

MULTIMODAL CARDIOVASCULAR AND NEUROLOGICAL IMAGING IN PREGNANCY: INTEGRATING MATERNAL AND FETAL DIAGNOSIS

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Pregnancy creates an unusually complex setting for diagnostic imaging. Maternal disease, fetal development, gestational age, radiation exposure, contrast administration, and clinical urgency must often be weighed at the same time. Cardiovascular and neurological disorders warrant particular attention: pregnancy may reveal previously silent disease, modify the course of pre-existing conditions, or precipitate pregnancy-specific emergencies, including peripartum cardiomyopathy, hypertensive neurological syndromes, cerebral venous thrombosis, acute ischemic stroke, and aortic disease. Prenatal imaging has an equally important role in detecting congenital heart disease and abnormalities of the fetal central nervous system. No single imaging technique is sufficient in every clinical setting. Ultrasound and echocardiography remain the first-line modalities because they are widely available, permit real-time dynamic assessment, and do not involve ionizing radiation. Magnetic resonance imaging adds structural, functional, vascular, and tissue-characterization information without radiation exposure. Its contribution is especially valuable in maternal neurological disorders, complex cardiovascular disease, and fetal neuroimaging. Computed tomography, however, remains indispensable when life-threatening maternal pathology requires rapid diagnosis; pregnancy alone should not preclude its use when the examination is clinically justified. For detailed prenatal cardiovascular and neurological assessment, fetal echocardiography and targeted neurosonography remain the principal techniques. In selected cases, fetal MRI may provide additional diagnostic information, refine anatomical characterization, and improve prognostic assessment. This review examines the contemporary applications, strengths, limitations, and safety considerations of multimodal cardiovascular and neurological imaging during pregnancy and proposes integrated diagnostic pathways for maternal and fetal disease.

Keywords: pregnancy; multimodal imaging; echocardiography; cardiovascular magnetic resonance; fetal MRI; fetal echocardiography; neurosonography; stroke; congenital heart disease; fetal brain.

INTRODUCTION

Diagnostic imaging during pregnancy involves two patients, not one. Physiological cardiovascular adaptation, changes in coagulation, hormonal influences, and altered vascular integrity may resemble disease, complicate its recognition, or predispose to genuine pathology. Cardiovascular disease remains a major cause of maternal morbidity. Pregnancy and the puerperium are also associated with several neurological disorders, notably hypertensive encephalopathy, posterior

reversible encephalopathy syndrome (PRES), cerebral venous thrombosis, and stroke [1–4].

The relevant question is therefore not simply *which modality is safest?* A more clinically useful formulation is: *which modality can answer the specific diagnostic question accurately and without avoidable delay, while limiting unnecessary risk to both mother and fetus?*

When diagnostically suitable, ultrasonography and MRI are preferred because neither uses ionizing radiation. This preference should not, however, become an absolute restriction.

Radiography and CT must not be withheld when clinically necessary, since fetal radiation exposure from most diagnostic examinations remains substantially below the thresholds associated with deterministic injury. Gadolinium-based contrast administration requires greater caution and should generally be reserved for circumstances in which it is expected to provide information that would materially alter diagnosis, management, or clinical outcome [2–5].

The 2025 ESC pregnancy guidelines also place multidisciplinary assessment at the centre of cardiovascular care during pregnancy, particularly

for women with established or suspected cardiovascular disease. Such evaluation should be coordinated through the Pregnancy Heart Team framework [1].

FUNDAMENTAL PRINCIPLES OF IMAGING DURING PREGNANCY

The choice of imaging modality should be based on the clinical question, diagnostic performance, gestational age, urgency and expected impact on management [1–4].

Modality	Ionizing radiation	Major role in pregnancy	Main limitation
Ultrasound/echocardiography	No	First-line maternal and fetal imaging	Operator and acoustic-window dependent
Doppler ultrasound	No	Hemodynamics, fetal/placental circulation	Angle and technique dependent
MRI	No	Brain, cardiovascular anatomy, fetal CNS, tissue characterization	Motion, availability, examination duration
CMR	No	Ventricular function, aorta, congenital disease, cardiomyopathy	ECG/gating and maternal tolerance
CT/CTA	Yes	Acute hemorrhage, stroke pathways, aorta, pulmonary disease	Radiation/iodinated contrast considerations
Catheter angiography	Yes	Selected diagnostic/interventional emergencies	Invasive; radiation exposure
Nuclear imaging	Yes	Highly selected functional indications	Radiation and tracer-specific considerations

The guiding principle is diagnostic justification rather than avoidance of imaging. Delay is not benign. When maternal pulmonary embolism, aortic dissection, intracranial hemorrhage or acute ischemic stroke is suspected, postponing definitive diagnosis may expose both mother and fetus to risks substantially greater than those associated with an appropriately selected and optimized imaging examination [1–3].

MATERNAL CARDIOVASCULAR IMAGING

Echocardiography

Transthoracic echocardiography is the primary cardiovascular imaging modality during pregnancy. It provides rapid assessment of [1,3]:

- ventricular size and systolic function;
- valvular disease;
- pulmonary pressures;

- congenital heart disease;
- intracardiac masses and thrombi;
- pericardial disease;
- aortic root dimensions;
- hemodynamic consequences of pregnancy-related cardiovascular disease.

Pregnancy itself changes cardiovascular measurements. Plasma-volume expansion increases preload and cardiac output, while modest increases in ventricular volumes and myocardial mass may reflect physiological adaptation rather than disease. Context therefore matters. Echocardiographic findings should be interpreted with reference to gestational age and the expected haemodynamic changes of pregnancy [1,3,4].

Strain imaging may reveal subtle myocardial dysfunction before a measurable decline in ejection fraction becomes apparent. Its incremental value in routine surveillance during pregnancy, however, remains uncertain, and acquisition and interpretation have yet to be fully standardized [3].

Echocardiographic strain imaging may reveal subtle myocardial dysfunction before ejection

fraction declines. Its incremental value in routine pregnancy surveillance, however, remains uncertain,

and its application has not yet been fully standardized [3].

