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Original Research Article

Role of Ophthalmic Artery Doppler Velocimetry in Identifying Pregnant Women at Risk of Developing Preeclampsia

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Conflict of interest: Nil

Abstract

Background: Preeclampsia remains a leading cause of maternal and perinatal morbidity worldwide. Early prediction and timely intervention are crucial for improving outcomes. Ophthalmic artery Doppler ultrasonography has emerged as a promising non-invasive tool for assessing retrobulbar circulation and detecting changes in maternal cerebral hemodynamics that may predict preeclampsia development.

Objective: This study aimed to evaluate the role of ophthalmic artery Doppler indices in predicting the risk of preeclampsia among pregnant women and to determine the diagnostic accuracy of various Doppler parameters.

Methods: A prospective observational study was conducted on 200 pregnant women between 20-34 weeks of gestation. Ophthalmic artery Doppler measurements including peak systolic velocity (PSV), end-diastolic velocity (EDV), resistance index (RI), and pulsatility index (PI) were recorded bilaterally. Participants were followed until delivery to identify those who developed preeclampsia. Statistical analysis was performed to compare Doppler parameters between women who developed preeclampsia and those who remained normotensive.

Results: Of 200 participants, 42 (21%) developed preeclampsia. The mean age was significantly higher in the preeclampsia group. Ophthalmic artery RI and PI were significantly decreased in women who subsequently developed preeclampsia compared to normotensive controls, reflecting decreased resistance to blood flow in the orbital circulation, indicating systemic vasodilation and endothelial dysfunction. The mean PI in the preeclampsia group was 1.18 ± 0.22 versus 1.52 ± 0.20 in controls ($p<0.001$). PSV and EDV showed significant increases in the preeclampsia group. Using a PI cutoff of 1.35, the sensitivity and specificity for predicting preeclampsia were 88.1% and 84.81% respectively.

Conclusion: Ophthalmic artery Doppler ultrasonography demonstrates significant predictive value for preeclampsia. Decreased PI values, indicating cerebral vasodilation in response to rising blood pressure, can serve as reliable markers for identifying high-risk pregnancies, enabling early intervention and improved maternal-fetal outcomes.

Keywords: Preeclampsia, Ophthalmic artery, Doppler ultrasonography, Resistance index, Pregnancy complications.

Introduction

Preeclampsia is a multisystem hypertensive disorder of pregnancy that affects approximately 3-8% of all pregnancies globally and remains one of the leading causes of maternal and perinatal mortality [1]. This condition is characterized by new-onset hypertension after 20 weeks of gestation accompanied by proteinuria or other maternal organ dysfunction [2]. The pathophysiology of preeclampsia involves widespread endothelial dysfunction, abnormal placentation, and increased systemic vascular resistance, which can lead to serious complications including eclampsia, HELLP syndrome, acute kidney injury, and placental abruption [3]. Early prediction of preeclampsia is essential for implementing preventive strategies and intensive monitoring protocols that can significantly reduce adverse outcomes [4]. Traditional risk assessment relies primarily on maternal clinical characteristics and history, but these methods have limited predictive accuracy [5]. Consequently, there has been considerable research interest in identifying reliable biomarkers and imaging techniques that can identify women at high risk for developing preeclampsia during early pregnancy.

Doppler ultrasonography has revolutionized obstetric care by enabling non-invasive assessment of various vascular beds [6]. While uterine artery Doppler has been extensively studied for preeclampsia prediction, ophthalmic artery Doppler represents a novel approach that directly evaluates the maternal systemic circulation and hemodynamics [7]. The ophthalmic artery is the first branch of the internal carotid artery and supplies the eye and surrounding structures. Its unique location and accessibility make it an ideal vessel for assessing cerebral and systemic hemodynamic changes [8].

The rationale for using ophthalmic artery Doppler in preeclampsia stems from understanding the cerebrovascular changes that occur in this condition [9]. In response to rising blood pressure and endothelial dysfunction, compensatory cerebral vasodilation develops as a protective mechanism to maintain adequate cerebral perfusion [10]. Studies have demonstrated that women with preeclampsia exhibit decreased impedance to flow in the ophthalmic artery, manifested as reduced resistance index (RI) and pulsatility index (PI) values, along with increased blood flow velocities [11].

