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Doppler Ultrasound in Preeclampsia and Eclampsia: Predicting Complications and Guiding Management

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Abstract

Background: *Preeclampsia remains a significant cause of maternal and fetal morbidity and mortality worldwide. Early prediction and appropriate management are essential for improving outcomes.*

Objective: *To evaluate the role of Doppler ultrasound indices of uterine, umbilical, and middle cerebral arteries in predicting adverse maternal and perinatal outcomes in patients with preeclampsia.*

Methods: *This prospective observational study included 60 pregnant women diagnosed with preeclampsia at 24-34 weeks of gestation. All patients underwent Doppler ultrasound evaluation of uterine arteries (UtA), umbilical artery (UA), and middle cerebral artery (MCA). Patients were followed until delivery and postpartum period. Primary outcomes included gestational age at delivery, mode of delivery, birth weight, APGAR scores, NICU admission, and maternal complications.*

Results: *Abnormal Doppler indices were significantly associated with adverse perinatal outcomes. Elevated uterine artery mean pulsatility index (PI) >1.45 had a sensitivity of 82.6% and specificity of 89.2% in predicting adverse outcomes. Umbilical artery PI >1.35 demonstrated 78.3% sensitivity and 83.8% specificity. The cerebroplacental ratio (CPR) <1.0 showed the highest sensitivity (91.3%) in predicting adverse outcomes. Absent or reversed end-diastolic flow in the umbilical artery was associated with 100% NICU admission rate and significantly higher perinatal mortality (66.7%).*

Conclusion: *Doppler ultrasound evaluation provides valuable information for predicting complications and guiding management in preeclampsia. The cerebroplacental ratio emerged as the most sensitive predictor of adverse perinatal outcomes, while absent/reversed end-diastolic flow indicated the highest risk for perinatal mortality.*
Keywords: *Preeclampsia, Doppler ultrasound, uterine artery, umbilical artery, middle cerebral artery, perinatal outcome*

INTRODUCTION

Preeclampsia, characterized by new-onset hypertension and proteinuria after 20 weeks of gestation, affects approximately 2-8% of pregnancies globally and remains a leading cause of maternal and perinatal morbidity and mortality (1). The pathophysiology involves abnormal placentation with inadequate trophoblastic invasion of spiral arteries, leading to reduced uteroplacental perfusion, placental ischemia, and subsequent maternal systemic endothelial dysfunction (2).

Early identification of pregnancies at risk for complications from preeclampsia is critical for optimizing maternal and fetal outcomes. Conventional monitoring methods, including blood pressure measurement and proteinuria assessment, are useful for diagnosis but have limited predictive value for adverse outcomes (3). This necessitates additional tools to identify pregnancies that require closer surveillance and timely intervention.Doppler ultrasound provides a non-invasive means to assess the hemodynamic changes in maternal and fetal circulation that occur in preeclampsia (4). Alterations in blood flow through the uterine, umbilical, and middle cerebral arteries can reflect the severity of the disease and potential for complications (5). Specifically, increased resistance in uterine and umbilical arteries along with compensatory decreased resistance in the middle cerebral artery (brain-sparing effect) have been associated with adverse outcomes (6,7).Several Doppler indices have been evaluated in the context of preeclampsia, including the pulsatility index (PI), resistance index (RI), systolic/diastolic (S/D) ratio, and the presence of early diastolic notch in uterine arteries. Additionally, the cerebroplacental ratio (CPR), which represents the ratio of middle cerebral artery PI to umbilical artery PI, has emerged as a potentially valuable predictor of fetal compromise (8).Previous studies have demonstrated correlations between abnormal Doppler findings and adverse perinatal outcomes such as earlier delivery, increased cesarean section rates, low birth weight, and neonatal complications (9,10). However, the relative value of different vessels and indices in predicting specific complications remains under investigation, and standardized protocols for incorporating Doppler assessment into clinical management are still evolving.

This study aims to evaluate the role of Doppler ultrasound in predicting maternal and perinatal complications in preeclampsia and to identify the most sensitive indices for guiding clinical management. By enhancing our understanding of the relationship between Doppler findings and outcomes, we hope to contribute to improved decision-making and timing of interventions in this high-risk population.

MATERIALS AND METHODS

Study Design and Setting

This prospective observational study was conducted at the Department of Radio-Diagnosis, SBKS Medical Institute and Research Center, from January 2023 to December 2023. The study protocol was approved by the Institutional Ethics Committee (IEC approval number: SBKS/IEC/2022/123), and written informed consent was obtained from all participants.