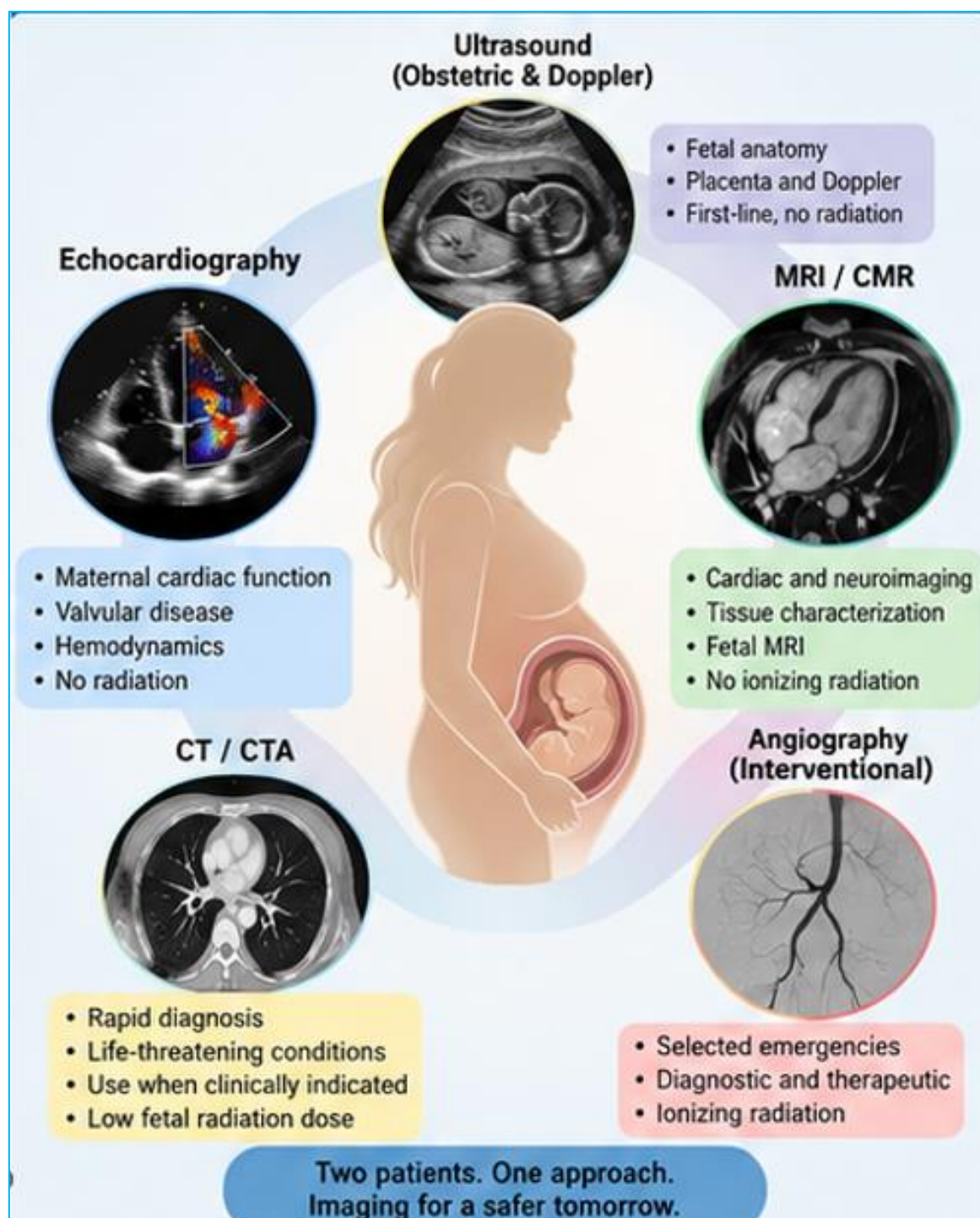


Fig. 1 – Multimodal imaging in pregnancy: overview.

Cardiovascular Magnetic Resonance

CMR is particularly valuable when echocardiography is inconclusive or when ventricular volumes, vascular anatomy, or

myocardial tissue require more precise assessment. Non-contrast CMR has therefore emerged as an important adjunct in pregnant patients with suspected or established cardiovascular disease [1,3,4].

Its clinical applications are broad.

Cardiomyopathy. CMR provides accurate quantification of LV and RV volumes and systolic function, especially when acoustic windows are poor or echocardiographic measurements remain uncertain [3,4].

Congenital heart disease. Complex ventricular geometry may be delineated more clearly, as may systemic and pulmonary venous connections and extracardiac vascular anatomy [3,4].

Aortic disease. Non-contrast MR angiographic techniques permit evaluation of the thoracic aorta without exposure to ionizing radiation (Fig. 2) [1,3,4].

Myocardial characterization. Native T1 and T2 mapping may contribute when inflammatory or infiltrative myocardial disease is suspected, without requiring gadolinium administration [3,4].

Not every observed change is pathological. Serial CMR studies have documented pregnancy-related increases in ventricular dimensions and myocardial mass, with at least partial regression after delivery. Physiological remodeling must therefore be considered when scans obtained during pregnancy and the postpartum period are interpreted [4].

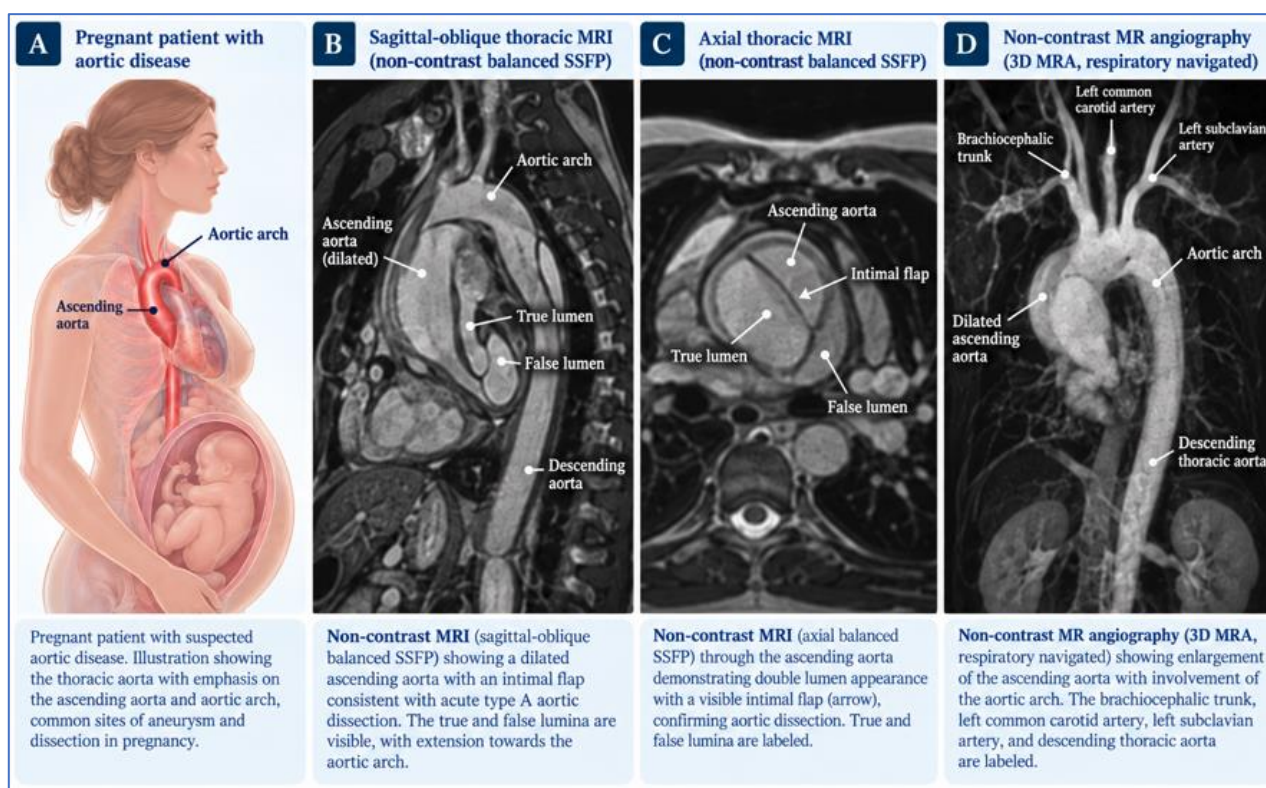


Fig. 2 – Maternal non-contrast aortic MRI.

