First Trimester Uterine Artery Doppler US For Prediction Of Pre-Eclampsia In Individuals At Risk In Erbil Maternity Teaching Hospital

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Abstract

Background:
Pre-eclampsia remains a leading cause of maternal and perinatal morbidity and mortality worldwide. Because the pathological processes underlying pre-eclampsia begin early in pregnancy, first-trimester uterine artery Doppler ultrasonography has been proposed as a noninvasive tool for early risk prediction, particularly in high-risk populations.
Objective:
To evaluate the effectiveness and diagnostic performance of first-trimester uterine artery Doppler ultrasonography in predicting the development of pre-eclampsia among pregnant women at high risk.
Methods:
This prospective observational study was conducted at Erbil Maternity Teaching Hospital between January and October 2025. Fifty pregnant women with established risk factors for pre-eclampsia underwent uterine artery Doppler ultrasonography at 11–14 weeks of gestation. The mean uterine artery pulsatility index (PI) and the presence of early bilateral deep diastolic notching were assessed. Participants were followed until delivery to determine the occurrence of pre-eclampsia. Diagnostic accuracy was evaluated using receiver operating characteristic (ROC) curve analysis, and predictors were examined using multivariable logistic regression analysis.
Results:
Pre-eclampsia developed in 10 (20%) of the participants. The first-trimester mean uterine artery PI demonstrated moderate predictive accuracy for pre-eclampsia (AUC = 0.774; 95% CI: 0.644–0.903; p = 0.008). A PI cut-off value of ≥2.55 yielded a sensitivity of 70% and a specificity of 70%. Early bilateral deep diastolic notching in uterine artery was significantly associated with the development of pre-eclampsia (OR = 16.7; 95% CI: 1.9–145.8; p = 0.003) and remained an independent predictor after adjustment (adjusted OR = 11.37; 95% CI: 1.15–112.14; p = 0.037).
Conclusion:
First-trimester uterine artery Doppler ultrasonography shows moderate accuracy in predicting pre-eclampsia among high-risk pregnancies, with early bilateral deep diastolic notching in uterine artery providing strong independent prognostic value. As a readily available and cost-effective screening modality, uterine artery Doppler assessment may support early risk stratification and targeted antenatal surveillance, particularly in resource-limited settings.

Keywords: Pre-eclampsia; Uterine artery Doppler; First trimester; Pulsatility index; High-risk pregnancy; Prediction; Maternal outcomes.

Introduction

Pre-eclampsia (PE) is a pregnancy-specific disorder occurring after 20 weeks of gestation, defined by new-onset hypertension (typically >149/90) and protein in the urine or end-organ dysfunction. Eclampsia is the severe, life-threatening progression of preeclampsia, defined by the development of generalized seizures or coma, remains one of the most severe complications of pregnancy and continues to be a leading cause of maternal and perinatal morbidity and mortality worldwide [1]. It affects approximately 2%–8% of pregnancies globally and is associated with tens of thousands of maternal deaths and hundreds of thousands of fetal and neonatal deaths each year [2].

PE primarily develops because of abnormal placentation. Inadequate trophoblastic invasion of the uterine spiral arterioles prevents normal vascular remodeling, resulting in increased resistance within the uteroplacental circulation. This process leads to reduced placental perfusion and widespread maternal endothelial dysfunction, ultimately contributing to the development of hypertension and other systemic complications [3–5].

Because these pathological placental changes occur very early in pregnancy, often long before the clinical signs of PE become apparent, early screening and risk prediction strategies are critically important [6].

First-trimester uterine artery Doppler ultrasonography (UtA-Doppler) has emerged as one of the most widely studied methods for the early identification of abnormal uteroplacental blood flow and has developed into a noninvasive and reproducible diagnostic technique [7]. Several longitudinal studies have demonstrated that elevated first-trimester mean uterine artery pulsatility index (PI), a Doppler-derived measure that reflects resistance to blood flow within a vessel, and bilateral deep diastolic notching are significantly associated with an increased risk of developing PE, as well as other adverse pregnancy outcomes such as intrauterine growth restriction (IUGR) and preterm birth [8,9].

