Predicting Preeclampsia Using Placental Laterality and Uterine Artery Doppler: Clinical Performance, Pitfalls, and Imaging Protocols

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Abstract

Background: Preeclampsia remains one of the leading causes of maternal and perinatal morbidity and mortality worldwide. Despite advances in obstetric care, early identification of women at increased risk continues to be a clinical challenge. Abnormal placentation and impaired spiral artery remodeling are central to the pathophysiology of preeclampsia and precede the onset of clinical disease by several weeks to months. Ultrasound-based markers, particularly placental location and uterine artery Doppler velocimetry, offer a noninvasive window into these early placental changes and have gained increasing attention as screening tools during the first and second trimesters of pregnancy.

Aim: This review aims to critically evaluate the role of placental laterality and uterine artery Doppler abnormalities in predicting preeclampsia, with emphasis on clinical performance, methodological limitations, and standardized imaging protocols from a radiology perspective. The review synthesizes current evidence on the biological plausibility, diagnostic accuracy, and practical applicability of these sonographic markers, both individually and in combination.

Placental laterality, defined as predominant placental implantation on one side of the uterine cavity, has been associated with asymmetric uterine perfusion and an increased risk of preeclampsia in several observational studies. Uterine artery Doppler assessment, particularly elevated pulsatility index and the presence of early diastolic notching, reflects increased downstream resistance due to inadequate trophoblastic invasion. Evidence suggests that combining placental laterality with uterine artery Doppler indices improves predictive performance compared with either parameter alone, especially for early-onset and severe forms of preeclampsia. However, variability in study design, gestational age at assessment, Doppler thresholds, and operator technique contributes to inconsistent results across the literature.

Conclusion: Placental location and uterine artery Doppler represent valuable, accessible imaging markers for preeclampsia risk assessment, particularly when integrated into multimodal screening strategies. Awareness of technical pitfalls, adherence to standardized imaging protocols, and appropriate interpretation within clinical context are essential to maximize their predictive value. Further large-scale, prospective studies are required to refine cutoff values, validate combined models, and define the optimal role of these techniques in routine antenatal care.

Keywords: *Placental Location, Uterine Artery Doppler, Preeclampsia*

Introduction

Preeclampsia is a hypertensive disorder unique to pregnancy and remains a leading cause of maternal and perinatal morbidity and mortality, with important short-term risks (eclampsia, stroke, renal and hepatic dysfunction) and long-term maternal cardiovascular sequelae. Its clinical diagnosis and classification are standardized in major obstetric guidance, which also emphasizes the need for early identification of women at risk to reduce preventable complications. [1]

Epidemiologically, preeclampsia and other hypertensive disorders of pregnancy contribute substantially to adverse outcomes worldwide, and their burden is clinically meaningful even in well-resourced settings. The heterogeneity of presentation (early vs late onset; mild vs severe features) complicates prediction, because screening tests perform differently depending on phenotype and gestational age at delivery. [2]

From a mechanistic perspective, preeclampsia is strongly linked to abnormal placentation and impaired spiral artery remodeling, leading to a high-resistance uteroplacental circulation. Placental ischemia and oxidative stress are followed by maternal endothelial dysfunction and a systemic inflammatory/antiangiogenic state, forming the biological rationale for imaging strategies that interrogate uteroplacental perfusion before symptoms appear. [3]

The “deep placentation” concept further integrates preeclampsia within a spectrum of disorders arising from inadequate transformation of the uterine spiral arteries. This framework is valuable for radiologists because it connects early placental implantation biology with downstream hemodynamic signatures visible on uterine artery Doppler velocimetry. [4]

Ultrasound is the first-line imaging modality for placental assessment and is uniquely positioned to provide both structural and functional information. Systematic placental imaging supports evaluation of placental morphology, site, and related abnormalities, and it is particularly relevant in pregnancy disorders where placental disease precedes maternal clinical manifestations. [5]

