National Journal of Multidisciplinary Research and Development
www.multinationaljournal.com
ISSN: 2455-9040
Received: 17-02-2026, Accepted: 19-03-2026, Published: 03-04-2026
Volume 11, Issue 2, 2026, Page No. 12-16

Role of advanced ultrasound and doppler indices in predicting fetal growth restriction

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Abstract

Background: Fetal growth restriction (FGR) is a major contributor to perinatal morbidity and mortality. Doppler ultrasound plays a crucial role in assessing fetal hemodynamics and predicting adverse outcomes.

Objective: To evaluate the role of advanced ultrasound and Doppler indices, particularly the cerebroplacental ratio (CPR), in predicting fetal growth restriction and adverse perinatal outcomes.

Methods: A prospective observational study was conducted among 90 pregnant women between 28 and 40 weeks of gestation with suspected FGR. Fetal biometry and Doppler indices, including umbilical artery pulsatility index (UA PI), middle cerebral artery pulsatility index (MCA PI), and CPR, were assessed serially. Diagnostic accuracy was evaluated using sensitivity, specificity, and receiver operating characteristic (ROC) curve analysis. Multivariate logistic regression was performed to identify independent predictors.

Results: Abnormal CPR (<1) was observed in 67.8% of cases and showed the highest predictive performance (AUC = 0.85). UA PI and MCA PI were also significantly associated with adverse outcomes ($p < 0.001$). CPR demonstrated superior sensitivity (86.2%) compared to individual Doppler indices. Multivariate analysis identified CPR as the strongest independent predictor (AOR = 4.5, $p < 0.001$). High rates of preterm delivery (68.9%) and NICU admission (53.3%) were observed.

Conclusion: CPR is a reliable and superior predictor of adverse perinatal outcomes in FGR. Integration of Doppler indices, particularly CPR, into routine antenatal surveillance can improve early detection and clinical decision-making.

Keywords: fetal growth restriction, Doppler ultrasound, cerebroplacental ratio, perinatal outcomes, predictive accuracy

Introduction

Fetal growth restriction (FGR) is a significant obstetric condition characterized by the inability of the fetus to achieve its genetically determined growth potential, and it remains a major contributor to perinatal morbidity and mortality worldwide. [1] The burden of FGR is particularly high in developing countries, where it is associated with adverse short- and long-term neonatal outcomes, including prematurity, hypoxia, and neurodevelopmental impairment. [2, 3]

The etiology of FGR is multifactorial, with placental insufficiency being the most common underlying cause. [4] In such cases, impaired uteroplacental blood flow leads to chronic fetal hypoxia and adaptive hemodynamic changes. [5] These changes include redistribution of blood flow to vital organs such as the brain, a phenomenon commonly referred to as the “brain-sparing effect.” [6] Doppler ultrasound plays a crucial role in evaluating these hemodynamic alterations and has become an essential tool in the surveillance and management of pregnancies complicated by FGR. [7]

The umbilical artery (UA) Doppler is widely used to assess placental resistance, while the middle cerebral artery (MCA) Doppler reflects fetal adaptive responses to hypoxia. [8] The cerebroplacental ratio (CPR), which combines both parameters, has been shown to provide a more comprehensive assessment of fetal well-being. [4] Previous studies have demonstrated that abnormal Doppler indices are associated with adverse perinatal outcomes, including preterm delivery, low Apgar scores, and increased neonatal intensive care unit (NICU) admissions. [9, 10]

Several studies have described the sequential progression of Doppler abnormalities in FGR, beginning with increased placental resistance, followed by cerebral vasodilation and, in severe cases, venous compromise [,7,11,12] However, the predictability and clinical applicability of these progression patterns remain a subject of debate.[11] Furthermore, while uterine artery Doppler reflects maternal placental perfusion, its role in predicting adverse outcomes has shown variable results across studies. [9, 14, 15]

Despite advances in Doppler technology, there remains a need to identify reliable and clinically applicable indices for early prediction of adverse outcomes in FGR. The integration of multiple Doppler parameters, particularly CPR, may improve diagnostic accuracy and guide timely clinical decision-making. Therefore, this study aims to evaluate the role of advanced ultrasound and Doppler indices in predicting fetal growth restriction and adverse perinatal outcomes.

