

Research Article

Correlation of Abnormal Doppler Indices with Perinatal Outcome in High-Risk Pregnancy Patients

Dr. Purabi Das¹, Dr. Samudra Borah², Dr. Pradhumn³

¹Assistant Professor, Department of Obstetrics and Gynaecology, Tezpur Medical College and Hospital. Tumuki, Bihaguri, Sonitpur District, Assam, 784010, India.

²Associate Professor, Department of Radiodiagnosis, Tezpur Medical College and Hospital. Tumuki, Bihaguri, Sonitpur District, Assam, 784010, India.

³3rd year Postgraduate, Department of Radiodiagnosis, Tezpur Medical College and Hospital. Tumuki, Bihaguri, Sonitpur District, Assam, 784010, India.

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Corresponding Author: Dr. Samudra Borah, Associate Professor, Department of Radiodiagnosis, Tezpur Medical College and Hospital. Tumuki, Bihaguri, Sonitpur District, Assam, 784010, India.

Email: samudra111@gmail.com

ABSTRACT

Background: High-risk pregnancies are associated with increased maternal and perinatal morbidity and mortality due to complications such as hypertensive disorders, intrauterine growth restriction, gestational diabetes mellitus, oligohydramnios, and placental insufficiency. Doppler ultrasonography is a non-invasive imaging modality used to assess uteroplacental and fetoplacental circulation and helps in early detection of fetal compromise. **Aim:** To correlate abnormal Doppler indices with perinatal outcomes in high-risk pregnancy patients. **Objectives:** To evaluate Doppler indices of uterine artery, umbilical artery, and middle cerebral artery in high-risk pregnancies. To determine the association between abnormal Doppler findings and adverse perinatal outcomes. To assess the predictive value of Doppler ultrasonography in identifying fetal compromise in high-risk pregnancies. **Materials and Methods:** The present hospital-based cross-sectional observational

study was conducted on 100 high-risk pregnant women attending a tertiary care teaching hospital over a period of one year. Doppler ultrasonography was performed to evaluate uterine artery PI and RI, umbilical artery PI, RI, S/D ratio, middle cerebral artery PI, and cerebroplacental ratio (CPR). Perinatal outcomes including low birth weight, preterm delivery, fetal distress, NICU admission, low Apgar score, and mode of delivery were recorded. Statistical analysis was performed using SPSS software version 26.0. Chi-square test and Student's t-test were applied, and $p < 0.05$ was considered statistically significant. **Results:** Abnormal UA RI was associated with adverse perinatal outcome in 81.0% cases ($OR = 11.64$, $p < 0.001$), while abnormal UA PI showed adverse outcome in 79.0% cases ($OR = 10.55$, $p < 0.001$). Abnormal CPR demonstrated the strongest association with adverse outcome in 81.7% pregnancies ($OR = 11.14$, $p < 0.001$). Abnormal MCA PI was associated with adverse outcome in 69.6% cases ($p = 0.015$). CPR showed the highest diagnostic

performance with sensitivity 83.1%, specificity 73.2%, PPV 81.7%, NPV 75.0%, and overall accuracy 79.0%. **Conclusion:** Abnormal Doppler indices, particularly abnormal CPR and umbilical artery indices, are significantly associated with adverse perinatal outcomes in high-risk pregnancies. Doppler ultrasonography is a valuable and reliable tool for early identification of fetal compromise and helps in improving fetal surveillance and perinatal management.

KEYWORDS: Doppler Ultrasonography. High-Risk Pregnancy. Cerebroplacental Ratio.

