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Review Article

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Fetal magnetic resonance imaging in prenatal surgical planning: a comprehensive review

Abstract

Fetal magnetic resonance imaging (MRI) has emerged as an important adjunct to ultrasonography in the prenatal evaluation of congenital anomalies that may require surgical intervention after birth. While ultrasound remains the primary screening modality in prenatal imaging, fetal MRI provides superior soft-tissue contrast, multiplanar capability and improved visualization in cases where ultrasound assessment is limited. This review summarizes the role of fetal MRI in prenatal surgical planning across major organ systems, including congenital diaphragmatic hernia, myelomeningocele, sacrococcygeal teratoma, thoracic anomalies, abdominal wall defects and genitourinary malformations. MRI contributes not only to improved anatomical characterization but also to prognostic assessment, delivery planning and preparation for postnatal surgical management. In addition, MRI findings facilitate multidisciplinary decision-making and more accurate parental counselling. With continuing advances in imaging technology and increasing clinical experience, fetal MRI has become an essential complementary tool in modern prenatal care for surgical conditions.

Keywords: fetal MRI, prenatal diagnosis, congenital anomalies, surgical planning, prenatal counselling

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Introduction

Advances in prenatal imaging have significantly improved the early detection and management of congenital anomalies. Ultrasonography remains the cornerstone of prenatal screening and diagnosis; however, certain conditions require additional imaging to clarify complex anatomy and improve prognostic assessment.[1]. Fetal magnetic resonance imaging (MRI) has increasingly become an important complementary modality in such situations.[2]

Fetal MRI provides several advantages over ultrasound, including excellent soft-tissue contrast, a large field of view and multiplanar imaging capability. These features improve visualization of fetal structures and better characterize anomalies when ultrasound findings are inconclusive. MRI is particularly useful when ultrasound evaluation is limited by oligohydramnios, maternal obesity, or unfavorable fetal position.[3]

Typically performed after 18–20 weeks of gestation, fetal MRI uses ultrafast imaging sequences that minimize motion artifacts caused by fetal movement. Importantly, MRI does not require ionizing radiation or intravenous contrast agents and large population studies have demonstrated no association between prenatal MRI exposure and adverse childhood outcomes.[4]

This synthesis focuses specifically on how fetal MRI informs surgical planning rather than simply confirming diagnoses, highlighting clinical scenarios where MRI influences decision-making (Figure 1). Conditions in which MRI findings directly influence decisions about fetal intervention, delivery timing and mode, surgical approach and postnatal management have been examined, to provide paediatric surgeons with practical guidance on when to request fetal MRI and how to interpret its findings in the context of surgical planning. The major congenital anomalies in which fetal MRI contributes to prenatal surgical planning have been summarized in Table 1.

Table 1 Major congenital anomalies where fetal MRI contributes to prenatal surgical planning

Congenital condition	Key MRI findings	Clinical relevance
Congenital diaphragmatic hernia (CDH)	Total fetal lung volume (TFLV), o/e lung volume ratio, liver herniation	Prognosis of pulmonary hypoplasia, selection for fetoscopic endoluminal tracheal occlusion (FETO), delivery planning
Myelomeningocele	Spinal defect level, Chiari II mal formation, ventriculomegaly	Selection for fetal surgery and prediction of neurological outcomes
Sacrococcygeal teratoma (SCT)	Tumor size, intrapelvic extension, solid vs cystic components	Tumor staging (Altman classification), surgical planning, delivery planning
Congenital pulmonary airway malformation (CPAM)	Lesion volume, cystic/solid morphology, mediastinal shift	Hydrops risk prediction and postnatal surgical planning
Airway-compressing cervical masses	Airway compression, tracheal displacement	Planning ex-utero intrapartum treatment (EXIT) procedure
Abdominal wall defects	Herniated organs, bowel dilation, liver involvement	Identification of complex defects and neonatal surgical planning
Gastrointestinal obstruction	Dilated bowel loops, level of obstruction	Localization of obstruction and postnatal surgical preparation
Genitourinary anomalies	Bladder distension, hydroureteronephrosis, renal dysplasia	Assessment of renal prognosis and planning fetal/postnatal intervention

This table summarizes major congenital anomalies in which fetal MRI provides critical information for prenatal surgical planning. The listed MRI findings assist clinicians in anatomical characterization, prognostic assessment, multidisciplinary decision-making, delivery planning and preparation for postnatal surgical management