In addition, previous research has reported that first-trimester uterine artery Doppler ultrasonography demonstrates moderate predictive value for early-onset PE and other hypertensive disorders of pregnancy, highlighting its potential clinical utility as a screening tool [10].

Due to its noninvasive nature, ease of performance, and availability during routine first-trimester ultrasound examinations, uterine artery Doppler assessment enables the early identification of women at increased risk before the onset of clinical disease. Consequently, UtA-Doppler has been proposed as a useful and cost-effective screening method, particularly in low-resource settings [11,12].

In settings such as the Kurdistan Region of Iraq, where access to advanced screening and intensive antenatal surveillance may be limited, early and accessible predictive tools are essential. Therefore, this study was conducted at Erbil Maternity Teaching Hospital to evaluate the usefulness of first-trimester uterine artery Doppler ultrasonography in predicting adverse pregnancy outcomes, particularly pre-eclampsia. Specifically, the study aims to assess its role among at-risk pregnant women by describing their sociodemographic and clinical characteristics, determining the occurrence of pre-eclampsia, examining the relationship between uterine artery Doppler indices measured at 11–14 weeks of gestation and subsequent development of pre-eclampsia, and evaluating the effectiveness of this screening method in identifying women at increased risk.

Methodology

Ethical approval for this study was obtained from the Medical Research Scientific and Ethics Committee of the Kurdistan Higher Council of Medical Specialties (KHCMS) prior to data collection. The study was conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants after a full explanation of the study objectives, procedures, potential benefits, and risks, and confidentiality was ensured using coded identifiers.

This prospective observational cohort study was conducted at Erbil Maternity Teaching Hospital in Erbil City, Kurdistan Region of Iraq, the largest tertiary maternity referral center in the region. The study was carried out over a nine-month period from 1st January 2025 to 31st October 2025, during which pregnant women were recruited in the first trimester and followed throughout pregnancy to assess the development of pre-eclampsia.

The study population included pregnant women attending the antenatal care clinic in the first trimester (≤13 weeks of gestation) who had at least one known risk factor for pre-eclampsia. A non-probability convenience sampling technique was used, whereby eligible women were consecutively recruited after screening. Of 68 women initially assessed, 18 were excluded due to ineligibility or refusal to participate, resulting in a final sample of 50 participants who completed follow-up until delivery. This sample size was considered appropriate based on feasibility, the exploratory nature of the study, and consistency with similar preliminary studies.

Inclusion criteria comprised first-trimester pregnancy, presence of one or more risk factors for pre-eclampsia (including previous pre-eclampsia, chronic hypertension, diabetes mellitus, renal or autoimmune disease, advanced maternal age, obesity, or family history), confirmed viable pregnancy, ability to comply with study procedures, and provision of informed consent. Exclusion criteria included non-viable pregnancy, major fetal anomalies, severe maternal illness requiring urgent intervention, inability or unwillingness to comply with study procedures, use of medications affecting uteroplacental blood flow, and language barriers preventing informed consent (Figure 1).

Data collection was performed using structured questionnaires, face-to-face interviews, clinical examination, and review of antenatal records. Collected data included sociodemographic characteristics, obstetric history, clinical risk factors, blood pressure measurements, uterine artery Doppler indices, and maternal and fetal outcomes.

All participants underwent uterine artery Doppler ultrasonography between 11 and 14 weeks of gestation using a **GE** Voluson E6 ultrasound machine (GE Healthcare, USA) as part of routine first-trimester assessment. The uterine arteries were identified at the cervico-uterine junction using color Doppler imaging, and pulsed Doppler was applied with an insonation angle of less than 60°. Doppler waveforms were obtained from at least three consecutive cardiac cycles, and the pulsatility index (PI) was measured for both right and left uterine arteries, with calculation of the mean PI. The presence of bilateral deep diastolic notching was also assessed. All examinations were conducted using a standardized protocol by experienced radiologists who were blinded to pregnancy outcomes.

