Section: Miscellaneous

Original Research Article

PROSPECTIVE STUDY OF UTERINE ARTERY DOPPLER INDICES FOR PREDICTING PRE-ECLAMPSIA IN HIGH-RISK PREGNANCIES

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ABSTRACT

Background: Pre-eclampsia is an important hypertensive disorder of pregnancy associated with significant maternal and perinatal morbidity. Early identification of high-risk women is essential for closer antenatal surveillance and timely intervention. Uterine artery Doppler is a non-invasive method that reflects uteroplacental blood flow resistance and may help predict the subsequent development of pre-eclampsia. **Aim:** To evaluate the role of uterine artery Doppler indices in predicting pre-eclampsia among high-risk pregnant women attending a tertiary care hospital.

Materials and Methods: This hospital-based prospective observational study included 125 high-risk pregnant women with singleton viable pregnancies between 20 and 24 weeks of gestation. All participants underwent clinical evaluation, blood pressure measurement, baseline investigations, and uterine artery Doppler assessment. Doppler parameters studied included pulsatility index, resistance index, systolic-to-diastolic ratio, and the presence of unilateral or bilateral early diastolic notching. Participants were followed until delivery to assess the development of pre-eclampsia and maternal and perinatal outcomes. Data were entered into Microsoft Excel and analysed using IBM SPSS Statistics for Windows, version 27.0. A p-value <0.05 was considered statistically significant.

Results: Out of 125 high-risk pregnant women, 30 developed pre-eclampsia, giving an incidence of 24.00%. Women who developed pre-eclampsia had significantly higher maternal age, body mass index, mean arterial pressure, and higher prevalence of previous pre-eclampsia, chronic hypertension, and obesity. Mean uterine artery pulsatility index, resistance index, and systolic-to-diastolic ratio were significantly higher in the pre-eclampsia group compared with the normotensive group. Abnormal uterine artery Doppler findings were observed in 83.33% of women with pre-eclampsia compared with 17.89% of normotensive women. Mean PI >1.45 showed sensitivity of 80.00%, specificity of 85.26%, and accuracy of 84.00%. Combined abnormal Doppler findings showed sensitivity of 83.33%, specificity of 82.11%, and negative predictive value of 93.98%. Pre-eclampsia was significantly associated with preterm birth, fetal growth restriction, low birth weight, oligohydramnios, caesarean delivery, and neonatal intensive care unit admission.

Conclusion: Uterine artery Doppler is a useful non-invasive screening tool for predicting pre-eclampsia in high-risk pregnancies. Increased Doppler indices and bilateral notching are significantly associated with later development of pre-eclampsia. Incorporating Doppler assessment into high-risk antenatal care may improve early risk stratification and pregnancy outcomes.

Keywords: Pre-eclampsia; Uterine artery Doppler; High-risk pregnancy; Pulsatility index; Pregnancy outcome.

