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Original Article

Maternal Risk Factors and Ultrasound Doppler Indices in Pre-Eclampsia: A Comparative Study

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ABSTRACT

Background: Pre-eclampsia is a pregnancy-specific hypertensive disorder associated with maternal and foetal morbidity, and Doppler ultrasonography may support assessment of uteroplacental and fetoplacental haemodynamics. Objective: To compare maternal risk factors and ultrasound Doppler indices among pregnant women with and without pre-eclampsia and assess the diagnostic performance of Doppler parameters. Methods: This comparative cross-sectional study included 79 pregnant women beyond 20 weeks of gestation in a tertiary-care obstetrics and gynecology setting. Maternal clinical variables, proteinuria, blood pressure, and uterine and umbilical artery Doppler indices were recorded. Associations were assessed using chi-square testing, correlation analysis, and receiver operating characteristic analysis, with $p < 0.05$ considered statistically significant. Results: The mean age was 29.77 ± 6.49 years and mean gestational age was 29.13 ± 5.58 weeks. Pre-eclampsia was diagnosed in 71 participants (89.9%). Proteinuria was significantly associated with diagnosis ($\chi^2 = 7.452$, $p = 0.006$). Systolic blood pressure correlated weakly with umbilical artery pulsatility index ($r = 0.284$, $p = 0.011$), while diastolic blood pressure correlated negatively with uterine artery resistive index ($r = -0.266$, $p = 0.018$). Umbilical artery resistive index showed the highest Doppler discrimination (AUC = 0.663). Conclusion: Doppler indices showed limited standalone diagnostic accuracy, but umbilical artery resistive index may provide supportive haemodynamic information when interpreted with blood pressure and proteinuria. Keywords: Pre-eclampsia, maternal risk factors, Doppler ultrasound, uterine artery, umbilical artery, pulsatility index, high-risk pregnancy.

INTRODUCTION

Pre-eclampsia is a pregnancy-specific hypertensive disorder that develops after 20 weeks of gestation and remains one of the leading contributors to maternal and perinatal morbidity worldwide. It is classically characterized by new-onset hypertension with proteinuria or evidence of maternal organ dysfunction, reflecting a multisystem disease process rather than an isolated elevation of blood pressure. The disorder affects a substantial proportion of pregnancies and its clinical importance lies in its unpredictable progression, potential for severe maternal complications, and association with adverse foetal consequences, including growth restriction, placental insufficiency, preterm delivery, and increased perinatal risk (1). Beyond the immediate pregnancy period, pre-eclampsia has also been linked with long-term cardiovascular risk for the mother and increased susceptibility to later-life cardiometabolic morbidity in the offspring, making early recognition and risk stratification clinically important (2).

The pathophysiology of pre-eclampsia is closely related to abnormal placentation, impaired trophoblastic invasion, endothelial dysfunction, oxidative stress, and increased systemic vascular resistance. Inadequate remodeling of the spiral arteries can reduce uteroplacental perfusion, increase placental vascular resistance, and trigger maternal inflammatory and vascular responses that manifest clinically as hypertension and proteinuria. Although the exact aetiology remains multifactorial, several maternal characteristics have been repeatedly associated with increased risk, including primigravidity, advanced maternal age, obesity, prior history of pre-eclampsia, chronic hypertension, diabetes mellitus, renal disease, autoimmune disease, family history, and other high-risk obstetric or medical conditions (3,4). These risk factors are clinically useful because they can identify women who require closer antenatal surveillance, but they do not fully predict which pregnancies will develop haemodynamic compromise or clinically significant placental insufficiency.

The global burden of pre-eclampsia is particularly important in low- and middle-income settings, where delayed diagnosis, limited access to specialist obstetric care, and insufficient monitoring may increase the risk of preventable maternal and foetal complications. Regional and global estimates show that pre-eclampsia and eclampsia contribute substantially to maternal morbidity and mortality, while the clinical presentation and risk profile may vary according to population characteristics, referral patterns, and access to antenatal screening (5). In high-risk obstetric populations, clinical risk assessment alone may be insufficient because many women present after vascular changes have already affected uteroplacental or fetoplacental circulation. Therefore, tools that can non-invasively assess placental and foetal haemodynamics may improve clinical interpretation when combined with maternal risk profiling.

