Review Article
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Role of Color Doppler in Intrauterine Growth Restriction: A Comprehensive Review

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Abstract

Background: *Fetal growth restriction (FGR), formerly termed intrauterine growth restriction (IUGR), is an important cause of perinatal morbidity and mortality. Although grey-scale ultrasound identifies abnormal fetal growth through biometric measurements, Doppler ultrasound provides additional information on fetal and placental haemodynamic adaptation.*

Objective: *To review the role of Color Doppler and Doppler velocimetry in the diagnosis, surveillance, and risk stratification of pregnancies complicated by FGR, focusing on the umbilical artery (UA), middle cerebral artery (MCA), cerebroplacental ratio (CPR), uterine arteries, and ductus venosus (DV).*

Methods: *This narrative review synthesises evidence from international guidelines, systematic reviews, meta-analyses, randomised trials, and major observational studies. Emphasis was placed on Doppler pathophysiology, technical principles, abnormal waveform interpretation, early- versus late-onset FGR, and implications for surveillance and delivery timing.*

Results: *UA Doppler is the most established fetal Doppler assessment and reflects placental vascular resistance. Progressive placental dysfunction is associated with increased pulsatility followed by reduced, absent, and reversed end-diastolic flow, indicating increasing perinatal risk. MCA Doppler may demonstrate cerebral redistribution or "brain sparing" during hypoxic stress. CPR integrates placental and cerebral haemodynamics and may improve risk stratification, particularly in late-onset FGR. DV Doppler reflects cardiovascular compromise and is particularly valuable in severe early-onset FGR. However, recommendations for routine MCA, CPR, and DV assessment vary among professional bodies.*

Conclusion: *Doppler assessment is integral to FGR surveillance. UA Doppler remains the cornerstone, while MCA, CPR, uterine artery, and DV Doppler provide complementary information in selected cases. Findings should be interpreted alongside fetal biometry, amniotic fluid, cardiotocography, gestational age, and maternal clinical status.*

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Introduction

How well a fetus grows depends on an interplay between its own genetic growth potential, the mother's health, placental performance, and the surrounding environment. When growth is pathologically curtailed, the fetus may face sustained hypoxia, cardiovascular adaptation, metabolic disturbance, and a higher chance of stillbirth or neonatal illness. "Small for gestational age" (SGA) and "fetal growth restriction" (FGR) are related but not interchangeable terms. A fetus can be SGA simply because it is constitutionally small and otherwise well, whereas FGR implies that the fetus has fallen short of its own growth potential — most often because the placenta is not supplying it adequately. Current international guidance stresses that biometry, growth trend, Doppler findings and the wider clinical picture together — not size alone — are what separate the two. Ultrasound sits at the centre of diagnosing suspected FGR. Measurements such as abdominal

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circumference, head circumference, biparietal diameter, femur length and estimated fetal weight give structural evidence that growth has deviated from expectation. Size alone, however, says little about how compromised the fetus actually is.

This is where Doppler ultrasound comes in — it looks at function rather than just structure, examining flow in the maternal, placental and fetal vessels. Color Doppler makes vessels visible and lets the operator position the spectral sample volume accurately; used together, color mapping and pulsed-wave Doppler give both an anatomical picture and a haemodynamic one.

The International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) treats Doppler assessment of the fetoplacental circulation as a core part of the work-up and has published standardised techniques for examining the uterine arteries, umbilical arteries, middle cerebral artery (MCA) and ductus venosus.[1]

Pathophysiological Basis of Doppler Changes in FGR

Placental insufficiency is the mechanism most often responsible for placenta-mediated FGR.

In a normally progressing pregnancy, trophoblast cells invade the maternal spiral arteries and convert them into a wide, low-resistance vascular bed. When this invasion is incomplete, the resulting maternal vascular malperfusion leaves the uteroplacental circulation with abnormally high resistance.

This sets off a fairly predictable cascade:

Abnormal placentation → raised placental resistance → abnormal uterine/umbilical artery Doppler → redistribution of fetal blood flow → cardiac strain → venous Doppler changes → fetal decompensation

How severe this cascade becomes, and in what order the changes appear, differs between fetuses affected early versus late in pregnancy.

Early-onset FGR

Generally defined as onset before 32 weeks, early-onset FGR is usually the more severe phenotype, often accompanied by hypertensive disease of pregnancy and marked abnormalities on umbilical artery and ductus venosus Doppler. ISUOG describes a recognisable progression of abnormality across the umbilical artery, MCA and ductus venosus in these cases.[3]

Late-onset FGR

Arising at or beyond 32 weeks, late-onset FGR can be harder to spot because the fetus is often not dramatically small. Here, cerebral redistribution and changes in MCA/CPR tend to be more informative than gross umbilical artery abnormality.