Placental laterality—when the placenta is predominantly implanted to the right or left of the uterine midline—has been studied as a pragmatic sonographic marker of asymmetric uterine perfusion. Clinical evidence suggests that lateral placentation may be associated with an increased risk of developing preeclampsia, supporting its potential role as a simple screening variable within routine obstetric ultrasound. [6]

Uterine artery Doppler velocimetry evaluates downstream placental resistance and is classically interpreted using indices such as pulsatility index and qualitative findings such as early diastolic notching. Abnormal uterine artery Doppler has been linked to subsequent preeclampsia and its severity/earlier delivery, reinforcing its role as an imaging biomarker of impaired placentation and motivating combined strategies with placental laterality to improve prediction. [7]

Pathophysiology of Preeclampsia Relevant to Imaging

Preeclampsia originates from abnormal placental development during early gestation, particularly involving defective trophoblastic invasion of the maternal decidua and myometrium. In normal pregnancy, extravillous trophoblasts transform the spiral arteries into dilated, low-resistance vessels capable of sustaining increased uteroplacental blood flow. In preeclampsia, this physiological remodeling is incomplete, resulting in narrow, high-resistance vessels that limit placental perfusion and predispose to ischemia. These early abnormalities form the biological foundation for imaging-based predictors that assess placental structure and uterine artery hemodynamics. [8]

The concept of disordered deep placentation places preeclampsia within a spectrum of obstetric syndromes that share a common origin in impaired spiral artery transformation. Histopathologic studies have consistently demonstrated persistence of smooth muscle and elastic tissue in spiral arteries from pregnancies complicated by preeclampsia, explaining the increased resistance detected by uterine artery Doppler velocimetry. This pathophysiological insight directly links Doppler waveform abnormalities with underlying placental vascular pathology. [9]

Placental hypoperfusion leads to a hypoxic and oxidative intrauterine environment, which stimulates the release of antiangiogenic factors such as soluble fms-like tyrosine kinase-1 and soluble endoglin into the maternal circulation. These factors disrupt endothelial function systemically, producing the maternal manifestations of hypertension, proteinuria, and multi-organ involvement. Imaging markers that reflect placental perfusion abnormalities therefore indirectly signal the molecular cascade that precedes clinical disease. [10]

The uterine artery Doppler waveform is influenced not only by placental resistance but also by complex interactions between maternal cardiovascular adaptation and placental vascular development. Computational and physiologic models have demonstrated that increased impedance in the placental vascular bed and inadequate spiral artery conversion result in elevated pulsatility indices and persistent early diastolic notching. These Doppler features are thus physiologic surrogates of impaired placentation rather than isolated hemodynamic phenomena. [11]

Placental implantation site further modifies uteroplacental perfusion patterns. Laterally implanted placentas rely predominantly on the ipsilateral uterine artery, with reduced compensatory contribution from the contralateral side. In the setting of impaired spiral artery remodeling, this asymmetric blood supply may exacerbate placental hypoperfusion, explaining the observed association between placental laterality and increased risk of preeclampsia. This mechanism provides a biologically plausible explanation for combining placental site assessment with uterine artery Doppler in predictive models. [12]

From an imaging perspective, understanding these pathophysiological processes is essential for correct interpretation of uterine artery Doppler findings and placental location. Radiologists must recognize that Doppler abnormalities represent downstream manifestations of placental disease rather than primary vascular pathology. This perspective supports the integration of structural and functional placental imaging as complementary tools for early risk stratification in preeclampsia. [13]

Placental Development and Sonographic Assessment

Normal placental development is a highly regulated process that begins in early gestation and is essential for adequate fetal growth and maternal adaptation to pregnancy. Implantation involves coordinated trophoblastic proliferation, differentiation, and invasion, followed by establishment of the intervillous circulation. These processes determine placental size, shape, location, and vascular architecture, all of which can be assessed to varying degrees by ultrasound. Disruptions at any stage of placental development may manifest as abnormal morphology or perfusion patterns detectable on imaging and are central to the pathogenesis of preeclampsia. [14]