PERIPARTUM CARDIOMYOPATHY

Multimodal imaging has particular relevance in peripartum cardiomyopathy (PPCM) [6,7].

Echocardiography remains the first examination. It rapidly establishes LV ejection fraction and ventricular dimensions while also assessing RV involvement, valvular regurgitation, and intracardiac thrombus [6].

CMR may then offer more reproducible quantification of ventricular function, particularly

when echocardiographic assessment is limited or equivocal. It can also provide information on myocardial edema and fibrosis and may help distinguish PPCM from alternative diagnoses. Marked LV dysfunction carries a risk of intracardiac thrombus formation; cardiac imaging findings may therefore influence the investigation and management of neurological complications [6,7].

This cardiovascular–neurological interface becomes most apparent when PPCM is complicated by systemic embolization [6,7].

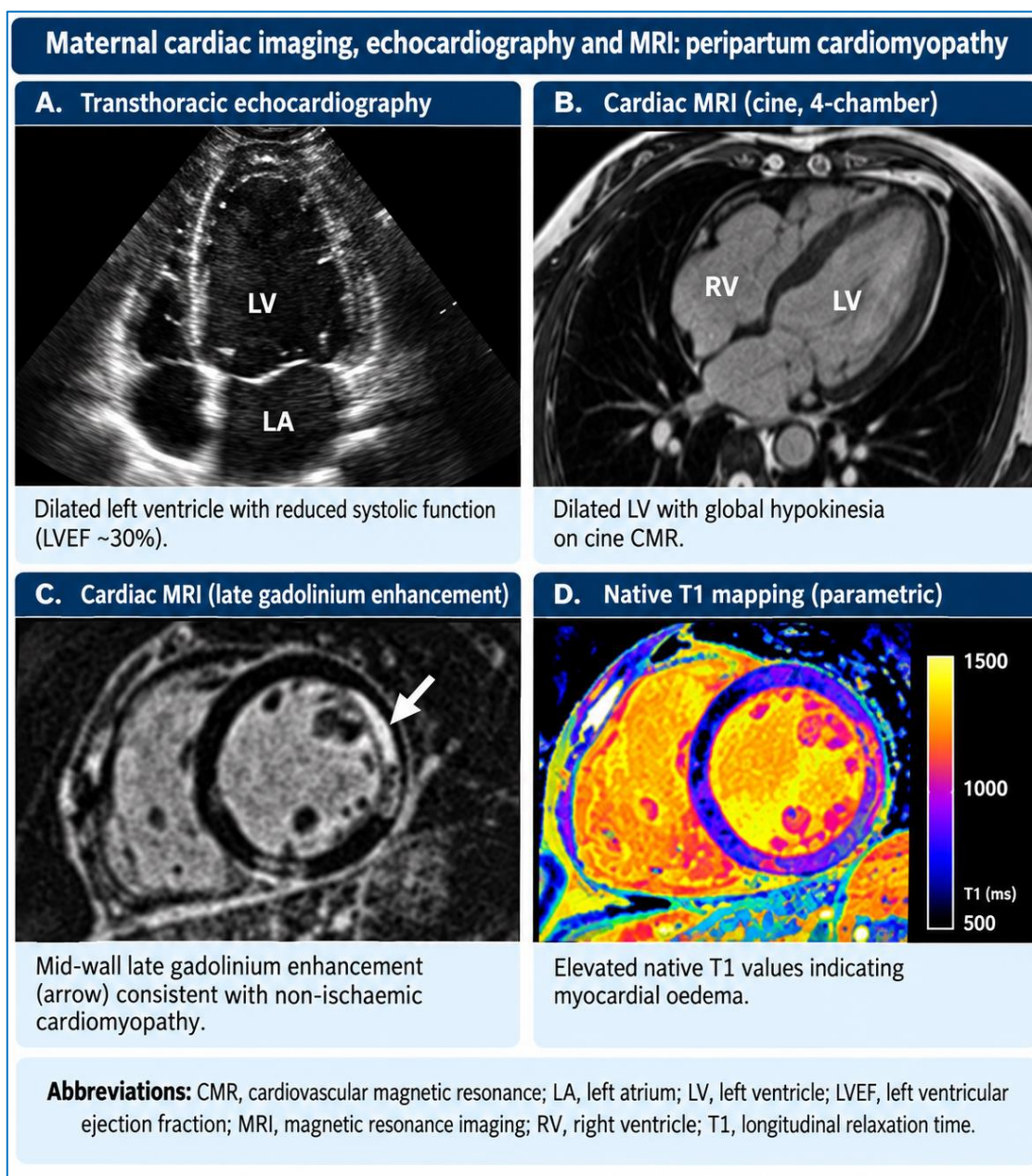


Fig. 3 – Maternal cardiac imaging, echocardiography and MRI: peripartum cardiomyopathy.

MATERNAL NEUROLOGICAL IMAGING

Acute neurological deficit

Pregnancy should not delay standard emergency neurological imaging [8–11].

The priority in an acute focal deficit is to differentiate:

- ischemic stroke (Fig. 4);
- intracranial hemorrhage;
- cerebral venous thrombosis;
- reversible vasoconstriction;
- PRES;

- arterial dissection;
- aneurysmal subarachnoid hemorrhage.

MRI avoids ionizing radiation and provides sensitive characterization of cerebral tissue. In suspected acute stroke, a focused protocol may include diffusion-weighted imaging with ADC maps, FLAIR, susceptibility-sensitive sequences, and non-contrast time-of-flight angiography [8–11].

CT remains appropriate when time is critical, MRI is not readily available, or intracranial hemorrhage must be identified without delay. Pregnancy alone should not preclude a medically necessary CT examination [2,8–11].