Participants were followed throughout pregnancy via routine antenatal visits and medical record review until delivery. The primary outcome was the development of pre-eclampsia after 20 weeks of gestation, defined by blood pressure ≥140/90 mmHg on two occasions, with proteinuria and/or evidence of maternal organ dysfunction. Complete maternal and fetal outcome data were recorded for all participants.

Statistical analysis was performed using SPSS version 27. Continuous variables were summarized using mean ± standard deviation or median with interquartile range, while categorical variables were presented as frequencies and percentages. Group comparisons were conducted using independent t-tests or Mann–Whitney U tests, and categorical variables were analyzed using Chi-square or Fisher's exact tests. Receiver operating characteristic (ROC) curve analysis was used to assess the predictive performance of uterine artery Doppler indices, and multivariable logistic regression was performed to identify independent predictors of pre-eclampsia. A p-value <0.05 was considered statistically significant.

Measures to reduce bias included consecutive recruitment, standardized data collection procedures, use of the same ultrasound equipment, and blinding of radiologists to outcomes. Blood pressure measurements were obtained using calibrated instruments, and data quality was ensured through regular review and verification. Data were securely stored in a password-protected database, with paper records kept in locked cabinets, and all information was retained in accordance with institutional policy.

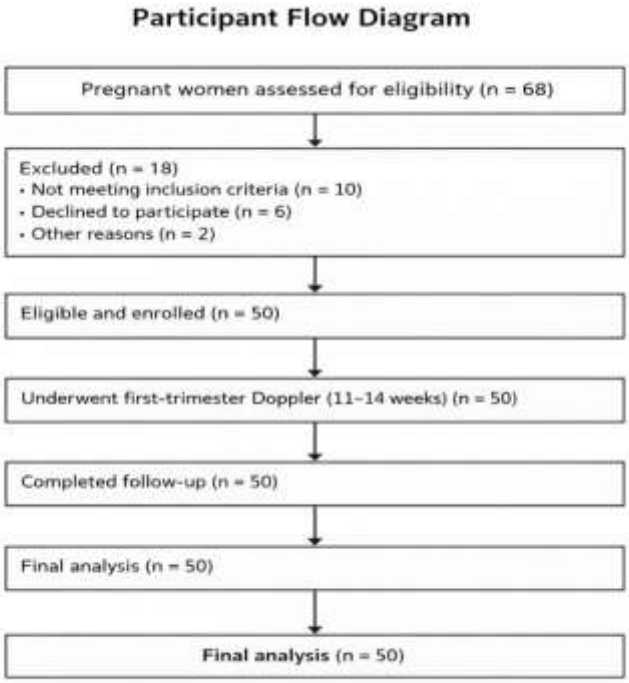

Figure 1. Participant flow diagram illustrating the recruitment, eligibility screening, enrollment, follow-up, and final analysis of pregnant women included in the study.

Results

A total of 50 pregnant women were included in the study. The majority of participants were aged 18–35 years (84.0%), while 16.0% were aged ≥36 years. According to the WHO BMI classification, obesity was highly prevalent, with 66.0% of women categorized as obese and 28.0% overweight, whereas only 6.0% had a normal BMI.

Most participants were parous (78.0%), educated (94.0%), and resided in urban areas (96.0%). The majority belonged to the middle socioeconomic class (84.0%), and 72.0% were housewives. A family history of hypertension was reported by 52.0% of participants, while none of the women were receiving antihypertensive medication during early pregnancy. However, 20.0% developed severe hypertension (≥160/110 mmHg) later in pregnancy (Table 1).

Table 1. Baseline Sociodemographic and Clinical Characteristics of the Study Participants (N = 50)

Variable	Category	Frequency (n)	Percentage (%)
Age group (years)	18–35	42	84.0
	≥36	8	16.0
BMI category (WHO classification)	Normal	3	6.0
	Overweight	14	28.0
	Obese class I	25	50.0
	Obese class II	4	8.0
	Obese class III	4	8.0
Parity status	Parous	39	78.0
	Nulliparous	11	22.0
Education level	Non-educated	3	6.0
	Educated	47	94.0
Socioeconomic status	Low	3	6.0
	Medium	42	84.0
	High	5	10.0
Residence	Rural	2	4.0
	Urban	48	96.0
Occupation	Housewife	36	72.0
	Employed	14	28.0
Family history of hypertension	Negative	24	48.0
	Positive	26	52.0
Hypertension under medication	No	50	100.0
Late pregnancy blood pressure	Normal	40	80.0
	≥160/110 mmHg	10	20.0

First-trimester uterine artery Doppler assessment demonstrated that most participants (66.0%) had a mean uterine artery pulsatility index (PI) between 1 and 2, while 20.0% exhibited markedly elevated PI values (>2.5).