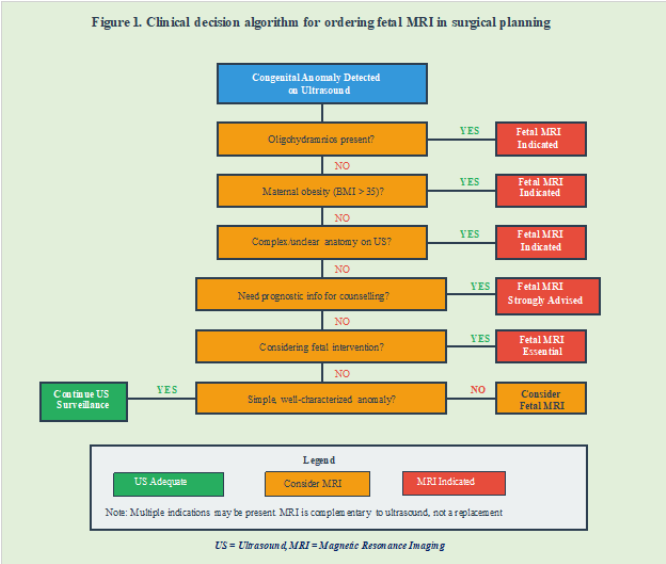

Figure 1 Clinical decision algorithm for ordering fetal MRI in surgical planning.

The algorithm illustrates key clinical scenarios in which fetal MRI should be considered following the detection of a congenital anomaly on ultrasound. MRI is recommended when ultrasound evaluation is limited (oligohydramnios, maternal obesity, or complex/unclear anatomy), when additional prognostic information is required for counselling, or when fetal intervention is being considered. In simple, well-characterized anomalies, continued ultrasound surveillance may be sufficient.

Technical aspects of fetal MRI

Modern fetal MRI relies primarily on rapid T2-weighted imaging techniques such as single-shot fast spin-echo (SSFSE) or half-Fourier acquisition single-shot turbo spin-echo (HASTE) sequences, which enable rapid image acquisition and reduce motion artifacts.[5]

MRI examinations are typically performed on 1.5-T or 3-T scanners with the mother positioned supine or in the left lateral decubitus position to avoid inferior vena cava compression in advanced pregnancy.[6] Multiplanar imaging allows detailed evaluation of fetal organs and anatomical relationships. Three-dimensional reconstruction techniques can further enhance anatomical understanding and assist in surgical planning.[7]

T1-weighted sequences provide complementary information in specific situations. The fetal liver normally appears hyperintense due to high iron content, while meconium within the bowel becomes hyperintense after approximately 20 weeks of gestation.[8] Unlike ultrasound, MRI image quality is largely unaffected by maternal body habitus or reduced amniotic fluid volume, making it particularly valuable in challenging imaging conditions.[9]

The complementary strengths of ultrasound and fetal MRI across different fetal organ systems have been summarized in Figure 2.

Congenital diaphragmatic hernia: the paradigm for MRI-guided surgical planning

Congenital diaphragmatic hernia (CDH) exemplifies how fetal MRI has transformed prenatal surgical assessment. While ultrasound readily diagnoses CDH by showing abdominal contents in the chest, MRI provides critical prognostic information that guides the entire management strategy.

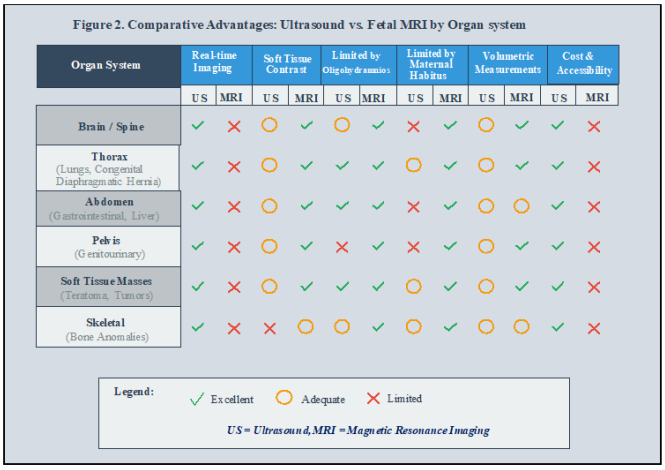

Figure 2 Comparative advantages of ultrasound versus MRI by organ system.