INTRODUCTION

Pre-eclampsia is one of the most important hypertensive disorders of pregnancy and remains a major cause of maternal, fetal and neonatal morbidity worldwide. It is classically diagnosed after 20 weeks of gestation and is characterised by new-onset hypertension with proteinuria or evidence of maternal organ dysfunction and uteroplacental compromise. The condition may progress rapidly and can involve the kidneys, liver, central nervous system, coagulation system and placenta. Because its clinical presentation is often silent in the early stages, prediction before the onset of overt disease is an important component of antenatal care, especially in women who already have high-risk features.[1] The pathogenesis of pre-eclampsia is closely related to abnormal placentation, endothelial dysfunction and altered maternal vascular response to pregnancy. In normal pregnancy, trophoblastic invasion converts the spiral arteries into low-resistance vessels capable of maintaining adequate uteroplacental perfusion. In pre-eclampsia, this remodelling is incomplete, leading to increased downstream resistance, reduced placental blood flow and release of antiangiogenic and inflammatory mediators into the maternal circulation. These changes explain why pre-eclampsia is not only a disorder of blood pressure but a multisystem disease with important consequences for both mother and fetus.[2] High-risk pregnancies require particular attention because the probability of developing pre-eclampsia is influenced by both maternal and obstetric characteristics. Women with chronic hypertension, previous pre-eclampsia, diabetes mellitus, renal disease, autoimmune disease, obesity, advanced maternal age, nulliparity, family history of pre-eclampsia or previous adverse placental outcomes are more likely to develop hypertensive complications. Identification of these women early in pregnancy allows clinicians to intensify surveillance, optimise modifiable risk factors, initiate preventive strategies where indicated and plan timely referral to higher-level care.[3] Although clinical risk-factor assessment is useful, it has limited accuracy when used alone. Therefore, modern prediction strategies increasingly combine maternal history with biophysical and biochemical markers. Among the biophysical tools, uterine artery Doppler has gained importance because it is non-invasive, reproducible and can be performed during routine obstetric ultrasonography. By assessing blood-flow impedance in the uterine arteries, Doppler examination provides indirect information about placental vascular development and uteroplacental resistance. Abnormal waveforms, particularly increased pulsatility index, increased resistance index, raised systolic-to-diastolic ratio and persistence of early diastolic notching, may indicate impaired trophoblastic invasion and increased risk of later pre-eclampsia.[4] Uterine artery Doppler indices are especially relevant in high-risk pregnancies because the pre-test probability of disease is already elevated in this group. In such women, abnormal Doppler findings may help distinguish those who require closer follow-up from those who may continue routine high-risk antenatal care. The pulsatility index is commonly considered one of the most useful parameters because it reflects the degree of downstream vascular resistance throughout the cardiac cycle. Resistance index and systolic-to-diastolic ratio also provide useful information, while the presence of unilateral or bilateral early diastolic notching may suggest persistent high-resistance uteroplacental circulation.[5] The timing of Doppler evaluation is also important. First-trimester screening allows early risk stratification and may support preventive interventions, while second-trimester assessment is useful because abnormal uterine artery resistance persisting beyond the period of placental development is more closely related to later placental dysfunction. In many tertiary care settings, uterine artery Doppler is practical because it can be incorporated into routine anomaly scans or targeted high-risk antenatal assessments without causing discomfort to the patient. This makes it a valuable investigation in resource-conscious clinical environments where advanced biochemical markers may not always be available.[6]

MATERIALS AND METHODS

This hospital-based prospective observational study was conducted in the Department of Obstetrics and Gynaecology at a tertiary care hospital. The study was designed to evaluate the usefulness of uterine artery Doppler indices in predicting the subsequent development of pre-eclampsia among pregnant women with one or more high-risk factors. A total of 125 high-risk pregnant women attending the antenatal outpatient department or admitted to the obstetric unit were enrolled in the study. Eligible participants were recruited consecutively after assessment of the inclusion and exclusion criteria. Each participant was followed prospectively until delivery to determine the occurrence of pre-eclampsia and other maternal and perinatal outcomes.

Inclusion Criteria

Pregnant women aged 18–40 years with a viable singleton pregnancy between 20 and 24 weeks of gestation were included. Women were considered high risk when they had one or more recognised risk factors for pre-eclampsia, including a previous history of pre-eclampsia, chronic hypertension, pregestational or gestational diabetes mellitus, chronic kidney disease, autoimmune disease, obesity, primigravidity, advanced maternal age, family history of pre-eclampsia, previous fetal growth restriction, previous unexplained stillbirth, or a long interpregnancy interval. Only women who provided written informed consent and were willing to undergo follow-up until delivery were enrolled.

Exclusion Criteria

Women with established pre-eclampsia at the time of recruitment, multiple pregnancy, major fetal congenital anomaly, molar pregnancy, active vaginal bleeding, haemodynamic instability, or serious maternal illness requiring immediate termination of pregnancy were excluded. Women with technically inadequate Doppler recordings, uncertain gestational age, or those who were unlikely to complete follow-up were also excluded.

Methodology

Gestational Age Assessment: Gestational age was determined from the first day of the last menstrual period and confirmed by an early pregnancy ultrasound examination. When there was a clinically significant discrepancy between menstrual dating and ultrasonographic dating, the gestational age estimated from the earliest available ultrasound examination was considered.

Clinical Evaluation: A detailed history was obtained from each participant, including maternal age, residence, socioeconomic status, parity, gravidity, previous obstetric outcomes, history of pre-eclampsia, family history of hypertension or pre-eclampsia, pre-existing medical disorders, medication use, smoking status, and interpregnancy interval. General physical and obstetric examinations were performed. Maternal height and weight were recorded, and body mass index was calculated in kilograms per square metre.

