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Role of Fetal MRI in Prenatal Diagnosis of Congenital Anomalies

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Abstract **Original Research Article**

MRI has been increasingly used for detailed visualization of the fetus in utero as well as pregnancy structures. Yet, the familiarity of radiologists and clinicians with fetal MRI is still limited. This article provides a practical approach to fetal MR imaging. Fetal MRI is an interactive scanning of the moving fetus owed to the use of fast sequences. Single-shot fast spin-echo (SSFSE) T2-weighted imaging is a standard sequence. T1-weighted sequences are primarily used to demonstrate fat, calcification and hemorrhage. Balanced steady-state free-precession (SSFP), are beneficial in demonstrating fetal structures as the heart and vessels. Diffusion weighted imaging (DWI), MR spectroscopy (MRS), and diffusion tensor imaging (DTI) have potential applications in fetal imaging. Knowing the developing fetal MR anatomy is essential to detect abnormalities. MR evaluation of the developing fetal brain should include recognition of the multilayered-appearance of the cerebral parenchyma, knowledge of the timing of sulci appearance, myelination and changes in ventricular size. With advanced gestation, fetal organs as lungs and kidneys show significant changes in volume and T2-signal. Through a systematic approach, the normal anatomy of the developing fetus is shown to contrast with a wide spectrum of fetal disorders. The abnormalities displayed are graded in severity from simple common lesions to more complex rare cases. Complete fetal MRI is fulfilled by careful evaluation of the placenta, umbilical cord and amniotic cavity. Accurate interpretation of fetal MRI can provide valuable information that helps prenatal counseling, facilitate management decisions, guide therapy, and support research studies.

I. 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. The main drawback of MRI was fetal motion which was overcome in the 1990s with the development of ultrafast sequences. 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. Fetal MRI is indicated in pregnant women when other nonionizing diagnostic imaging methods are inadequate or when the examination provides important information that would otherwise require exposure to ionizing radiation. The quality of fetal MRI is comparable to postnatal MRI,

facilitating discussion of surgical treatment options.

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 and 3T MR, MRI is best performed after completion of organogenesis (16 weeks).The patients are advised to fast for 4 h prior to the study, to reduce bowel peristalsis artifacts and to prevent post-prandial 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.

II. FETAL MRI ETHICS

MRI is a noninvasive diagnostic examination that does not involve ionizing radiation with no known associated negative side effects or reported delayed sequels [6]. The American College of Radiology white paper on MR safety states that pregnant patients can be accepted to undergo MR images at any stage of pregnancy if the risk-benefit ratio to the patient warrants that the study be performed [7] and only if other non-ionizing diagnostic imaging methods are inadequate. However, it is prudent to wait until 17–18th weeks of gestation before performing fetal MRI because of the potential risk to the developing fetus and the current limitations of fetal MRI created by the small size and excessive motion of younger fetuses [8]. A written informed consent is usually required from the pregnant woman prior to fetal MRI.

III. FETAL MRI TECHNIQUE AND SEQUENCES

MR studies are best performed on a MRI system with field strength of 1.5 T and 3T. 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 gap and a large field of view, followed by a T2W_TSE sequence of the mother, to visualize the position of the fetus, placenta, and cervix as well as assess the uterus. Sequences should be performed in the coronal, sagittal, and axial planes through the region of interest for confirming/ excluding the suspected fetal anomalies. This is followed by sequences through the rest of the fetus to rule out /detect associated anomalies. Ultrafast T2W sequences known as single shot rapid acquisition with refocused echoes (i.e. single shot fast spin echo or half Fourier acquired single shot turbo spin echo) are often used. Single images acquired in less than 1 s, decrease the artifacts from fetal motion. In addition to the regular T2W_TSE and balanced turbo field echo (BTFE) sequences for evaluating the fetus, T1 weighted image (T1WI) sequences of the fetal abdomen in the sagittal and coronal planes help to confirm the presence of meconium (which appears bright on T1WI) in the large bowel and rectum, up to the anal verge. It should be noted that BTFE, being a heavily T2W sequence, demonstrates fetal anatomy better at an early gestational age, as compared to the regular T2W sequence.