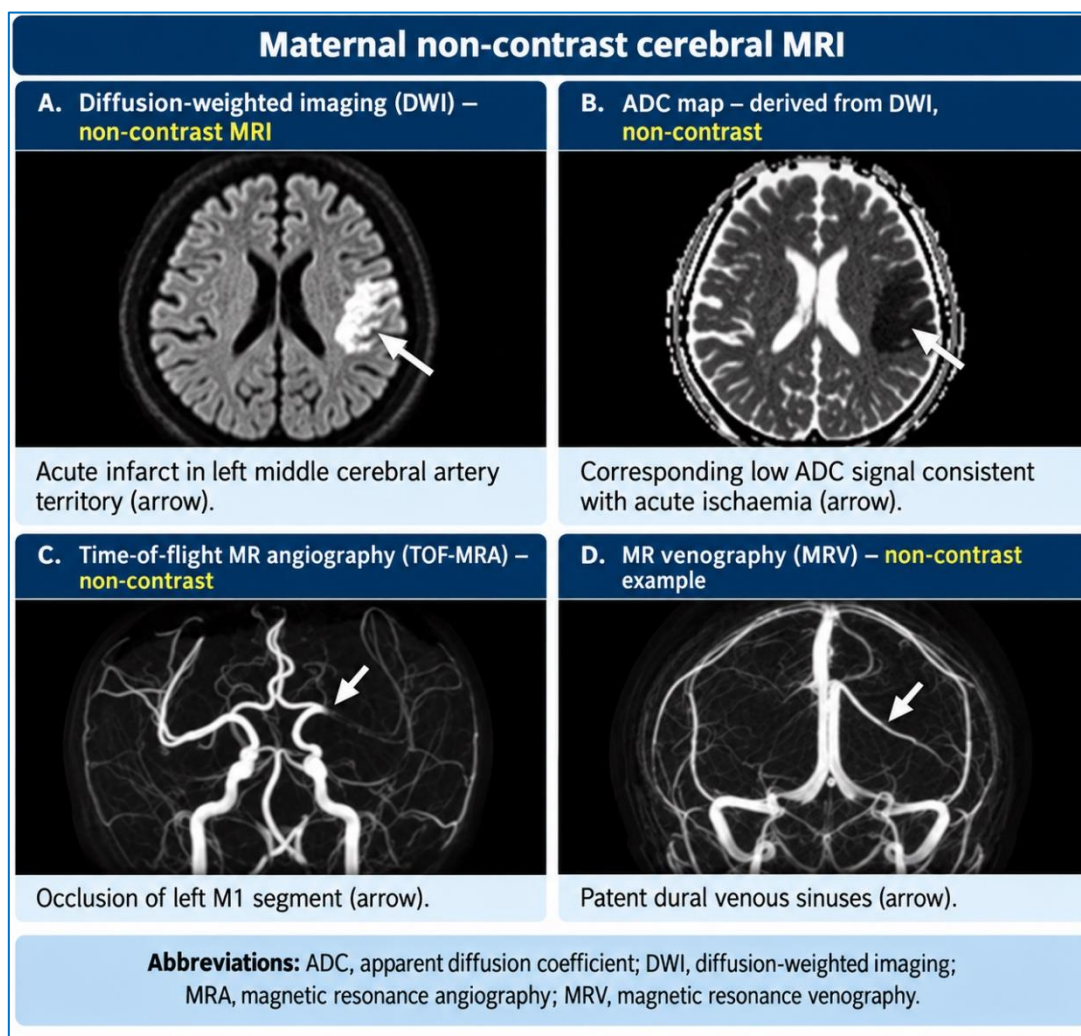


Fig. 4 – Maternal non-contrast cerebral MRI.

Cerebral venous thrombosis

Pregnancy and the puerperium represent recognized prothrombotic states. MRI combined with MR venography can demonstrate [12,13]:

- thrombus-related signal alteration;
- absence of normal venous flow;
- venous congestion;
- edema;
- venous infarction;
- secondary hemorrhage.

CT venography remains a reasonable rapid alternative when MRI is unavailable or contraindicated [10–13].

PRES and hypertensive disease

Hypertensive disorders of pregnancy – most notably pre-eclampsia and eclampsia – may be complicated by posterior reversible encephalopathy

syndrome (PRES). Clinical presentation varies. Headache, seizures, altered consciousness, visual disturbance, and focal neurological deficits are common manifestations. In suspected PRES, MRI is especially informative: FLAIR typically demonstrates vasogenic edema in the posterior cerebral regions, although the abnormalities may extend to the frontal or temporal lobes, cerebellum, brainstem, or basal ganglia [14].

Diffusion-weighted imaging helps differentiate predominantly vasogenic edema from superimposed areas of cytotoxic injury [14].

Intracranial vascular disease

MRI/MRA and CT/CTA offer complementary information in the assessment of intracranial aneurysms, arterial dissections, and vascular malformations. The choice between them depends on the clinical urgency, suspected lesion, local

availability, and the level of anatomical detail required [8,10,11].

Catheter angiography is invasive and should be used selectively. Its superior spatial and temporal resolution – and the opportunity to proceed directly to endovascular treatment – may nevertheless

justify its use in appropriately selected cases [8,10,11].

In a life-threatening cerebrovascular emergency, pregnancy alone should not delay or preclude necessary neurovascular imaging or treatment [2,8].

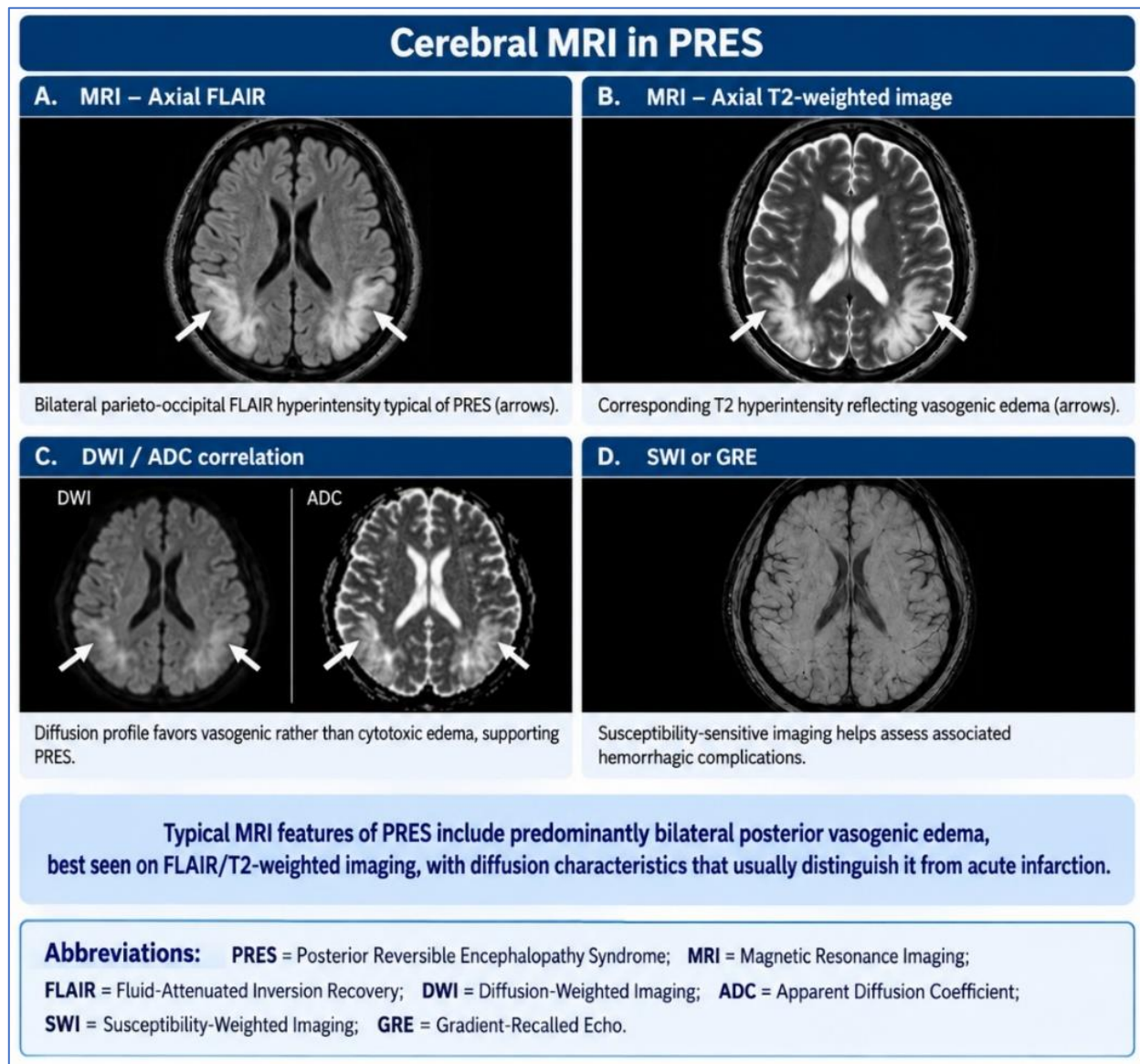


Fig. 5 – Cerebral MRI in PRES.