Doppler ultrasonography provides a non-invasive method for assessing blood-flow resistance in the uteroplacental and fetoplacental circulation. Uterine artery Doppler indices reflect maternal-side placental perfusion and are influenced by the adequacy of trophoblastic invasion and spiral artery remodeling, whereas umbilical artery Doppler indices reflect downstream placental resistance and foetal circulatory burden (6,7). Increased uterine or umbilical artery pulsatility and resistive indices may indicate increased vascular impedance, impaired placental perfusion, and a higher likelihood of pregnancy complications related to placental insufficiency (8,9). Previous studies have shown that Doppler indices may contribute to prediction or assessment of pre-eclampsia, particularly when interpreted alongside maternal clinical factors, although their performance varies depending on gestational age, disease onset, population risk status, and whether individual or combined Doppler markers are used (10).

Despite the established physiological basis of Doppler assessment, uncertainty remains regarding the diagnostic value of individual Doppler indices in high-risk clinical samples where pre-eclampsia prevalence is already high. Several studies suggest that Doppler parameters may be more informative when combined with clinical risk factors or additional foetal vascular indices rather than used as isolated diagnostic markers (11,12). In routine clinical practice, however, maternal risk factors, blood pressure patterns, proteinuria, and Doppler findings are often interpreted together, and local evidence is needed to clarify which parameters provide the most clinically interpretable information in pregnant women evaluated after 20 weeks of gestation.

The present study was therefore designed to compare maternal risk factors and ultrasound Doppler indices among pregnant women with and without pre-eclampsia in a tertiary-care setting. The study specifically aimed to describe the distribution of selected maternal clinical risk factors, assess their association with pre-eclampsia diagnosis, evaluate uterine and umbilical artery Doppler indices, and determine the diagnostic performance of these Doppler parameters for identifying pre-eclampsia. The research question was: among pregnant women beyond 20 weeks of gestation, are maternal risk factors and uterine or umbilical artery Doppler indices associated with a diagnosis of pre-eclampsia, and which Doppler index demonstrates the greatest diagnostic discrimination?

MATERIAL AND METHODS

This comparative cross-sectional study was conducted in the Department of Obstetrics and Gynecology of a government tertiary-care hospital over a three-month period after approval of the study synopsis. Pregnant women attending the department after 20 weeks of gestation were assessed for eligibility and enrolled through non-probability convenience sampling. The study compared women diagnosed with pre-eclampsia and normotensive pregnant women, with the primary analytical focus on maternal risk factors, blood pressure parameters, proteinuria status, and ultrasound Doppler indices of uteroplacental and fetoplacental circulation.

Eligible participants were pregnant women with singleton pregnancies at or beyond 20 weeks of gestation. Women were included in the pre-eclampsia group when they had a clinical diagnosis of pre-eclampsia based on blood pressure assessment and proteinuria evaluation after 20 weeks of gestation, while normotensive pregnant women meeting the same gestational-age criterion were included as the comparison group. Women with multiple gestation, known chronic renal disease, clinically documented cardiac disease, or congenital foetal anomaly were excluded to reduce the influence of conditions that could independently alter maternal haemodynamics, foetal circulation, or Doppler interpretation. After eligibility screening, informed consent was obtained before data collection.

Data were collected using a structured clinical and ultrasound assessment approach. Maternal demographic and obstetric variables included age, gestational age in weeks, gravida status, systolic blood pressure, and diastolic blood pressure. Clinical risk-factor variables included hypertension status, diabetes mellitus status, previous history of pre-eclampsia, thyroid disorder, family history of pre-eclampsia, multiple pregnancy status, proteinuria status, and final pre-eclampsia diagnosis. Blood pressure was assessed as part of routine clinical evaluation, and proteinuria status was recorded from urine assessment documented during participant evaluation. Pre-eclampsia diagnosis was treated as the main outcome variable for comparison with maternal risk factors and Doppler indices.