IV. METHODS

This is a prospective, observational, cross-sectional, and single-institution study conducted in Department of Radiodiagnosis of our tertiary level institute. The study is and was conducted after obtaining approval of the institutional ethics committee. A total of 20 consenting pregnant mothers having singleton fetuses with suspected anomalies pertaining to GUS diagnosed on a previous ultrasound and having gestation age > 18 weeks were enrolled in the study. The common indication for fetal MRI in intracranial abnormalities were corpus callosum agenesis. We excluded cases with cardiac abnormalities because it is a well known fact that fetal MRI is inappropriate for those cases.

V. RESULTS

There were a total of 20 participants in our study group with a mean age of 22 years ± 3 years. The youngest member was 19 years, and the eldest was 29 years of age. The gestation ages of examined fetuses ranged from 18 weeks and 1 day to 35 weeks and 0 day. In 20 cases total, fetal MRI was performed for 12 possible cases of intracranial abnormality cases, 2 intrabdominal abnormalities, 2 intrathoracic abnormality cases, 2 head and neck abnormality cases and other 4 cases of other abnormalities. In many cases, MRI picked up additional findings which ranged from pulmonary hypoplasia, nuchal hygroma, pleural effusion, and placenta previa.

Table 1: Indications of fetal MRI

Fetal organs	Indication main category	Indication sub category
Brain	Congenital anomalies	Ventriculomegaly; corpus callosal dysgenesis; holoprosencephaly; posterior fossa anomalies; malformations of cerebral cortical development
	Screening fetuses with a family risk for brain anomalies	E.g. corpus callosal dysgenesis; malformations of cerebral cortical development
Spine	Congenital anomalies	Neural tube defects; sacrococcygeal teratomas; caudal regression/sacral agenesis; vertebral anomalies

Fetal organs	Indication main category	Indication sub category
Skull, face and neck	Masses of the face and neck	Venolymphatic malformations; hemangiomas; goiter; teratomas; facial clefts
Thorax	Masses	Congenital pulmonary airway malformations (congenital cystic adenomatoid malformation; sequestration, and congenital lobar emphysema); congenital diaphragmatic hernia; effusion
	Volumetric assessment of lung	Cases at risk for pulmonary hypoplasia secondary to oligohydramnios, chest mass, or skeletal dysplasias
Abdomen, retroperitoneal and pelvis	Mass	Abdominal– bowel anomalies such as megacystis, omphalocele, pelvic cyst.; tumors (e.g. hemangiomas, neuroblastomas, sacrococcygeal teratomas, and suprarenal or renal masses); complex genitourinary anomalies (e.g. cloaca); renal anomalies in cases of severe oligohydramnios.
Fetal surgery assessment		Meningomyelocele; sacrococcygeal teratomas; processes obstructing the airway (e.g. neck mass or congenital high airway obstruction); complications of monochorionic twins needing surgery; and chest masses.

N.B. The indications of fetal magnetic resonance imaging are according to the recommendations of the American College of Radiology (ACR), and Society for Pediatric Radiology (SPR) [5].

Intracranial abnormalities

There were 12 cases of intracranial abnormalities in the final diagnosis confirmed. In 8 cases (suspicious of corpus callosum agenesis), 2 cases turned out normal, which were suspected on USG which were coincident with the official reading of fetal MRI. In two cases intracranial hemorrhage were suspected by prenatal USG out of them one turned out to be normal. In addition, two which showed non-specific abnormality except ventriculomegaly showed no additional abnormality in fetal MRI. Figure 1 represents a case in which absent cavum septum pellucidum, ventriculomegaly was suspected by prenatal diagnosis and later turned out to agenesis of corpus callosum (ACC) by fetal MRI. A case diagnosed as suspicious Arnold chiari by ultrasonography due to lemon shaped appearance of skull, ventriculomegaly and spina bifida was later diagnosed as Arnold chiari malforamation since it showed a brain stem herniation and spina bifida and lemon shaped skull on fetal MRI (Fig 2).