Regarding early diastolic notch morphology, unilateral notching was observed in 54.0% of cases, bilateral notching in 34.0%, and deep bilateral notching in 12.0% of pregnancies.

These findings indicate that a considerable proportion of women demonstrated abnormal uteroplacental Doppler patterns during early pregnancy, suggesting increased placental vascular resistance (Table 2).

Table 2. Distribution of First-Trimester Uterine Artery Doppler Parameters (n = 50)

Parameter	Category	Frequency (n)	Percentage (%)
Mean uterine artery PI	1 – 2	33	66.0
	2 – 2.5	7	14.0
	> 2.5	10	20.0

Early diastolic notch	Unilateral	27	54.0
	Bilateral	17	34.0
	Deep bilateral	6	12.0

Women with elevated uterine artery PI had a substantially higher occurrence of preeclampsia compared with those with normal PI values (70.0% vs 2.5%, $\chi^2 = 27.121$, $p < 0.001$).
Similarly, early deep bilateral uterine artery notching showed a strong association with preeclampsia ($\chi^2 = 28.540$, $p < 0.001$). Notably, deep bilateral notching was present in 60.0% of women who developed preeclampsia but was not observed among normotensive pregnancies.
These findings highlight the potential importance of early Doppler abnormalities as markers of impaired placentation and subsequent hypertensive complications (Table 3).

Table 3. Association Between Doppler Findings and Development of Preeclampsia

Variable	Category	No PE (n=40)	PE (n=10)	Total	P-value
PI category	Normal PI	39 (97.5%)	3 (30.0%)	42	
	High PI	1 (2.5%)	7 (70.0%)	8	<0.001
Early diastolic notch	Unilateral	26 (65.0%)	1 (10.0%)	27	
	Bilateral	14 (35.0%)	3 (30.0%)	17	
	Deep bilateral	0 (0.0%)	6 (60.0%)	6	<0.001

Statistical tests: Chi-square test.

An increase in mean uterine artery PI during the first trimester was independently associated with a higher likelihood of preeclampsia (adjusted OR = 4.57, 95% CI: 1.38–15.12; p = 0.013).
Similarly, the presence of early deep bilateral uterine artery notching remained a significant independent predictor (adjusted OR = 3.71, 95% CI: 1.26–10.94; p = 0.017).
The regression model was statistically significant (Omnibus $\chi^2 = 22.4$, $p < 0.001$) and demonstrated good explanatory power, accounting for approximately 51% of the variance in preeclampsia occurrence (Nagelkerke $R^2 = 0.51$).
These results indicate that both quantitative (PI) and qualitative (notching) Doppler parameters provide independent predictive information for early identification of women at increased risk of preeclampsia (Table 4).

Table 4. Multivariable Binary Logistic Regression Analysis for Predictors of Preeclampsia

Predictor	B	SE	Wald χ^2	p-value	Adjusted OR	95% CI
Mean uterine artery PI (1st trimester)	1.52	0.61	6.21	0.013	4.57	1.38–15.12
Early deep bilateral uterine artery notch	1.31	0.55	5.66	0.017	3.71	1.26–10.94
Constant	−5.28	1.72	9.43	0.002	—	—

Model statistics:
Omnibus $\chi^2 = 22.4$, $p < 0.001$
Nagelkerke $R^2 = 0.51$

Receiver operating characteristic (ROC) analysis demonstrated that first-trimester mean uterine artery PI had moderate discriminative ability for predicting preeclampsia, with an area under the curve (AUC) of 0.774.
Using a cut-off value of PI ≥ 2.55, the test achieved a sensitivity of 70.0% and specificity of 97.5%, with positive predictive value (PPV) of 87.5%, negative predictive value (NPV) of 92.9%, and an overall accuracy of 92.0%.
In comparison, early bilateral uterine artery notching demonstrated higher sensitivity (90.0%) but lower specificity (65.0%), with an overall diagnostic accuracy of 70.0%.
These findings suggest that uterine artery PI provides stronger specificity for prediction, whereas bilateral notching may serve as a sensitive early screening marker (Table 5 and Figure 2).