Comparative matrix showing relative strengths and limitations of ultrasound and MRI across different fetal organ systems and imaging characteristics. Green checkmarks indicate excellent performance; yellow circles indicate adequate performance; red crosses indicate significant limitations. This matrix demonstrates the complementary roles of both modalities in prenatal diagnosis, with MRI particularly advantageous in settings of oligohydramnios, maternal obesity, and when superior soft tissue contrast is required for surgical planning.

The key contribution of MRI in CDH is lung volume measurement. Multiple studies have demonstrated that total fetal lung volume (TFLV) and the observed-to-expected lung volume ratio (o/e TFLV) are powerful predictors of neonatal survival and need for extracorporeal membrane oxygenation (ECMO).[10–12] Fetuses with o/e TFLV below 25% have significantly worse outcomes than those with values above this threshold. This information allows for more accurate parental counselling and helps tertiary centres prepare appropriate resources.[13] The prognostic role of fetal MRI in congenital diaphragmatic hernia have been illustrated in Figure 3.

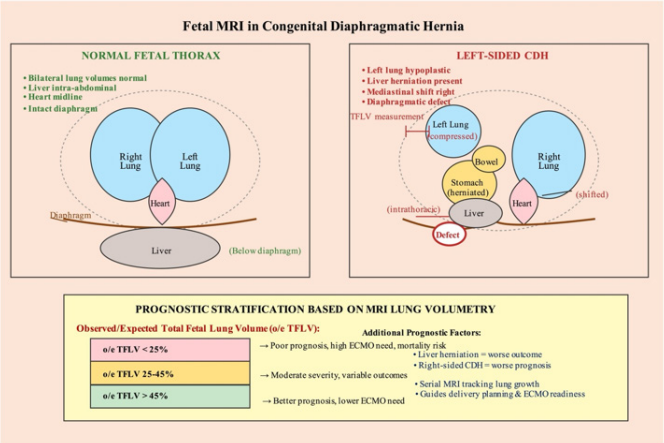

Figure 3 Fetal MRI findings in congenital diaphragmatic hernia with prognostic stratification

Schematic comparison of normal fetal thorax (left panel) versus left-sided congenital diaphragmatic hernia on fetal MRI (right panel). Key anatomical features and measurements are annotated, including herniated abdominal contents, compressed ipsilateral lung, mediastinal shift, and liver position. The prognostic information box displays observed-to-expected total fetal lung volume (o/e TFLV) thresholds that predict neonatal survival and need for Extracorporeal Membrane Oxygenation (ECMO) support, demonstrating

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how quantitative MRI measurements directly inform surgical planning and parental counselling.

Beyond volumetry, MRI provides superior characterization of liver position. Whether the liver is intrathoracic or remains intra-abdominal is a major prognostic factor, with liver herniation associated with more severe pulmonary hypoplasia and worse outcomes.[14] The multiplanar capability of MRI allows precise assessment of liver position when ultrasound findings are equivocal, particularly in right-sided CDH, where liver echogenicity mimics lung tissue.

Serial fetal MRI examinations can track lung growth over time. Recent studies have shown that fetuses with poor interval lung growth between the second and third trimester scans have worse outcomes than those maintaining growth velocity.[15,16] This dynamic assessment helps refine prognosis and allows for individualized counselling as pregnancy progresses.

The MRI findings in CDH directly influence several clinical decisions. Fetuses with severe pulmonary hypoplasia may be candidates for fetal endoscopic tracheal occlusion (FETO) at specialized centres.[17] For those managed expectantly, predicted severity guides delivery planning, severely affected fetuses should be delivered at centres with ECMO capability and experienced surgical teams. Postnatal management, including timing of surgical repair and need for delayed versus early surgery, can be anticipated based on prenatal MRI assessment of disease severity.

Myelomeningocele: MRI in the fetal surgery era

The Management of Myelomeningocele Study (MOMS trial) demonstrated that prenatal repair of myelomeningocele improves outcomes compared to postnatal surgery, reducing the need for ventriculoperitoneal shunting and improving motor function.[18] This breakthrough has made fetal MRI indispensable in the evaluation and management of fetuses with spinal dysraphism.