From a radiologic standpoint, ultrasound remains the primary modality for placental evaluation due to its safety, accessibility, and ability to provide real-time structural and functional information. Systematic sonographic assessment of the placenta includes evaluation of placental location, thickness, echotexture, cord insertion, and relationship to the cervical os. Such a structured approach improves detection of placental abnormalities and ensures reproducibility across examinations, which is particularly important when placental findings are used for risk prediction rather than purely descriptive purposes. [15]

Placental location is typically classified as anterior, posterior, fundal, lateral, or low-lying, with lateral placentation defined by predominant implantation on either side of the uterine midline. Accurate localization requires careful scanning in multiple planes, particularly in early and mid-gestation when uterine orientation and placental migration may affect apparent position. Misclassification of placental site can occur if imaging is limited or if uterine rotation is not considered, underscoring the need for standardized imaging technique when placental laterality is used as a predictive marker. [16]

Beyond location, placental morphology provides additional insight into placental health. Abnormal placental thickness, heterogeneous echotexture, calcifications, or focal lesions have been associated with adverse pregnancy outcomes, including hypertensive disorders. While these features are not specific to preeclampsia, they reflect underlying placental dysfunction and may coexist with abnormal uterine artery Doppler findings, reinforcing the concept of a global placental disease process rather than isolated vascular abnormalities. [17]

Advanced imaging perspectives emphasize that placental structure and function are tightly interrelated. Sonographic findings must therefore be interpreted in the context of gestational age and normal placental maturation. Overinterpretation of physiological changes as pathology can reduce specificity, whereas failure to recognize subtle deviations from normal may delay identification of at-risk pregnancies. This balance is particularly relevant when placental assessment is incorporated into screening strategies rather than diagnostic pathways. [18]

In clinical practice, placental sonographic assessment is most valuable when integrated with functional evaluation of uteroplacental blood flow. Structural features such as placental laterality provide contextual information that complements uterine artery Doppler velocimetry, helping radiologists and obstetricians understand whether abnormal flow patterns are likely related to implantation site, placental vascular development, or systemic maternal factors. Such integration strengthens the biological plausibility and interpretive confidence of imaging-based prediction models for preeclampsia. [19]

Placental Laterality: Definition, Classification, and Biological Rationale

Placental laterality refers to predominant implantation of the placenta on either the right or left side of the uterine cavity rather than a central or fundal position. Sonographically, laterality is typically defined when more than two-thirds of the placental mass is located to one side of the uterine midline. This classification is most reliably performed during the second trimester, when placental margins are clearly delineated and before significant uterine enlargement alters spatial relationships. Accurate identification of placental laterality is essential when it is used as a predictive imaging marker rather than a descriptive finding. [20]

The classification of placental location includes central (anterior, posterior, or fundal) and lateral implantation, with lateral placentas further categorized as right- or left-sided. Standard obstetric ultrasound practice emphasizes placental localization primarily to exclude placenta previa; however, from a radiologic research perspective, more precise mapping of placental position is required. Failure to apply consistent definitions of laterality has contributed to heterogeneity in published studies and variable associations with preeclampsia risk. [21]

The biological rationale linking placental laterality to preeclampsia risk centers on asymmetric uterine perfusion. In centrally located placentas, both uterine arteries contribute relatively equally to placental blood supply. In contrast, laterally implanted placentas depend predominantly on the ipsilateral uterine artery, with reduced compensatory flow from the contralateral side. If spiral artery remodeling is impaired, this asymmetric dependence may exacerbate placental hypoperfusion, particularly when the dominant uterine artery exhibits increased resistance. [22]

Anatomical variations of the uterine arteries further support this hypothesis. Differences in uterine artery caliber, branching patterns, and anastomotic connections can influence regional uterine perfusion. When placentation occurs laterally, these anatomical variations may magnify disparities in blood flow, predisposing to abnormal uteroplacental circulation. Such considerations are particularly relevant in the interpretation of unilateral uterine artery Doppler abnormalities in pregnancies with lateral placentation. [23]