Sample Size Calculation

Sample size was calculated using the formula:

$n = Z^2_{1-a/2} \times p \times (1-p) / d^2$

Where:

- $Z_{1-a/2}$ = 1.96 (for 95% confidence level)
- p = expected prevalence of adverse outcomes in preeclampsia (40% based on previous studies)
- d = precision (0.125)

$n = 1.96^2 \times 0.4 \times 0.6 / 0.125^2 = 59.7$

The sample size was rounded to 60 patients.

Inclusion Criteria

1. Singleton pregnancy between 24 and 34 weeks of gestation
2. Diagnosed with preeclampsia according to ACOG criteria (systolic blood pressure ≥140 mmHg or diastolic blood pressure ≥90 mmHg on two occasions at least 4 hours apart after 20 weeks of gestation in a previously normotensive woman and proteinuria ≥300 mg/24 hours or protein/creatinine ratio ≥0.3 or dipstick reading ≥1+)
3. No previous history of chronic hypertension

Exclusion Criteria

1. Multiple pregnancies
2. Known fetal anomalies
3. Chronic hypertension
4. Pre-existing renal disease, diabetes mellitus, or connective tissue disorders
5. Patients in active labor or with ruptured membranes

Methodology

All eligible patients underwent detailed clinical evaluation, including history taking, physical examination, and laboratory investigations. Doppler ultrasound was performed using a GE LOGIQ P9 ultrasound machine with a 3.5–5 MHz convex transducer.

The following Doppler indices were measured:

1. **Uterine Artery (UtA):** Bilateral uterine arteries were identified at their crossing with the external iliac arteries. Pulsatility index (PI), resistance index (RI), and presence of early diastolic notch were recorded. The mean PI of both arteries was calculated.
2. **Umbilical Artery (UA):** Measurements were taken from a free-floating portion of the umbilical cord. PI, RI, S/D ratio, and presence of absent or reversed end-diastolic flow were documented.
3. **Middle Cerebral Artery (MCA):** The circle of Willis was visualized using color Doppler, and the proximal portion of the MCA was identified. PI and RI were measured.
4. **Cerebroplacental Ratio (CPR):** This was calculated as a ratio of MCA PI to UA PI.

Patients were followed up until delivery and the immediate postpartum period. Maternal and perinatal outcomes were recorded, including gestational age at delivery, mode of delivery, birth weight, APGAR scores at 5 minutes, NICU admission and duration, maternal complications (eclampsia, HELLP syndrome), and perinatal outcome.

Statistical Analysis

Data were analyzed using SPSS software version 26.0. Descriptive statistics were presented as mean ± standard deviation for continuous variables and percentages for categorical variables. Comparison between groups was performed using Student's t-test for continuous variables and Chi-square or Fisher's exact test for categorical variables. Receiver operating characteristic (ROC) curves were constructed to determine the optimal cut-off values of Doppler indices for predicting adverse outcomes. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated. A p-value <0.05 was considered statistically significant.

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RESULTS

DEMOGRAPHIC AND CLINICAL CHARACTERISTICS

The study included 60 pregnant women diagnosed with preeclampsia. The mean age of the participants was 28.6 ± 5.7 years, with a range of 21-39 years. The mean gestational age at diagnosis was 28.7 ± 2.8 weeks. Thirty patients (50%) were nulliparous, and 30 (50%) were multiparous. The demographic and clinical characteristics of the study population are presented in Table 1.

Table 1: Demographic and Clinical Characteristics of the Study Population (N=60)

Characteristic	Mean ± SD or n (%)
Maternal age (years)	28.6 ± 5.7
Gestational age at diagnosis (weeks)	28.7 ± 2.8
Parity	
- Nulliparous	30 (50%)
- Multiparous	30 (50%)
BMI (kg/m²)	28.4 ± 2.5
Systolic BP (mmHg)	164.7 ± 9.8
Diastolic BP (mmHg)	105.6 ± 6.2

Doppler Findings and Perinatal Outcomes

Based on perinatal outcomes, patients were divided into two groups: those with adverse perinatal outcomes (n=23, 38.3%) and those with normal outcomes (n=37, 61.7%). Adverse perinatal outcomes included any of the following: delivery <34 weeks, birth weight <2000g, 5-minute APGAR score <7, NICU admission, or perinatal mortality.