FETAL CARDIOVASCULAR IMAGING

Screening ultrasound

Prenatal ultrasound remains the cornerstone of fetal cardiovascular screening. Current guidance emphasizes systematic evaluation rather than reliance on a single four-chamber view. Outflow-tract and great-vessel views

materially improve the detection of congenital heart disease [15,16].

The standard examination evaluates:

- situs and cardiac position;
- four-chamber anatomy;
- ventricular symmetry;
- atrioventricular connections;
- ventricular outflow tracts;
- three-vessel view;

- three-vessel-and-trachea view;
- rhythm and heart rate.

When abnormalities are detected or the pregnancy carries increased fetal cardiac risk, formal fetal echocardiography is indicated [15,16].

Advanced fetal echocardiography

Fetal echocardiography extends conventional anatomic imaging with functional and hemodynamic assessment through [15,16]:

- color Doppler;
- pulsed-wave Doppler;

- M-mode;
- tissue Doppler;
- ventricular functional assessment;
- evaluation of atrial and ductal shunting;
- rhythm characterization.

Recent guidance continues to position comprehensive fetal echocardiography as the principal diagnostic test for congenital heart disease after abnormal screening or in high-risk pregnancies (Fig. 6) [15,16].

FETAL CARDIAC MRI

Fetal cardiovascular MRI is one of the most rapidly developing areas of prenatal imaging [17–20].

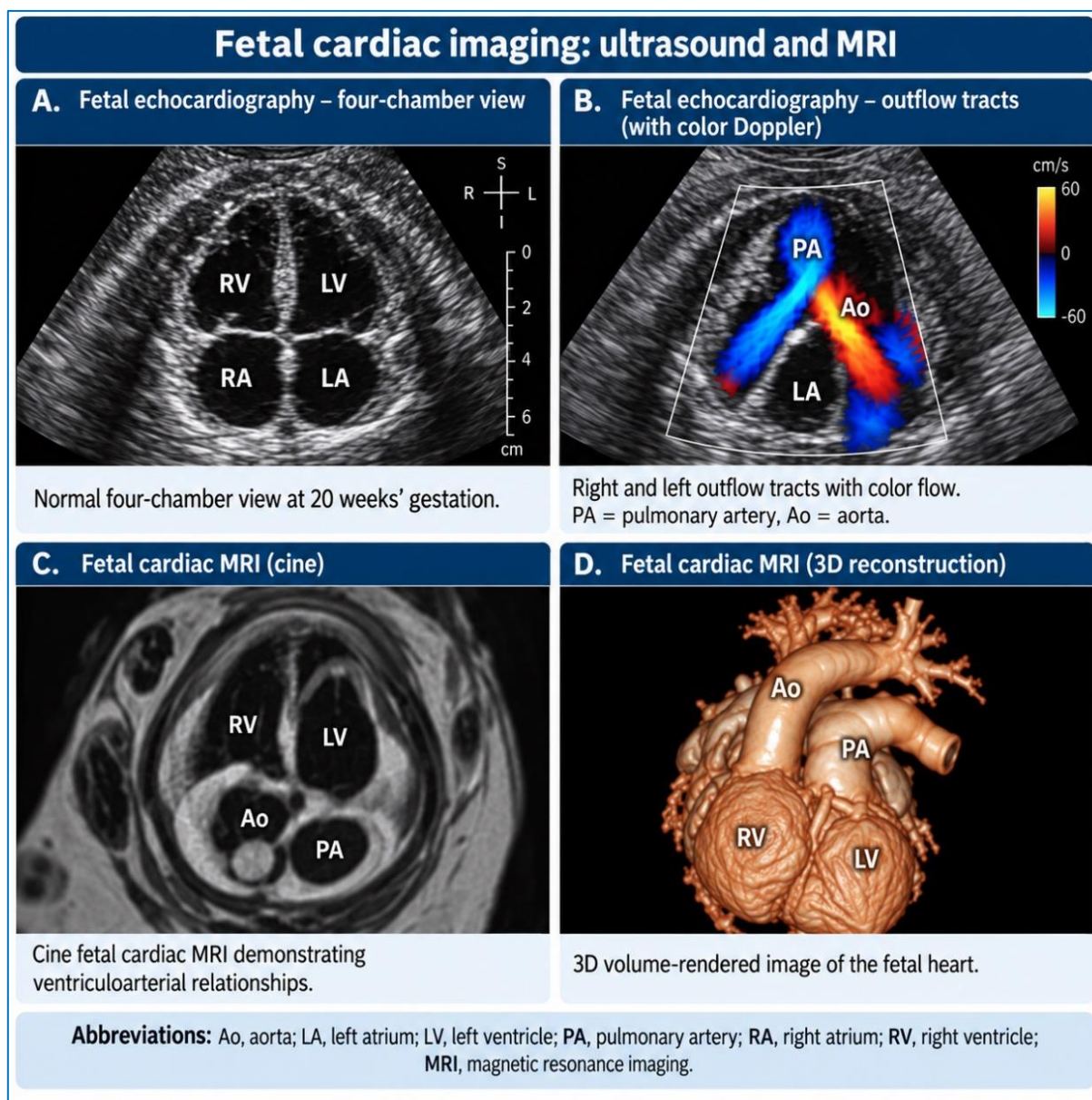


Fig. 6 – Fetal cardiovascular ultrasound and MRI.

Historically, fetal cardiac MRI was severely restricted by fetal motion and the absence of a conventional ECG signal. Advances in motion correction and fetal cardiac gating—including metric-optimized gating, self-gating and Doppler ultrasound-based gating—now permit cine imaging of the fetal heart [17–20].

Emerging applications include:

- clarification of intracardiac anatomy when ultrasound is limited;
- evaluation of great-vessel relationships;
- venous anomalies;
- quantification of fetal blood flow;
- estimation of oxygen delivery;
- assessment of placental-fetal cardiovascular interactions;
- complex congenital heart disease.

Fetal MRI remains complementary rather than a replacement for fetal echocardiography. Current evidence supports particular benefit when sonographic visualization is impaired by fetal position, maternal body habitus, oligohydramnios or complex thoracic anatomy [17–21].

Cine fetal cardiac MRI can delineate ventricular morphology and ventriculoarterial relationships in complex congenital heart disease. Contemporary gating techniques are expanding its diagnostic potential (Fig. 6) [17–20].