Color Doppler and Spectral Doppler: Complementary Roles

Color Doppler paints flow onto the image according to direction and speed, which makes it excellent for finding vessels — but it is essentially a localisation tool rather than a measurement one.

It helps to keep the different modes distinct:

- Color-flow mapping — shows where vessels are and which way blood is moving.
- Power Doppler — more sensitive to slow flow, but gives no directional information.
- Pulsed-wave spectral Doppler — generates the velocity-time waveform from which quantitative indices are derived.
- Continuous-wave Doppler — rarely used in fetal work compared with pulsed-wave technique.

In short, Color Doppler's job is to help the operator find and confirm the vessel; the numbers that actually matter clinically in FGR — PI, RI, S/D ratio — come from the spectral trace.

Umbilical Artery Doppler

Why it matters

Of all the fetal Doppler vessels, the umbilical artery (UA) has by far the strongest evidence base in FGR, acting as an indirect gauge of placental vascular resistance.

ISUOG recommends UA Doppler as part of managing growth-restricted fetuses precisely because it helps separate genuine placental disease from the constitutionally small fetus.[3]

Once a diagnosis of FGR has been made, the Society for Maternal-Fetal Medicine (SMFM) advises repeating UA Doppler at intervals to watch for deterioration.[2]

Doppler indices

The three indices in routine use are:

Pulsatility Index (PI) = (Peak systolic velocity − End diastolic velocity) / Mean velocity

Resistance Index (RI) = (Peak systolic velocity − End diastolic velocity) / Peak systolic velocity

Systolic/Diastolic ratio (S/D) = Peak systolic velocity / End diastolic velocity

PI is the most widely used of the three because it is less sensitive to the absolute velocity recorded and is generally reported against gestational-age-specific charts.

Progressive abnormality

As placental resistance climbs, the UA waveform tends to move through a recognisable sequence:

Normal end-diastolic flow → reduced end-diastolic flow → absent end-diastolic velocity (AEDV) → reversed end-diastolic velocity (REDV)

AEDV and REDV both signal advanced placental vascular disease and a sharply higher risk to the fetus. A systematic review and meta-analysis found the odds of fetal death to be markedly higher in early-onset growth-restricted fetuses once UA or ductus venosus end-diastolic flow became abnormal.[6]

Middle Cerebral Artery Doppler

The middle cerebral artery (MCA) is the vessel of choice for assessing how the fetal brain is adapting haemodynamically.

Under chronic hypoxic stress, the fetal cardiovascular system can redirect output preferentially toward the brain — the well-known "brain-sparing" response.

Color Doppler is used first to identify the circle of Willis and the proximal MCA; pulsed-wave Doppler is then applied following a standardised technique. ISUOG recommends obtaining a suitable axial view of the fetal brain, locating the proximal MCA, and placing the sample volume in the proximal third of the vessel.[3]

Cerebral vasodilatation shows up as:

- falling MCA vascular resistance;
- a lower MCA PI;
- increased diastolic flow;
- a reduced cerebroplacental ratio.

An abnormal MCA trace can therefore be read as a sign that the fetus is actively adapting to hypoxaemia — but it should always be interpreted against gestational age and the broader clinical context, not on its own.

Cerebroplacental Ratio

The cerebroplacental ratio (CPR) merges the MCA and UA Doppler measurements into one figure:

CPR = MCA PI / UA PI

A low CPR can reflect raised placental resistance, reduced cerebral resistance, or both together — giving a combined snapshot of placental and cerebral status.

A number of studies link an abnormal CPR to poorer perinatal outcomes; one meta-analysis found it associated with higher rates of caesarean delivery for fetal distress, lower Apgar scores, NICU admission and neonatal complications.[4]

The evidence is not entirely consistent, however. An individual-participant-data meta-analysis concluded that CPR added little beyond what UA PI alone already predicted for a composite adverse perinatal outcome.[5]

Taken together, CPR is probably best used as a complementary risk-stratification tool rather than a stand-alone trigger for intervention.

Ductus Venosus Doppler

The ductus venosus (DV) links the umbilical vein to the inferior vena cava and is central to fetal circulatory physiology.

In severe early-onset FGR, worsening placental insufficiency can raise cardiac afterload to the point where cardiac function itself starts to suffer — a change that can be picked up on the DV waveform.

Key abnormal features include:

- raised DV PI;
- reduced forward flow during atrial contraction;
- an absent A-wave;
- a reversed A-wave.

These findings carry particular weight in severe early-onset disease.

The TRUFFLE trial, which compared different fetal-monitoring strategies in very preterm FGR, demonstrated the clinical value of combining ductus venosus Doppler with computerised cardiotocography when deciding on delivery timing.[7]

A separate systematic review confirmed a substantially raised risk of fetal death in early FGR once DV end-diastolic velocity became absent or reversed.[6]

Uterine Artery Doppler

Uterine artery Doppler looks mainly at the maternal side of the uteroplacental circulation. Abnormal patterns include:

- raised uterine artery PI;
- a persistent early diastolic notch;
- generally increased resistance.