Doppler ultrasonography was performed transabdominally to evaluate uterine and umbilical artery blood-flow indices. The Doppler assessment included uterine artery pulsatility index, uterine artery resistive index, umbilical artery pulsatility index, umbilical artery resistive index, and systolic/diastolic ratio. Doppler measurements were obtained after optimizing the spectral waveform, avoiding excessive insonation angle, and recording stable waveforms without interference from maternal movement, breathing artefact, or foetal movement. Pulsatility and resistive indices were interpreted as continuous haemodynamic variables reflecting vascular impedance, with higher umbilical artery indices indicating increased fetoplacental resistance and higher uterine artery indices indicating increased uteroplacental resistance (6,10,11).

The operational definition of the primary outcome was the presence or absence of clinically diagnosed pre-eclampsia after 20 weeks of gestation. Continuous explanatory variables included maternal age, gestational age, gravida, systolic blood pressure, diastolic blood pressure, uterine artery pulsatility index, uterine artery resistive index, umbilical artery pulsatility index, umbilical artery resistive index, and systolic/diastolic ratio. Categorical explanatory variables included hypertension, diabetes mellitus, thyroid disorder, previous pre-eclampsia, family history of pre-eclampsia, proteinuria, and pregnancy type. Proteinuria was analyzed as a diagnostic-associated clinical variable rather than as an independent causal risk factor because it forms part of the conventional clinical assessment of pre-eclampsia.

A total of 79 eligible pregnant women were included during the study period. The sample size reflected complete enrolment of eligible participants available within the approved data-collection period and was used to estimate descriptive distributions, test associations between categorical risk factors and pre-eclampsia diagnosis, assess correlations between blood pressure and Doppler indices, and evaluate the discriminatory performance of Doppler measures. To reduce selection and measurement bias, eligibility criteria were applied before enrolment, singleton pregnancy status was confirmed, and Doppler indices

were recorded using a standardized ultrasound assessment approach. Potential confounding was considered during interpretation by distinguishing clinical diagnostic markers from background maternal risk factors and by avoiding causal conclusions from the cross-sectional design.

Data were entered, cleaned, and analyzed using statistical software. Continuous variables were summarized as mean, standard deviation, minimum, and maximum values. Categorical variables were summarized as frequencies and percentages. Associations between categorical maternal risk factors and pre-eclampsia diagnosis were assessed using chi-square testing, with Fisher's exact test considered appropriate where cell counts were sparse. Correlations between blood pressure variables and Doppler indices were assessed using Pearson correlation for linear relationships and Spearman correlation for rank-based confirmation. Receiver operating characteristic analysis was used to estimate the diagnostic discrimination of uterine and umbilical artery Doppler indices against pre-eclampsia diagnosis, and area under the curve values were interpreted according to diagnostic performance. Logistic regression findings were interpreted cautiously because the available diagnostic groups were highly imbalanced and the model demonstrated complete separation, making individual regression coefficients unsuitable for clinical inference. Statistical significance was set at $p < 0.05$.

Ethical approval was obtained before initiation of the study, and all participants were enrolled after informed consent. Participant confidentiality was maintained during data handling and analysis. Data integrity was supported through structured data recording, review of entered values for completeness and plausibility, consistent coding of categorical variables, and verification of continuous Doppler and blood pressure entries before statistical analysis. The study was reported as an observational comparative analysis, and interpretation was restricted to associations and diagnostic discrimination rather than causal inference.

RESULTS

A total of 79 pregnant women beyond 20 weeks of gestation were included in the analysis. The mean maternal age was 29.77 ± 6.49 years, with an age range of 20 to 40 years. The mean gestational age was 29.13 ± 5.58 weeks, indicating that the study population included women from mid-pregnancy onward rather than only third-trimester pregnancies. The mean gravida was 2.34 ± 1.07, with values ranging from 1 to 4. The overall mean systolic blood pressure was 142.18 ± 16.86 mmHg, while the mean diastolic blood pressure was 91.22 ± 12.06 mmHg. Doppler assessment showed a mean uterine artery pulsatility index of 1.37 ± 0.29 and mean uterine artery resistive index of 0.67 ± 0.14. The mean umbilical artery pulsatility index was 1.22 ± 0.24, mean umbilical artery resistive index was 0.70 ± 0.12, and mean systolic/diastolic ratio was 3.75 ± 1.02. The descriptive profile demonstrates that the cohort had elevated average blood pressure values and measurable uteroplacental and fetoplacental Doppler resistance indices across the full study sample.