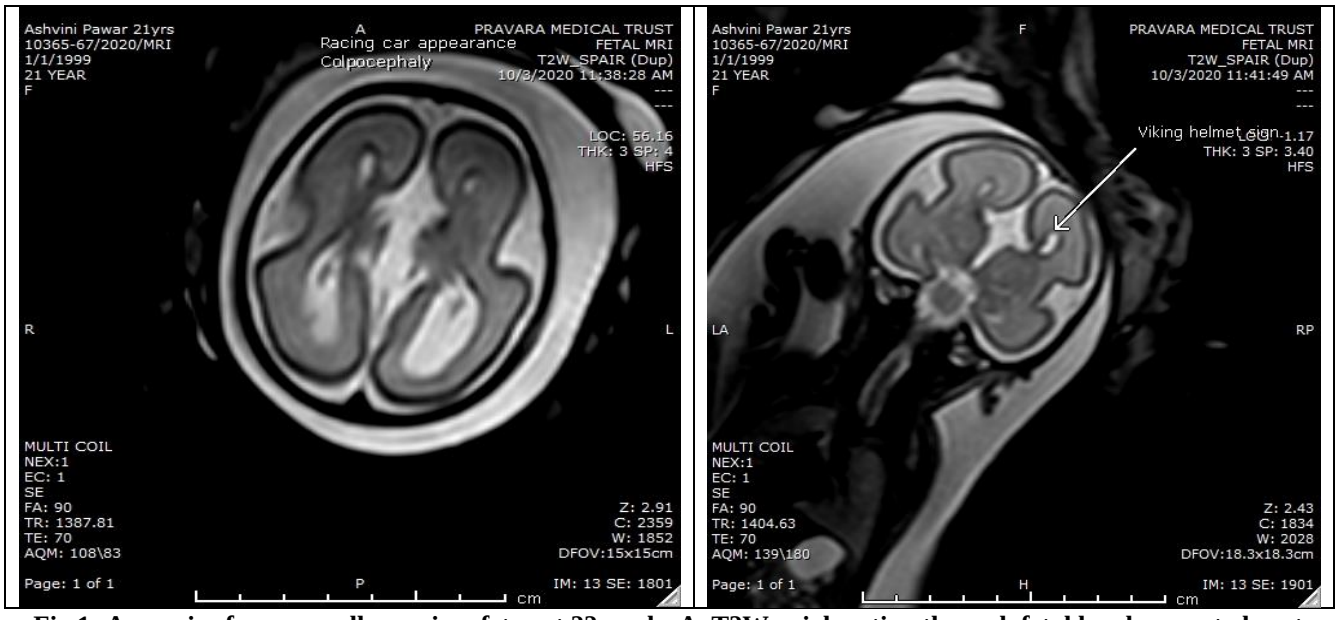

Fig 1: Agenesis of corpus callosum in a fetus at 22 weeks A. T2W axial section through fetal head suggest absent cacum septum pellucidum with ventriculomegaly and colpocephaly giving 'racing car appearance' B. T2W coronal image showing lack of normal connecting white matter fibre with 'viking helmet sign'