Ultrasound determines the spinal level of the defect and assesses for hindbrain herniation, but MRI provides a more detailed neurological assessment crucial for candidacy determination and surgical planning. MRI clearly demonstrates the degree of Chiari II malformation, showing cerebellar herniation, tectal beaking and the configuration of the posterior fossa.[19] These findings help predict which fetuses will benefit most from prenatal intervention.

A critical role of MRI is detecting associated brain anomalies that might influence the decision for fetal surgery. Corpus callosum abnormalities, gray matter heterotopia and severe ventriculomegaly are better visualized on MRI than ultrasound.[20] Recent studies have shown that fetuses with these additional findings may have less favourable outcomes even after prenatal repair, information that must be incorporated into counselling.[21]

The size and configuration of the myelomeningocele sac itself influence the surgical approach. Large defects may require tissue matrix for closure, while smaller defects can often be closed primarily. The multiplanar imaging of MRI allows surgeons to plan their approach and anticipate technical challenges.

For fetuses undergoing prenatal myelomeningocele repair, MRI plays a unique role in post-procedural assessment. Follow-up MRI performed 2-4 weeks after fetal surgery can document reversal of hindbrain herniation, which occurs in approximately 30-40% of cases.[22] The presence or absence of this reversal provides early prognostic information about the need for postnatal shunting.

MRI findings also guide postnatal management. Knowing the exact level and extent of the defect helps neonatal teams prepare for specific functional deficits. Associated findings like tethered cord, syringomyelia or hydrocephalus can be anticipated, ensuring appropriate monitoring and timely intervention when needed.

Sacrococcygeal teratoma: defining extent and guiding delivery

Sacrococcygeal teratoma (SCT) is the most common tumour in newborns and fetal MRI has proven invaluable in its prenatal assessment. While ultrasound identifies the mass and can characterize its cystic versus solid components, MRI provides superior definition of intrapelvic and intra-abdominal extension, information critical for surgical planning.

The Altman classification divides SCT into four types based on whether the tumor is external or internal.[23] Type I tumors are almost entirely external, Type II tumors have significant but smaller internal components, Type III tumors are primarily internal with external extension and Type IV tumors are entirely presacral. Surgical approach, operative time and risk of complications vary significantly among these types. Studies have shown that ultrasound misclassifies tumour type in up to 36% of cases, whereas MRI achieves nearly perfect concordance with surgical findings.[24] The intrapelvic component is particularly important for surgical planning. Tumors extending into the pelvis can compress the bladder, rectum, or ureters, potentially causing hydronephrosis or bowel obstruction. Intraspinal extension, though rare, must be ruled out as it significantly complicates surgical management. The ability of MRI to visualize these structures without obstruction from pelvic bones makes it the superior modality for this assessment.

Tumour content characterization by MRI helps predict operative challenges. Highly vascular tumours demonstrate flow voids on MRI sequences and may require preoperative embolization or careful vascular control during surgery. Predominantly cystic tumours, while often benign, can be large and may compress adjacent structures. Solid components raise concern for immature or malignant elements, though histologic diagnosis ultimately requires pathology.

MRI findings directly influence delivery planning for SCT. Tumours larger than 5 cm typically mandate caesarean delivery to prevent tumour rupture, which can cause life-threatening haemorrhage.[25] The degree of vascularity and presence of placentomegaly or fetal hydrops indicate high-output cardiac failure, prompting delivery at a tertiary centre with paediatric surgery, cardiovascular surgery and neonatology immediately available.

For the unusual circumstance where fetal intervention is considered, such as radiofrequency ablation for growing tumours causing hydrops, MRI provides detailed anatomical mapping of feeding vessels and tumour characteristics that guide the procedure.

Thoracic anomalies beyond CDH

The fetal thorax contains several lesions that may require postnatal surgery and MRI excels at characterizing these masses and their physiologic impact. Congenital pulmonary airway malformation (CPAM), bronchopulmonary sequestration and mediastinal masses each have specific MRI features that guide management.

CPAM appears as a hyperintense lung mass on T2-weighted imaging, with appearance varying from macrocystic (few large cysts) to microcystic (numerous small cysts appearing solid). The CPAM volume ratio (CVR), calculated by dividing the lesion volume by head

circumference, predicts the risk of hydrops. Lesions with CVR greater than 1.6 have a higher risk and may require fetal intervention or close surveillance.[26] MRI provides more accurate volume measurements than ultrasound, particularly for lesions in locations difficult to access sonographically.