Clinical studies investigating placental laterality have demonstrated associations with adverse pregnancy outcomes, including preeclampsia, fetal growth restriction, and low birth weight. Although not all studies report consistent findings, those employing standardized definitions and adequate sample sizes have shown higher rates of preeclampsia among women with lateral placentas compared with centrally located placentas. These observations reinforce the concept that placental site is not merely an anatomical descriptor but may reflect underlying placental vascular vulnerability. [24]

From an imaging standpoint, placental laterality offers an attractive screening variable because it can be assessed during routine obstetric ultrasound without additional equipment or significant time. However, its predictive utility depends on meticulous technique, correct midline identification, and awareness of potential confounders such as uterine rotation and placental migration. When interpreted within a structured imaging protocol and combined with uterine artery Doppler findings, placental laterality may contribute meaningful incremental value to preeclampsia risk assessment. [25]

Placental Laterality as a Predictor of Preeclampsia: Clinical Evidence and Outcomes

Early observational studies first proposed placental laterality as a potential predictor of hypertensive disorders of pregnancy by demonstrating higher rates of preeclampsia in women with laterally implanted placentas compared with those with central placentation. These studies suggested that lateral placentation may serve as a surrogate marker of asymmetric uterine perfusion, particularly in the presence of impaired spiral artery remodeling. Although initially exploratory, these findings stimulated further investigation into placental site as a low-cost, ultrasound-based screening parameter. [26]

Subsequent cohort studies strengthened the evidence base by evaluating placental laterality in larger populations and correlating sonographic findings with pregnancy outcomes. Several investigators reported a statistically significant association between lateral placental location and increased incidence of preeclampsia, as well as related complications such as fetal growth restriction and low birth weight. Importantly, these associations were more pronounced when placental laterality was assessed in the mid-trimester, highlighting the influence of gestational age on predictive performance. [27]

Placental laterality has also been examined in relation to uterine artery Doppler findings, revealing that lateral placentas are more frequently associated with abnormal Doppler indices on the ipsilateral side. This observation supports the hypothesis that laterality reflects not only anatomical placement but also functional vascular compromise. In pregnancies complicated by preeclampsia, unilateral persistence of high-resistance flow patterns appears more common when placentation is lateral, reinforcing the biological plausibility of this association. [28]

However, not all studies have demonstrated a strong or independent predictive role for placental laterality. Variability in study design, inconsistent definitions of laterality, and differences in outcome classification have contributed to conflicting results across the literature. Some investigations have shown that placental laterality alone has limited sensitivity and specificity, particularly for late-onset preeclampsia, suggesting that its role as a standalone screening tool may be modest. [29]

Comparative analyses indicate that placental laterality performs better when combined with other clinical or imaging markers. When incorporated alongside uterine artery Doppler velocimetry, maternal risk factors, or biochemical markers, placental laterality may improve overall risk stratification. This synergistic effect underscores the concept that preeclampsia is a multifactorial disorder and that no single imaging parameter is sufficient to capture its complexity. [30]

From a radiologic perspective, the clinical value of placental laterality lies in its simplicity and reproducibility when standardized protocols are applied. It requires no additional equipment, contrast, or post-processing, making it particularly attractive in resource-limited settings. Nevertheless, radiologists and sonographers must recognize its limitations and avoid overreliance on placental site in isolation, instead interpreting it as one component of a broader, multimodal screening strategy for preeclampsia. [31]

Uterine Artery Doppler: Principles, Physics, and Imaging Technique

Uterine artery Doppler ultrasonography is a functional imaging technique that evaluates resistance to blood flow within the uterine arteries and serves as an indirect marker of placental vascular development. The Doppler waveform reflects downstream impedance within the uteroplacental circulation and is influenced by the degree of spiral artery remodeling. In pregnancies that later develop preeclampsia, increased resistance within the placental bed results in characteristic waveform abnormalities that can be detected weeks before clinical disease onset. [32]

From a physics perspective, Doppler ultrasound is based on the frequency shift that occurs when sound waves are reflected by moving red blood cells. Accurate uterine artery Doppler assessment requires optimization of technical parameters, including appropriate insonation angle, pulse repetition frequency, and wall filter settings. Failure to adhere to these principles may lead to erroneous velocity measurements and misinterpretation of Doppler indices, reducing the reliability of uterine artery Doppler as a predictive tool. [33]