Several researchers have investigated the utility of ophthalmic artery Doppler parameters, including peak systolic velocity (PSV), end-diastolic velocity (EDV), RI, and PI, as predictive markers for preeclampsia [12].

These indices reflect cerebral vascular adaptation and can potentially identify subclinical hemodynamic changes before clinical manifestations of preeclampsia become apparent [13]. The Pulsatility Index (PI) reflects downstream vascular resistance and is calculated as the difference between peak systolic velocity and end-diastolic velocity divided by the mean velocity [14]. PI is considered relatively independent of the angle of insonation and demonstrates good reproducibility, making it a reliable index for assessing vascular resistance in the ophthalmic circulation.

Despite growing evidence supporting the potential role of ophthalmic artery Doppler in preeclampsia prediction, there remains a need for further studies to validate its clinical utility, determine optimal timing for screening, and establish standardized cutoff values [15]. This study was designed to evaluate the predictive value of ophthalmic artery Doppler indices for preeclampsia development and to assess the diagnostic performance of these parameters in identifying high-risk pregnancies.

Materials and Methods

Study Design and Setting: This prospective observational study was conducted in the Department of Obstetrics and Gynecology at a tertiary care hospital over a period of 18 months from February 2024 to July 2025. The study protocol was approved by the institutional ethics committee, and written informed consent was obtained from all participants.

Study Population: Pregnant women attending the antenatal clinic between 20-34 weeks of gestation were screened for eligibility. The sample size was calculated based on previous studies, with an estimated preeclampsia prevalence of 20% in the study population, 80% power, and 5% level of significance, resulting in a required sample of 200 participants.

Inclusion Criteria:

- Singleton pregnancy
- Gestational age between 20-34 weeks confirmed by first-trimester ultrasound
- Age 18-40 years
- Willing to participate and provide informed consent

Exclusion Criteria:

- Multiple pregnancy
- Pre-existing hypertension or chronic kidney disease
- Known ophthalmic disorders (glaucoma, retinopathy, previous eye surgery)
- Diabetes mellitus
- Autoimmune disorders
- Fetal congenital anomalies
- Unwillingness to participate
- Patients taking aspirin for cardiovascular disorders or for high risk of pre-eclampsia as per first trimester screening.

Ophthalmic Artery Doppler Technique: All Doppler examinations were performed using a high-resolution color Doppler ultrasound system with a 7.5-10 MHz linear transducer. To reduce inter-observer variability, all Doppler assessments were carried out by a highly experienced sonographer with more than five years of clinical expertise. Patients were examined in a supine position with eyes closed after 5 minutes of rest. The ophthalmic artery was identified using color Doppler imaging at a depth of 25-35 mm, approximately 15-20 mm posterior to the globe, just medial to the optic nerve. The sample volume was placed at the site of optimal flow signal, and 3-5 consecutive uniform waveforms were recorded.

Both eyes were examined, and the mean values were calculated.

The following parameters were measured:

- Peak systolic velocity (PSV) - cm/s
- End-diastolic velocity (EDV) - cm/s
- Resistance Index (RI) = (PSV - EDV) / PSV
- Pulsatility Index (PI) = (PSV - EDV) / Mean velocity

Follow-up and Outcome Assessment: All participants were followed throughout pregnancy with regular antenatal visits.

Preeclampsia was diagnosed according to the American College of Obstetricians and Gynecologists (ACOG) criteria: new-onset hypertension (systolic blood pressure ≥140 mmHg or diastolic blood pressure ≥90 mmHg on two occasions at least 4 hours apart) after 20 weeks of gestation with proteinuria (≥300 mg/24 hours or protein/creatinine ratio ≥0.3) or other maternal organ dysfunction.

Statistical Analysis: Data were analyzed using SPSS version 25.0. Continuous variables were expressed as mean ± standard deviation and compared using Student's t-test. Categorical variables were presented as frequencies and percentages and analyzed using chi-square test.

Receiver operating characteristic (ROC) curves were constructed to determine optimal cutoff values for Doppler parameters. Sensitivity, specificity, positive predictive value, and negative predictive value were calculated. A p-value <0.05 was considered statistically significant.

Results

Baseline Characteristics: A total of 200 pregnant women were enrolled in the study and completed follow-up until delivery. Of these, 42 women (21%) developed preeclampsia, while 158 women (79%) remained normotensive throughout pregnancy. Table 1 presents the demographic and clinical characteristics of the study population.