Table 1. Descriptive Statistics of Maternal Clinical and Doppler Variables Among Pregnant Women Beyond 20 Weeks of Gestation (N = 79)

Variable	N	Minimum	Maximum	Mean	Standard Deviation
Age, years	79	20	40	29.77	6.49
Gestational age, weeks	79	20	38	29.13	5.58
Gravida	79	1	4	2.34	1.07
Systolic blood pressure, mmHg	79	111	170	142.18	16.86
Diastolic blood pressure, mmHg	79	70	110	91.22	12.06
Uterine artery pulsatility index	79	0.80	1.77	1.37	0.29
Uterine artery resistive index	79	0.41	0.90	0.67	0.14
Umbilical artery pulsatility index	79	0.81	1.60	1.22	0.24
Umbilical artery resistive index	79	0.50	0.89	0.70	0.12
Systolic/diastolic ratio	79	2.05	5.49	3.75	1.02

Among categorical clinical variables, 45 women (57.0%) were recorded as having hypertension and 34 women (43.0%) were not hypertensive. Diabetes mellitus was present in 39 participants (49.4%), while

40 participants (50.6%) did not have diabetes mellitus. A previous history of pre-eclampsia was reported in 37 women (46.8%), thyroid disorder in 43 women (54.4%), and family history of pre-eclampsia in 30 women (38.0%). All participants had singleton pregnancies; therefore, multiple pregnancy was a constant variable and was not suitable for inferential comparison. Proteinuria was present in 36 participants (45.6%) and absent in 43 participants (54.4%). Overall, 71 participants (89.9%) were diagnosed with pre-eclampsia, while 8 participants (10.1%) were classified as non-pre-eclamptic, confirming a highly imbalanced diagnostic distribution.

Table 2. Frequency Distribution of Maternal Risk Factors and Diagnostic Variables (N = 79)

Variable / Category	Frequency	Percentage
Hypertension — No	34	43.0
Hypertension — Yes	45	57.0
Diabetes mellitus — No	40	50.6
Diabetes mellitus — Yes	39	49.4
Previous pre-eclampsia — No	42	53.2
Previous pre-eclampsia — Yes	37	46.8
Thyroid disorder — No	36	45.6
Thyroid disorder — Yes	43	54.4
Family history of pre-eclampsia — No	49	62.0
Family history of pre-eclampsia — Yes	30	38.0
Multiple pregnancy — No	79	100.0
Proteinuria — No	43	54.4
Proteinuria — Yes	36	45.6
Pre-eclampsia diagnosis — No	8	10.1
Pre-eclampsia diagnosis — Yes	71	89.9

The association analysis between categorical maternal variables and pre-eclampsia diagnosis showed that proteinuria was the only variable significantly associated with diagnosis. Proteinuria demonstrated a chi-square value of 7.452 with 1 degree of freedom and a statistically significant p-value of 0.006. All 36 women with proteinuria were diagnosed with pre-eclampsia, while among the 43 women without proteinuria, 35 were diagnosed with pre-eclampsia and 8 were not diagnosed with pre-eclampsia. Hypertension was not significantly associated with diagnosis when analyzed as a categorical variable ($\chi^2 = 0.111$, $p = 0.739$), despite being present in 57.0% of the total sample. Diabetes mellitus ($\chi^2 = 0.614$, $p = 0.433$), thyroid disorder ($\chi^2 = 0.070$, $p = 0.791$), previous pre-eclampsia ($\chi^2 = 0.877$, $p = 0.349$), and family history of pre-eclampsia ($\chi^2 = 0.001$, $p = 0.977$) also showed no statistically significant association with diagnosis. Multiple pregnancy was not tested because it was constant across the sample.