Table 5. Diagnostic Performance of Uterine Artery Doppler Parameters for Predicting Preeclampsia

Test	Cut-off	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)	AUC

Mean uterine artery PI	≥2.55	70.0	97.5	87.5	92.9	92.0	0.774
Early bilateral uterine artery notch	—	90.0	65.0	39.1	96.3	70.0	—

AUC = Area Under Curve.

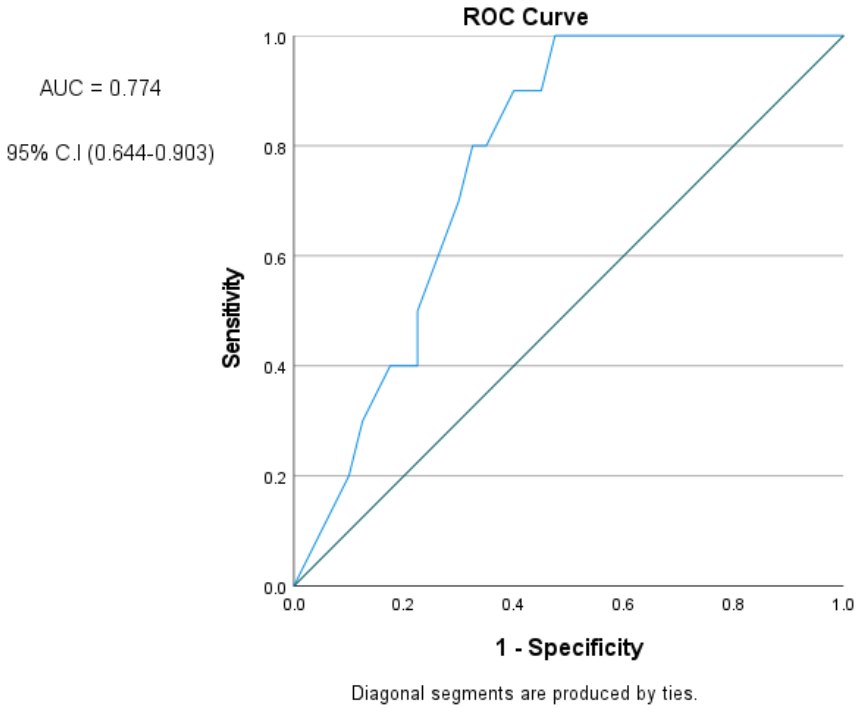

Figure 2. ROC curve of first-trimester mean uterine artery PI for prediction of preeclampsia.

Pregnancy outcomes differed significantly between women with normal uterine artery PI (<2.55) and those with elevated PI (≥2.55).

Women with elevated PI had a markedly higher incidence of preeclampsia (87.5% vs 7.1%; OR = 91.0; p < 0.001) and early-onset preeclampsia (OR = 66.5; p < 0.001).

Furthermore, elevated PI was significantly associated with several adverse perinatal outcomes, including low birth weight (OR = 20.0; p = 0.004), preterm delivery (OR = 12.0; p = 0.024), fetal growth restriction (OR = 21.7; p = 0.001), and neonatal intensive care unit (NICU) admission (OR = 20.0; p = 0.004). These findings indicate that elevated uterine artery resistance in early pregnancy is strongly associated with placental insufficiency–related complications and adverse neonatal outcomes (Table 6).