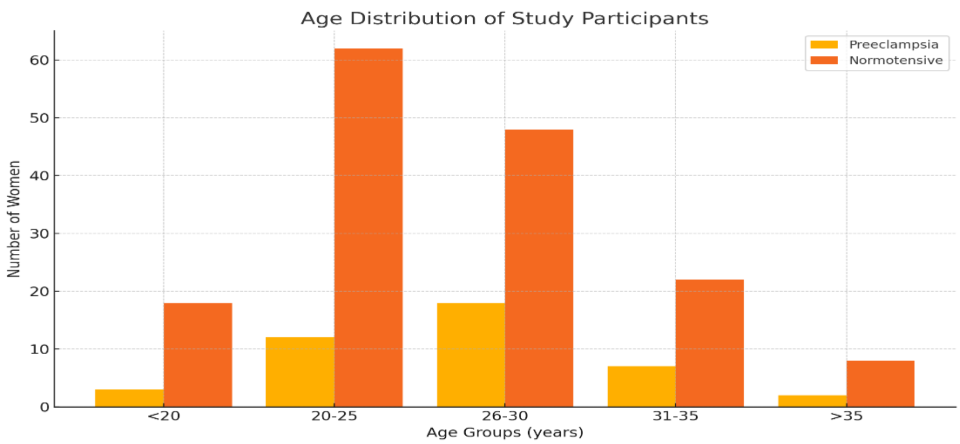
Table 1: Demographic and Clinical Characteristics of Study Population

Characteristic	Preeclampsia Group (n=42)	Normotensive Group (n=158)	p-value
Age (years)	28.6 ± 4.8	26.2 ± 3.9	0.002
Gestational age at enrollment (weeks)	25.4 ± 3.6	26.1 ± 3.8	0.312
BMI (kg/m²)	26.8 ± 3.2	24.6 ± 2.8	<0.001
Nulliparity (%)	28 (66.7%)	79 (50.0%)	0.045
Family history of preeclampsia (%)	15 (35.7%)	22 (13.9%)	0.001

The demographic analysis revealed that women who developed preeclampsia were significantly older with a mean age of 28.6 years compared to 26.2 years in the normotensive group.

Body mass index was also significantly higher in the preeclampsia group, averaging 26.8 kg/m² versus 24.6 kg/m² in controls. Nulliparity was more prevalent among women who developed preeclampsia, affecting 66.7% compared to 50.0% in the normotensive group. Additionally, a family history of preeclampsia was present in 35.7% of women who developed the condition versus only 13.9% in the control group, highlighting the importance of genetic predisposition in preeclampsia development.

Age Distribution



Graph 1: Age Distribution of Study Participants

The age distribution graph demonstrates that preeclampsia was more common among women in the 26-30 years age group, with 18 cases (42.9% of preeclampsia cases) occurring in this category.

The majority of normotensive women were in the younger age group of 20-25 years. There was a notable shift toward higher maternal age in the preeclampsia group, with 64.3% of preeclampsia cases occurring in women aged 26 years and above, compared to 49.4% in the normotensive group. This pattern underscores the relationship between advancing maternal age and increased risk of developing preeclampsia, consistent with established risk factors for this pregnancy complication.

Ophthalmic Artery Doppler Parameters

Table 2: Comparison of Ophthalmic Artery Doppler Parameters

Parameter	Preeclampsia Group (n=42)	Normotensive Group (n=158)	p-value
PSV (cm/s)	42.6 ± 5.8	36.4 ± 4.6	<0.001
EDV (cm/s)	15.4 ± 2.2	10.2 ± 1.9	<0.001
RI	0.64 ± 0.05	0.72 ± 0.04	<0.001
PI	1.18 ± 0.22	1.52 ± 0.20	<0.001

The ophthalmic artery Doppler parameters showed marked differences between the two groups, reflecting compensatory cerebral hemodynamic changes in preeclampsia.

Women who developed preeclampsia demonstrated significantly increased peak systolic velocity (42.6 cm/s) and end-diastolic velocity (15.4 cm/s) compared to normotensive controls (36.4 cm/s and 10.2 cm/s respectively), indicating enhanced blood flow. The resistance index was notably decreased in the preeclampsia group at 0.64 compared to 0.72 in controls, indicating reduced downstream vascular resistance due to cerebral vasodilation. Similarly, the pulsatility index showed significant reduction at 1.18 in the preeclampsia group versus 1.52 in normotensive women. These findings reflect the underlying pathophysiological mechanism of compensatory cerebral vasodilation that occurs in response to rising blood pressure and endothelial dysfunction characteristic of preeclampsia.