Table 3. Association Between Maternal Categorical Variables and Pre-Eclampsia Diagnosis (N = 79)

Variable	Chi-Square	df	p-value
Hypertension	0.111	1	0.739
Diabetes mellitus	0.614	1	0.433
Thyroid disorder	0.070	1	0.791
Previous pre-eclampsia	0.877	1	0.349
Family history of pre-eclampsia	0.001	1	0.977
Multiple pregnancy	—	—	—
Proteinuria	7.452	1	0.006

Blood pressure and selected Doppler indices were further examined using correlation analysis. Systolic blood pressure showed a weak but statistically significant positive correlation with umbilical artery pulsatility index, indicating that higher systolic blood pressure was associated with higher umbilical artery vascular impedance. The Pearson correlation coefficient was $r = 0.284$ with $p = 0.011$, and this finding was supported by Spearman correlation, which showed $\rho = 0.279$ with $p = 0.013$. Diastolic blood pressure showed a weak but statistically significant negative correlation with uterine artery resistive index, with Pearson $r = -0.266$ and $p = 0.018$, supported by Spearman $\rho = -0.276$ and $p = 0.014$. Although these correlations were statistically significant, their magnitude was weak, indicating limited linear association at the individual-patient level.

Table 4. Significant Correlations Between Blood Pressure and Doppler Indices

Clinical Variable	Doppler Variable	Pearson r	Pearson p-value	Spearman ρ	Spearman p-value
Systolic blood pressure	Umbilical artery pulsatility index	0.284	0.011	0.279	0.013
Diastolic blood pressure	Uterine artery resistive index	−0.266	0.018	−0.276	0.014

Screening of continuous and diagnostic variables suggested that blood pressure parameters and gravida were among the strongest individual contributors to pre-eclampsia classification. Diastolic blood pressure showed the highest individual score statistic (Score = 10.413, p = 0.001), followed by systolic blood pressure (Score = 8.687, p = 0.003), gravida (Score = 8.363, p = 0.004), and proteinuria (Score = 7.452, p = 0.006). However, the full binary logistic regression model demonstrated complete separation and did not converge, making individual regression coefficients unsuitable for clinical interpretation. Therefore, these screening statistics should be interpreted as indicators of univariable association rather than independent adjusted predictors.

Table 5. Univariable Screening Statistics for Variables Contributing to Pre-Eclampsia Classification

Variable	Score Statistic	p-value
Diastolic blood pressure	10.413	0.001
Systolic blood pressure	8.687	0.003
Gravida	8.363	0.004
Proteinuria	7.452	0.006

Receiver operating characteristic analysis was performed to assess the diagnostic discrimination of Doppler indices for pre-eclampsia diagnosis. Among the five Doppler measures evaluated, umbilical artery resistive index showed the highest area under the curve, with an AUC of 0.663, indicating fair but limited discriminatory ability. Umbilical artery pulsatility index had an AUC of 0.547 and the systolic/diastolic ratio had an AUC of 0.525, both reflecting poor diagnostic discrimination. Uterine artery pulsatility index had an AUC of 0.456, and uterine artery resistive index had an AUC of 0.404, indicating that these uterine artery indices did not discriminate pre-eclampsia diagnosis effectively in this imbalanced high-risk sample. Overall, the ROC findings suggest that individual Doppler indices alone had limited diagnostic value, with umbilical artery resistive index performing better than the other measured Doppler parameters.

Table 6. Diagnostic Accuracy of Doppler Indices for Pre-Eclampsia Diagnosis Based on ROC Analysis

Doppler Measure	AUC
Uterine artery pulsatility index	0.456
Uterine artery resistive index	0.404
Umbilical artery pulsatility index	0.547
Umbilical artery resistive index	0.663
Systolic/diastolic ratio	0.525

In summary, this comparative cross-sectional analysis of 79 pregnant women showed a high prevalence of pre-eclampsia diagnosis, with 71 participants (89.9%) classified as pre-eclamptic and 8 participants (10.1%) classified as non-pre-eclamptic. Proteinuria was significantly associated with diagnosis (χ^2 = 7.452, p = 0.006), but its interpretation requires caution because it is closely linked to clinical diagnostic criteria. Blood pressure parameters showed the strongest univariable contribution to classification, with diastolic blood pressure demonstrating the highest score statistic (10.413, p = 0.001). Doppler indices showed limited standalone diagnostic accuracy, although umbilical artery resistive index had the highest AUC at 0.663. These findings indicate that, within this high-risk and diagnostically imbalanced sample, Doppler indices were more clinically interpretable as supportive haemodynamic markers than as independent diagnostic tools.