Table 6. Maternal and Neonatal Outcomes According to Uterine Artery PI Category

Variable	Normal PI (n=42)	High PI (n=8)	OR (95% CI)	p-value
Preeclampsia	3 (7.1%)	7 (87.5%)	91.0 (8.24–1005.04)	<0.001
Early-onset preeclampsia	4 (9.5%)	7 (87.5%)	66.50 (6.44–686.83)	<0.001
Low birth weight	2 (4.8%)	4 (50.0%)	20.00 (2.75–145.48)	0.004
Preterm delivery	2 (4.8%)	3 (37.5%)	12.00 (1.60–90.13)	0.024
Fetal growth restriction	3 (7.1%)	5 (62.5%)	21.67 (3.40–137.99)	0.001
NICU admission	2 (4.8%)	4 (50.0%)	20.00 (2.75–145.48)	0.004

Spearman correlation analysis demonstrated a strong positive correlation between mean uterine artery PI and preeclampsia (ρ = 0.661, p < 0.001).
Gestational age at birth showed a strong negative correlation with preeclampsia (ρ = −0.634, p < 0.001), indicating that pregnancies complicated by preeclampsia were associated with earlier delivery.
Maternal age showed a weak but statistically significant positive correlation with preeclampsia (ρ = 0.296, p = 0.037), whereas BMI was not significantly correlated with the occurrence of preeclampsia (ρ = 0.042, p = 0.774) (Figure 3).

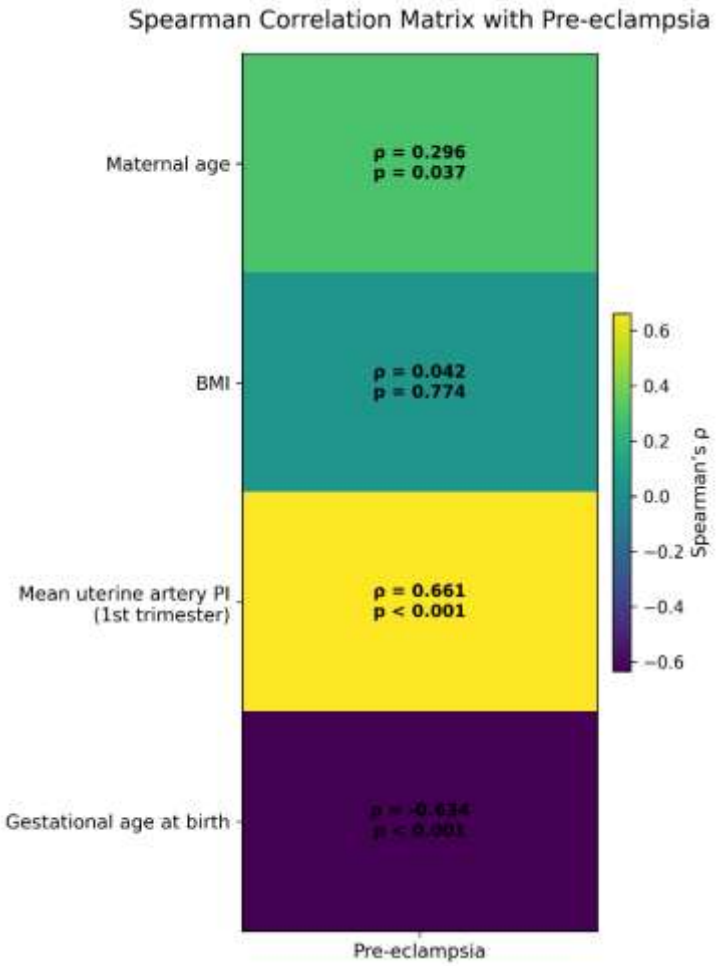

Figure 3. Spearman correlation matrix between maternal characteristics, Doppler parameters, and pre-eclampsia.