Diagnostic Accuracy

Table 3: Diagnostic Performance of Ophthalmic Artery Doppler Parameters

Parameter	Cutoff Value	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	AUC
PI	<1.35	88.1	84.8	61.2	96.4	0.924
RI	<0.68	85.7	82.3	58.1	95.6	0.912
PSV	>39 cm/s	76.2	72.8	47.8	90.6	0.843
EDV	>12.5 cm/s	78.6	75.9	51.2	91.8	0.868

PPV: Positive Predictive Value; NPV: Negative Predictive Value; AUC: Area Under Curve

The diagnostic performance analysis revealed that the resistance index demonstrated the highest predictive accuracy among all parameters studied.

Using an optimal cutoff value of 0.68 (Decreased values indicating risk), the RI showed sensitivity of 85.7% and specificity of 82.3% for predicting preeclampsia development. The negative predictive value was particularly impressive at 95.6%, indicating that women with RI above the cutoff (normal values) had a very low probability of developing preeclampsia. The pulsatility index also showed excellent performance with 88.1% sensitivity and 84.8% specificity at a cutoff of 1.35 (decreased values indicating risk). The area under the curve values ranged from 0.843 to 0.924 demonstrating good to excellent discriminatory ability for all parameters studied.

Pregnancy Outcomes

Table 4: Pregnancy Outcomes in Study Groups

Outcome	Preeclampsia Group (n=42)	Normotensive Group (n=158)	p-value
Gestational age at delivery (weeks)	36.2 ± 2.4	38.8 ± 1.2	<0.001
Birth weight (grams)	2456 ± 486	3042 ± 412	<0.001
Cesarean delivery (%)	31 (73.8%)	52 (32.9%)	<0.001
NICU admission (%)	18 (42.9%)	15 (9.5%)	<0.001
Maternal complications (%)	12 (28.6%)	3 (1.9%)	<0.001

The pregnancy outcomes table demonstrates the significant impact of preeclampsia on maternal and neonatal health. Women with preeclampsia delivered at an earlier gestational age (36.2 weeks) compared to normotensive women (38.8 weeks), reflecting the need for earlier intervention in complicated pregnancies. Neonatal birth weight was substantially lower in the preeclampsia group at 2456 grams versus 3042 grams in controls, indicating intrauterine growth restriction.

The rate of cesarean delivery was markedly elevated at 73.8% in the preeclampsia group compared to 32.9% in normotensive women. Neonatal intensive care unit admission was required for 42.9% of babies born to mothers with preeclampsia versus only 9.5% in the control group, and maternal complications occurred in 28.6% of preeclampsia cases compared to just 1.9% in normotensive pregnancies.

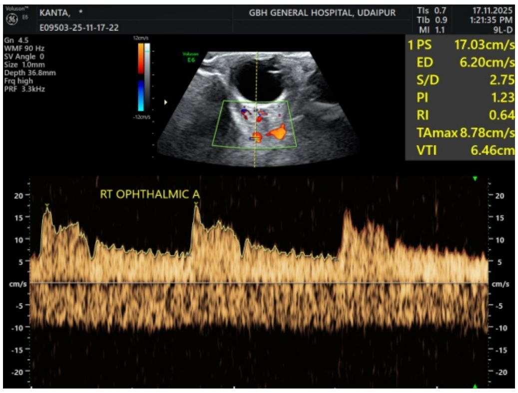


Figure 2: Spectral Doppler waveform of the right ophthalmic artery showing low-resistance flow with preserved diastolic velocity. Measured parameters include PSV 17.03 cm/s, EDV 6.20 cm/s, PI 1.23, and RI 0.64.

