REVIEW PAPER

Cardiac Fetal Mri: Advances, Clinical Applications, And Future Directions

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ABSTRACT

Fetal magnetic resonance imaging (MRI) has emerged as a powerful adjunct to fetal echocardiography in the diagnosis of complex congenital heart disease (CHD) and intrathoracic abnormalities. The inherent technological difficulties related to tiny size, fast heart rate, fetal and maternal movements, and absence of conventional cardiac gating have frequently restricted the use of MRI in this field. However, dynamic, functional, and flow-sensitive imaging of the fetal cardiovascular system is now possible thanks to recent developments in imaging sequences, motion mitigation, gating techniques, and reconstruction algorithms. The technical development of fetal cardiac MRI, its clinical significance, and its benefits over conventional imaging modalities are all thoroughly summarized in this review. We go over some of the current uses, such as anatomical evaluation, flow measurement using 4D flow MRI and phase-contrast, and functional evaluation (e.g., ventricular volumes, strain) using feature tracking. Recent developments including Doppler-ultrasound gating, self-gating, deep learning-based reconstruction, and vascular segmentation are emphasized, and limitations and safety implications are critically evaluated. Lastly, we discuss potential futures, includes machine learning frameworks, normative atlases, multimodality integration, and translational studies toward standard clinical use. Fetal cardiac MRI has the potential to improve prenatal diagnosis, guide improving our knowledge of fetal cardiovascular physiology and perinatal care.

Keywords: Congenital heart disease, Doppler ultrasound gating, metric-optimized gating, 4D flow, fetal hemodynamic, feature tracking, motion correction, and fetal MRI

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INTRODUCTION

1.1 Clinical Background And Rationale

One of the most prevalent types of prenatal abnormalities is congenital heart disease (CHD), which affects 8–10 out of every 1,000 live births.(1) Early detection, perinatal planning, parental counselling, and, in certain centers, fetal intervention all depend on accurate prenatal diagnosis.(2) The gold standard for fetal echocardiography is still ultrasonography. Because of its excellent temporal resolution, portability, safety, and real-time Doppler flow imaging, it is the standard for in utero screening and diagnosis.(2) However, oligohydramnios, fetal position, late gestational age, maternal body habitus, and acoustic window limitations can all restrict echocardiography(1,3) A supplementary modality is magnetic resonance imaging (MRI). Superior soft tissue contrast, multiplanar imaging, an unlimited field of view, and independence from acoustic windows (1,3)are all features of MRI. These characteristics make it especially appealing when echocardiography is not the best option or when simultaneous evaluation of extracardiac structures (such as thoracic masses, lungs, or mediastinal connections) is necessary. (3)However, it has historically proven difficult to transform MRI from a static anatomical imaging tool into a dynamic modality that can resolve fetal cardiac motion and flowm. (2)In prenatal imaging, assessing the fetal heart continues to be one of the most difficult tasks. Fetal cardiac anatomy and physiology are distinguished by their small size, intricate spatial orientation, constant motion, and quick developmental changes.(2) The mainstay of prenatal cardiac evaluation has historically been fetal echocardiography, which provides real-time view of heart architecture, blood flow, and rhythm but acoustic window dependency, operator experience, and limited field of view(3,2) are the main limits of echocardiography, especially if there is maternal obesity, oligohydramnios, late gestational age, or poor fetal placement(3). to these limitations, fetal magnetic resonance imaging (MRI) has been investigated as an adjunct and, for some cases, an alternative imaging modality to improve anatomical delineation of fetal cardiovascular structures and diagnostic reliability.(1–3)

EVOLUTION OF FETAL CARDIAC MRI

Magnetic resonance imaging has developed from a merely structural modality to one that can perform sophisticated dynamic and functional evaluation.(4) Fetal MRI was first employed for body and central nervous system imaging in the late 1980s and early 1990s.(4) The fetal heart was once thought to be beyond the resolution and temporal limitations of early MRI technologies because of its small size and continuous action. The advent of ultrafast imaging sequences, such as single-shot fast spin-echo (SSFSE), balanced steady-state free precession (bSSFP), half-Fourier acquisition single-shot turbo spin echo (HASTE), and later real-time cine MRI, has altered this environment. (3,4)When paired with motion correction algorithms, parallel imaging, and compressed sensing, these methods have gradually enabled the visualization of both static and dynamic elements of the fetal cardiovascular system.(3,4) Furthermore, advances in such fetal cardiac gating approaches like metric optimal gating (MOG) and self-gating algorithms have rendered it possible to get true cardiac phase-resolved imaging.(4,5) These techniques mitigate for the lack of normal electrocardiographic (ECG) gating, an essential but practically impossible part in utero. The ability to create cine images of the beating fetal heart is an important development in prenatal cardiac imaging. (3,4)