Blood Pressure and Mean Arterial Pressure: Blood pressure was measured using a calibrated sphygmomanometer or validated automated blood pressure device after the participant had rested for at least five minutes. The woman was seated or placed in a semi-recumbent position with the arm supported at the level of the heart. An appropriately sized cuff was used. Two blood pressure readings were obtained at least five minutes apart, and the average value was recorded. Mean arterial pressure was calculated using the formula: diastolic blood pressure plus one-third of the difference between systolic and diastolic blood pressure.

Baseline Laboratory Investigations: Baseline investigations included haemoglobin concentration, platelet count, serum creatinine, serum uric acid, liver transaminases, random or fasting blood glucose, and urinary protein assessment, wherever clinically indicated. Urinary protein was initially evaluated using a dipstick test. Women with suspected proteinuria underwent further assessment using a spot urine protein-to-creatinine ratio or 24-hour urinary protein estimation according to the hospital protocol.

Ultrasound and Uterine Artery Doppler Examination: Ultrasonography was performed using a standard ultrasound machine equipped with colour and pulsed-wave Doppler facilities. The examination included confirmation of fetal viability, fetal number, placental location, fetal biometry, estimated fetal weight, amniotic fluid volume, and exclusion of major structural abnormalities. Uterine artery Doppler assessment was performed by a trained radiologist or obstetrician using a standardised technique.

Doppler Technique: The uterine arteries were identified using colour Doppler at the level of their apparent crossover with the external iliac arteries. Pulsed-wave Doppler was applied with an appropriate sample volume, and the insonation angle was maintained as low as technically possible. At least three consecutive, uniform waveforms were obtained from each uterine artery. Measurements were taken during the absence of maternal and fetal movement to minimise artefacts.

Uterine Artery Doppler Parameters: The principal Doppler parameters recorded were the right and left uterine artery pulsatility index, resistance index, systolic-to-diastolic ratio, and the presence or absence of an early diastolic notch. The mean uterine artery pulsatility index and mean resistance index were calculated by averaging the values obtained from the right and left uterine arteries. The presence of unilateral or bilateral early diastolic notching was documented separately. Abnormal uterine artery Doppler was defined according to the gestational age-specific reference range used by the study institution, particularly a mean pulsatility index above the 95th percentile and/or the presence of bilateral early diastolic notching.

Follow-Up and Outcome Assessment: All enrolled women received routine antenatal care and were followed until delivery. At each antenatal visit, blood pressure, maternal weight gain, symptoms suggestive of pre-eclampsia, urine protein, fetal growth, and maternal or fetal complications were assessed. Additional laboratory investigations and fetal surveillance were performed whenever clinically indicated. The treating obstetric team remained responsible for clinical management, and Doppler findings did not interfere with standard care.

Diagnosis of Pre-Eclampsia: Pre-eclampsia was diagnosed when a previously normotensive woman developed systolic blood pressure of at least 140 mmHg and/or diastolic blood pressure of at least 90 mmHg after 20 weeks of gestation on two measurements, together with proteinuria. In the absence of proteinuria, pre-eclampsia was diagnosed when new-onset hypertension was associated with maternal organ dysfunction, including thrombocytopenia, renal impairment, impaired liver function, pulmonary oedema, persistent neurological symptoms, or uteroplacental dysfunction such as fetal growth restriction.

Statistical Analysis

Data were entered into Microsoft Excel and analysed using IBM SPSS Statistics for Windows, version 27.0. Continuous variables were expressed as mean ± standard deviation or median with interquartile range, while categorical variables were presented as frequencies and percentages. Appropriate tests, including Student's *t*-test, Mann–Whitney *U* test, chi-square test, and ROC curve analysis, were applied. A *p*-value <0.05 was considered statistically significant.

RESULTS

A total of 125 high-risk pregnant women were enrolled in the study and followed until delivery. Of these, 30 women (24.00%) developed pre-eclampsia, while 95 women (76.00%) remained normotensive throughout pregnancy.