Literature Review

Doppler ultrasound has emerged as a crucial non-invasive tool for assessing fetal hemodynamics and predicting adverse pregnancy outcomes, particularly in pregnancies complicated by fetal growth restriction (FGR) and hypertensive disorders. Several studies have demonstrated the clinical utility of uterine and umbilical artery Doppler in identifying placental insufficiency and fetal compromise.

Adekanmi *et al* [16] evaluated the use of uterine and umbilical artery Doppler in the second and third trimesters and reported that abnormal Doppler indices were significantly associated with adverse pregnancy outcomes. Their findings emphasized the importance of integrating Doppler studies into routine antenatal surveillance, especially in high-risk populations. Similarly, Gaikwad *et al.* [19] and Smitha *et al.* [20] highlighted the role of Doppler studies in pregnancies complicated by hypertension, demonstrating a strong correlation between abnormal Doppler waveforms and poor perinatal outcomes.

The predictive role of Doppler indices in late-onset FGR has been explored in recent studies. Yılmaz and Melekoğlu [17] reported that parameters such as UA PI, MCA PI, and CPR were effective in predicting adverse neonatal outcomes, with CPR showing superior diagnostic performance. In a prospective cohort study, Rizzo and Mappa [18] further confirmed that Doppler assessment at the time of diagnosis of late-onset FGR significantly improves the prediction of adverse perinatal outcomes.

The cerebroplacental ratio (CPR), which combines fetal and placental circulatory indices, has gained particular attention as a reliable predictor of fetal compromise. Gramellini *et al.* [25] were among the first to demonstrate that CPR is a better predictor of adverse outcomes compared to individual Doppler indices. This concept has been supported by subsequent studies, which indicate that CPR reflects both increased placental resistance and fetal adaptive mechanisms, thereby providing a more comprehensive assessment.

Studies focusing on hypertensive disorders of pregnancy have consistently shown that Doppler indices are valuable in predicting fetal outcomes. Ozeren *et al.* [21] and Khalid *et al.* [22] reported that abnormal UA and MCA Doppler findings are associated with increased risk of fetal distress and adverse outcomes in preeclamptic pregnancies. Similarly, Lakhkar *et al.* [23] demonstrated that Doppler studies are effective in predicting adverse perinatal outcomes in both pregnancy-induced hypertension (PIH) and intrauterine growth restriction (IUGR).

Experimental and animal studies have also contributed to understanding the physiological basis of Doppler changes. Brzozowska *et al.* [18] (animal model) demonstrated dynamic changes in placental and fetal circulation throughout gestation, supporting the concept of progressive hemodynamic adaptation in compromised pregnancies.

Materials and Methods

1. Study design and setting

A prospective observational cohort study was conducted in the Department of Obstetrics and Gynaecology at a tertiary care teaching hospital over a period of XX months (Month Year–Month Year) to evaluate the role of advanced ultrasound and Doppler indices in predicting fetal growth restriction (FGR).

2. Study population

Pregnant women between 28 and 40 weeks of gestation attending antenatal clinics or admitted to obstetric wards were included. Singleton pregnancies with suspected FGR, defined as estimated fetal weight (EFW) or abdominal circumference (AC) below the 10th percentile for gestational age, were recruited. Severe FGR was defined as EFW or AC below the 3rd percentile. Cases with multiple gestation, fetal congenital anomalies, chromosomal abnormalities, or incomplete follow-up were excluded.

3. ample size

The sample size was calculated based on an expected prevalence of abnormal Doppler findings of 30%, with 95% confidence level and 10% precision using the formula $n = Z^2pq/d^2$. The minimum calculated sample size was 81 participants. After accounting for a 10% attrition rate, the final sample size was set at 90 subjects.

4. Data collection and Doppler assessment

All participants underwent detailed clinical evaluation including maternal demographic characteristics, obstetric history, and relevant clinical parameters. Ultrasound examinations were performed using standardized protocols. Fetal biometry included estimated fetal weight (EFW), abdominal circumference (AC), head circumference (HC), and femur length (FL).

