebral palsy in survivor of monochorionic twins with co-twin demise</td>
<td>Family counseling, delivery planning, and postnatal management</td>
</tr>
<tr>
<td>twins</td>
<td>– Conjoined twins</td>
<td></td>
</tr>
<tr>
<td>Interventions</td>
<td>– Meningomyelocele</td>
<td>To diagnose and monitor the degree of hindbrain herniation before and after in utero closure of meningo(myelo)cele</td>
</tr>
<tr>
<td></td>
<td>– Congenital high airway obstruction</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Sensitivity and specificity of ultrasound and MRI in detection of morbidly adherent placenta.

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>US: obliteration of retroplacental sonolucent line</td>
<td>44</td>
<td>95</td>
</tr>
<tr>
<td>US: prominent placental lacunae</td>
<td>54</td>
<td>88</td>
</tr>
<tr>
<td>US+Color Doppler: increased vascularity of uterine serosa/bladder interface</td>
<td>77</td>
<td>79</td>
</tr>
<tr>
<td>US+3D Power Doppler: intraplacental hypervascularity</td>
<td>90 (PPV 70%)</td>
<td>89</td>
</tr>
<tr>
<td>US+3D Power Doppler: inseparable cotyledon and intervillous circulations</td>
<td>90 (PPV 70%)</td>
<td>89</td>
</tr>
<tr>
<td>US+3D Power Doppler: multiple coherent vessels at the uterine serosa-bladder interface</td>
<td>97 (PPV 77%)</td>
<td>92</td>
</tr>
<tr>
<td>MRIa</td>
<td>88</td>
<td>100</td>
</tr>
</tbody>
</table>

US=Ultrasound, MRI=magnetic resonance imaging, 3D=three-dimensional, PPV=positive predictive value.  
aThe findings of MAP from MRI include uterine bulging, heterogeneous signal intensity of the placenta, hypervascular signal intensity of the placenta, and direct visualization of the invasion of nearby organs [21].

The MRI may be used when diagnosis of MAP by ultrasound is uncertain. The advantages of MRI to improve sensitivity and specificity in diagnosis of MAP are shown in Table 3 [25, 26]. Furthermore, MRI may be used for placental mapping and planning the operation in abnormal invasive placentation. It is also important to note that the radiologists who interpret MRI images of MAP have to be familiar with placental anatomy. It might be more appropriate to do the two-step approach in pregnant women with risk factors of having MAP; including placenta previa or low-lying placenta, previous cesarean section, and previous myomectomy. Ultrasound should be the primary tool to diagnose or exclude MAP. The MRI will be offered only when prenatal ultrasound could not exclude MAP. Ultrasound examination can accurately predict MAP in 30 of 39 high-risk women, and correctly rule out MAP in 398 of 414 high-risk women (sensitivity 0.77, specificity 0.96) [25]. In women with inconclusive ultrasound examination, MRI will then be offered. The MRI can accurately predict MAP in 23 of 26 cases, and can correctly rule out MAP in 14 of 14 cases (sensitivity 0.88, specificity 1.0) [25].

Fetal central nervous system anomalies and functional neuroimaging

Suspicion of fetal central nervous system (CNS) anomalies is the most common indication of fetal MRI. Assessment of CNS includes fetal brain, spinal cord, skull, and vertebral...
column. Sonographic assessment of fetal brain is a challenge because the view is obstructed by two bony plates; fetal skull and maternal pelvis. To avoid the bony pelvis of the mother, the transvaginal sonographic approach is often used. Image quality of intracranial structures can be improved by aligning the ultrasound beam through the fetal cranial sutures. In experienced hands, ultrasound alone is adequate to identify serious anomalies, such as holoprosencephaly and hydranencephaly. Significant neurodevelopmental delay in the childhood period is definite in these conditions, and confirmation with MRI is not needed. Proper counseling, as well as clinical decisions either to perform additional invasive diagnostic procedures, to terminate pregnancy, or to go on with the knowledge of adverse neurodevelopmental outcomes of the baby can be proceeded with this conclusive ultrasound finding.

There are a few selected cases of fetal intracranial abnormalities where ultrasound diagnosis is inconclusive. This can be due to two major reasons. First, certain fetal CNS disorders can be very subtle in nature. Neural migration disorders, resulting in abnormality of cerebral cortical development, may have a slightly dysmorphic Sylvian fissure found on the anterior coronal cut of transvaginal ultrasound examination. In suspicious cases, MRI may show smooth cortical brain surface in classic lissencephaly. Second, ultrasound visualization of CNS structures may not be adequate. Suboptimal appreciation of fetal intracranial structures can be a result of maternal adiposity, pelvic tumor (i.e. fibroids), nonvertex position of the fetus, or an obstructed view from the fetal bony structures (i.e. limbs) or the co-twin. With proper sequence setting, MRI can still obtain good signaling through the fetal and maternal bony structures.