Table 1: Baseline Demographic and Clinical Characteristics According to the Development of Pre-eclampsia

Table 1 compares the baseline demographic and clinical characteristics of women who developed pre-eclampsia with those who remained normotensive. The mean maternal age was significantly higher among women who developed pre-eclampsia (29.80 ± 4.60 years) compared to those who did not develop the disease (27.20 ± 4.10 years) (p=0.008). Similarly, the mean body mass index was significantly greater in the pre-eclampsia group (29.70 ± 3.80 kg/m²) than in the normotensive group (26.50 ± 3.40 kg/m²) (p<0.001), indicating that increased maternal age and obesity were important risk factors for the development of pre-eclampsia. Primigravidity was observed in 60.00% of women who developed pre-eclampsia compared with 40.00% among those who remained normotensive; however, the difference did not reach statistical significance (p=0.055). A previous history of pre-eclampsia was significantly more common among women who subsequently developed pre-eclampsia (33.33%) than among those who remained normotensive (12.63%) (p=0.009). Likewise, chronic hypertension was present in 26.67% of women with pre-eclampsia compared with only 8.42% of women without pre-eclampsia, demonstrating a statistically significant association (p=0.009). Obesity was identified in nearly half of the women who developed pre-eclampsia (46.67%), compared with 23.16% of women who remained normotensive, and this difference was statistically significant (p=0.013). Although diabetes mellitus and a family history of pre-eclampsia were more frequent among women who developed pre-eclampsia, the differences were not statistically significant (p=0.110 and p=0.060, respectively).

Table 2: Comparison of Mean Arterial Pressure and Uterine Artery Doppler Findings

Table 2 presents the comparison of mean arterial pressure and uterine artery Doppler parameters between women who developed pre-eclampsia and those who remained normotensive. Women who subsequently developed pre-eclampsia had significantly higher mean arterial pressure values at the time of Doppler assessment (96.80 ± 7.10 mmHg) compared with women who remained normotensive (88.60 ± 6.30 mmHg) (p<0.001). The mean uterine artery pulsatility index was significantly elevated in the pre-eclampsia group (1.72 ± 0.42) compared to the normotensive group (1.12 ± 0.28) (p<0.001). Similarly, the mean uterine artery resistance index was significantly higher among women who developed pre-eclampsia (0.68 ± 0.09) than among those who did not (0.54 ± 0.07) (p<0.001). The mean systolic-to-diastolic ratio was also markedly increased in the pre-eclampsia group (3.75 ± 0.81 versus 2.61 ± 0.59; p<0.001). With regard to qualitative Doppler findings, unilateral early diastolic notching was observed more frequently among women who developed pre-eclampsia (26.67%) than among normotensive women (14.74%), although the difference was not statistically significant (p=0.135). In contrast, bilateral early diastolic notching was present in more than half of the women who developed pre-eclampsia (53.33%) compared with only 6.32% of women who remained normotensive, representing a highly significant association (p<0.001). Furthermore, abnormal uterine artery Doppler findings were detected in 83.33% of women who developed pre-eclampsia compared with only 17.89% of women who remained normotensive (p<0.001).

Table 3: Association Between Abnormal Uterine Artery Doppler and Pre-eclampsia

Table 3 demonstrates the relationship between abnormal uterine artery Doppler findings and the occurrence of pre-eclampsia. Among the 125 participants, 42 women (33.60%) exhibited abnormal uterine artery Doppler findings, whereas 83 women (66.40%) had normal Doppler studies. Of the women with abnormal Doppler findings, 25 (59.52%) subsequently developed pre-eclampsia, while only 17 (40.48%) remained normotensive. In contrast, among women with normal Doppler findings, only 5 (6.02%) developed pre-eclampsia, whereas 78 (93.98%) remained normotensive. The association between abnormal uterine artery Doppler findings and the development of pre-eclampsia was highly significant (p<0.001).

Table 4: Predictive Performance of Uterine Artery Doppler Parameters for Pre-eclampsia

Table 4 evaluates the diagnostic performance of various uterine artery Doppler parameters for predicting pre-eclampsia. The mean pulsatility index greater than 1.45 demonstrated a sensitivity of 80.00% and specificity of 85.26%, with an overall diagnostic accuracy of 84.00%. The area under the ROC curve was 0.83 (95% CI: 0.73–0.92), indicating good discriminative ability for predicting pre-eclampsia (p<0.001). Additionally, the negative predictive value was high (93.10%), suggesting that women with normal PI values were unlikely to develop pre-eclampsia. The resistance index greater than 0.62 showed a sensitivity of 73.33%, specificity of 83.16%, and diagnostic accuracy of 80.80%, with an AUC of 0.78 (95% CI: 0.68–0.89) (p<0.001). Likewise, an S/D ratio greater than 3.20 yielded a sensitivity of 70.00%, specificity of 81.05%, and accuracy of 78.40%, with an AUC of 0.76 (95% CI: 0.65–0.86) (p<0.001). Bilateral early diastolic notching demonstrated the highest specificity (93.68%) and positive predictive value (72.73%) among all evaluated parameters, indicating that its presence strongly suggested an increased risk of pre-

eclampsia. However, its sensitivity was comparatively lower (53.33%), suggesting that many women who developed pre-eclampsia did not exhibit bilateral notching. The combined abnormal Doppler criterion showed the highest sensitivity (83.33%) and a high negative predictive value (93.98%), with an AUC of 0.83 (95% CI: 0.73–0.92) and an overall accuracy of 82.40%.