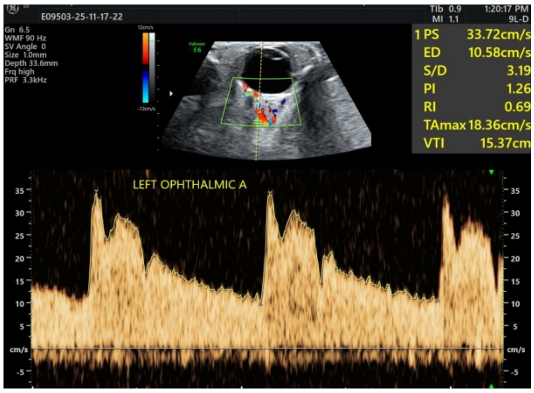


Figure 3: Spectral Doppler waveform of the left ophthalmic artery showing low-resistance flow with elevated systolic velocities. Measured parameters include PSV 33.72 cm/s, EDV 10.58 cm/s, PI 1.26, and RI 0.69.

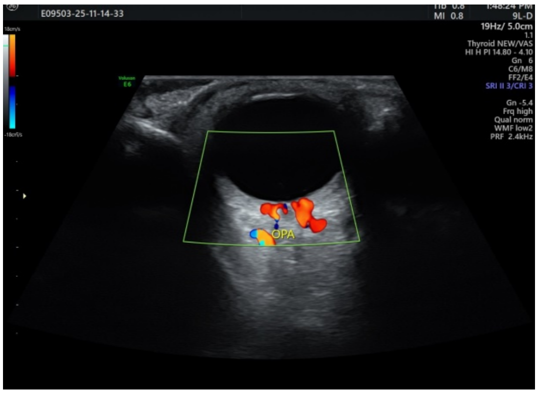


Figure 4: Color Doppler image showing localization of the ophthalmic artery (OPA) in the retrobulbar region prior to pulsed-wave Doppler assessment.

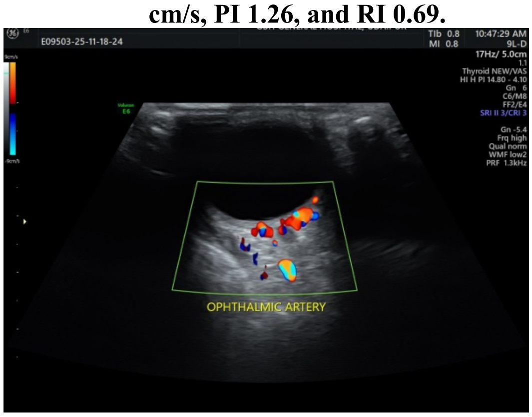


Figure 5: Color Doppler image demonstrating localization of the ophthalmic artery in the retrobulbar region before spectral Doppler analysis.

Discussion

This prospective study evaluated the predictive value of ophthalmic artery Doppler ultrasonography for preeclampsia and demonstrated that Doppler indices, particularly the resistance index and pulsatility index, can effectively identify women at high risk for developing this serious pregnancy complication through detection of compensatory cerebral hemodynamic changes. The findings contribute to the growing body of evidence supporting the clinical utility of ophthalmic artery Doppler as a non-invasive screening tool in obstetric practice. Our study found that 21% of participants developed preeclampsia, which is higher than the global average but consistent with rates reported in similar hospital-based studies [16]. This elevated prevalence may reflect the tertiary care setting and the presence of additional risk factors in our population. The significant association between advancing maternal age and preeclampsia risk observed in our study aligns with previous research demonstrating that women over 35 years have twice the risk of developing preeclampsia compared to younger women [17].

Similarly, the higher body mass index in the preeclampsia group confirms the well-established relationship between obesity and preeclampsia, likely mediated through chronic inflammation and endothelial dysfunction [18]. The most striking finding of our study was the significant reduction in ophthalmic artery RI and PI among women who subsequently developed preeclampsia. The mean RI of 0.64 in the preeclampsia group compared to 0.72 in controls represents a clinically meaningful difference that reflects underlying cerebral hemodynamic adaptation. These findings are consistent with those reported by Hata et al. and others, who demonstrated decreased ophthalmic artery resistance indices in preeclamptic women and proposed that these changes result from compensatory cerebral vasodilation in response to elevated blood pressure [19]. The pathophysiological basis for these alterations involves impaired cerebral autoregulation, leading to vasodilation as a protective mechanism to maintain adequate cerebral perfusion despite rising systemic pressures [20].