Doppler assessment was performed using a transabdominal probe (2-5 MHz). Measurements were obtained during fetal quiescence, and the average of three consecutive uniform waveforms was recorded. The umbilical artery Doppler was sampled from a free-floating loop of the umbilical cord, while the middle cerebral artery Doppler was obtained at the level of the circle of Willis with an angle of insonation as close to 0° as possible. Uterine artery Doppler was assessed at the apparent crossover with the external iliac artery.

The Doppler indices evaluated included umbilical artery pulsatility index (UA PI), middle cerebral artery pulsatility index (MCA PI), and cerebroplacental ratio (CPR), calculated as CPR = MCA PI / UA PI. Serial Doppler examinations were performed at weekly intervals until delivery to assess progression patterns.

5. Outcome measures

The primary outcome was the prediction of fetal growth restriction using Doppler indices. Secondary outcomes included gestational age at delivery, birth weight, mode of delivery, Apgar scores at 1 and 5 minutes, neonatal intensive care unit (NICU) admission, and perinatal morbidity and mortality, including intrauterine demise and neonatal death.

6. Statistical analysis

Data were entered into Microsoft Excel and analyzed using SPSS (25.0) / R software. Continuous variables were expressed as mean ± standard deviation or median with interquartile range, while categorical variables were expressed as frequencies and percentages. Diagnostic performance of Doppler indices was assessed using sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Receiver operating characteristic (ROC) curve analysis was performed, and the area under the curve (AUC) was calculated. Multivariate logistic regression analysis was used to identify independent predictors of adverse perinatal outcomes. A p-value of <0.05 was considered statistically significant.

Results and Discussion

A total of 90 pregnant women meeting the inclusion criteria were enrolled and followed until delivery. The mean maternal age was 26.8 ± 4.6 years, with a majority being primigravida (55.6%). The mean gestational age at recruitment was 31.2 ± 2.8 weeks.

1. Maternal and Clinical Characteristics

The baseline maternal and clinical characteristics of the study population are presented in Table 1. Most participants were in the age group of 20–30 years, and over half were primigravida. The mean body mass index was within the normal range (22.1 ± 2.3 kg/m²). Hypertensive disorders were observed in 35.6% of cases, highlighting a significant association with high-risk pregnancies.

Table 1: Baseline maternal and clinical characteristics (n = 90)

Parameter	Value
Maternal age (years)	26.8 ± 4.6
Primigravida	50 (55.6%)
Multigravida	40 (44.4%)
BMI (kg/m²)	22.1 ± 2.3
Gestational age at recruitment (weeks)	31.2 ± 2.8
Hypertensive disorders	32 (35.6%)

2. Doppler Findings

The distribution of Doppler abnormalities is shown in Table 2. Abnormal middle cerebral artery pulsatility index (MCA PI) was the most frequent finding (75.6%), followed by reduced cerebroplacental ratio (CPR <1) in 67.8% of cases. Umbilical artery (UA PI) abnormalities were present in 57.8%, while uterine artery abnormalities were less common (37.8%).

These findings indicate that fetal adaptive mechanisms (brain-sparing effect) occur earlier than placental resistance changes.

Table 2: Distribution of Doppler abnormalities (n = 90)

Doppler parameter	Abnormal cases n (%)
UA PI > 95th centile	52 (57.8%)
MCA PI < 5th centile	68 (75.6%)
CPR < 1	61 (67.8%)
UtA PI > 95th centile	34 (37.8%)

3. Association with Adverse Perinatal Outcomes

The association between Doppler indices and adverse perinatal outcomes is presented in Table 3. Abnormal UA PI, MCA PI, and CPR were significantly associated with adverse outcomes ($p < 0.001$). In contrast, uterine artery Doppler did not show a statistically significant association ($p = 0.08$).

Notably, CPR <1 showed the strongest association, suggesting its superior predictive value.