Table 5: Maternal and Perinatal Outcomes According to Pre-eclampsia Status

Table 5 compares maternal and perinatal outcomes between women who developed pre-eclampsia and those who remained normotensive. Preterm birth occurred in 43.33% of women with pre-eclampsia compared with only 10.53% of normotensive women, representing a highly significant difference (p<0.001). Similarly, fetal growth restriction was significantly more common among women with pre-eclampsia (40.00%) than among those without pre-eclampsia (8.42%) (p<0.001). Low birth weight was observed in half of the neonates born to mothers with pre-eclampsia (50.00%), compared with only 15.79% among the normotensive group (p<0.001). Oligohydramnios was also significantly more frequent in pregnancies complicated by pre-eclampsia (26.67% versus 8.42%; p=0.009). Furthermore, fetal distress occurred in 30.00% of pregnancies affected by pre-eclampsia compared with 12.63% of normotensive pregnancies (p=0.027). The rate of caesarean delivery was significantly higher among women with pre-eclampsia (63.33%) than among those without pre-eclampsia (41.05%) (p=0.033). Admission to the neonatal intensive care unit was required for 36.67% of neonates born to mothers with pre-eclampsia, compared with only 9.47% among neonates born to normotensive mothers (p<0.001), reflecting the greater neonatal morbidity associated with pre-eclampsia. Although stillbirth occurred more frequently among women with pre-eclampsia (6.67%) compared with normotensive women (1.05%), the difference did not achieve statistical significance (p=0.143).

Table 1: Baseline demographic and clinical characteristics according to the development of pre-eclampsia

Parameter	Pre-eclampsia (n=30)	No pre-eclampsia (n=95)	p-value
Maternal age, years, mean ± SD	29.80 ± 4.60	27.20 ± 4.10	0.008
Body mass index, kg/m², mean ± SD	29.70 ± 3.80	26.50 ± 3.40	<0.001
Primigravida	18 (60.00%)	38 (40.00%)	0.055
Previous history of pre-eclampsia	10 (33.33%)	12 (12.63%)	0.009
Chronic hypertension	8 (26.67%)	8 (8.42%)	0.009
Diabetes mellitus	7 (23.33%)	11 (11.58%)	0.110
Obesity	14 (46.67%)	22 (23.16%)	0.013
Family history of pre-eclampsia	9 (30.00%)	14 (14.74%)	0.060

Table 2: Comparison of mean arterial pressure and uterine artery Doppler findings

Parameter	Pre-eclampsia (n=30)	No pre-eclampsia (n=95)	p-value
Mean arterial pressure, mmHg	96.80 ± 7.10	88.60 ± 6.30	<0.001
Mean uterine artery pulsatility index	1.72 ± 0.42	1.12 ± 0.28	<0.001
Mean uterine artery resistance index	0.68 ± 0.09	0.54 ± 0.07	<0.001
Mean systolic-to-diastolic ratio	3.75 ± 0.81	2.61 ± 0.59	<0.001
Unilateral early diastolic notch	8 (26.67%)	14 (14.74%)	0.135
Bilateral early diastolic notch	16 (53.33%)	6 (6.32%)	<0.001
Abnormal uterine artery Doppler	25 (83.33%)	17 (17.89%)	<0.001

Table 3: Association between abnormal uterine artery Doppler and pre-eclampsia

Uterine artery Doppler result	Total, n (%)	Developed pre-eclampsia, n (%)	No pre-eclampsia, n (%)	p-value
Abnormal Doppler	42 (33.60%)	25 (59.52%)	17 (40.48%)	<0.001
Normal Doppler	83 (66.40%)	5 (6.02%)	78 (93.98%)	
Total	**125 (100.00%)**	**30 (24.00%)**	**95 (76.00%)**	

Table 4: Predictive performance of uterine artery Doppler parameters for pre-eclampsia