An abnormal trace here points toward impaired placentation and a higher risk of both pre-eclampsia and FGR.

Its main value lies in risk assessment and evaluating placental function early on — it is not meant to substitute for UA Doppler once FGR has actually been diagnosed.

Doppler Patterns in Early- and Late-Onset FGR

The differences below underline why one fixed Doppler strategy cannot be applied uniformly to every FGR pregnancy.

Feature	Early-onset FGR	Late-onset FGR
Gestational age	< 32 weeks	≥ 32 weeks
Placental dysfunction	Usually severe	Often milder
UA Doppler	Frequently abnormal	May stay normal
MCA Doppler	Can become abnormal	Cerebral redistribution often prominent

CPR	May be abnormal	Potentially informative
DV Doppler	Important in severe cases	Usually less prominent
Maternal hypertension	Common	Less frequent
Perinatal risk	High	Raised, but generally lower than early-onset disease

Differentiating SGA from FGR with Doppler

Doppler's biggest practical contribution may be helping tell a constitutionally small fetus apart from one genuinely compromised by placental disease.

Constitutionally small fetus

Typically shows an estimated fetal weight below the 10th percentile but with a normal growth trajectory, normal UA Doppler, normal MCA/CPR, normal liquor volume, and no maternal or placental disease.

Pathological FGR

Typically shows a falling growth velocity, estimated weight or abdominal circumference below expectation, abnormal UA Doppler, abnormal MCA/CPR, abnormal uterine artery Doppler, oligohydramnios, maternal hypertensive disease, and other evidence of placental dysfunction.

Doppler, in other words, adds a functional layer on top of the purely structural information from biometry.

Doppler Surveillance and Timing of Delivery

The point of Doppler surveillance is not simply to confirm that the placenta is failing, but to catch deterioration early enough to choose the best moment for delivery.

SMFM guidance recommends serial UA Doppler once FGR has been diagnosed, with surveillance stepped up when diastolic flow falls, when the fetus is severely small, and especially once AEDV or REDV appears.[2]

Broadly, SMFM suggests:

- UA Doppler roughly every one to two weeks in established FGR;
- more frequent testing once UA flow becomes abnormal;
- two to three times weekly once AEDV develops;
- intensified surveillance, with delivery actively considered, once REDV appears.

Suggested delivery timing:

- 38–39 weeks for FGR with normal UA Doppler and an estimated weight between the 3rd and 10th percentile;
- 37 weeks for severe FGR, or reduced UA diastolic flow without AEDV/REDV;
- 33–34 weeks once AEDV is present;
- 30–32 weeks once REDV is present, depending on the overall clinical picture.

These figures are guideline defaults and need to be adjusted for gestational age, other fetal testing, maternal disease, neonatal facilities, and local protocol.

Comparing Major Guidelines

International bodies do not entirely agree on how much weight to give each Doppler vessel.

SMFM leans heavily on umbilical artery Doppler and does not recommend routine use of MCA, DV, or uterine artery Doppler for everyday clinical decisions in FGR.[2]

ISUOG takes a broader view, folding in MCA, CPR and DV Doppler where clinically appropriate — particularly useful for telling early- and late-onset FGR apart and gauging fetal adaptation.[1r]

The practical takeaway is that clinicians should work to a clearly agreed local protocol, recognising that international guidance is not fully harmonised on this point.

Technical Considerations in Doppler Examination

Getting reliable Doppler measurements depends on careful technique:

- Correct vessel identification using Color Doppler.
- An appropriate insonation angle and sampling approach.
- Correct placement of the sample volume.
- Suitable pulse-repetition frequency and velocity scale.
- Appropriate wall-filter setting.
- Avoiding excessive transducer pressure on the vessel.
- Capturing several consistent, consecutive waveforms.
- Using gestational-age-appropriate reference ranges.
- Keeping technique consistent across serial scans on the same patient.

ISUOG stresses standardised acquisition and interpretation because small differences in method can meaningfully shift the measured values.[3]

A systematic review of published reference ranges found considerable variation across standards for UA PI, MCA PI and CPR — a reminder of how much methodological standardisation is still needed.[9]

Advantages of Color Doppler in FGR

- Non-invasive — No ionising radiation, no instrumentation of the fetus.
- Real-time vascular visualisation — Fetal and placental vessels can be identified as the scan proceeds.
- Functional assessment — Adds information about vascular resistance and circulatory adaptation that biometry alone cannot give.
- Serial monitoring — Can be repeated through pregnancy to track how the picture is evolving.
- Risk stratification — Abnormal findings flag fetuses who need closer attention.
- Guides management — UA Doppler findings in particular shape how often to monitor and when to consider delivery.