FETAL NEUROLOGICAL IMAGING

Screening neurosonography

Ultrasound is the primary screening modality for the fetal central nervous system. recommends systematic evaluation during the mid-trimester anomaly examination, while acknowledging that several severe CNS abnormalities can already be identified during late first-trimester imaging [22].

The basic study evaluates structures including:

- lateral ventricles;
- cavum septi pellucidi;
- midline;
- thalami;
- posterior fossa;
- cerebellum;

- cisterna magna;
- skull shape;
- spine.

Abnormalities detected on routine examination should prompt targeted fetal neurosonography [22,23].

Targeted neurosonography

Dedicated neurosonography enables multiplanar assessment using transabdominal and, when appropriate, transvaginal techniques [23].

Coronal and sagittal views provide detailed assessment of structures that cannot be fully evaluated in standard axial screening planes. Targeted examination is particularly useful for [23]:

- corpus callosum abnormalities;
- cortical malformations;
- posterior-fossa abnormalities;
- ventriculomegaly;
- intracranial hemorrhage;
- midline anomalies;
- spinal dysraphism.
- Three-dimensional ultrasound can assist in acquiring reproducible multiplanar datasets and evaluating complex midline anatomy [23].

FETAL BRAIN MRI

Fetal MRI is the principal second-line technique when a suspected CNS abnormality cannot be fully characterized by ultrasound. It is not intended for universal screening. Current guidance positions fetal MRI as a complement to expert sonography, particularly when additional anatomical detail may alter diagnosis, counselling, or perinatal management [21,24].

Major indications include:

Ventriculomegaly. MRI may disclose associated cortical, commissural, or posterior-fossa abnormalities that are not apparent on ultrasound [21,24].

Corpus callosum abnormalities. Direct sagittal imaging can confirm complete or partial agenesis and may identify additional anomalies [21,24,25].

Posterior-fossa pathology. The cerebellar vermis, brainstem, and adjacent structures are often more clearly delineated with MRI [21,24].

Cortical development. Sulcation and gyration can be assessed in relation to gestational age, allowing abnormalities of cortical maturation to be recognized [21,24].

Ischemic or hemorrhagic injury. MRI may define the distribution and extent of parenchymal damage and demonstrate associated developmental abnormalities [21,24].

Congenital infection. Destructive lesions, disordered cortical development, and other forms of CNS involvement may be detected and characterized [21,24].

Three-dimensional ultrasound remains useful. It permits acquisition of reproducible multiplanar datasets and can improve assessment of complex midline anatomy [23].

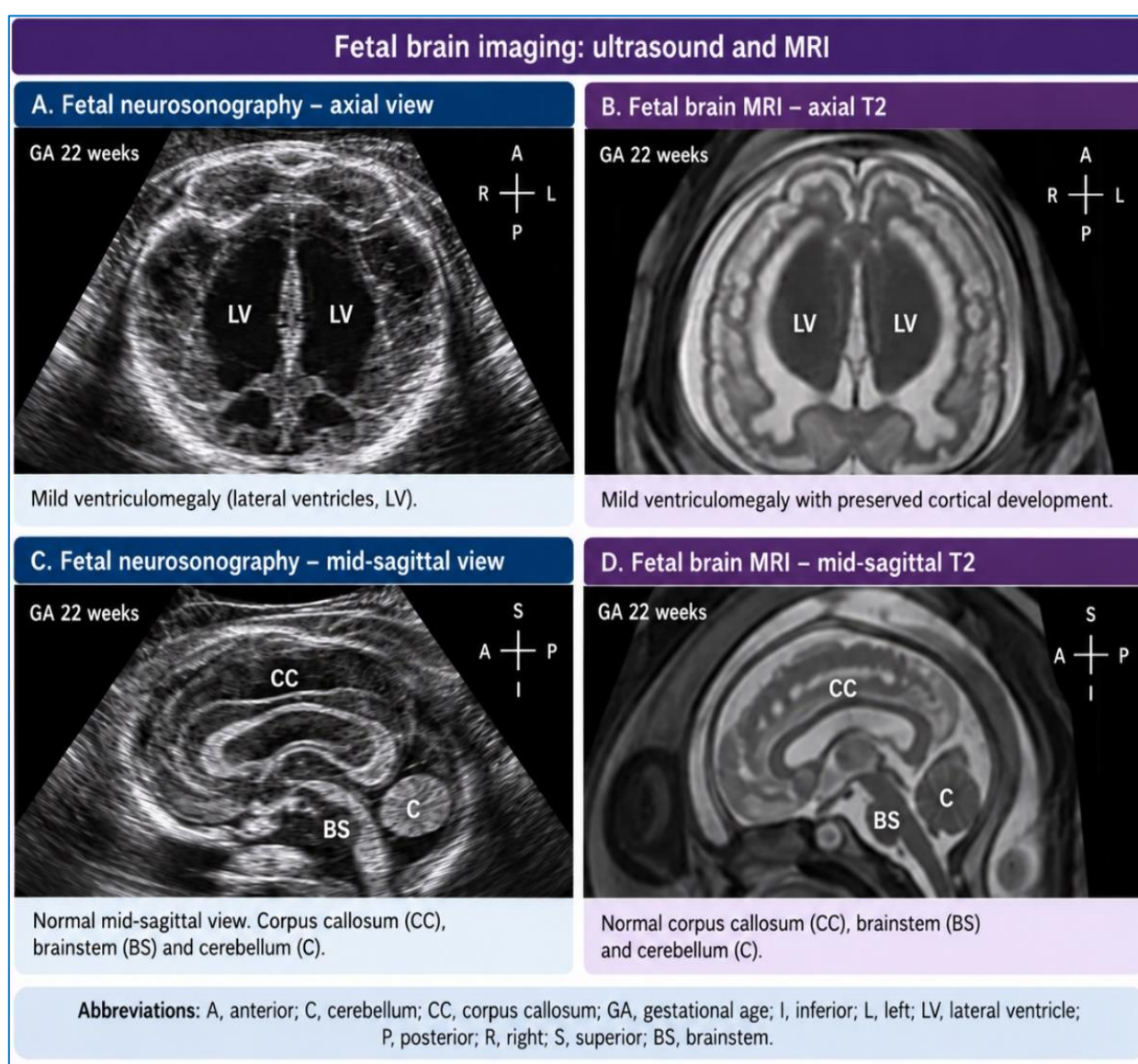


Fig. 7 – Fetal brain imaging: ultrasound and MRI.

Multiplanar MRI is particularly valuable for evaluating the corpus callosum and detecting

associated cerebral anomalies following suspicious neurosonography [21,24,25].

Recent literature increasingly investigates quantitative fetal brain MRI, including volumetry, diffusion imaging and objective maturation

biomarkers. These approaches may eventually improve prognostic counseling, although most are not yet routine clinical standards [24].