The MRI has been used extensively in fetuses with borderline ventriculomegaly (lateral cerebral ventricle width of 11–15 mm). Cerebral ventriculomegaly is the first, and sometimes the only in utero finding in some CNS anomalies, such as abnormal cerebral cortical development, and lesions in the posterior fossa. The MR examination of fetuses with borderline ventriculomegaly can offer appreciation of the whole brain, as well as detailed characterization of the specific parts of interest. There were 44% ultrasound and 25% MRI examinations disagreement with postnatal diagnosis [27]. The MRI can either reverse the diagnosis or discover additional CNS findings in up to 55% of fetuses with borderline ventriculomegaly [24]. Figure 1 shows the difference in visual inspection of fetal brain from an ultrasound and MR image. This information will lead to a significant change in counseling and perinatal management plans. Subtle lesions with considerable clinical impact, such as agenesis of the corpus callosum or migrational disorders, can be diagnosed with higher accuracy by MRI. Vascular malformations, infarction (including those occurring in complicated monochorionic twins), and hemorrhage in the brain can be visualized more adequately with MRI [28].

A neural tube is a primitive bundle of nerves that folds to form the brain at the front end and the spinal cord at the rear end. Failure of this structure to close on the 28th conception day results in a broad spectrum of neural tube defects. Fetuses with open neural tube defect can have secondary malformations in the brain or spinal cord, such as ventriculomegaly as a result of Chiari II malformation. Defects at the vertebral column and changes of the intracranial structures can be diagnosed with careful ultrasound examination. However, the degree of hindbrain herniation

Figure 1: Comparison of fetal brain images from transvaginal ultrasound and MRI.
may not be clearly visible, especially if the fetus is not in the optimal position. Herniation of the cerebellar vermis can predict the likelihood of postnatal shunting. Therefore, if in utero repair of the defect is planned, it is advisable to perform MRI prior to the procedure [29]. This is for the purpose of standardized evaluation of the improvement of tonsillar herniation following the fetal surgery. Using a 3-Tesla MRI allows for a sharper soft tissue differentiation, which will be particularly helpful in fetal brain assessment. Recent study comparing image quality of fetal brain obtained from a 3- and 1.5-Tesla machine, from 12 patients showed equal (57%; 21/37) or superior (35%; 13/37) tissue contrast and equal (61%; 20/33) or superior (33%, 11/33) conspicuity of MRI image quality [30]. However, due to some safety concerns, it cannot be advisable to routinely use a 3-Tesla machine for all fetal brain imaging.

**Fetal intrathoracic lesions**

The MRI can provide an accurate estimation of lung volume of the fetus. Confirmation of fetal lung hypoplasia should be carried out when there is an oligohydramnios in the second trimester, congenital diaphragmatic hernia (CDH), distortion of thoracic cage in skeletal dysplasia, or tumor mass in the thorax of the fetus [31]. Diagnosis of congenital high airway obstruction (CHAOS) may not be conclusive on prenatal ultrasound examination. Other conditions, such as congenital pulmonary airway malformation (CPAM), may look almost identical to CHAOS by ultrasound examination. CPAM carries a much better prognosis than CHAOS. The MRI can differentiate these two conditions, and can locate the level of tracheal or bronchial obstruction in cases of CHAOS [32].

The MRI has been extensively used for further assessment of fetuses with CDH after ultrasound diagnosis. Survival rates of fetuses with isolated left-sided CDH decreases with low observed-to-expected fetal lung-to-head ratio (O/E LHR) in the second trimester. O/E LHR can be used to guide family counseling for prognosis, prenatal treatment with balloon tracheal occlusion, and immediate postnatal care. Total fetal lung volume (TFLV) measured from MRI is considered as the most accurate prognostic factor for neonatal survival [33]. Observed-to-expected TFLV of <35% has been linked with high neonatal mortality [34]. Mayer et al. from the Eurofetus group concluded that the side of diaphragmatic defect, position of the liver, and O/E TFLV, as determined on MRI were predictive of the outcome [35]. The quantitative evaluation of fetal lung using MRI, in association with ultrasound estimates, can help to predict the neonatal outcomes of prenatally diagnosed CDH, either with or without prenatal interventions, for the purpose of resource allocation and family counseling.

Additional adverse prognostic findings from MRI include dense signal intensity of contralateral lung field as well as small diameters of pulmonary artery and its branches, which are associated with adverse perinatal outcomes. When fetal tracheal occlusion is indicated, it is advisable to perform MRI prior to the insertion of the balloon. The MRI should then be repeated before or soon after the balloon retrieval to evaluate the effect of plugging to fetal lung expansion [36]. The MRI picture of fetal airway after balloon tracheal occlusion is shown in Figure 2.