Doppler parameter	Sensitivity	Specificity	PPV	NPV	Accuracy	AUC (95% CI)	p-value
Mean PI >1.45	80.00%	85.26%	63.16%	93.10%	84.00%	0.83 (0.73–0.92)	<0.001
Mean RI >0.62	73.33%	83.16%	57.89%	90.80%	80.80%	0.78 (0.68–0.89)	<0.001
S/D ratio >3.20	70.00%	81.05%	53.85%	89.53%	78.40%	0.76 (0.65–0.86)	<0.001
Bilateral early diastolic notch	53.33%	93.68%	72.73%	86.41%	84.00%	0.74 (0.62–0.85)	<0.001
Combined abnormal Doppler	83.33%	82.11%	59.52%	93.98%	82.40%	0.83 (0.73–0.92)	<0.001

PI: pulsatility index; RI: resistance index; S/D: systolic-to-diastolic ratio; PPV: positive predictive value; NPV: negative predictive value; AUC: area under the receiver operating characteristic curve.

Table 5: Maternal and perinatal outcomes according to pre-eclampsia status

Outcome	Pre-eclampsia (n=30)	No pre-eclampsia (n=95)	p-value
Preterm birth	13 (43.33%)	10 (10.53%)	<0.001
Fetal growth restriction	12 (40.00%)	8 (8.42%)	<0.001
Low birth weight	15 (50.00%)	15 (15.79%)	<0.001
Oligohydramnios	8 (26.67%)	8 (8.42%)	0.009
Fetal distress	9 (30.00%)	12 (12.63%)	0.027
Caesarean delivery	19 (63.33%)	39 (41.05%)	0.033
Neonatal intensive care unit admission	11 (36.67%)	9 (9.47%)	<0.001
Stillbirth	2 (6.67%)	1 (1.05%)	0.143

DISCUSSION

A total of 125 high-risk pregnant women were followed in the present study, out of which 30 women developed pre-eclampsia, giving an incidence of 24.00%. This incidence is comparable to the high-risk cohort reported by Coleman et al. (2000), where 32 of 116 pregnancies developed pre-eclampsia, corresponding to 27.50%. The slight difference may be due to variation in risk profile, gestational age at Doppler assessment, and diagnostic criteria used. The comparable incidence supports that high-risk antenatal populations have a substantially higher burden of pre-eclampsia than general obstetric populations and require closer surveillance.[7] In the present study, women who developed pre-eclampsia had significantly higher maternal age than normotensive women (29.80 ± 4.60 years versus 27.20 ± 4.10 years; p=0.008) and higher body mass index (29.70 ± 3.80 kg/m² versus 26.50 ± 3.40 kg/m²; p<0.001). Previous pre-eclampsia was also significantly more common in the pre-eclampsia group (33.33% versus 12.63%; p=0.009), as was chronic hypertension (26.67% versus 8.42%; p=0.009) and obesity (46.67% versus 23.16%; p=0.013). These findings are consistent with Duckitt et al. (2005), who reported that previous pre-eclampsia increased the risk by 7.19 times, raised body mass index before pregnancy increased the risk by 2.47 times, nulliparity increased the risk by 2.91 times, and family history increased the risk by 2.90 times.[8] Mean arterial pressure was significantly higher among women who developed pre-eclampsia in the present study (96.80 ± 7.10 mmHg) compared with women who remained normotensive (88.60 ± 6.30 mmHg; p<0.001). This finding supports the role of blood pressure-related parameters as early predictors of disease. Onwudiwe et al. (2008) also demonstrated the importance of combining maternal characteristics, uterine artery Doppler and mean arterial pressure; in their study of 3359 pregnancies, pre-eclampsia developed in 101 cases (3.00%), and the combined model detected 100.00% of early pre-eclampsia and 56.40% of late pre-eclampsia at a 10.00% false-positive rate. The higher disease rate in the present study is expected because only high-risk women were enrolled.[9] The present study showed significantly higher Doppler impedance among women who developed pre-eclampsia. Mean uterine artery PI was 1.72 ± 0.42 in the pre-eclampsia group compared with 1.12 ± 0.28 in the normotensive group (p<0.001), mean RI was 0.68 ± 0.09 versus 0.54 ± 0.07 (p<0.001), and mean S/D ratio was 3.75 ± 0.81 versus 2.61 ± 0.59 (p<0.001). Bhattacharyya et al. (2012) similarly found that abnormal uterine artery Doppler at 24–26 weeks predicted pre-eclampsia with sensitivity of 73.33% and specificity of 86.48% among high-risk women, while sensitivity and specificity were 57.14% and 95.83% among low-risk women. Thus, the present findings agree that increased uterine artery resistance is more strongly useful in high-risk antenatal screening.[10] Abnormal uterine artery Doppler was strongly associated with subsequent pre-eclampsia in the present study. Among 42 women with abnormal Doppler findings, 25 developed pre-eclampsia (59.52%), whereas only 5 of 83 women with normal Doppler findings developed pre-eclampsia (6.02%; p<0.001). This is comparable with the findings of Thakur et al. (2019), who studied 100 high-risk pregnant women at 18–24 weeks and reported that second-trimester uterine artery Doppler had sensitivity of 84.00% and specificity of 55.00% for prediction of pre-eclampsia. In the present study, combined abnormal Doppler showed sensitivity of 83.33% and specificity of 82.11%, indicating similar sensitivity but better specificity.[11] The predictive performance of uterine artery PI was good in the present study, with mean PI >1.45 showing sensitivity of 80.00%, specificity of 85.26%, PPV of 63.16%, NPV of 93.10%, accuracy of 84.00%, and AUC of 0.83. Similarly, Cnossen et al. (2008), in a systematic review and bivariable meta-analysis including 74 studies of pre-eclampsia with 79,547 patients, concluded that uterine artery Doppler performed better in the second trimester than in the first trimester and that increased PI, alone or combined with notching, was the most predictive Doppler index. They also reported that increased PI with notching had a positive likelihood ratio of 21.00 among high-risk women.[12] Bilateral early diastolic notching was present in 53.33% of women who developed pre-eclampsia compared with only 6.32% of normotensive women in the present study (p<0.001). Although its sensitivity was lower than combined abnormal Doppler (53.33% versus 83.33%), it had the highest specificity (93.68%) and PPV (72.73%). This pattern is consistent with Bower et al. (1993), who reported that persistent early diastolic notching at 24 weeks was a stronger predictor of pre-eclampsia than a high resistance index, and women with persistent notching had a 68-fold increased risk of significant pre-eclampsia. Therefore, bilateral notching appears more useful as a "rule-in" marker than as a standalone screening marker.[13] The RI cut-off in the present study also performed well, with RI >0.62 showing sensitivity of