The uterine arteries are typically identified at the level of the internal cervical os, where they cross over the external iliac arteries or along the lateral margins of the uterus using color Doppler guidance. Both transabdominal and transvaginal approaches can be used, although the transabdominal route is more commonly employed in routine screening. Precise vessel identification is essential to avoid sampling adjacent vessels, such as arcuate arteries, which can significantly alter Doppler measurements. [34]

Standard Doppler indices used in uterine artery assessment include the pulsatility index, resistance index, and systolic-to-diastolic ratio. Among these, the pulsatility index is most widely accepted due to its relative independence from heart rate and ease of reproducibility. Qualitative assessment for the presence of early diastolic notching is also important, as persistent notching beyond the first trimester is associated with increased placental vascular resistance. [35]

Gestational age has a critical influence on uterine artery Doppler waveforms. In normal pregnancies, progressive trophoblastic invasion leads to a gradual decline in uterine artery resistance as gestation advances. Therefore, interpretation of Doppler findings must be performed using gestational age–specific reference ranges. Abnormal results are typically defined by elevated pulsatility index values above the 90th or 95th percentile for gestational age, depending on the screening protocol used. [36]

Reproducibility and operator dependency remain important considerations in uterine artery Doppler imaging. Adequate training, standardized acquisition protocols, and consistent measurement techniques are necessary to minimize interobserver variability. From a radiologic standpoint, strict adherence to guideline-recommended methods enhances the clinical utility of uterine artery Doppler and supports its integration into structured screening programs for preeclampsia. [37]

Doppler Indices and Waveform Abnormalities: Physiologic Interpretation and Clinical Meaning

Uterine artery Doppler indices provide quantitative and qualitative information about downstream resistance within the uteroplacental circulation. Among these indices, the pulsatility index (PI) is most commonly used because it reflects the variability of blood flow velocity throughout the cardiac cycle and is relatively independent of absolute velocity measurements. Elevated PI values indicate increased impedance to flow and are strongly associated with impaired placental vascular development in pregnancies that later develop preeclampsia. [38]

The resistance index (RI) and systolic-to-diastolic (S/D) ratio are additional parameters that reflect vascular resistance, although they are more sensitive to heart rate and technical factors. While these indices can support interpretation, they are generally considered less robust than PI for screening purposes. Persistent elevation of RI or S/D ratio beyond the first trimester suggests failure of normal spiral artery remodeling and ongoing high-resistance flow within the uteroplacental circulation. [39]

Early diastolic notching is a qualitative Doppler feature that represents transient cessation or reversal of flow during early diastole. In normal pregnancy, this notch disappears as gestation advances and uterine artery resistance decreases. Persistence of unilateral or bilateral notching beyond 20–24 weeks of gestation has been consistently associated with an increased risk of preeclampsia and fetal growth restriction, reflecting sustained high resistance within the placental bed. [40]

The physiological basis of abnormal uterine artery waveforms has been further clarified through experimental and computational models. These models demonstrate that increased placental vascular resistance, reduced arterial compliance, and incomplete spiral artery transformation collectively contribute to elevated PI values and notching. Such findings support the interpretation of Doppler abnormalities as direct surrogates of placental vascular pathology rather than isolated maternal hemodynamic changes. [41]

Importantly, unilateral abnormalities in uterine artery Doppler waveforms may carry different clinical implications than bilateral abnormalities. Bilateral elevation of PI or bilateral notching generally reflects more widespread placental vascular compromise and is associated with a higher risk of early-onset and severe preeclampsia. In contrast, unilateral abnormalities may be influenced by placental laterality and asymmetric uterine perfusion, reinforcing the need to interpret Doppler findings in conjunction with placental location. [42]

From a clinical imaging perspective, abnormal uterine artery Doppler findings should be viewed as probabilistic rather than diagnostic markers. While they identify pregnancies at increased risk, they do not inevitably predict disease development. Their greatest value lies in stratifying risk and guiding closer surveillance or preventive interventions, particularly when combined with other imaging markers such as placental laterality and clinical risk factors. [43]