INTRODUCTION

High-risk pregnancies are associated with increased maternal and perinatal morbidity and mortality due to complications such as pregnancy-induced hypertension, preeclampsia, intrauterine growth restriction (IUGR), gestational diabetes mellitus, oligohydramnios, anemia, and placental insufficiency. These conditions adversely affect uteroplacental and fetoplacental circulation, resulting in fetal hypoxia, growth restriction, preterm delivery, low birth weight, fetal distress, and increased neonatal intensive care unit (NICU) admissions. Early identification of fetal compromise is therefore essential to improve perinatal outcomes and reduce fetal and neonatal mortality.^[1]

Conventional obstetric ultrasonography provides anatomical assessment of the fetus and placenta; however, it does not adequately assess fetal hemodynamic status. Doppler ultrasonography has emerged as an important non-invasive imaging modality that evaluates blood flow characteristics in maternal and fetal vessels and provides valuable information regarding placental perfusion and fetal circulation. Doppler velocimetry enables assessment of vascular resistance and fetal adaptive mechanisms by studying waveforms in the uterine artery, umbilical

artery, and middle cerebral artery. In normal pregnancy, placental vascular resistance progressively decreases with advancing gestation, leading to increased end-diastolic blood flow in the umbilical artery.^[2]

In cases of placental insufficiency, increased placental resistance causes elevated pulsatility index (PI), resistance index (RI), and systolic/diastolic (S/D) ratio in the umbilical artery. Severe compromise may result in absent or reversed end-diastolic flow, which is associated with poor fetal outcome. Similarly, hypoxic fetuses develop compensatory cerebral vasodilatation, known as the “brain-sparing effect,” reflected by reduced middle cerebral artery PI. The cerebroplacental ratio (CPR), derived from the ratio of MCA PI to UA PI, has been shown to be a sensitive indicator of fetal compromise and adverse perinatal outcome.^[3]

Several studies have demonstrated significant association between abnormal Doppler indices and adverse outcomes such as fetal distress, emergency cesarean section, low Apgar score, low birth weight, NICU admission, and perinatal mortality. Doppler ultrasonography has therefore become an integral component of fetal surveillance in high-risk pregnancies. It helps in identifying fetuses at risk, monitoring progression of placental insufficiency, guiding timing of delivery, and improving neonatal outcome through timely obstetric intervention. The present study was undertaken to evaluate the correlation between abnormal Doppler indices and perinatal outcomes in high-risk pregnancy patients and to assess the predictive value of Doppler ultrasonography in detecting adverse perinatal outcomes.^[4]

AIM

To correlate abnormal Doppler indices with perinatal outcomes in high-risk pregnancy patients.

OBJECTIVES

1. To evaluate Doppler indices of uterine artery, umbilical artery, and middle cerebral artery in high-risk pregnancies.
2. To determine the association between abnormal Doppler findings and adverse perinatal outcomes.
3. To assess the predictive value of Doppler ultrasonography in identifying fetal compromise in high-risk pregnancies.

MATERIALS AND METHODOLOGY

Source of Data

The data for the present study were collected from pregnant women attending the Department of Obstetrics and Gynecology and referred to the Department of Radiodiagnosis at the tertiary care teaching hospital. All eligible high-risk pregnant women who fulfilled the inclusion criteria during the study period were included in the study after obtaining informed written consent.

Study Design

The present study was a hospital-based cross-sectional observational study.

Study Location

The study was conducted in the Department of Radiodiagnosis in collaboration with the Department of Obstetrics and Gynecology at a tertiary care teaching hospital.

Study Duration

The study was conducted over a period of one year.

Sample Size

A total of 100 high-risk pregnant women were included in the study.

Inclusion Criteria

1. Pregnant women diagnosed as high-risk pregnancy.
2. Singleton pregnancy with gestational age ≥ 28 weeks.
3. Patients with hypertensive disorders of pregnancy, gestational diabetes

mellitus, anemia, oligohydramnios, fetal growth restriction, postdated pregnancy, or other obstetric high-risk factors.

4. Patients willing to participate in the study and provide informed consent.

Exclusion Criteria

1. Normal low-risk pregnancies.
2. Multiple gestation pregnancies.
3. Pregnancies with congenital fetal anomalies.
4. Patients with uncertain gestational age.
5. Patients unwilling to participate in the study.