Bronchopulmonary sequestration typically appears as a homogeneous, well-defined mass with T2 signal similar to or slightly higher than normal lung.[27] While ultrasound with colour Doppler can sometimes demonstrate the systemic arterial supply, MRI can confirm the diagnosis and clearly show the mass effect on adjacent structures. This information helps surgeons plan the operative approach and anticipate the vascular pedicle that must be ligated.

Masses causing airway obstruction, such as cervical teratomas, lymphatic malformations, or thyroid goitres, may require ex utero intrapartum treatment (EXIT) procedures to secure the airway before the placenta is separated.[28] MRI provides crucial information about the degree of airway compression, the presence of polyhydramnios (suggesting oesophageal obstruction) and the precise anatomy of the mass. This allows the multidisciplinary team to plan the EXIT procedure in detail, determining the type of airway intervention needed (intubation versus tracheostomy) and positioning the surgical team appropriately.

Abdominal Wall Defects and Gastrointestinal Anomalies

Gastroschisis and omphalocele are readily diagnosed by ultrasound but MRI provides complementary information, particularly relevant for complex cases. In gastroschisis, MRI can better assess bowel wall thickness and the presence of bowel dilation, features that may indicate complex gastroschisis with intestinal atresia or perforation. This distinction is important as complex cases require different surgical planning and have a worse prognosis.

For omphalocele, the strength of MRI lies in comprehensive evaluation for associated anomalies. The cross-sectional nature of MRI makes it less likely to miss additional findings like cardiac defects, diaphragmatic hernias or renal anomalies that cluster with omphalocele.[29] When the liver is herniated into a large omphalocele, MRI clearly demonstrates this finding and allows measurement of the defect size, both factors that influence surgical approach and predict prolonged respiratory morbidity.

Intestinal obstruction from various causes shows characteristic findings on MRI. Dilated, fluid-filled bowel loops have a high T2 signal and the level of obstruction can usually be determined.[30] The presence or absence of meconium in the distal colon on T1-weighted imaging helps distinguish high from low obstruction. For cases where prenatal diagnosis allows planned delivery at a surgical centre, the baby can have immediate postnatal evaluation and surgery without the risks of interhospital transfer.

Congenital abdominal masses, including ovarian cysts, mesenteric cysts and enteric duplications, are well-characterized on MRI. The signal characteristics help distinguish simple cysts from complex masses, guide counselling about the likelihood of spontaneous resolution versus the need for surgery and alert the surgical team to prepare for intervention if the mass is large or causing mass effect.

Genitourinary anomalies

The genitourinary system presents unique challenges for prenatal imaging as oligohydramnios frequently accompanies significant renal or urinary tract anomalies, limiting ultrasound visualization. MRI maintains excellent image quality regardless of amniotic fluid volume, making it particularly valuable in this setting.

Posterior urethral valves, the most common cause of bladder outlet obstruction in males, show characteristic features on MRI: thick-walled dilated bladder, bilateral hydroureteronephrosis and in severe cases, renal dysplasia.[31] MRI allows assessment of renal parenchymal thickness and cortical differentiation, providing prognostic information about future renal function.[32] This assessment is crucial when considering fetal intervention such as vesico-amniotic shunting, as fetuses with severely dysplastic kidneys are unlikely to benefit.

The distinction between obstructive lesions (ureteropelvic junction obstruction, ureterovesical junction obstruction) and non-obstructive conditions (multi-cystic dysplastic kidney, polycystic kidney disease) is often clearer on MRI than ultrasound.[33] For unilateral pathology, MRI provides excellent assessment of the contralateral kidney, information essential for counselling about long-term renal function and the need for close postnatal follow-up.

Cloacal malformations and complex anorectal anomalies present diagnostic challenges prenatally. The multiplanar capability of MRI allows detailed assessment of pelvic anatomy, helping identify the confluence of genitourinary and gastrointestinal tracts. Associated anomalies, including sacral dysgenesis, spinal anomalies and renal malformations are clearly demonstrated, allowing comprehensive surgical planning for what will be complex postnatal reconstruction.

Impact on multidisciplinary care and delivery planning

Perhaps the greatest value of MRI lies not in any single anatomical finding but in how it facilitates multidisciplinary communication and planning. The cross-sectional images are intuitively understood by surgeons, neonatologists, anesthesiologists and other specialists who will care for the newborn. This shared understanding improves coordination and preparation.