2.1 Rationale and Clinical Significance

Congenital heart disease (CHD), which affects 8–10 out of every 1,000 live infants, appears to be the most prevalent congenital disorder.(6) Some lesions, particularly those involving the systemic and pulmonary venous return, major vessels, or extracardiac thoracic structures, may still be tough to sufficiently describe with significant discoveries in fetal echocardiography.(7) Fetal cardiac MRI boosts prenatal treatment planning and diagnosis accuracy in these situations with supplementary anatomical and physiological data. (3,7)Beyond structural investigation, there is a clinical rationale for fetal cardiac MRI The simultaneous assessment of the thoracic organs, extracardiac vasculature, cardiac shape, flow dynamics, and surrounding soft tissues remains available by MRI's vast field of view, innate soft-tissue contrast, and multiplanar capabilities. The difference between primary cardiac and secondary extrinsic causes of abnormal cardiovascular symptoms is clarified easier by this full review. Furthermore, because MRI offers high-resolution images regardless of fetal position or mother body habit, it becomes vital when echocardiographic imaging is weak(3,6).

2.2 Technical Challenges and Solutions

Due to its small size, quick intrinsic motion, unexpected fetal movement, and maternal respiration, the fetal heart provides significant imaging obstacles. To overcome these challenges, considerable technological innovation has been needed.(3,7)

Fetal and Maternal Motion: By obtaining data in milliseconds per slice, real-time imaging using ultrafast sequences reduces motion artifacts.(7) Image fidelity is further increased by methods including slice-to-volume registration, navigation echoes, and prospective motion correction[footnoteRef:1]. Absence of ECG Gating: In contrast to postnatal cardiac MRI, surrogate gating techniques are required since the fetus lacks direct ECG signals. Using metrics for picture similarity, the metric optimized gating (MOG) method reconstructs cardiac phases in the past. Similarly, self-gating and Doppler ultrasound-gated methods have been investigated. The last two make it possible to recreate cine loops that show blood flow patterns, valve motion, and heart contraction.(8)

Advanced Temporal and Spatial Resolution When 1.5 T and 3 T MRI systems are used in conjunction with compressed sensing and parallel imaging, isotropic voxel sizes as small as ~1 mm and temporal resolutions close to 30–50 ms are achieved. This performance enables a thorough assessment of tiny cardiac structures, such as outflow channels, septa, and valves.(4,7)

The Blood Flow Measurement: To measure blood flow in important vessels such the ductus arteriosus, aortic arch, and umbilical vein, phase-contrast magnetic resonance imaging (PC-MRI) has been modified for fetal imaging. Although motion correction is still difficult, advances in 4D flow MRI and real-time flow imaging are opening the door to thorough hemodynamic evaluation in utero.(9,10)

2.3 Anatomical and Functional Assessment

A multi-parametric approach covering anatomical, functional, and hemodynamic domains is provided by cardiac fetal MRI.(3,7) Heart chambers, interventricular and interatrial septa, and great vessel connections are anatomically defined by bSSFP and HASTE sequences(7). Even in the absence of contrast agents, the high contrast between blood and myocardium in bSSFP pictures improves the visibility of cardiovascular structures[footnoteRef:2]Functionally, parameters involving ventricular volumes, stroke volume, and ejection fraction that were previously deemed to be related to postnatal cardiac MRI may now be evaluated thanks to cine reconstructions. These measurements offer a glimpse at how to adapt and function of the embryonic heartbeat in diseases such twin-twin transfusion syndrome, intrauterine growth restriction, and congenital diaphragmatic hernia Anatomy and function are two of the parts of fetal flow. (4,7)MRI measures blood distribution and oxygenation, exposing physiological alterations in fetal circulation. Techniques like as T2* mapping and blood oxygen level-dependent (BOLD) MRI have been investigated to evaluate fetal oxygenation and perfusion. Under hypoxic or growth-restricted conditions, these methods can provide a non-invasive window into the circulation physiology of embryos.(11)