Procedure and Methodology

After obtaining approval from the Institutional Ethics Committee, eligible pregnant women fulfilling the inclusion criteria were enrolled in the study. Detailed history regarding maternal age, parity, gestational age, obstetric history, and associated high-risk factors was recorded. General physical examination and obstetric examination findings were documented in a predesigned proforma.

All patients underwent ultrasonography and Doppler examination using a curvilinear transducer of appropriate frequency. Standard obstetric ultrasonography was first performed to assess fetal biometry, placental localization, fetal presentation, amniotic fluid index, and estimated fetal weight. Doppler velocimetry was subsequently performed under aseptic precautions and standardized protocol.

Umbilical artery Doppler was assessed from a free-floating loop of the umbilical cord, and the pulsatility index (PI), resistance index (RI), and systolic/diastolic (S/D) ratio were recorded. Middle cerebral artery Doppler was obtained from the proximal third of the MCA near its origin from the internal carotid artery, and MCA PI was measured. Cerebroplacental ratio (CPR) was calculated by dividing MCA PI by UA PI. Doppler indices were

interpreted according to gestational age-specific reference values, and abnormal indices were identified.

Patients were followed until delivery, and perinatal outcomes were recorded. Adverse perinatal outcomes included low birth weight, preterm delivery, fetal distress, low Apgar score, NICU admission, stillbirth, neonatal death, and need for emergency cesarean section. Correlation between abnormal Doppler findings and perinatal outcomes was analyzed.

Sample Processing

All Doppler measurements were obtained using standardized machine settings with proper insonation angle and adequate waveform acquisition. At least three consecutive similar waveforms were recorded, and average values were considered for analysis. The recorded Doppler indices and clinical details were entered into the master chart for statistical evaluation.

Statistical Methods

The collected data were entered in Microsoft Excel and analyzed using Statistical Package for Social Sciences (SPSS) software version 26.0. Continuous variables were expressed as mean $\pm$ standard deviation, while categorical variables were expressed as frequency and percentage. Chi-square test or Fisher's exact test was used for comparison of categorical variables. Student's t-test was used for comparison of continuous variables. Sensitivity, specificity, positive predictive value, negative predictive value, and diagnostic accuracy of Doppler indices were calculated. A p-value of less than 0.05 was considered statistically significant.

Data Collection

Data collection was performed using a structured case record proforma. Maternal demographic details, obstetric history, clinical findings, ultrasound findings, Doppler indices, and perinatal outcomes were systematically documented. All information was compiled and tabulated for statistical analysis and interpretation.

OBSERVATION AND RESULTS:

Table 1: Correlation of Abnormal Doppler Indices with Perinatal Outcomes in High-Risk Pregnancy Patients, N=100

Doppler Index	Adverse Outcome Present n (%)	Adverse Outcome Absent n (%)	Test value	OR / Mean Difference	95% CI	p-value
Abnormal UA RI	47 (81.0)	11 (19.0)	$\chi^2=31.42$	OR=11.64	4.42-30.62	<0.001
Abnormal UA PI	49 (79.0)	13 (21.0)	$\chi^2=28.76$	OR=10.55	4.15-26.82	<0.001
Abnormal UA S/D ratio	42 (73.7)	15 (26.3)	$\chi^2=9.87$	OR=4.10	1.67-10.05	0.002
Abnormal MCA PI	39 (69.6)	17 (30.4)	$\chi^2=5.92$	OR=2.75	1.20-6.29	0.015

Abnormal UA RI	49 (81.0)	11 (19.0)	$\chi^2=31.42$	OR=11.64	4.42-30.62	<0.001
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Table 1 demonstrates the correlation between abnormal Doppler indices and adverse perinatal outcomes among high-risk

pregnancy patients. Abnormal umbilical artery resistance index (UA RI) showed a strong association with adverse perinatal outcome, as 47 (81.0%) patients with abnormal UA RI developed adverse outcomes compared to only 11 (19.0%) without adverse outcomes. This association was highly statistically significant ($\chi^2=31.42$, $p<0.001$) with an odds ratio (OR) of 11.64 (95% CI: 4.42-30.62), indicating that patients with abnormal UA RI had nearly twelve times higher risk of adverse perinatal outcome. Similarly, abnormal umbilical artery pulsatility index (UA PI) was significantly associated with adverse outcomes, with 49 (79.0%) patients experiencing adverse outcomes ($\chi^2=28.76$, OR=10.55, 95% CI: 4.15-26.82, $p<0.001$).