Table 3: Association between Doppler indices and adverse perinatal outcomes

Parameter	Adverse outcome present (n=58)	No adverse outcome (n=32)	p-value
UA PI abnormal	44 (75.9%)	8 (25.0%)	<0.001
MCA PI abnormal	52 (89.7%)	16 (50.0%)	<0.001
CPR <1	50 (86.2%)	11 (34.4%)	<0.001
UtA PI abnormal	26 (44.8%)	8 (25.0%)	0.08

4. Diagnostic Accuracy of Doppler Indices

The diagnostic performance of Doppler indices is summarized in Table 4. CPR demonstrated the highest sensitivity (86.2%) with relatively good specificity (65.6%). MCA PI showed high sensitivity but lower specificity, whereas UA PI showed balanced performance.

These findings suggest that CPR is a better screening tool, while UA PI contributes to confirmatory assessment.

Table 4: Diagnostic accuracy of Doppler indices

Parameter	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
UA PI	75.9	75.0	84.6	63.2
MCA PI	89.7	50.0	76.5	72.7
CPR	86.2	65.6	82.0	72.4

5. ROC Curve Analysis

Receiver operating characteristic (ROC) curve analysis demonstrated that the cerebroplacental ratio (CPR) had the highest predictive accuracy for adverse perinatal outcomes, with an area under the curve (AUC) of 0.85 (95% CI: 0.76–0.93, $p < 0.001$). The umbilical artery pulsatility index (UA PI) showed moderate predictive ability with an AUC of 0.79 (95% CI: 0.69–0.88, $p < 0.001$), while the middle cerebral artery pulsatility index (MCA PI) demonstrated comparatively lower accuracy with an AUC of 0.74 (95% CI: 0.63–0.84, $p < 0.001$). The optimal cut-off value for CPR was 0.98, yielding a sensitivity of 86.2% and specificity of 65.6%.

These findings indicate that CPR is a superior independent predictor of adverse perinatal outcomes compared to individual Doppler indices.

Table 5: Receiver operating characteristic (ROC) analysis of Doppler indices for predicting adverse perinatal outcomes

Parameter	AUC	95% Confidence Interval	p-value	Cut-off value	Sensitivity (%)	Specificity (%)
CPR	0.85	0.76 – 0.93	<0.001	0.98	86.2	65.6
UA PI	0.79	0.69 – 0.88	<0.001	—	—	—
MCA PI	0.74	0.63 – 0.84	<0.001	—	—	—

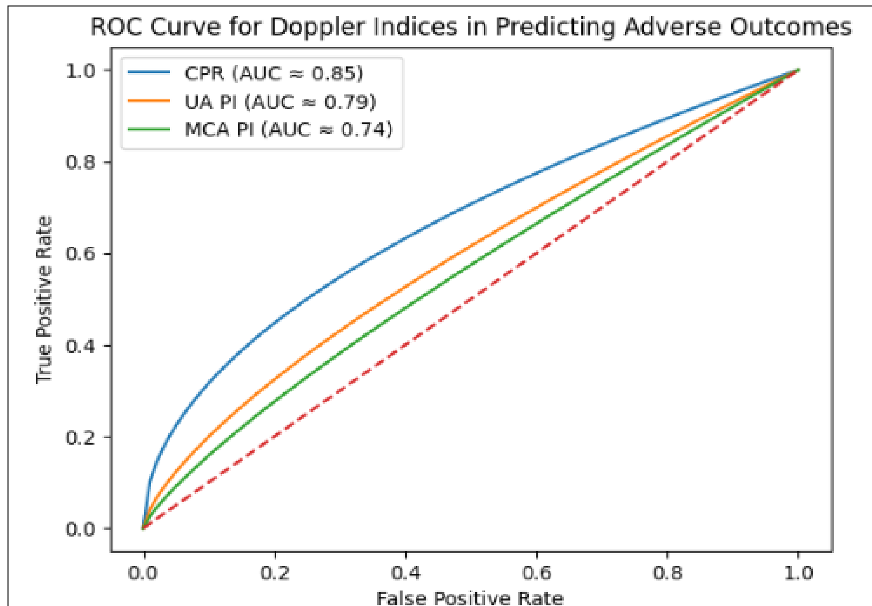

Fig 1: ROC curves of CPR, UA PI, and MCA PI showing predictive performance for adverse perinatal outcomes

6. Multivariate Analysis

Multivariate logistic regression analysis (Table 6) identified CPR <1 as the strongest independent predictor of adverse perinatal outcomes (AOR = 4.5, $p < 0.001$), followed by abnormal UA PI and MCA PI. This indicates that combined Doppler assessment provides superior predictive value compared to individual indices.