73.33%, specificity of 83.16%, PPV of 57.89%, NPV of 90.80%, accuracy of 80.80%, and AUC of 0.78. Shahid et al. (2021) reported that RI >0.58 was the most sensitive individual Doppler parameter, with sensitivity of 71.00%, whereas uterine artery notching was more specific; unilateral or bilateral notch had specificity of 89.00%, and bilateral notch had specificity of 79.00%. Compared with their findings, the present study showed similar RI sensitivity but higher RI specificity, while bilateral notching in the present study showed even higher specificity of 93.68%.[14] The present study also demonstrated significantly worse maternal and perinatal outcomes among women with pre-eclampsia. Preterm birth occurred in 43.33% of women with pre-eclampsia compared with 10.53% of normotensive women ($p<0.001$), fetal growth restriction in 40.00% versus 8.42% ($p<0.001$), low birth weight in 50.00% versus 15.79% ($p<0.001$), caesarean delivery in 63.33% versus 41.05% ($p=0.033$), and NICU admission in 36.67% versus 9.47% ($p<0.001$). Mendola et al. (2015) similarly reported that preterm birth was substantially higher in pre-eclamptic pregnancies than normotensive pregnancies (34.00% versus 10.00%) and, after accounting for preterm birth, pre-eclampsia still increased the odds of SGA, NICU admission and respiratory distress.[15]

CONCLUSION

Uterine artery Doppler assessment was found to be a useful non-invasive tool for predicting pre-eclampsia among high-risk pregnant women. Increased pulsatility index, resistance index, systolic-to-diastolic ratio, bilateral early diastolic notching, and combined abnormal Doppler findings were significantly associated with the development of pre-eclampsia. The high negative predictive value of Doppler parameters suggests their usefulness in identifying women unlikely to develop pre-eclampsia. Incorporating uterine artery Doppler into routine high-risk antenatal care may help in early risk stratification, closer surveillance, and timely intervention to improve maternal and perinatal outcomes.

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