Abnormal UA S/D ratio was also significantly related to adverse outcome, with 42 (73.7%) affected pregnancies showing adverse outcomes and an OR of 4.10 (95% CI: 1.67-10.05; $p=0.002$). Abnormal middle cerebral artery pulsatility index (MCA PI) demonstrated a comparatively weaker but still significant association with adverse outcomes, with 39 (69.6%) pregnancies developing complications ($\chi^2=5.92$, OR=2.75, 95% CI: 1.20-6.29; $p=0.015$). Among all Doppler parameters, abnormal cerebroplacental ratio (CPR) showed one of the strongest correlations with adverse outcome, with 49 (81.7%) pregnancies affected and an OR of 11.14 (95% CI: 4.25-29.18; $p<0.001$).

Table 2: Evaluation of Doppler Indices of Uterine Artery, Umbilical Artery and Middle Cerebral Artery, N=100

Doppler Parameter	Normal n (%) / Mean $\pm$ SD	Abnormal n (%) / Mean $\pm$ SD	Test value	95% CI	p-value
Uterine Artery PI	45 (45.0) / 0.82 $\pm$ 0.18	55 (55.0) / 1.48 $\pm$ 0.32	t=12.56	0.55-0.77	<0.001
Uterine Artery RI	47 (47.0) / 0.48 $\pm$ 0.09	53 (53.0) / 0.71 $\pm$ 0.12	t=10.74	0.19-0.27	<0.001
Umbilical Artery RI	42 (42.0) / 0.56 $\pm$ 0.07	58 (58.0) / 0.78 $\pm$ 0.10	t=12.32	0.18-0.26	<0.001
Umbilical Artery PI	38 (38.0) / 0.91 $\pm$ 0.15	62 (62.0) / 1.51 $\pm$ 0.28	t=12.41	0.50-0.70	<0.001
Umbilical Artery S/D Ratio	43 (43.0) / 2.52 $\pm$ 0.38	57 (57.0) / 4.10 $\pm$ 0.92	t=10.67	1.28-1.88	<0.001
Middle Cerebral Artery PI	44 (44.0) / 1.72 $\pm$ 0.30	56 (56.0) / 1.12 $\pm$ 0.24	t=11.13	0.49-0.71	<0.001

Table 2 presents the evaluation of Doppler indices of the uterine artery, umbilical artery, and middle cerebral artery among the study population. Abnormal uterine artery pulsatility index (PI) was observed in 55 (55.0%) patients, with a significantly higher mean value of 1.48 $\pm$ 0.32 compared to the normal group (0.82 $\pm$ 0.18). This difference was highly statistically significant (t=12.56, 95% CI: 0.55-0.77, $p<0.001$). Similarly,

abnormal uterine artery resistance index (RI) was found in 53 (53.0%) patients, with a mean value of 0.71 $\pm$ 0.12 compared to 0.48 $\pm$ 0.09 in the normal group (t=10.74, $p<0.001$). Abnormal umbilical artery RI was identified in 58 (58.0%) patients and showed significantly elevated mean values (0.78 $\pm$ 0.10) compared to normal pregnancies (0.56 $\pm$ 0.07), with a highly significant statistical difference (t=12.32, $p<0.001$).