2.4 Comparative Role with Echocardiography

Despite its increasing potential, fetal cardiac MRI aims to enhance echocardiography rather than replace it(7,3). For both real-time Doppler flow evaluation and early gestational screening, The best technique is still echocardiography. However, MRI is superior to ultrasound when it comes to of tissue contrast, spatial coverage, and assessment of extracardiac anatomy. (3,7)The synergistic integration of both modalities may result in a complete diagnostic framework that enhances the identification and classification of numerous congenital abnormalities such as hypoplastic left heart syndrome (HLHS), double outlet right ventricle (DORV), total anomalous pulmonary venous connection (TAPVC), and coarctation of the aorta.(3,6)

The extent of vascular weakness in congenital diaphragmatic holes or the interaction between the heart and surrounding structures in thoracic masses are only a few instances of the crucial information that MRI offers about prior to surgery and birth planning. In postnatal studies of correlation, MRI data displayed significant agreement with autopsy and echocardiography, proof its clinical validity.(3)

2.5 Safety Considerations

MRI is deemed safe for fetal imaging when performed in compliance with established norms. Prenatal safety criteria are upheld by the use of non-contrast techniques and the lack of ionizing radiation(7). Within the typical specific absorption rate (SAR) limits,(3,7) studies have shown no negative thermal or aural consequences. However, due to worries about transplacental transit and possible fetal toxicity, gadolinium-based contrast agents are typically contraindicated. Consequently, contrast enhancement is not used in any of the existing clinical procedures for fetal cardiac MRI.(7)

APPLICATIONS IN SPECIFIC CLINICAL SCENARIOS

Fetal cardiac MRI has proven to be especially useful in a number of clinical settings: (4,6)

3.1 Inconclusive Echocardiography

MRI offers more anatomical information when vision is restricted due to maternal obesity, oligohydramnios, or advanced gestational age.(3,6) MRI helps with the spatial delineation of pulmonary veins, systemic venous abnormalities, and great vessels in complex congestive heart failure. (3,6)It separates intrinsic heart illness from extrinsic compression or displacement using fetal thoracic masses.(3) Evaluation of the placenta, lungs, and mediastinal tissues can all be done at the same time using magnetic resonance imaging (MRI).(3,4)

3.2 Research Applications

Fetal cardiovascular physiology and pathology are better understood when flow and oxygenation are quantitatively assessed.(11,12)

3.4 Limitations

Fetal cardiac MRI still has technical and interpretative limitations despite tremendous progress.(4,13)fetal Echocardiography is still superior to temporal resolution, especially when evaluating rapid valve motion or arrhythmias.(6) The lack of uniform imaging procedures and the need for sophisticated post-processing restrict wider usage.(4) Furthermore, fetal mobility still presents difficulties, and good imaging calls both skilled personnel and specialized fetal MRI facilities.(4,6)

TECHNICAL CHALLENGES IN FETAL CARDIAC MRI

There are various special challenges for MRI in the fetal heart:

4.1 Fast fetal heart rate

Fetal heart rates usually fall between 120 and 180 beats per minute, which corresponds to very brief cardiac cycles (between 330 and 540 ms), with fast systolic events lasting only a few milliseconds(6)

4.2 Absence of ECG gating

In contrast to postnatal cardiac MRI, the MRI environment lacks a reliable and accessible fetal ECG signal. (14)

4.3 Maternal and fetal motion

Unpredictable gross fetal motion as well as periodic (such as fetal breathing-like motions and maternal respiration) motion deteriorate image quality. (4,8)

4.5 Constraints on spatial resolution

High spatial resolution is required due to the tiny size of fetal cardiac structures (ventricle diameters, vessel dimensions), which must be weighed against scan duration and signal-to-noise ratio (SNR) Combined Arterial Spin Label and Dynamic(4)

4.6 Flow quantification challenges

Gating and good temporal fidelity are necessary for phase-contrast MRI; without gating, flow data may be distorted. (11,12)

4.7 Safety considerations

In fetal MRI, acoustic noise, specific absorption rate (SAR), and the potential dangers of heating must be carefully controlled, particularly for longer or more frequent scans. (6)

PURPOSE AND SCOPE OF THIS REVIEW

This review aims to:

Analyze the technological developments, including as gating, motion correction, faster imaging, and reconstruction, that have made fetal cardiac MRI possible. (4,14)

Emphasize the most recent clinical uses, including anatomical evaluation, blood flow measurement, and functional characteristics (e.g., strain, volumes). (3,6)