For delivery planning, MRI findings often prove decisive. Mode of delivery (vaginal versus caesarean) may be influenced by tumour size, presence of large abdominal wall defects, or need for an EXIT procedure. Timing of delivery balances fetal maturity against risks of tumour growth, worsening hydrops, or other complications. Location of delivery must account for the severity of anticipated pathology. Highly complex cases require tertiary centres with full paediatric subspecialty support immediately available.

The postnatal surgical plan can be discussed prenatally with more precision when the MRI has clearly defined the anatomy. Surgeons know whether to expect a straightforward repair or complex reconstruction. They can anticipate the need for prosthetic materials, special instrumentation or prolonged operative time. Anaesthesiologists prepare for difficult airways or hemodynamic instability. The neonatal ICU allocates appropriate resources including ECMO capability, when predicted.

Parental counselling becomes more accurate and complete with MRI information. Families can be told not just what is wrong with their baby, but what to expect for surgery, hospital stay, long-term outcomes and potential complications. This allows them to make informed decisions about pregnancy management, delivery location and postnatal care preferences.

Limitations and challenges

Despite its advantages, fetal MRI has important limitations that must be recognized. Fetal motion remains problematic, particularly in the early second trimester when fetuses are most active.[34] Even with

fast sequences, some examinations yield suboptimal images requiring repeat scanning. Maternal factors, including claustrophobia, inability to lie still, or contraindications to MRI (though rare) can prevent examination.[35]

Image interpretation requires significant expertise. Radiologists must understand normal fetal development at each gestational age to distinguish pathology from normal variants. Inter-observer variability exists, particularly for measurements and subtle findings. Access to paediatric radiologists with specific fetal imaging expertise is limited outside major centres.

Cost and resource allocation present practical challenges. MRI is more expensive than ultrasound and requires scheduling, dedicated scanner time and specialized interpretation. Not all centres have the equipment or expertise to perform high-quality fetal MRI. These limitations mean MRI cannot and should not replace ultrasound but rather complement it in selected cases where the additional information will change management. Additional limitations include heterogeneity in MRI protocols across institutions and limited availability of specialized fetal MRI expertise in many healthcare settings.

Future directions

Fetal MRI continues to evolve with technological advances opening new possibilities. Three-dimensional reconstruction techniques allow the creation of physical or virtual 3D models from MRI data. These models can be used for surgical simulation, allowing surgeons to practice complex procedures before entering the operating room. They also serve as powerful tools for parental counselling, helping families visualize their baby's anatomy in ways that two-dimensional images cannot convey.

Diffusion-weighted imaging and advanced sequences like intravoxel incoherent motion (IVIM) imaging are being investigated for assessment of organ function. These techniques may eventually allow non-invasive evaluation of renal function, placental perfusion, or brain development, providing functional information beyond the anatomical detail currently available.

Artificial intelligence and machine learning applications are being developed for automated organ segmentation and volumetry.[36] These tools promise to make measurements more standardized and reproducible while reducing interpretation time. Computer-aided detection algorithms may help identify subtle anomalies that might otherwise be missed.

The transition from 1.5T to 3T imaging offers improved signal-to-noise ratio and better anatomical detail, though with increased artifacts that require careful technique optimization.[37] As experience with 3T fetal imaging grows, its advantages may become more routinely accessible.

Perhaps most importantly, ongoing research continues to refine our understanding of which MRI findings best predict postnatal outcomes. As larger cohorts with standardized imaging and long-term follow-up data become available, we will better understand the prognostic significance of specific MRI features and can counsel families with increasing accuracy.

Conclusion

Fetal magnetic resonance imaging has become an indispensable complementary tool in the prenatal evaluation of congenital anomalies that may require surgical intervention. Its superior soft-tissue contrast and multiplanar imaging capability provide critical information that enhances anatomical characterization, prognostic assessment, and multidisciplinary planning. When used alongside ultrasonography, fetal MRI significantly improves prenatal decision-making regarding delivery planning and postnatal surgical management. As imaging technology continues to evolve, fetal MRI is likely to play an increasingly important role in optimizing outcomes for fetuses with surgically correctable congenital anomalies.

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None.

Conflict of interest

There is no Conflict of interest.

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