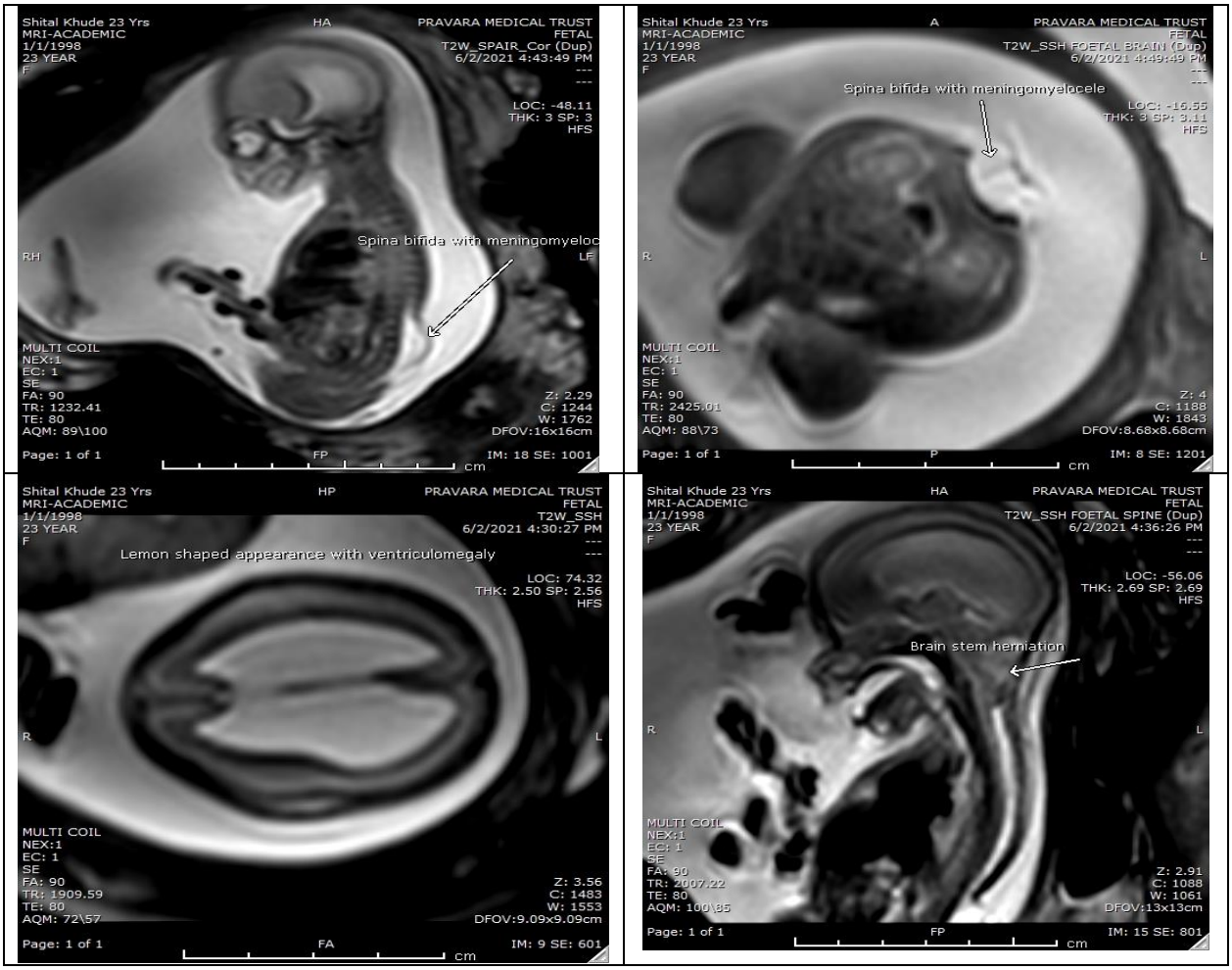

Fig 2: A case diagnosed as suspicious Arnold chiari by ultrasonography due to lemon shaped appearance of skull, ventriculomegaly and spina bifida was later diagnosed as Arnold chiari malforamation since it showed (A. B.) spina bifida with meningomyelocele, (C.) lemon shaped skull and (D.) brain stem herniation on fetal MRI

Intra-abdominal abnormalities

In 3 out of 20 cases, the final diagnosis was confirmed. MRI taken due to suspicious intra-abdominal cyst either overian, mesenteric or dermoid after fetal MRI final diagnosis was made as megacystis (Fig 3). In another 2 cases omphalocele/ gastroschisis were suspected on USG which turned out to be Omphalocele on fetal MRI with solid organ (liver, gall bladder, spleen, stomach) and bowel loops as content within (Fig 4).