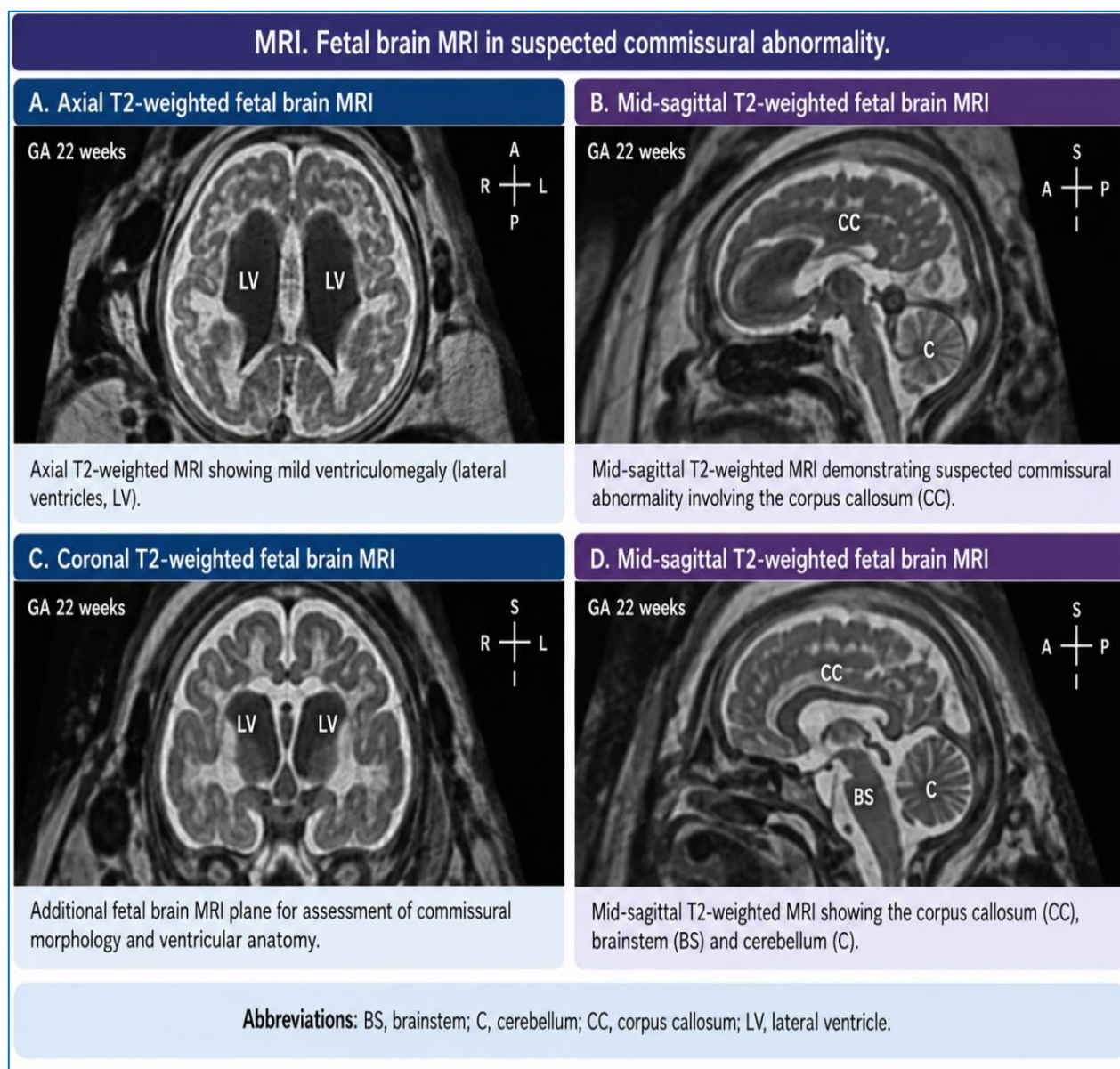


Fig. 8 – Fetal brain MRI in suspected commissural abnormality.

MATERNAL–FETAL INTEGRATION: WHY MULTIMODAL IMAGING MATTERS

The greatest value of multimodal imaging is not obtained by simply performing more examinations. Its value derives from selecting complementary modalities whose strengths address the limitations of one another [1,3,4,15,16,21–24].

A pregnant patient presenting with acute dyspnea, reduced LV function and neurological deficit illustrates this approach [1,3,4,6–11]:

- **Echocardiography** identifies ventricular dysfunction and possible intracardiac thrombus.
- **CMR** may clarify the cardiomyopathic phenotype and quantify biventricular function.
- **Brain MRI** determines the presence, age and distribution of cerebral ischemia.
- **MRA** evaluates the intracranial circulation.
- **Obstetric ultrasound** assesses fetal well-being.

The same principle applies to the fetus. An abnormal screening ultrasound may lead to targeted neurosonography, followed by

fetal MRI for additional anatomical characterization and multidisciplinary counseling [15,16,21–24].