Discussion

The present prospective study evaluated the predictive value of first-trimester uterine artery Doppler ultrasonography for identifying high-risk pregnant women who may subsequently develop pre-eclampsia. The findings demonstrated that abnormal uterine artery Doppler parameters, particularly elevated mean uterine artery pulsatility index (PI) and the presence of early deep bilateral uterine artery notching, were significantly associated with the later development of pre-eclampsia. These findings reinforce the concept that impaired uteroplacental perfusion during early pregnancy represents a key pathophysiological mechanism underlying hypertensive disorders of pregnancy [13]
In this study, pre-eclampsia occurred in 20% of participants, reflecting the high-risk nature of the population included. This prevalence is comparable to that reported by Bartsch et al.'s meta-analysis focusing on high-risk pregnancies, where the incidence of pre-eclampsia ranged between 15% and 30% depending on maternal characteristics and

screening strategies [14]. The relatively high incidence observed in this study highlights the clinical importance of early screening strategies in women with established risk factors for hypertensive disorders of pregnancy.

A major finding of the present study was the strong association between increased first-trimester uterine artery pulsatility index and the development of pre-eclampsia. Receiver operating characteristic analysis demonstrated moderate predictive accuracy, with an AUC of 0.774, indicating that uterine artery Doppler assessment provides meaningful diagnostic information for early risk stratification. Similar predictive performance has been reported in previous investigations evaluating the role of uterine artery Doppler screening in early pregnancy. Large prospective studies by Plasencia et al. [15], Oancea et al. [16], and Melchiorre et al. [17] have shown that increased uterine artery PI reflects abnormal placental vascular development and is associated with an increased risk of both early-onset and late-onset pre-eclampsia. Plasencia et al. reported that uterine artery PI showed expected detection rate of PET that needed to be delivered before 34 weeks was 82% for a false-positive probability of 10%, compared to 31% for late PET [15]. Oancea et al. reported early uterine artery Doppler screening at 11–14 WA can identify pregnancies that would have PE with a sensitivity of 61.5% and a specificity of 63.8% based on PI analysis [16]. Melchiorre et al.

The biological explanation for this relationship lies in the abnormal placentation process that characterizes pre-eclampsia. During normal pregnancy, trophoblastic cells invade the maternal spiral arteries, transforming them into low-resistance vessels capable of providing adequate uteroplacental perfusion. In pregnancies complicated by pre-eclampsia, this remodeling process is incomplete, leading to increased vascular resistance and reduced placental blood flow [18]. Uterine artery Doppler ultrasonography allows non-invasive assessment of these hemodynamic changes, making it a valuable tool for detecting early placental dysfunction.

The optimal PI cut-off value identified in the present study (≥2.55) demonstrated high specificity and moderate sensitivity for predicting pre-eclampsia. High specificity suggests that women with markedly elevated uterine artery PI values are very likely to develop hypertensive complications during pregnancy. Similar findings have been reported in previous studies evaluating the diagnostic performance of Doppler screening [19,20]. Although Doppler screening alone cannot identify all cases of pre-eclampsia, it remains a valuable component of integrated screening models that combine maternal characteristics, biochemical markers, and ultrasound parameters.

Another important observation in this study was the strong association between early deep bilateral uterine artery notching and the development of pre-eclampsia. Bilateral deep notching remained a significant independent predictor in multivariable logistic regression analysis. Previous research has shown that the presence of early bilateral deep diastolic notching indicates increased uteroplacental vascular resistance and abnormal trophoblastic invasion of the spiral arteries [21,22].

Importantly, persistent uterine artery notching beyond the first trimester has been associated with continued impairment of placental vascular remodeling. Studies have demonstrated that deep bilateral notching that persists into the second and third trimesters is strongly associated with placental insufficiency and hypertensive disorders of pregnancy [23,24]. In the present study, deep bilateral notching detected during the first trimester may therefore represent an early marker of defective placental vascular adaptation that persists later in pregnancy and contributes to the development of pre-eclampsia.

The regression analysis further demonstrated that both quantitative Doppler measurements (PI) and qualitative Doppler findings (notching) independently predicted the development of pre-eclampsia. These results support previous research indicating that combining different Doppler parameters may enhance screening accuracy. Crovetto and colleagues reported that integrating uterine artery Doppler indices with maternal risk factors significantly improves the predictive performance of early screening algorithms [25].