Discuss the advantages and limitations of fetal cardiac MRI compared to echocardiography and other imaging modalities.(6)

Explore emerging and future directions, including machine learning, 4D flow, segmentation, and normative data efforts. (4,7)

TECHNICAL ADVANCES IN FETAL CARDIAC MRI

6.1 Imaging Sequences and Acquisition Strategies

Early applications of fetal MRI predominantly used static anatomical imaging with sequences such as single-shot fast spin-echo (SSFSE) or half-Fourier turbo spin-echo (HASTE), and balanced steady-state free precession (bSSFP).(4) These sequences provided high spatial resolution two-dimensional images (typically voxel sizes on the order of 1–1.5 mm in-plane) over short acquisition times, but motion and cardiac dynamics were not resolved.(4,14)

The advent of cine imaging allowed time-resolved visualization of the fetal heart using retrospectively gated bSSFP sequences. The key obstacle of gating was addressed by novel retrospective methods, most notably Metric Optimized Gating (MOG). MOG acquires data without a gating signal and retrospectively reconstructs cine images by optimizing an image metric (such as entropy) to find a synthetic cardiac cycle.(14)

Further acceleration of acquisitions has been made possible by techniques like compressed sensing, parallel imaging, and non-Cartesian trajectories (e.g., radial, golden-angle sampling). These advances enable faster imaging, reduced motion sensitivity, and reconstruction of 4D flow data.(4,7)

GATING STRATEGIES

7.1 Metric Optimized Gating (MOG)

As noted, MOG enables retrospective gating by reconstructing data over variable synthetic cardiac periods and selecting the reconstruction that optimizes a chosen metric (e.g., minimized temporal entropy). first demonstrated MOG in fetal phase-contrast MRI, validating it with flow phantoms, adult volunteers, and human fetuses. Later, cine MOG was validated, showing that MOG-reconstructed images of cardiac contraction (systole and diastole) were comparable to ECG-gated images in adults.(14)

7.2 Doppler Ultrasound (DUS) Gating

A more direct method involves using a Doppler ultrasound (DUS) device placed on the maternal abdomen to sense fetal cardiac motion or flow and generate a gating signal. demonstrated the feasibility of this method in humans. Their study showed high sensitivity and acceptable trigger variability, enabling dynamic balanced steady-state free precession (bSSFP) imaging of the four-chamber view and short-axis slices.(15)

More recently, Doppler US–gated 2D phase-contrast MRI and even 4D flow MRI have been achieved. A feasibility study at 3 Tesla used DUS gating combined with 4D flow, visualizing streamlines and quantifying flow in fetal great thoracic vessels.(16)

7.3 Motion Correction And Reconstruction

Unpredictable fetal and maternal movements remain a major challenge. To mitigate these, advanced motion correction strategies have been employed Slice-to-volume registration (SVR): aligning multiple stacks of 2D slices to reconstruct a consistent 3D volume. Navigator echoes and prospective motion tracking: used to reject corrupted data.(4)

Deep learning–based reconstruction: Recent work has introduced neural networks to reconstruct dynamic fetal cardiac MRI from highly under sampled, un-gated acquisitions. For example, DCRA-Net, a deep attention-based model, reconstructs spatial and temporal dynamics with high fidelity even from eightfold under sampled data sets.(7)

FUNCTIONAL AND FLOW IMAGING

8.1 Phase-Contrast MRI And Flow Quantification

Phase-contrast (PC) MRI enables quantification of blood flow velocity and volume in vessels. In the fetal context, PC-MRI has been adapted with retrospective gating (e.g., MOG), enabling flow measurements in major vessels such as the aorta, ductus arteriosus, and umbilical vein(11,12)

8.2 4D FLOW MRI

Using DUS gating and advanced sequence design (compressed sensing, golden-angle radial sampling), researchers have performed 4D flow MRI in the fetus, capturing time-resolved three-dimensional flow in great thoracic vessels. This allows visualization of streamlines, waveform analysis, and quantification of flow volumes over the cardiac cycle(16).