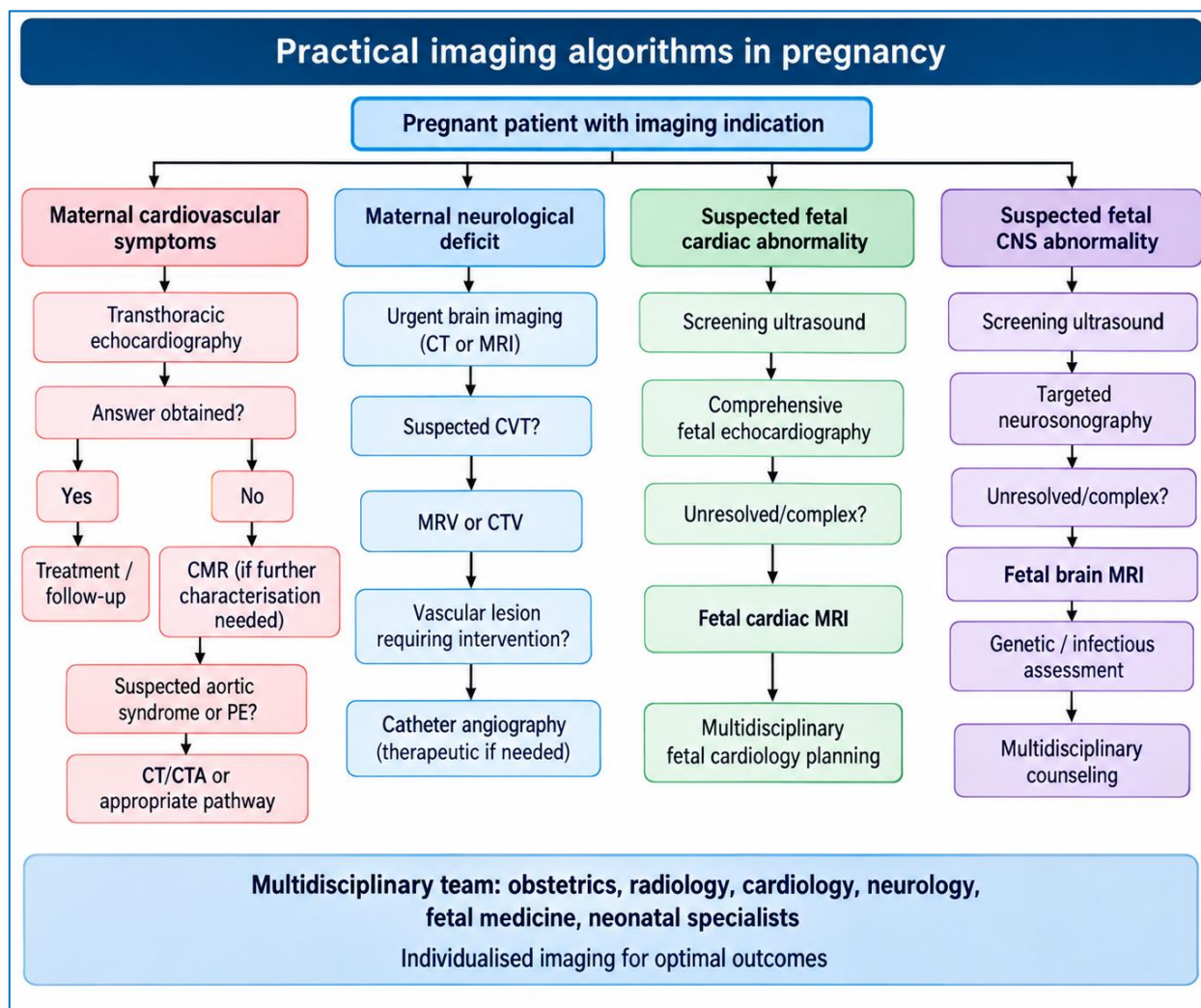


Fig. 9 – Suggested Practical Imaging Algorithms.

Maternal cardiovascular symptoms

Clinical suspicion → transthoracic echocardiography [1,3,4]

- If echocardiography provides an adequate diagnostic answer → treatment and follow-up;
- if the myocardial or ventricular question remains unresolved → CMR;
- if acute aortic syndrome is suspected → urgent cross-sectional angiographic imaging, selected according to clinical stability;
- if pulmonary embolism is suspected → a pregnancy-adapted diagnostic pathway, with thoracic imaging when indicated.

Maternal acute neurological deficit

Neurological emergency → immediate brain imaging [2,8–11]:

- CT/CTA when speed is critical, or
- MRI/MRA when it is rapidly available and appropriate to the diagnostic question.

Venography should be added when cerebral venous thrombosis is suspected. Catheter angiography is reserved for cases in which endovascular treatment is required.

Suspected fetal cardiac abnormality

Screening ultrasound → comprehensive fetal echocardiography → fetal cardiac MRI in selected complex or unresolved cases → multidisciplinary fetal cardiology planning [15–20].

Suspected fetal CNS abnormality

Screening ultrasound → expert targeted neurosonography → fetal brain MRI when further characterization is required → genetic or infectious assessment, where indicated → multidisciplinary counseling [21–24].

EMERGING TECHNOLOGIES

Pregnancy imaging is moving beyond morphology alone. Anatomical assessment is increasingly being combined with quantitative biomarkers and artificial intelligence, although the clinical maturity of these techniques remains variable [17–20,24].

In fetal cardiology, automated identification of standard cardiac planes and AI-assisted screening for congenital heart disease may reduce operator dependence. Their performance in routine practice, however, will require careful validation across different populations, equipment, and levels of operator experience [16].

Technical progress in fetal MRI has been substantial. Motion-corrected reconstruction can now generate high-resolution three-dimensional volumes despite fetal movement, while fetal cardiac MRI is developing toward more reliable cine, flow, and oxygenation measurements. Recent work has focused particularly on advanced gating, 4D-flow imaging, and quantitative assessment of tissue properties and blood flow [17–20].

Quantification may also extend fetal neuroimaging beyond conventional morphological diagnosis. Measurements of brain volume, cortical maturation, and diffusion characteristics could provide complementary information, particularly when developmental abnormalities are subtle or evolve with gestational age [24].

Maternal imaging is following a parallel course, with continued development of accelerated CMR, myocardial strain analysis, parametric mapping, and strategies for radiation-dose optimization [3,4].

SAFETY AND CONTRAST ADMINISTRATION

A clinically useful review should distinguish the biological and safety considerations specific to each modality.

Ultrasound. Ultrasound does not use ionizing radiation. Exposure should nevertheless be optimized in accordance with established acoustic-output principles [2,15,22].

MRI. Clinical MRI does not produce the ionizing-radiation effects associated with CT or radiography. When the anticipated diagnostic benefit is meaningful, it remains an important imaging option during pregnancy [2,5].

Gadolinium. Routine administration should be avoided. Use may be considered in selected circumstances when contrast-enhanced imaging is expected to provide information that would substantially influence maternal or fetal management [2,5].

CT and radiography. For most clinically appropriate diagnostic examinations, estimated fetal exposure is well below the thresholds associated with deterministic injury. A necessary examination should not be withheld solely because the patient is pregnant [2,3].

Iodinated contrast. Administration requires a clear clinical justification, based on whether vascular or tissue enhancement is necessary to answer the diagnostic question [2,5].

DISCUSSION

The traditional view of imaging during pregnancy as principally an exercise in radiation avoidance is too narrow. Contemporary practice is better framed around **risk optimization and diagnostic necessity**, with the potential harm of an examination weighed against the consequences of missed or delayed diagnosis [1–4].

Ultrasound remains central to fetal screening and is the first-line technique for most maternal cardiovascular assessments. It combines a favourable safety profile with real-time anatomical and physiological evaluation. Yet ultrasound does not answer every question. MRI may provide decisive additional information when sonographic visualization is limited, anatomy remains uncertain, or tissue characterization is required. CT retains an essential role in selected maternal emergencies; avoiding it without adequate clinical justification may cause harm by delaying diagnosis and treatment [1–4,15,16,21–23].

Fetal imaging has changed markedly. Expert neurosonography and fetal MRI are now used as complementary methods, each addressing limitations of the other, while fetal cardiac MRI appears to be moving from a largely research-based technique toward selected clinical applications. Recent work in fetal neuroimaging follows the same principle: diagnostic accuracy and prognostic

assessment may improve when ultrasound and MRI findings are integrated rather than treated as competing sources of information [15–25].

The preferred model is therefore a **hierarchical multimodal pathway**. Assessment begins with the least invasive modality likely to provide a reliable answer and proceeds only when clinically relevant uncertainty remains [1-4,15,16,21-24]

CONCLUSIONS

Multimodal imaging now occupies a central place in maternal–fetal medicine. Echocardiography, obstetric ultrasound, and neurosonography remain indispensable first-line examinations. MRI and CMR extend these assessments by providing structural, functional, and tissue-specific information without ionizing radiation. Fetal MRI, in particular, has changed the evaluation of complex CNS abnormalities and is beginning to contribute more substantially to fetal cardiovascular diagnosis. CT and angiographic techniques retain a different but no less important role: when a maternal emergency demands rapid, definitive diagnosis, they may be essential [1,3,4,15–24].

Modality selection should not follow a rigid hierarchy based solely on theoretical safety. Clinical urgency matters. So do diagnostic yield, gestational age, and the likelihood that imaging findings will alter management. Achieving this balance requires close collaboration among cardiology, neurology, radiology, fetal medicine, obstetrics, pediatric cardiology, and fetal neurology [1,2,5].

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