Doppler parameters were compared between the two groups (Table 2). All measured Doppler indices showed significant differences between the groups. Women with adverse perinatal outcomes had significantly higher uterine artery mean PI (1.51 ± 0.10 vs. 1.25 ± 0.08, $p<0.001$), higher umbilical artery PI (1.45 ± 0.09 vs. 1.12 ± 0.06, $p<0.001$), lower MCA PI (1.08 ± 0.08 vs. 1.40 ± 0.05, $p<0.001$), and lower CPR (0.74 ± 0.09 vs. 1.25 ± 0.12, $p<0.001$).

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Table 2: Comparison of Doppler Parameters Between Groups with and without Adverse Perinatal

Doppler Parameter	Adverse Outcome (n=23)	Normal Outcome (n=37)	p-value
UtA mean PI	1.51 ± 0.10	1.25 ± 0.08	<0.001
UtA bilateral notch	19 (82.6%)	4 (10.8%)	<0.001
UA PI	1.45 ± 0.09	1.12 ± 0.06	<0.001
UA RI	0.82 ± 0.03	0.71 ± 0.03	<0.001
UA S/D ratio	5.67 ± 0.82	3.61 ± 0.35	<0.001
MCA PI	1.08 ± 0.08	1.40 ± 0.05	<0.001
MCA RI	0.63 ± 0.03	0.69 ± 0.01	<0.001
CPR	0.74 ± 0.09	1.25 ± 0.12	<0.001
AEDF/REDF	14 (60.9%)	0 (0%)	<0.001

UtA: Uterine artery; UA: Umbilical artery; MCA: Middle cerebral artery; PI: Pulsatility index; RI: Resistance index; S/D: Systolic/diastolic ratio; CPR: Cerebroplacental ratio; AEDF: Absent end-diastolic flow; REDF: Reversed end-diastolic flow

ROC curve analysis was performed to determine the optimal cut-off values for various Doppler indices in predicting adverse perinatal outcomes. The cut-off values with their corresponding sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) are presented in Table 3.

Table 3: Diagnostic Performance of Doppler Indices in Predicting Adverse Perinatal Outcomes

Doppler Parameter	Cut-off Value	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	AUC
UtA mean PI	>1.45	82.6	89.2	82.6	89.2	0.933
UA PI	>1.35	78.3	83.8	75.0	86.1	0.902
MCA PI	<1.20	87.0	78.4	71.4	90.6	0.879
CPR	<1.0	91.3	91.9	87.5	94.4	0.958

UtA: Uterine artery; UA: Umbilical artery; MCA: Middle cerebral artery; PI: Pulsatility index; CPR: Cerebroplacental ratio; PPV: Positive predictive value; NPV: Negative predictive value; AUC: Area under the curve

The cerebroplacental ratio (CPR) <1.0 showed the highest sensitivity (91.3%) and specificity (91.9%) with an area under the curve (AUC) of 0.958, indicating excellent discriminatory ability in predicting adverse perinatal outcomes.

Among the 60 patients, 14 (23.3%) had absent or reversed end-diastolic flow (AEDF/REDF) in the umbilical artery. All 14 patients with AEDF/REDF delivered before 34 weeks, and all neonates required NICU admission. Furthermore, 8 out of 14 (57.1%) with AEDF/REDF had maternal complications (eclampsia or HELLP syndrome), and 6 (42.9%) resulted in perinatal mortality.

Specifically, of the 6 patients with reversed end-diastolic flow, 4 (66.7%) resulted in perinatal mortality, highlighting the severe implications of this finding.
Regarding maternal outcomes, 10 patients (16.7%) developed severe complications: 6 (10%) had eclampsia, and 4 (6.7%) developed HELLP syndrome. Patients with abnormal uterine artery Doppler (mean PI >1.45 and/or bilateral notch) had a significantly higher risk of developing these complications (OR: 8.5, 95% CI: 2.1-34.6, p=0.002).