First-Trimester Uterine Artery Doppler in Preeclampsia Prediction

First-trimester uterine artery Doppler assessment has gained increasing attention as part of early screening strategies for preeclampsia. Performed typically between 11 and 13+6 weeks of gestation, this early evaluation coincides with the period of trophoblastic invasion and spiral artery remodeling. Abnormal Doppler findings at this stage are thought to reflect early placental maladaptation, preceding both clinical disease and later structural placental changes. [44]

In normal pregnancy, uterine artery resistance is relatively high in the first trimester but begins to decline as placentation progresses. Persistently elevated pulsatility index values during this period suggest impaired vascular adaptation and have been associated with an increased risk of developing preeclampsia, particularly early-onset disease. First-trimester Doppler therefore offers a unique opportunity to identify high-risk pregnancies before the onset of irreversible placental pathology. [45]

Large prospective studies have demonstrated that first-trimester uterine artery Doppler alone has moderate predictive performance, with higher sensitivity for early-onset preeclampsia compared with late-onset disease. Its predictive value improves when Doppler findings are expressed as multiples of the median and interpreted using gestational age–specific reference ranges. These methodological refinements have enhanced the reproducibility and comparability of Doppler results across populations. [46]

Integration of first-trimester uterine artery Doppler into combined screening models has further strengthened its clinical utility. When combined with maternal demographic characteristics, medical history, and biochemical markers, Doppler assessment contributes significantly to risk stratification algorithms capable of identifying women who may benefit from prophylactic interventions such as low-dose aspirin. This multimodal approach reflects the multifactorial nature of preeclampsia pathogenesis. [47]

Despite its advantages, first-trimester uterine artery Doppler has limitations that must be acknowledged. Technical challenges related to small vessel caliber, fetal and maternal movement, and operator experience can affect measurement accuracy. Additionally, not all pregnancies with abnormal first-trimester Doppler findings progress to clinically significant disease, underscoring the importance of cautious interpretation and avoidance of overdiagnosis. [48]

From a radiologic standpoint, first-trimester uterine artery Doppler should be performed using standardized acquisition protocols and interpreted within the context of comprehensive screening strategies. Its role is best viewed as an early risk assessment tool rather than a diagnostic test, providing a foundation for tailored surveillance and preventive care in pregnancies at increased risk for preeclampsia. [49]

Second-Trimester Uterine Artery Doppler: Predictive Performance and Clinical Implications

Second-trimester uterine artery Doppler assessment, usually performed between 20 and 24 weeks of gestation, represents the most extensively studied time point for Doppler-based prediction of preeclampsia. By this stage, normal spiral artery remodeling should be largely complete, and uterine artery resistance is expected to have significantly decreased. Persistence of high-resistance flow patterns during the second trimester therefore strongly suggests abnormal placentation and ongoing uteroplacental vascular compromise. [50]

Multiple studies have demonstrated that elevated uterine artery pulsatility index and persistent early diastolic notching in the second trimester are associated with an increased risk of preeclampsia, particularly early-onset and severe forms of the disease. Bilateral abnormalities confer a higher risk than unilateral findings and are more closely linked to adverse maternal and fetal outcomes, including fetal growth restriction and preterm delivery. These observations support the continued clinical relevance of second-trimester Doppler screening. [51]

Compared with first-trimester Doppler, second-trimester uterine artery assessment generally shows higher specificity but lower sensitivity for preeclampsia prediction. Its predictive performance is strongest for early-onset disease and pregnancies complicated by placental insufficiency. Late-onset preeclampsia, which is more closely related to maternal constitutional factors, is less consistently associated with abnormal second-trimester Doppler findings. [52]

Sequential Doppler assessment between the first and second trimesters provides additional prognostic information. Pregnancies in which uterine artery resistance remains elevated or worsens over time are at significantly higher risk than those showing normalization of Doppler indices. This dynamic evaluation underscores the importance of interpreting uterine artery Doppler as a longitudinal marker of placental vascular adaptation rather than a single static measurement. [53]