Umbilical artery PI was abnormal in 62 (62.0%) patients and demonstrated markedly increased mean values (1.51 ± 0.28) in comparison to normal pregnancies (0.91 ± 0.15), which was statistically significant ($t=12.41$, $p<0.001$). Likewise, abnormal umbilical artery S/D ratio was noted in 57 (57.0%) patients, with a

significantly higher mean value of 4.10 ± 0.92 compared to 2.52 ± 0.38 among normal cases ($t=10.67$, $p<0.001$). In contrast, middle cerebral artery PI was reduced in abnormal cases, with 56 (56.0%) patients showing abnormal MCA PI values of 1.12 ± 0.24 compared to 1.72 ± 0.30 in normal pregnancies ($t=11.13$, $p<0.001$).

Table 3: Association Between Abnormal Doppler Findings and Adverse Perinatal Outcomes, N=100

Doppler Finding	Adverse Outcome n (%)	Normal Outcome n (%)	Test value	OR	95% CI	p-value
Any abnormal Doppler finding	54 (78.3)	15 (21.7)	$\chi^2=24.91$	9.36	3.34-26.20	<0.001
Abnormal UA PI	49 (79.0)	13 (21.0)	$\chi^2=28.76$	10.55	4.15-26.82	<0.001
Abnormal UA RI	47 (81.0)	11 (19.0)	$\chi^2=31.42$	11.64	4.42-30.62	<0.001
Abnormal MCA PI	39 (69.6)	17 (30.4)	$\chi^2=5.92$	2.75	1.20-6.29	0.015
Abnormal CPR	49 (81.7)	11 (18.3)	$\chi^2=30.18$	11.14	4.25-29.18	<0.001

Table 3 shows the association between abnormal Doppler findings and adverse perinatal outcomes. The presence of any abnormal Doppler finding was significantly associated with adverse perinatal outcomes, with 54 (78.3%) patients developing complications compared to only 15 (21.7%) patients with normal outcomes. This association was highly significant ($\chi^2=24.91$, OR=9.36, 95% CI: 3.34-26.20, $p<0.001$). Abnormal umbilical artery pulsatility index (UA PI) was strongly associated with adverse outcome, with 49 (79.0%) pregnancies showing complications and an odds ratio of 10.55 (95% CI: 4.15-26.82, $p<0.001$).

Similarly, abnormal UA RI demonstrated one of the strongest associations with poor perinatal outcome, as 47 (81.0%) pregnancies developed adverse outcomes, with an OR of 11.64 (95% CI: 4.42-30.62, $p<0.001$). Abnormal MCA PI was also significantly associated with adverse outcome, though the strength of association was relatively lower (OR=2.75, 95% CI: 1.20-6.29, $p=0.015$). Abnormal cerebroplacental ratio (CPR) showed a very strong relationship with adverse perinatal outcome, with 49 (81.7%) pregnancies affected and an OR of 11.14 (95% CI: 4.25-29.18, $p<0.001$).

Table 4: Predictive Value of Doppler Ultrasonography in Identifying Fetal Compromise, N=100

Doppler Parameter	Sensitivity %	Specificity %	PPV %	NPV %	Accuracy %	95% CI for Accuracy	p-value
UA RI	79.7	73.2	81.0	71.4	77.0	67.5-84.8	<0.001

UA PI	83.1	68.3	79.0	73.7	77.0	67.5-84.8	<0.001
UA S/D Ratio	71.2	63.4	73.7	60.5	68.0	57.9-77.0	0.002
MCA PI	66.1	58.5	69.6	54.5	63.0	52.8-72.4	0.015
CPR	83.1	73.2	81.7	75.0	79.0	69.7-86.5	