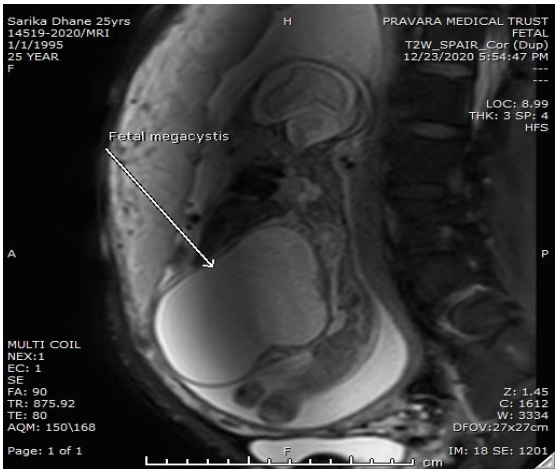

Fig 3: A case of megacystis on sagittal T2W image showing large intraabdominal cystic lesion and later confirmed as megacystis on post natal ultrasound

Intrathoracic abnormalities

In 3 cases, fetal MRI was taken due to suspicious of chest abnormalities. One case was suspected to be pulmonary sequestration or CPAM (congenital pulmonary adenomatoid malformation) and one and congenital diaphragmatic henia. One case was suspected to be as pulmonary hypoplasia. In all these 3 cases diagnosis were confirmed.

Other abnormalities

In 4 cases fetal MRI was taken due to suspicious of facial, neck and other limb abnormalities. In all these four cases final diagnosis confirmed. One case was diagnosed as thanatophoric dysplasia type I, one was diagnosed as isolated short limbs with brachycephaly. The other abnormalities were found as described below:

Occipital Encephalocele, Septo-optic dysplasia, Fetal hydrops with cystic hygroma, Semilobar holoprosencephaly, Bilateral club foot, Acrania anencephaly sequence, Late subacute subdural hemorrhage.

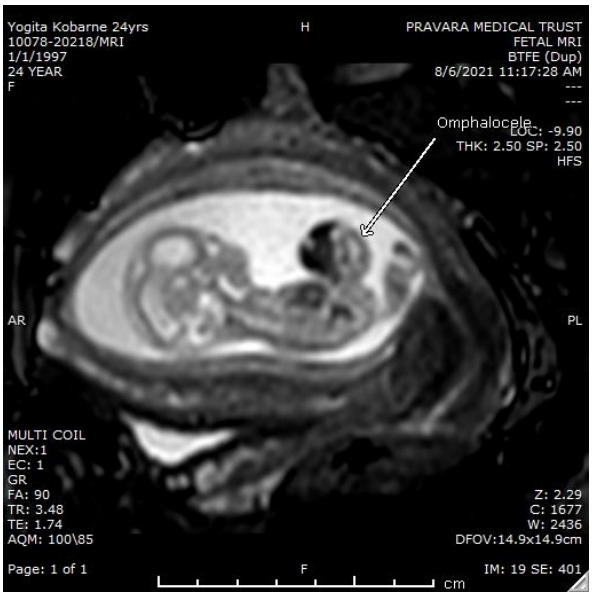

Fig 4: A case omphalocele on sagittal BTFE image showing liver and bowel loops within the lesion

DISCUSSION

In recent years, MRI has come to play an increasingly important role in fetal anomaly scanning. Its domain has expanded from being an adjunctive modality to one which is poised to become integral to fetal imaging protocols. This is because of several advantages like the superior soft-tissue contrast, development of ultrafast sequences, and ability to overcome the limitations of ultrasound like a poor sonic window in maternal obesity, oligohydramnios, and bony ossification [4-6].