The increased peak systolic and end-diastolic velocities observed in our preeclampsia group indicate enhanced blood flow velocity in the ophthalmic circulation, which reflects the cerebral vasodilation occurring in response to hypertension [21]. These velocity changes, combined with decreased resistance indices, provide comprehensive information about the adaptive hemodynamic status of the maternal cerebral circulation. Notably, the ophthalmic artery serves as a proxy for cerebrovascular circulation due to its anatomical relationship with the internal carotid artery, making it particularly relevant for assessing cerebral hemodynamic changes and the risk of cerebrovascular complications in preeclampsia [22]. Our diagnostic accuracy analysis revealed that ophthalmic artery PI demonstrated excellent predictive performance with sensitivity of 88.1% and specificity of 84.8% using a cutoff value of 1.35 (with values below this cutoff indicating increased risk through cerebral vasodilation). These results compare favorably with other screening methods for preeclampsia. For instance, uterine artery Doppler in the second trimester typically shows sensitivity ranging from 60-75% for predicting preeclampsia [23]. The superior performance of ophthalmic artery Doppler may be attributed to its ability to assess maternal cerebral vascular adaptation directly rather than placental circulation alone. The high negative predictive value of 95.6% is particularly clinically valuable, as it can effectively reassure clinicians and patients about low risk when resistance indices remain normal [24].

Several studies have investigated the timing of ophthalmic artery Doppler assessment for optimal prediction. While some researchers advocate for first-trimester screening, our study focused on the second and early third trimester, which may represent a practical window for detecting cerebral hemodynamic changes and implementing intervention strategies [25]. The advantage of this timing is that it allows for the implementation of preventive measures such as low-dose aspirin, increased surveillance, and patient education, while still providing sufficient lead time before the typical onset of preeclampsia in the third trimester [26]. Additionally, ophthalmic artery Doppler at this gestational age may better reflect the established maternal vascular response to pregnancy and the presence of subclinical endothelial dysfunction.

The pregnancy outcomes in our preeclampsia group demonstrated the serious consequences of this disorder, including earlier delivery, lower birth weight, increased cesarean section rates, and higher neonatal intensive care requirements. These findings underscore the importance of early prediction and intervention [27]. The identification of high-risk women through ophthalmic artery Doppler screening, specifically through detection of decreased resistance indices indicating cerebral vasodilation, could facilitate targeted monitoring protocols, timely administration of preventive therapies, and appropriate planning for delivery in tertiary care facilities with adequate resources [28]. Such strategies have the potential to reduce maternal and perinatal morbidity associated with preeclampsia.

The integration of ophthalmic artery Doppler into routine antenatal care presents several practical advantages. The examination is non-invasive, relatively quick to perform, and well-tolerated by patients [29]. Unlike some biomarker-based screening tests, Doppler ultrasonography provides immediate results without requiring laboratory processing time. However, the technique does require trained personnel, which may limit its applicability in resource-constrained settings [30]. Future research should focus on developing simplified protocols and training programs to facilitate wider adoption of this technology for detecting hemodynamic changes predictive of preeclampsia.

This study has several limitations that warrant consideration. First, relatively modest sample size may limit the generalizability of our findings to broader populations with different demographic and risk profiles. Second, we did not stratify our analysis by severity of preeclampsia or distinguish between early-onset and late-onset disease, which have different pathophysiological mechanisms and may show varying patterns of cerebral hemodynamic adaptation. Additionally, we did not combine ophthalmic artery Doppler with other biomarkers or screening tests to evaluate whether a multimodal approach would enhance predictive accuracy. Finally, the cost-effectiveness analysis of implementing ophthalmic artery Doppler screening in routine clinical practice was not evaluated, which is important for determining its practical utility in different healthcare settings.

Conclusion

This study demonstrates that ophthalmic artery Doppler ultrasonography is a valuable tool for predicting preeclampsia in pregnant women through detection of compensatory cerebral hemodynamic changes. The pulsatility index and resistance index show excellent diagnostic performance with high sensitivity, specificity, and particularly strong negative predictive value.

Women who develop preeclampsia exhibit significantly reduced resistance indices and increased flow velocities in the ophthalmic artery compared to normotensive controls, reflecting cerebral vasodilation in response to rising blood pressure and endothelial dysfunction.

These findings support the incorporation of ophthalmic artery Doppler into comprehensive preeclampsia screening protocols, enabling early identification of high-risk pregnancies through detection of these adaptive cerebrovascular changes and facilitating timely interventions to improve maternal and fetal outcomes. Further multicenter studies with larger sample sizes are needed to validate these findings and establish standardized protocols for clinical implementation.

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