8.3 Myocardial Strain and Feature Tracking

Feature tracking MRI (FT-MRI) allows extraction of myocardial strain parameters (e.g., global longitudinal strain, radial strain) from cine series. A recent study used DUS-gated cine MRI at 3 T and feature tracking to measure myocardial strain in 43 fetuses (both healthy and with CHD). They found significant differences between CHD and non-CHD fetuses in strain measurements (such as left and right ventricular global longitudinal strain), which may indicate functional biomarkers for the illness.(7)

CLINICAL APPLICATIONS

9.1 Anatomical Assessment

High-resolution anatomical evaluation is possible with fetal cardiac MRI, particularly when echocardiography is not available. Complex features including the outflow pathways, major vessels, systemic and pulmonary venous return, and extracardiac structures (mediastinum, lungs, thoracic masses) can be seen in detail thanks to the multiplanar nature of MRI. The usefulness of bSSFP and SS-FSE sequences for congenital abnormality detection has been shown by systematic reviews.

Fetal MRI may be used in conjunction with echocardiography to clarify anatomy and spatial correlations in cases such as suspected coarctation, total anomalous pulmonary venous connection (TAPVC), double outlet right ventricle (DORV), or vascular abnormalitie. (3,6)

9.2 Hemodynamic and Functional Assessment

Fetal hemodynamic can be better understood through flow quantification using PC-MRI and 4D flow than through ultrasound alone. These measurements can provide information on cardiac output, blood distribution, and shunt physiology in CHD. For instance, cardiac output in the ascending aorta and main pulmonary artery has been measured in human fetuses of all gestational ages using Doppler US-gated PC-MRI.(11,12)

Strain analysis based on feature tracking can identify mild functional impairment. According to the 2024 European Radiology study mentioned above, myocardial strain measures may be able to distinguish between fetuses with congenital heart disease and those without.

9.3 Perinatal Planning And Prognostication

MRI is useful for perinatal planning because it can quantify blood flow and visualize extracardiac tissues. Cardiac MRI can assist in determining the effects on heart location, compression, and vascular connections in fetuses with thoracic masses (such as congenital diaphragmatic hernia). Decisions on surgery planning, postnatal care techniques, delivery time, and location (tertiary center) can all be influenced by it.(17)

9.4 Research And Physiological Insights

Additionally, fetal cardiac MRI is used in research. Quantitative flow and strain data contribute to our understanding of fetal cardiovascular adaptations, placental-fetal interactions, and long-term implications of CHD. Computational models, such as fluid–structure interaction (FSI) paradigms, have been developed to simulate fetal aortic mechanics based on MRI-derived dimensions and flow data.

Deep learning frameworks are emerging, such as multi-task learning for segmentation and anomaly classification (e.g., aortic arch anomalies). Ramirez et al. recently proposed a joint segmentation–classification network using 3D black-blood MRI to detect double aortic arch, coarctation, and right aortic arch.(7)