Table 4 evaluates the predictive value of Doppler ultrasonography in identifying fetal compromise among high-risk pregnancies. Umbilical artery resistance index (UA RI) demonstrated good predictive performance with sensitivity of 79.7%, specificity of 73.2%, positive predictive value (PPV) of 81.0%, negative predictive value (NPV) of 71.4%, and overall diagnostic accuracy of 77.0% (95% CI: 67.5-84.8; $p < 0.001$). Umbilical artery pulsatility index (UA PI) showed slightly higher sensitivity of 83.1% with specificity of 68.3%, PPV of 79.0%, NPV of 73.7%, and overall accuracy of 77.0%, which was highly statistically significant ($p < 0.001$). Umbilical artery S/D ratio demonstrated comparatively lower predictive values, with sensitivity of 71.2%, specificity of 63.4%, and overall accuracy of 68.0% (95% CI: 57.9-77.0; $p = 0.002$). Middle cerebral artery PI had the lowest predictive performance among the studied parameters, with sensitivity of 66.1%, specificity of 58.5%, PPV of 69.6%, NPV of 54.5%, and accuracy of 63.0% (95% CI: 52.8-72.4; $p = 0.015$). Among all Doppler indices, cerebroplacental ratio (CPR) demonstrated the best predictive performance with sensitivity of 83.1%, specificity of 73.2%, PPV of 81.7%, NPV of 75.0%, and highest diagnostic accuracy of 79.0% (95% CI: 69.7-86.5).

DISCUSSION

In the present study, abnormal Doppler indices showed a strong correlation with adverse perinatal outcomes in high-risk pregnancies. Abnormal UA RI was associated with adverse outcome in 47 (81.0%) cases, with OR 11.64, 95% CI 4.42-

30.62 and $p < 0.001$. Similarly, abnormal UA PI showed adverse outcome in 49 (79.0%) cases, with OR 10.55, 95% CI 4.15-26.82 and $p < 0.001$. These findings indicate that increased placental vascular resistance, reflected by raised umbilical artery Doppler indices, is a strong predictor of fetal compromise. This is comparable with Stumpfe et al.(2019)^[1], who reported that abnormal Doppler parameters were significantly associated with adverse perinatal outcomes and fetal compromise at term. El-Demiry et al.(2020)^[2] also observed that abnormal umbilical artery Doppler indices in severe preeclampsia were significantly associated with poor neonatal outcome and increased NICU admissions.

Abnormal UA S/D ratio was significantly associated with adverse outcome in 42 (73.7%) cases, with OR 4.10, 95% CI 1.67-10.05 and $p = 0.002$. This shows that raised systolic-diastolic ratio is a useful marker of impaired fetoplacental circulation, although its predictive strength was lower than UA PI and UA RI. Similar findings were reported by Dixit et al.(2024)^[3], who demonstrated that elevated umbilical artery S/D ratio was associated with intrauterine growth restriction, fetal distress, and adverse neonatal outcome. In the present study, abnormal MCA PI was associated with adverse outcome in 39 (69.6%) cases, with OR 2.75, 95% CI 1.20-6.29 and $p = 0.015$. Although statistically significant, its association was weaker than umbilical artery indices. This supports the findings of Pinki et al.(2024)^[4], who suggested that MCA Doppler reflects fetal compensatory redistribution or brain-sparing response, but

isolated MCA changes may be less predictive than combined Doppler parameters.

The present study also found that abnormal CPR was strongly associated with adverse perinatal outcome, as 49 (81.7%) cases with abnormal CPR developed adverse outcomes, with OR 11.14, 95% CI 4.25-29.18 and $p < 0.001$. CPR had one of the strongest associations among all Doppler parameters, indicating that combined assessment of placental resistance and fetal cerebral redistribution is superior to isolated vessel assessment. This finding is in agreement with Peixoto et al.(2016)^[5], who reported that cerebroplacental ratio was a better predictor of adverse perinatal outcome than isolated umbilical or cerebral Doppler parameters alone. Similarly, Sharma et al.(2016)^[6] emphasized that low CPR was significantly associated with fetal distress, emergency caesarean section, low Apgar score, intrauterine growth restriction, and NICU admission.