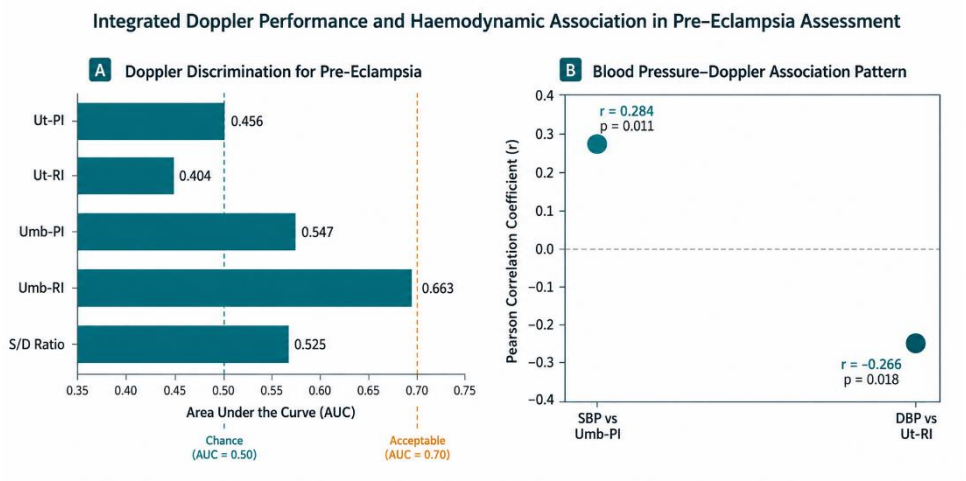

Figure 1. Integrated Doppler Performance and Haemodynamic Association in Pre-Eclampsia Assessment.

Panel A shows the comparative diagnostic discrimination of Doppler indices for pre-eclampsia diagnosis, with umbilical artery resistive index demonstrating the highest AUC value at 0.663, indicating fair but limited discrimination, while umbilical artery pulsatility index (AUC = 0.547), systolic/diastolic ratio (AUC = 0.525), uterine artery pulsatility index (AUC = 0.456), and uterine artery resistive index (AUC = 0.404) showed poor standalone diagnostic performance. Panel B demonstrates the significant haemodynamic associations identified in the study, where systolic blood pressure showed a weak positive correlation with umbilical artery pulsatility index ($r = 0.284$, $p = 0.011$), while diastolic blood pressure showed a weak negative correlation with uterine artery resistive index ($r = -0.266$, $p = 0.018$). Together, the pattern suggests that umbilical artery resistance may provide more clinically interpretable Doppler information than uterine artery indices in this high-risk, diagnostically imbalanced sample, although the weak correlation magnitudes and modest AUC values support its use as an adjunctive rather than independent diagnostic marker.

DISCUSSION

This comparative cross-sectional study evaluated maternal clinical risk factors and ultrasound Doppler indices among 79 pregnant women beyond 20 weeks of gestation, of whom 71 participants (89.9%) were diagnosed with pre-eclampsia and 8 participants (10.1%) were classified as non-pre-eclamptic. The cohort represented a high-risk tertiary-care population, as reflected by the elevated mean systolic blood pressure of 142.18 ± 16.86 mmHg and mean diastolic blood pressure of 91.22 ± 12.06 mmHg. The principal findings were that proteinuria showed a statistically significant association with pre-eclampsia diagnosis, blood pressure parameters demonstrated the strongest univariable contribution to classification, and Doppler indices showed limited standalone diagnostic accuracy, with umbilical artery resistive index showing the highest but still modest discriminatory value. These findings support the clinical value of integrated maternal and Doppler assessment, while also showing that isolated Doppler indices should not be interpreted as independent diagnostic tools in a highly imbalanced high-risk sample.