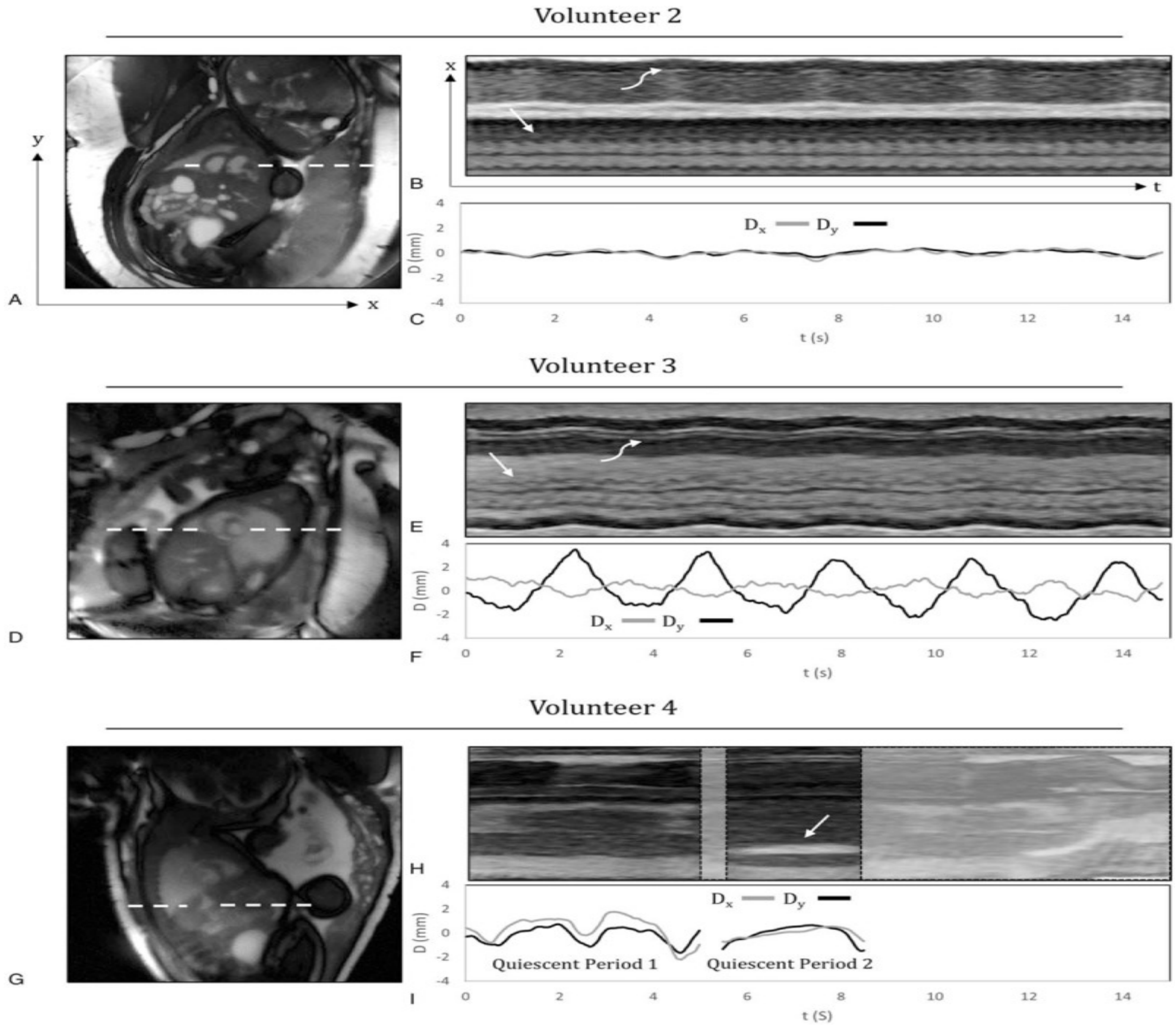

Fig.4 -Real-time reconstructions of the fetal heart for 3 volunteers with increasing levels of motion, Roy CW, van Amerom JFP, Marini D, Seed M, Macgowan CK. Fetal Cardiac MRI. Top Magn Reson Imaging. 2019 Oct;28(5):235–44. doi:10.1097/RMR.0000000000000218 PubMed PMID: 31592990; PubMed Central PMCID: PMC6791520.(18)

ADVANTAGES OF FETAL CARDIAC MRI

Superior Tissue Contrast & Multiplanar Imaging: MRI provides excellent soft-tissue contrast, enabling delineation of myocardium, vascular walls, and extracardiac structures in multiple orientations.(4,6)

Large Field of View: MRI can capture the heart in relation to the lungs, mediastinum, placenta, and maternal structures in one examination. (3,18)

Quantitative Flow & Function: Techniques like phase-contrast and 4D flow MRI, and feature tracking for strain, permit objective quantification of blood flow and myocardial deformation. (11,17)

Less Dependent on an Operator than Ultrasound: MRI can standardize views and measurements, reducing inter-operator variability, while fetal echocardiography mostly relies on operator skills and acoustic windows. (3,6)

In no way impacted by the limitations of technology: MRI is not affected by fetal position, oligohydramnios, or maternal obesity, in compared with ultrasonography.(6)

Safe: Ionizing radiation is not used in MRI; SAR and acoustic exposure are kept within tolerable ranges for the fetus with the correct methods. (6)

LIMITATIONS

Despite encouraging progress, fetal cardiac MRI has several limitations.

11.1 Resolution of Duration

Even with MOG or DUS gating, MRI's temporal resolution (~ 20–50 ms) is still lower than echocardiography, which may make it more difficult to discern rapidly moving structures like valves.(18)

11.2 Sensitivity to motion

Motion correction is helpful yet it is not perfect; data could be stained by mother breathing, repositioning, and large fetal movements. Gating Errors: Extremely erratic rhythms or subpar imaging settings.(14,18)

11.3 Gating Failures

MOG reconstructions can fail due to very irregular rhythms or poor imaging conditions; the DUS signal may be lost due to fetal movement or improper probe positioning. Patient Comfort and Scan Duration Longer scan time and patient discomfort could limit clinical value(8,16)