Beyond predicting maternal hypertensive disorders, this study also demonstrated a strong association between abnormal uterine artery Doppler findings and adverse perinatal outcomes, including low birth weight, preterm delivery, fetal growth restriction, and neonatal intensive care unit admission. These findings are consistent with previous studies demonstrating that impaired uteroplacental circulation contributes to placental insufficiency and compromised fetal growth [26–28]. Reduced placental blood flow limits the transfer of oxygen and nutrients to the developing fetus, increasing the risk of intrauterine growth restriction and premature birth.

Correlation analysis in this study showed a strong positive relationship between uterine artery PI and pre-eclampsia, while gestational age at delivery was negatively correlated with the disorder. These findings are consistent with the

well-established association between hypertensive disorders of pregnancy and earlier delivery due to maternal or fetal complications [29,30].

Clinical Implications

The findings of this study have important implications for clinical practice, particularly in resource-limited healthcare settings. Uterine artery Doppler ultrasonography is a non-invasive, relatively inexpensive, and widely available imaging technique that can easily be incorporated into routine first-trimester ultrasound examinations. Early identification of women at increased risk of pre-eclampsia allows clinicians to implement preventive strategies such as low-dose aspirin prophylaxis, which has been shown to significantly reduce the incidence of pre-eclampsia when initiated before 16 weeks of gestation [31,32].

In regions such as the Kurdistan Region of Iraq, where access to advanced biochemical screening tests may be limited, uterine artery Doppler screening may represent a practical and cost-effective approach for improving early detection of high-risk pregnancies.

Strengths and Limitations

This study has several strengths. First, the prospective design allowed uterine artery Doppler measurements to be obtained before the development of clinical disease, reducing the likelihood of reverse causation. Second, Doppler examinations were performed using standardized protocols by experienced radiologists, which minimized measurement variability and enhanced reliability of the results. Third, this study provides important local evidence from the Kurdistan Region, where limited data are available regarding early screening for pre-eclampsia.

However, several limitations should also be acknowledged. The sample size was relatively small, which may limit the statistical power and generalizability of the findings. Larger multicenter studies are required to confirm the predictive performance of uterine artery Doppler screening in this population. Additionally, the study focused exclusively on women with pre-existing risk factors, which may limit extrapolation of the results to low-risk populations. Finally, biochemical markers such as placental growth factor (PlGF) and pregnancy-associated plasma protein-A (PAPP-A) were not included in the screening model. Previous studies have shown that combining Doppler parameters with biochemical markers improves the predictive accuracy of early screening strategies [33,34].

Conclusion

Overall, the findings of this study suggest that first-trimester uterine artery Doppler ultrasonography is a valuable tool for early identification of pregnant women at increased risk of pre-eclampsia, particularly among high-risk populations. Elevated mean uterine artery pulsatility index and early deep bilateral uterine artery notching were strongly associated with the development of pre-eclampsia and adverse perinatal outcomes. Incorporating uterine artery Doppler assessment into routine early pregnancy screening may facilitate early risk stratification and allow timely preventive interventions aimed at reducing maternal and neonatal morbidity.

Abbreviations

PE – Pre-eclampsia
UtA-Doppler – Uterine artery Doppler ultrasonography
PI – Pulsatility index
ROC – Receiver operating characteristic
AUC – Area under the curve
OR – Odds ratio
aOR – Adjusted odds ratio
CI – Confidence interval
PPV – Positive predictive value
NPV – Negative predictive value
ANC – Antenatal care
IUGR – Intrauterine growth restriction
NICU – Neonatal intensive care unit

SD – Standard deviation
IQR – Interquartile range

Declarations

Ethics Approval and Consent to Participate

Ethical approval for this study was obtained from the Research Ethics Committee of the relevant institutional authority. All procedures performed in this study were conducted in accordance with the ethical standards of the institutional research committee and with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment in the study.

Consent for Publication

Not applicable.

Availability of Data and Materials

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare that they have no competing interests.

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Author Contributions

Both authors contributed substantially to the study. Author 1 conceptualized the study, designed the methodology, supervised data collection, and contributed to manuscript drafting and revision. Author 2 participated in data collection, data analysis, interpretation of results, and manuscript preparation. Both authors reviewed and approved the final version of the manuscript.

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