Proteinuria was the only categorical variable significantly associated with pre-eclampsia diagnosis, with a chi-square value of 7.452 and $p = 0.006$. All 36 participants with proteinuria were diagnosed with pre-eclampsia, while among the 43 participants without proteinuria, 35 were still diagnosed with pre-eclampsia and 8 were not diagnosed with pre-eclampsia. This pattern confirms the diagnostic importance of proteinuria but also highlights an important interpretive limitation: proteinuria is closely related to the clinical definition of pre-eclampsia and should therefore be interpreted as a diagnostic-associated marker rather than an independent causal risk factor. The persistence of pre-eclampsia diagnosis among participants without proteinuria is also clinically relevant because contemporary diagnostic approaches recognize that pre-eclampsia may occur with maternal organ dysfunction even in the absence of marked proteinuria. Therefore, the study findings support continued evaluation of

proteinuria as part of maternal assessment, but they do not justify treating proteinuria as a standalone predictor independent of diagnostic criteria.

Other maternal clinical factors, including hypertension, diabetes mellitus, thyroid disorder, previous pre-eclampsia, and family history of pre-eclampsia, did not show statistically significant categorical associations with diagnosis in the available analysis. This finding should not be interpreted as evidence that these variables are clinically unimportant. Instead, the lack of significant association is likely influenced by the severe diagnostic imbalance of the sample, where only 8 women were non-pre-eclamptic. Such imbalance limits statistical power, reduces between-group contrast, and may obscure associations that would be detectable in a larger and more evenly distributed comparative cohort. Previous literature has consistently identified advanced maternal age, primigravidity, obesity, pre-existing hypertension, diabetes mellitus, renal disease, previous pre-eclampsia, and family history as relevant risk factors for pre-eclampsia, indicating that the present null findings are more likely related to sample structure than biological absence of association (13–17).

The univariable screening statistics showed that blood pressure parameters were the strongest contributors to pre-eclampsia classification. Diastolic blood pressure had the highest score statistic (10.413, $p = 0.001$), followed by systolic blood pressure (8.687, $p = 0.003$), gravida (8.363, $p = 0.004$), and proteinuria (7.452, $p = 0.006$). These findings are clinically plausible because sustained blood pressure elevation after 20 weeks of gestation remains central to pre-eclampsia recognition and risk monitoring. The relevance of gravida is also biologically plausible because primigravidity and lower parity have been associated with increased pre-eclampsia risk, potentially reflecting immunological and vascular adaptation mechanisms during pregnancy (16,20). However, because the logistic regression model demonstrated complete separation and failed to converge, these variables cannot be interpreted as independent adjusted predictors from the current dataset. The non-convergent model indicates that standard maximum likelihood logistic regression was unsuitable for this imbalanced dataset, and future analysis would require a larger control group or penalized approaches such as Firth logistic regression.

The correlation analysis provided additional haemodynamic insight. Systolic blood pressure showed a weak but statistically significant positive correlation with umbilical artery pulsatility index (Pearson $r = 0.284$, $p = 0.011$; Spearman $\rho = 0.279$, $p = 0.013$), suggesting that higher maternal systolic pressure was associated with greater umbilical artery impedance. This finding is consistent with the pathophysiological basis of pre-eclampsia, where endothelial dysfunction, abnormal placentation, and increased placental vascular resistance may affect both maternal blood pressure and fetoplacental circulation. Although the correlation magnitude was weak, its direction supports the concept that maternal haemodynamic stress may be accompanied by measurable changes in umbilical artery Doppler indices. Previous work has shown that abnormal umbilical artery and middle cerebral artery Doppler patterns may help identify foetal compromise and adverse perinatal outcomes in pre-eclamptic pregnancies, especially when Doppler indices are interpreted in combination rather than individually (21).

Diastolic blood pressure showed a weak negative correlation with uterine artery resistive index (Pearson $r = -0.266$, $p = 0.018$; Spearman $\rho = -0.276$, $p = 0.014$). This inverse association should be interpreted cautiously because it may reflect the heterogeneity of disease onset, gestational age, referral pattern, or vascular adaptation in the cohort rather than a simple physiological relationship. Uterine artery indices are generally considered markers of uteroplacental resistance and impaired spiral artery remodeling, but their diagnostic utility varies across populations, gestational windows, and risk profiles. Meta-analytic evidence has shown that uterine artery pulsatility index can contribute to pre-eclampsia prediction, but its performance is influenced by timing of assessment, population risk level, and whether it is combined with maternal factors or biomarkers (15). In the present study, uterine artery indices were weak diagnostic discriminators, suggesting that their isolated value in an already high-risk referral population may be limited.