Limitations

- Operator dependence — Poor vessel identification or incorrect sampling produces unreliable readings.
- Reference-range variation — Different charts and cut-offs can classify the same measurement differently.
- Gestational-age dependence — Normal values shift continually through pregnancy.
- Biological variability — Fetal movement, breathing, heart rate, maternal position and transient physiological changes can all move the numbers.

- Uneven evidence base — UA Doppler is well supported, but the added clinical value of MCA and CPR remains debated.
- Not a substitute for full assessment — Doppler cannot replace biometry, liquor assessment, fetal movement monitoring, cardiotocography or overall clinical judgement.

Evidence for the Cerebroplacental Ratio

CPR has drawn a lot of attention, particularly for late-onset FGR.

One systematic review and meta-analysis linked an abnormal CPR to several adverse perinatal outcomes.[4]

A later individual-participant-data meta-analysis, however, found that adding CPR on top of UA PI improved prediction of a composite adverse outcome only marginally.[5]

This gap is worth noting: an association between a test result and a poor outcome does not automatically mean that acting on that test result changes the outcome.

CPR therefore looks useful for risk stratification, but more prospective evidence is needed before it can be relied on to replace, or routinely supplement, UA Doppler in management protocols.

Recent Evidence on MCA Doppler

Evidence on MCA Doppler used in isolation is also still developing. A recent systematic review and meta-analysis found only moderate accuracy for MCA PI in predicting adverse outcomes among growth-restricted fetuses, with pooled sensitivity and specificity too modest to support its use as a stand-alone predictor.[14]

This supports the broader principle that MCA findings should be weighed within the overall clinical picture rather than acted on in isolation.

A Practical Clinical Algorithm

Suspected FGR

↓ Ultrasound biometry + EFW/AC + liquor assessment

↓ Assess gestational age and growth trajectory

↓ Color Doppler localisation

↓ Umbilical artery Doppler

- Normal UA Doppler → continue routine surveillance based on gestational age and risk; consider MCA/CPR where clinically useful.
- Raised UA PI / reduced diastolic flow → step up surveillance; repeat Doppler and fetal assessment.
- AEDV → intensive surveillance; reassess gestational age and fetal condition; consider hospital admission depending on circumstances.
- REDV → very high-risk finding; intensive surveillance; corticosteroids where appropriate; consider delivery based on gestational age and full fetal/maternal assessment.

For severe early-onset FGR, specialist fetal-medicine teams often combine UA Doppler, MCA/CPR, DV Doppler, CTG/short-term variation, and biophysical profile assessment into a single management plan.

Future Directions

Areas that would benefit from further work include: internationally standardised Doppler reference ranges; automated waveform analysis; AI-assisted detection of abnormal patterns; better

integration of Doppler with growth trajectory; combining Doppler with placental biomarkers; improved prediction of stillbirth and neonatal morbidity; long-term neurodevelopmental follow-up; individualised delivery timing; and prospective randomised trials testing whether Doppler-guided management genuinely improves neonatal outcomes.

Automated, AI-assisted quantitative ultrasound may, in time, reduce operator dependence and improve reproducibility across centres.

20. Conclusion

Color Doppler occupies an important place in evaluating pregnancies with suspected IUGR/FGR. Its strongest, best-proven use remains umbilical artery assessment, which indirectly gauges placental vascular resistance and helps identify fetuses at elevated risk of adverse perinatal outcome.

MCA Doppler adds information about cerebral adaptation, and the CPR brings placental and cerebral data together in one index. Ductus venosus Doppler offers further insight into cardiovascular strain, particularly in severe early-onset disease, while uterine artery Doppler speaks to the maternal side of the circulation and to impaired placentation.

None of these findings should be read alone. Sound management depends on combining fetal biometry, growth trend, UA Doppler, MCA/CPR where relevant, DV Doppler in selected severe cases, liquor volume, cardiotocography, maternal status and gestational age.

The evidence base is strongest for UA Doppler as the backbone of surveillance in confirmed FGR; the roles of MCA, CPR and DV vary with the FGR phenotype and the guideline being followed. Future work should aim to standardise thresholds and clarify whether Doppler-guided management truly improves not just short-term perinatal outcomes but long-term neurodevelopment as well.

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14. Recent evidence on MCA Doppler suggests moderate predictive accuracy when used alone in growth-restricted pregnancies, underscoring the need for standardised prospective studies before isolated MCA Doppler is used as a management trigger.

15. Recent diagnostic research continues to evaluate CPR as a predictor of adverse outcomes in IUGR pregnancies, supporting its potential as an adjunct to conventional Doppler assessment while highlighting the need for further validation.