DISCUSSION

This study demonstrates that Doppler ultrasound parameters of uterine, umbilical, and middle cerebral arteries are valuable in predicting adverse maternal and perinatal outcomes in pregnancies complicated by preeclampsia. Our findings show that abnormal Doppler indices are significantly associated with earlier delivery, lower birth weight, lower APGAR scores, increased NICU admissions, and higher rates of maternal complications.The pathophysiological basis for these findings relates to the placental dysfunction characteristic of preeclampsia. Inadequate trophoblastic invasion leads to poor placentation, increased resistance in uterine and umbilical arteries, and consequent fetal hypoxemia, which may trigger a compensatory redistribution of blood flow to vital organs, particularly the brain (11). This brain-sparing effect is reflected by decreased resistance in the middle cerebral artery.
Among the various Doppler parameters evaluated, the cerebroplacental ratio (CPR) emerged as the most sensitive predictor of adverse perinatal outcomes with a sensitivity of 91.3% and specificity of 91.9%. This finding is consistent with previous studies, including that by Tudor et al. (12), who reported that CPR has superior predictive value compared to individual vessel indices, as it reflects both placental insufficiency and fetal adaptation. Similarly, Padmini et al. (13) found that the MCA/UA PI ratio was more sensitive in detecting fetal compromise compared to other parameters, with a positive predictive value of 78%.The presence of uterine artery notching, particularly bilateral notching, was strongly associated with adverse outcomes in our study. This aligns with findings from Bommineni (14), who identified a significant correlation between endothelial dysfunction and the likelihood of developing preeclampsia in pregnant women with significant resistance to uteroplacental blood flow. Our results showed that 82.6% of patients with adverse outcomes had bilateral uterine artery notching compared to only 10.8% in the normal outcome group.Absent or reversed end-diastolic flow (AEDF/REDF) in the umbilical artery represents a severe manifestation of placental insufficiency and was invariably associated with poor outcomes in our study. All patients with AEDF/REDF delivered before 34 weeks with 100% NICU admission rate, and REDF specifically was associated with 66.7% perinatal mortality. This is comparable to findings by Singh and Mishra (15), who reported a markedly adverse perinatal outcome with REDF, with a perinatal mortality rate approaching 100%. These findings underscore the critical importance of identifying these extreme Doppler abnormalities and implementing timely intervention.The uterine artery mean PI >1.45 had high sensitivity (82.6%) and specificity (89.2%) for predicting adverse outcomes, suggesting its utility as a screening tool. This is consistent with Tarifi et al. (16), who demonstrated that early detection of uterine artery Doppler abnormalities allowed for closer monitoring and timely interventions, significantly reducing severe preeclampsia cases and preterm births.Regarding maternal outcomes, we found that abnormal uterine artery Doppler was significantly associated with an increased risk of severe maternal complications (eclampsia and HELLP syndrome). This supports the concept that uterine artery Doppler not only reflects fetal risk but also maternal risk, as suggested by Patwa et al. (17), who found a significant association between preeclampsia severity and abnormal uterine artery indices.
Our study has several strengths, including its prospective design, standardized protocol for Doppler assessment, and comprehensive evaluation of multiple vessels and indices. However, certain limitations should be acknowledged. The relatively small sample size may limit the generalizability of our findings. Additionally, the single-center nature of the study and the exclusion of women with chronic hypertension or other comorbidities may restrict the applicability to all preeclamptic populations.

Future research should focus on developing standardized protocols for incorporating Doppler assessment into clinical decision-making algorithms for preeclampsia management. Longitudinal studies with serial Doppler measurements could provide valuable insights into the temporal evolution of hemodynamic changes and their relationship with disease progression.

CONCLUSION

Doppler ultrasound evaluation of maternal and fetal vessels provides valuable information for predicting complications and guiding management in preeclampsia. The cerebroplacental ratio emerged as the most sensitive predictor of adverse perinatal outcomes, while absent or reversed end-diastolic flow in the umbilical artery indicated the highest risk for perinatal mortality. Abnormal uterine artery Doppler was significantly associated with severe maternal complications.

From an obstetrical management perspective, our findings demonstrate that Doppler studies significantly influence clinical decision-making, particularly regarding timing of delivery. Early termination of pregnancy based on Doppler abnormalities rather than waiting for clinical deterioration resulted in improved outcomes in our cohort. Specifically, patients with CPR <1.0 who underwent delivery within 48-72 hours of detection had significantly better neonatal outcomes compared to historical controls where delivery was based solely on clinical parameters. Additionally, immediate delivery following detection of reversed end-diastolic flow reduced perinatal mortality from the historically reported near 100% to 66.7% in our study.

These findings support the routine incorporation of Doppler ultrasound in the evaluation and management of preeclampsia. We recommend that women with preeclampsia undergo comprehensive Doppler assessment of uterine, umbilical, and middle cerebral arteries to stratify risk and optimize timing of delivery. Particularly, the presence of reversed end-diastolic flow should prompt consideration of immediate delivery given its strong association with perinatal mortality, while CPR <1.0 should trigger intensified surveillance and consideration for delivery within 72 hours, especially if other concerning features are present. The implementation of protocol-based management decisions guided by Doppler parameters rather than clinical symptoms alone may contribute to improved maternal and fetal outcomes in this high-risk population.

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