The ROC analysis further supports cautious interpretation of Doppler findings. Umbilical artery resistive index had the highest AUC value at 0.663, indicating fair but limited discrimination. Umbilical artery pulsatility index had an AUC of 0.547 and the systolic/diastolic ratio had an AUC of 0.525, while uterine artery pulsatility index and uterine artery resistive index showed AUC values of 0.456 and 0.404, respectively. These findings indicate that individual Doppler indices, particularly uterine artery indices, were not strong standalone diagnostic markers in this sample. This contrasts with studies reporting better diagnostic performance of uterine artery Doppler when used in first- or second-trimester screening models, especially when combined with maternal risk factors, placental biomarkers, or additional Doppler parameters (19,22,24–26). The discrepancy is likely explained by the timing and composition of the present cohort, which included a high proportion of already diagnosed pre-eclamptic participants and a very small comparison group.

The relatively better performance of umbilical artery resistive index compared with uterine artery indices may reflect the clinical stage at which participants were assessed. Uterine artery Doppler is more directly linked to maternal-side placentation and may be more useful earlier in pregnancy, whereas umbilical artery indices may better reflect fetoplacental resistance once placental disease has become clinically evident. Prior studies have suggested that combined foetal Doppler assessment, including umbilical artery, middle cerebral artery, and cerebroplacental ratio, may improve interpretation of foetal compromise in pre-eclampsia compared with reliance on a single index (21). Since middle cerebral artery Doppler and cerebroplacental ratio were not included in the available analysis, the present study cannot determine whether combined foetal Doppler markers would have improved diagnostic or prognostic performance.

The study has several important limitations. The sample size was modest and the diagnostic groups were highly imbalanced, with only 8 non-pre-eclamptic participants, limiting the reliability of comparative statistics and multivariable modelling. The cross-sectional design prevents causal inference and does not allow assessment of temporal progression from maternal risk factors to Doppler abnormalities or adverse outcomes. The study objective originally referred to severity and maternal or foetal outcomes, but the available dataset did not include severity classification, neonatal outcome measures, foetal growth outcomes, delivery timing, or maternal complication endpoints; therefore, interpretation must remain restricted to diagnosis-associated clinical and Doppler variables. Doppler ultrasound is also operator-dependent, and reproducibility would be strengthened by reporting machine specifications, operator training, blinding, repeated measurement procedures, and intra- or interobserver reliability. Despite these limitations, the study provides useful local evidence showing that Umb-RI may be the most informative single Doppler index in this dataset, while also reinforcing that Doppler indices should be interpreted as adjunctive markers within a broader clinical assessment framework.

CONCLUSION

This comparative cross-sectional study of 79 pregnant women beyond 20 weeks of gestation found that pre-eclampsia was present in 71 participants (89.9%), reflecting a high-risk tertiary-care population. Proteinuria was significantly associated with pre-eclampsia diagnosis ($\chi^2 = 7.452$, $p = 0.006$), while diastolic blood pressure, systolic blood pressure, gravida, and proteinuria showed significant univariable contribution to diagnostic classification. Doppler indices demonstrated limited standalone diagnostic accuracy, with umbilical artery resistive index showing the highest discrimination among measured Doppler parameters (AUC = 0.663), whereas uterine artery indices and systolic/diastolic ratio showed poor discrimination. Systolic blood pressure was weakly but significantly correlated with umbilical artery pulsatility index, and diastolic blood pressure was weakly negatively correlated with uterine artery resistive index, suggesting measurable but modest haemodynamic associations. Overall, the findings indicate that Doppler ultrasound may provide supportive information in the evaluation of pre-eclampsia, particularly through umbilical artery resistance assessment, but should be interpreted alongside blood pressure, proteinuria, and maternal clinical risk factors rather than used as an isolated diagnostic tool.

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