Nowadays, we use fetal MRI to evaluate some fetal abnormalities such as complete or partial agenesis of corpus callosum, malformation of posterior fossa, bilateral renal agenesis and congenital diaphragmatic hernias. The initial assessment of the fetal genito-urinary system is invariably performed by ultrasound. Unfortunately, ultrasound as a standalone modality may be inadequate or inconclusive in many of the fetuses harboring these anomalies due to a frequent association of oligohydramnios or anhydramnios [7]. Thus, further assessment by fetal MRI is warranted in such cases for a more complete and informative anomaly evaluation. Ultrafast T2W sequence has long been considered as the mainstay of genito-urinary system imaging on fetal MRI as it is relatively resistant to fetal motion due to sub-second slice acquisition and also provides exquisitely detailed images of fetal anatomy with high contrast and resolution. T1-weighted sequences like VIBE and faster versions like turbo FLASH are acquired as an add-on sequence in fetal GU imaging protocols. They are plagued by lower spatial resolution and susceptibility to fetal motion, but nonetheless have an undeniable complementary value for evaluation of fetal gastrointestinal tract, liver, and in the detection of hemorrhage/calcification. DWI sequence is an important component of fetal MRI GU imaging protocols in many institutions. Owing to the high water content of fetal organs, the echoplanar DWI images are acquired at low b values of 400–700 to attain a better contrast. DWI sequences are particularly useful in the detection of renal parenchyma and assessment of its functionality. The normal fetal kidneys show restricted diffusion owing to the high cellularity resulting in a high DWI signal. This sequence is useful in making a confidant diagnosis of renal developmental abnormalities like renal agenesis or ectopia. An empty renal fossa in combination with absent DWI bright signal elsewhere favors agenesis while empty renal fossa with extrarenal/ pelvic location of bright signal points to ectopia. MRI is also useful in the assessment of any associated anorectal abnormalities which can occur as part of VATER (vertebral, anal atresia, trachea-esophageal fistula, renal anomalies syndrome). The various genital system diseases such as ovarian cysts or diseases affecting perineal structures like cloacal exstrophy can be also better characterized by this modality. Since the impact of taking fetal MRI on fetal organogenesis was not fully known, the modality has been usually applied after 2nd trimester. As for intravenous contrast media, since there is no proven level of safety, its use is prohibited. Fetal MRI is beneficial as problem solving tool rather than main diagnostic modality.

In this study 18 out of 20 confirmed final diagnosis, the final diagnosis was changed after taking MRI. However, there is little statistical evidence supporting the accuracy of fetal MRI, because of follow up losses, including pregnancy termination and transferal to other hospitals. The same is true in this study, for were able to obtain only 12 cases with confirmed final diagnosis out of 56 cases with fetal

MRI data available. Fetal MRI has an advantage over USG in evaluating and diagnosing posterior fossa abnormalities, brain development according to neuronal migration, gyral formation and myelination. In intracranial abnormalities, it is known that the common indication for taking fetal MRI includes ventriculomegaly, agenesis corpus callosum, Dandy walker malformation or variant, Arnold chiari malformation and holoprosencephaly. In cases of ventriculomegaly, prognosis is poor because the fetuses with ventriculomegaly as fetuses with ventriculomegaly are usually associated with other malformations in the CNS and with mental retardation. The most common reason for taking fetal MRI in this study was also corpus callosum agenesis, dandy walker malformation or variant, ventriculomegaly and non visualization of cavum septum pellucidum. This study shows usefulness of taking fetal MRI as problem solving tool. In 3 out of 12 cases of intracranial abnormalities final diagnosis were changed and those changes are consistent with fetal MRI. As for intrathoracic abnormalities results of USG and fetal MRI was not so different from each other in this study. It is known that fetal MRI is superior to USG in calculating lung volume and herniated liver volume so as to predict postnatal prognosis and diagnosing atypical intrathoracic masses.

Although USG provides abundant information in evaluating fetal structural abnormalities and fetal well being, the ultrasonographic findings are occasionally inconclusive or insufficient for choosing proper management and prenatal counselling. In these cases alternative imaging with MRI can be helpful. So in this study we suggest that the fetal MRI is useful for evaluation of intracranial and intrabdominal abnormalities in some cases but not diagnosing in other abnormalities. Further studies are needed, however, to decide the proper indication for fetal MRI. In future improvements in MRI and USG technology will improve our ability to assess fetuses.

CONCLUSION

Fetal MRI plays an important role in a confident assessment of anomalies affecting neural tube defects, CNS and genito-urinary system. It overcomes the obstacles posed by a lack of amniotic fluid and has added value in terms of refining, modifying, or adding to the diagnostic information provided by ultrasound. It has a promising role in the detection of additional abnormalities pointing to an underlying syndromal etiology or give added information on extrarenal organ systems like lung hypoplasia. It also has the potential to guide management strategies and influence parental counseling. In many non-lethal anomalies of GUS, accurate and timely diagnosis by fetal MRI can result in the institution of appropriate therapeutic intervention which can translate into improved survival benefit and better quality of post-natal life. Fetal MRI is hence recommended in the diagnostic workup of genitourinary tract anomalies whenever ultrasound is non-informative or equivocal.

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