Congenital diaphragmatic hernia cases diagnosed prenatally are more likely to have extra diaphragmatic malformations, particularly in cardiovascular, skeletal, genitourinary, and nervous system [37]. Survival of CDH with associated malformations is poor, compared to the isolated CDH cases. The MRI has the benefit of larger field of view that allows for an evaluation of the whole fetus in a single plane. Certain anomalies can cause decreased liquor volume, which hinder the image quality from ultrasound examination. The MRI can maintain its soft tissue delineation quality, making the anatomical assessment and plans for neonatal resuscitation in this difficult situation more accurate.

![Figure 2: MRI of the fetus with congenital diaphragmatic hernia 3 weeks after tracheal occlusion. The balloon was filled with saline solution, which shows the signal intensity equivalent to the amniotic fluid in the oropharynx. Note the dilatation with trachea and bronchi distal to the occlusion. The fluid that was trapped in trachea-bronchial tree of the fetus was hypercellular, hence it shows hypersignaling on the MR image.](image-url)
Malformations at fetal head and neck regions

Tumor mass located on the anterior neck of the fetus may obstruct vaginal delivery because it prevents fetal neck from fully flexion. Common tumors in the head and neck area of the fetus are lymphangioma, hemangioma, goiter, and teratoma. These tumors can compromise the airway and pose a significant challenge to neonatal intubation. The MRI can provide valuable information, including the size, depth of invasion of lymphatic-vascular tumor in the fetal neck, deviation and patency of the airway, and pressure effect on the surrounding neck structures. If airway patency is questionable, *ex utero* intrapartum treatment (EXIT) can be planned [38]. An immediate postnatal surgical plan can be made based on the information obtained from fetal MRI.

Miscellaneous

In addition to the aforementioned conditions that MRI is complimentary to ultrasound in fetal assessment, there are some other conditions where MRI may also be useful. The MRI can provide a higher resolution for soft tissue characteristic, therefore, it can be used to assess the invasion of soft tissue tumor in the fetus after the diagnosis is made by an ultrasound.

The advent of “open field MRI machine” allows for a larger opening, which may suit patients who are claustrophobic, obese, or even during active labor. “Real-time MRI” using an open field machine can be used to demonstrate the progression of the fetal head descent and angulation during active labor [39, 40]. With a dedicated sequence, real-time MRI can be particularly useful for fetal cardiac assessment, which may lead to more effective antenatal intervention [41]. And lastly, MRI has been selectively used as an alternative for “less invasive” fetal autopsy [42].

Contraindications for fetal MRI

Pregnant women who have a metallic implant in a soft tissue organ (i.e. aneurysmal clip in the brain) cannot have an MRI. The powerful magnetic field can dislodge the device. Pregnant women with metallic screws in their pelvic bones or hip joint prosthesis should be cautioned with MRI because they will distort the magnetic field and create image artifacts. Patients with cardiovascular implanted electronic devices such as cardiac pacemakers or cardioverter defibrillators (ICDs) have long been prohibited from undergoing MRI due to the risk of MR-related device malfunction and death. However, novel models of pacemaker that are “leadless” may be amendable with MRI at a lower magnetic field intensity (1.5 Tesla). It is imperative to consult with the cardiologists and their manufacturers before MRI is performed in these high-risk patients [43].

Women with anxiety disorders and severe claustrophobia may not be able to tolerate an MRI scan. This may be resolved by emotional support and medical sedation to make the scan more tolerable. Open scanners are now available, and should be more acceptable with this group of patients [44].

Recommendations

1. **In terms of clinical practice.** Ultrasound remains the first, and most of the time the only, imaging tool required to make a diagnosis of fetal anomalies. Fetal MRI should be offered only when ultrasound cannot provide certain information that affects the counseling, prenatal intervention, pregnancy course, and delivery plan. This is particularly true for assessment of the fetal central nervous system. Costs, risks, and benefits of MRI during pregnancy have to be thoroughly discussed, and written informed consent is required.

2. **In terms of technique.** A 1.5-Tesla MRI machine with a fast T2-weighted single-shot technique is recommended for the detection of common fetal malformations. For superior soft tissue characterization, a 3-Tesla machine may be chosen, but the patient has to be aware of its potential thermal effect and motion artifacts. More advanced MRI sequences may be applied according to specific cases. Gadolinium-based contrast agents should not be used during pregnancy.

3. **In terms of appropriate gestational age for fetal MRI.** Fetal MRI should be avoided in the first half of pregnancy due to small fetal structures and motion artifact. Second (gestational weeks) and third trimesters of pregnancy are the good time to perform MRI.

4. **In terms of indication of fetal MRI.** Major indications of fetal MRI include, but are not restricted to suspicion of morbidly adherent placenta (for MRI power of exclusion), selected cases of fetal brain anomalies, thoracic lesions (especially congenital diaphragmatic hernia), and soft tissue tumors at head and neck.
regions (to determine the invasiveness and necessity to perform EXIT.

5. **In terms of research.** MRI is a viable tool for non-invasive interrogation of the fetus and the placenta.

**References**


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