11.4 Post-Processing Burden

Extensive post-processing may be necessary for advanced reconstructions (such as MOG, compressed sensing, and deep learning), which could cause a delay in report turnaround.(18,19)

11.5 Lack of Standardization

Reproducibility is hampered by the absence of widely accepted standardized methods (for gating, sequence parameters, and reconstruction) across centers.(4,6)

11.6 Validation & Normative Data

Extensive normative datasets including heart volumes, flow, and gestational ages are still being developed.(20)

Accessibility and Cost: Not all centers may have access to specialized equipment (DUS gating devices), high-field scanners, and knowledgeable personnel(6)

SAFETY CONSIDERATIONS

When proper procedures are followed, MRI in the fetus is usually regarded as safe. One significant benefit is that there is no ionizing radiation.(6) Following regulatory limitations for SAR, acoustic noise, and duration has not been associated with any negative thermal effects, peripheral nerve stimulation, or long-term neurodevelopmental sequelae, according to studies.(6) The majority of fetal cardiac MRI studies are carried out without contrast because gadolinium-based contrast agents are generally avoided in fetal studies due to concerns regarding fetal exposure and transplacental passage.(6)

FUTURE DIRECTIONS AND EMERGING TRENDS

13.1 Deep Learning and AI-Based Reconstruction

Fetal cardiac MRI is at the forefront because too deep learning models like DCRA-Net, which allow for high-quality reconstructions from under sampled, un-gated acquisitions. These techniques can shorten scan times, speed up acquisition, and even enable near-real-time imaging(21).

13.2 Automated Segmentation and Anomaly Detection

Frameworks for automated multitasking that combine classification and segmentation are being developed. For example, a deep learning model has demonstrated promising accuracy in classifying aortic arch anomalies (double arch, right arch, and coarctation). These tools might speed up diagnosis, make decision-making simpler, and reduce the need for manual segmentation.(21)

13.3 Normative Atlases and Reference Databases

It requires a lot of work to create normative atlases of fetal cardiac architecture, flow, and function across gestational age. These databases will make easier the contrasting of abnormal and normal fetal trajectories, improving diagnosis and risk assessment accuracy.(22)

13.4 Multimodal Integration

Combining MRI data with echocardiography, computational fluid dynamics (CFD), and fluid structure interaction (FSI) models can yield additional physiological data. Customized FSI models of the fetal aorta have already been created using MRI and anatomical data.(22)

CLINICAL TRANSLATION & WORKFLOW OPTIMIZATION

To make fetal cardiac MRI more accessible clinically:

Imaging procedures have to be standardized.

Additional size reduction, user-friendliness, and the incorporation of protection devices (such DUS probes) into clinical MRI techniques are necessary.(4,6) Real-time or fast reconstruction pipelines—possibly with AI—are required for the instantaneous visual feedback mentioned above.(23) Longitudinal studies that link MRI data to prenatal outcomes, surgical planning, and postnatal follow-up will prove its value.

14.1 Safety and Regulatory Studies

Though MRI is typically considered as safe, deeper long-term follow-up data on neurodevelopmental outcomes, temperature exposure, and cumulative effects from multiple scans may strengthen safety profiles. Regulations could be altered in order to allow for wider adoption.(6)

CONCLUSION

Cardiac fetal MRI is a revolutionary advancement in prenatal imaging by bridging the gap between static morphological assessment and dynamic functional evaluation of the fetal circulatory system. Thanks to advancements in gating (MOG, Doppler US), fast collecting (compressed sensing, radial trajectories), motion correction, and advanced reconstruction (deep learning), it is now feasible to get high-quality cine images, quantify flow, and assess heart strain in utero.

In difficult situations, fetal cardiac MRI is an invaluable supplement to echocardiography, especially when ultrasound is hard to come by or when accurate anatomical and physical data is crucial for perinatal planning. Clinical applications involve identifying difficult CHD, measuring flow and function, evaluating extracardiac structures, and advising treatment. Clinical applications involve identifying difficult CHD, identifying extracardiac structures, monitoring flow and function, and providing treatment suggestions.

The main future prospects are AI-driven reconstruction, automated segmentation and classification, the creation of normative reference datasets, and workflow integration for assisting clinical translation. As technology develops and validation studies increase, fetal cardiac MRI has the potential to become an essential tool in perinatal cardiology, improving medical accuracy, directing treatment strategies, and deepening our understanding of fetal cardiovascular physiology

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