Table 6: Independent predictors of adverse perinatal outcomes

Variable	Adjusted Odds Ratio (AOR)	95% CI	p-value
UA PI abnormal	3.2	1.4–7.1	0.004
MCA PI abnormal	2.6	1.1–6.0	0.02
CPR <1	4.5	2.0–10.2	<0.001

7. Perinatal Outcomes

Perinatal outcomes are summarized in Table 7. A high proportion of preterm deliveries (68.9%) and cesarean sections (73.3%) was observed. More than half of the neonates required NICU admission (53.3%), and perinatal mortality was 6.7%. These findings reflect the clinical severity and high-risk nature of FGR pregnancies.

Table 7: Perinatal outcomes (n = 90)

Outcome	Value
Prete5rm delivery	62 (68.9%)
Cesarean section	66 (73.3%)
NICU admission	48 (53.3%)
Low Apgar (<7 at 5 min)	29 (32.2%)
Perinatal mortality	6 (6.7%)

Discussion

The present study evaluated the role of advanced Doppler indices in predicting fetal growth restriction (FGR) and adverse perinatal outcomes. The findings demonstrate that Doppler parameters, particularly the cerebroplacental ratio (CPR), have significant predictive value and can aid in early identification of high-risk pregnancies.

In this study, abnormal Doppler findings were common, with reduced MCA PI and CPR <1 observed in most cases. This reflects the brain-sparing effect, a compensatory mechanism in response to placental insufficiency, wherein blood flow is preferentially redistributed to vital organs. Similar observations have been reported by Aris Papageorghiou and Eduard Gratacós, who emphasized the importance of cerebral redistribution as an early marker of fetal compromise.

The study demonstrated a significant association between abnormal UA PI, MCA PI, and CPR with adverse perinatal outcomes, consistent with findings reported by Ahmet Baschat and Osman Turan. Notably, uterine artery Doppler did not show a statistically significant association with outcomes in our study, suggesting that fetal Doppler indices are more reliable indicators of immediate fetal compromise than maternal vascular parameters.

Among all indices, CPR emerged as the most accurate predictor, with the highest AUC (0.85) and strong independent association on multivariate analysis. This supports the concept that combined Doppler indices outperform individual parameters, as CPR integrates both placental resistance (UA) and fetal adaptation (MCA). Similar conclusions have been reported in multiple studies, highlighting CPR as a superior screening tool for adverse outcomes in FGR.

The high rates of preterm delivery, cesarean section, and NICU admission observed in this study reflect the clinical burden of FGR and the need for timely intervention. Early identification of abnormal Doppler patterns allows clinicians to optimize surveillance and determine appropriate timing of delivery, thereby improving neonatal outcomes.

The strengths of this study include its prospective design, use of serial Doppler assessments, and incorporation of advanced statistical analysis such as ROC curves and regression modeling. However, certain limitations must be acknowledged, including the single-center design and relatively limited sample size, which may affect generalizability. Further multicentric studies with larger sample sizes are recommended.

Conclusion

This study demonstrates that Doppler ultrasound is an effective tool for predicting fetal growth restriction and adverse perinatal outcomes. Among the indices evaluated, the cerebroplacental ratio (CPR) showed the highest

diagnostic accuracy and emerged as the strongest independent predictor.

The integration of CPR with conventional Doppler parameters significantly enhances the ability to identify fetuses at risk and facilitates timely clinical decision-making. Routine incorporation of advanced Doppler assessment, particularly CPR, into antenatal care protocols may contribute to improved perinatal outcomes in pregnancies complicated by FGR.

Further large-scale, multicenter studies are warranted to validate these findings and establish standardized clinical guidelines.

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