In the evaluation of Doppler indices, uterine artery PI and RI were abnormal in 55.0% and 53.0% cases respectively, with significantly higher mean values in abnormal groups. This suggests impaired uteroplacental perfusion in more than half of high-risk pregnancy patients. Reddy et al.(2015)^[7] reported that increased uterine artery resistance and persistent notching were associated with preeclampsia, fetal growth restriction, and adverse neonatal outcomes. In the present study, umbilical artery PI was abnormal in 62.0%, UA RI in 58.0%, and UA S/D ratio in 57.0% cases, all showing highly significant differences between normal and abnormal groups ($p < 0.001$). These findings reinforce the role of umbilical artery Doppler as a direct marker of placental vascular resistance. According to Dall'Asta et al.(2023)^[8], abnormal uterine and umbilical artery Doppler findings were important predictors of adverse perinatal outcome and useful

surveillance tools even in low-risk term pregnancies.

Regarding predictive value, CPR showed the highest overall diagnostic accuracy of 79.0%, with sensitivity 83.1%, specificity 73.2%, PPV 81.7%, and NPV 75.0%. UA PI and UA RI also demonstrated good predictive performance, each with 77.0% accuracy. UA PI showed sensitivity of 83.1%, while UA RI showed specificity of 73.2%. UA S/D ratio had moderate predictive value with accuracy of 68.0%, while MCA PI had the lowest predictive performance with accuracy of 63.0%. These results suggest that CPR, followed by UA PI and UA RI, were the most useful Doppler parameters for predicting fetal compromise. Agrawal et al.(2016)^[9] similarly concluded that fetal Doppler, particularly CPR and umbilical artery indices, had good predictive value for adverse perinatal outcomes in preeclamptic pregnancies. Vannevel et al.(2022)^[10] also highlighted the importance of antenatal Doppler screening in identifying fetuses at risk of adverse outcomes, emphasizing the usefulness of abnormal resistance indices in predicting fetal compromise across multiple populations.

CONCLUSION

The present study concluded that abnormal Doppler indices are significantly associated with adverse perinatal outcomes in high-risk pregnancies. Increased umbilical artery resistance index (UA RI), pulsatility index (UA PI), and systolic/diastolic (S/D) ratio reflected increased placental vascular resistance and were strongly correlated with fetal compromise, low birth weight, preterm delivery, fetal distress, and NICU admission. Reduced middle cerebral artery pulsatility index (MCA PI) indicated fetal adaptive cerebral redistribution due to hypoxia, while abnormal cerebroplacental ratio (CPR) demonstrated the strongest predictive value for adverse perinatal outcome. Among all

Doppler parameters, CPR showed the highest sensitivity, specificity, and overall diagnostic accuracy in identifying fetal compromise. Doppler ultrasonography proved to be a reliable, non-invasive, and effective modality for fetal surveillance in high-risk pregnancies. Early identification of abnormal Doppler findings allows timely obstetric intervention and appropriate perinatal management, thereby reducing fetal morbidity and mortality. Routine incorporation of Doppler assessment in high-risk pregnancies can significantly improve perinatal outcome and guide clinical decision-making.

LIMITATIONS OF THE STUDY

1. The study was conducted at a single tertiary care center, limiting generalization of results to the wider population.
2. The sample size was relatively small (100 patients), which may reduce statistical power.
3. Only high-risk pregnancies were included; comparison with normal low-risk pregnancies was not performed.
4. Long-term neonatal follow-up and neurodevelopmental outcomes were not assessed.
5. Doppler measurements are operator-dependent and subject to inter-observer variability.
6. Serial Doppler follow-up at multiple gestational intervals was not uniformly performed in all patients.
7. Advanced Doppler parameters such as ductus venosus and umbilical venous Doppler were not evaluated.
8. Confounding maternal factors such as severity of hypertension, nutritional status, and socioeconomic conditions were not analyzed separately.
9. The study design was observational and cross-sectional, which limits establishment of causal relationship.
10. Some adverse outcomes may have been influenced by obstetric interventions and

management decisions after Doppler evaluation.

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