From a clinical standpoint, abnormal second-trimester uterine artery Doppler findings warrant closer maternal and fetal surveillance. Although Doppler abnormalities alone do not mandate intervention, they can guide risk stratification and inform decisions regarding follow-up imaging, blood pressure monitoring, and timing of delivery in high-risk pregnancies. Their value is maximized when integrated with placental location, fetal growth assessment, and maternal clinical risk factors. [54]

In radiologic practice, second-trimester uterine artery Doppler remains a cornerstone of imaging-based evaluation for placental insufficiency. Standardized acquisition techniques, use of gestational age–specific reference ranges, and consistent reporting of quantitative and qualitative findings are essential to ensure reproducibility and meaningful clinical interpretation. When combined with placental laterality, second-trimester Doppler provides a robust, biologically grounded framework for predicting preeclampsia. [55]

Combined Role of Placental Laterality and Uterine Artery Doppler in Preeclampsia Prediction

Combining placental laterality with uterine artery Doppler assessment is conceptually attractive because it integrates a structural marker (implantation site) with a functional marker (uteroplacental vascular resistance). Placental laterality may identify pregnancies prone to asymmetric uterine perfusion, while uterine artery Doppler quantifies the hemodynamic consequence of impaired spiral artery remodeling. This combined approach aligns well with the underlying biology of preeclampsia, where implantation and vascular adaptation are interdependent processes. [56]

Clinical observations suggest that lateral placentation is frequently accompanied by higher impedance in the ipsilateral uterine artery, and in some cases, persistent unilateral notching. When Doppler abnormalities occur in a pregnancy with lateral placental implantation, the plausibility of true uteroplacental insufficiency increases, reducing the likelihood that the abnormal waveform reflects technical error or transient maternal hemodynamic variation. Therefore, interpreting Doppler indices in the context of placental site can improve diagnostic confidence and risk communication. [57]

Several studies evaluating placental laterality as a risk marker have reported improved predictive accuracy when uterine artery Doppler is incorporated. In such models, the combined presence of lateral placenta and abnormal uterine artery Doppler indices has been associated with a higher incidence of preeclampsia than either factor alone. This suggests additive or synergistic predictive value and supports integrating both parameters into structured ultrasound reporting, particularly during the mid-trimester anatomy scan. [58]

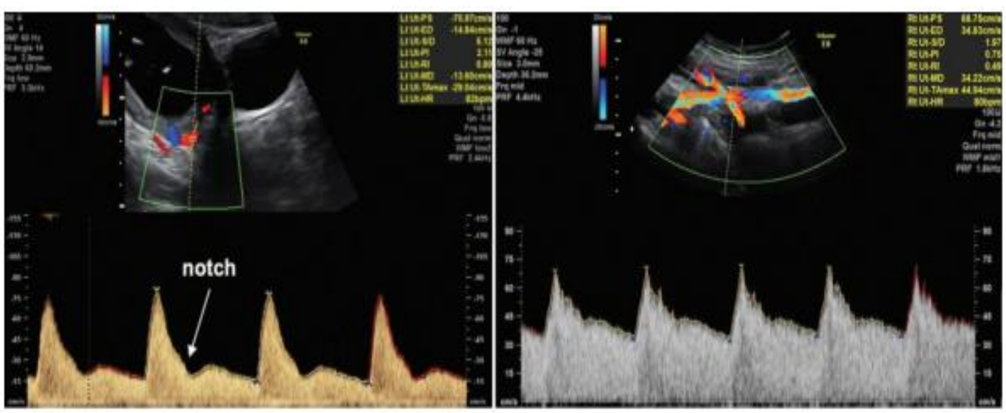

Fig. (1): Doppler velocimetry of the uterine arteries showing a high resistance pattern with notching between the systolic and the diastolic components of the wave (A), characteristic of the first trimester, and a low resistance pattern (B), characteristic of the second trimester (Quoted from Pedroso et al., 2018)

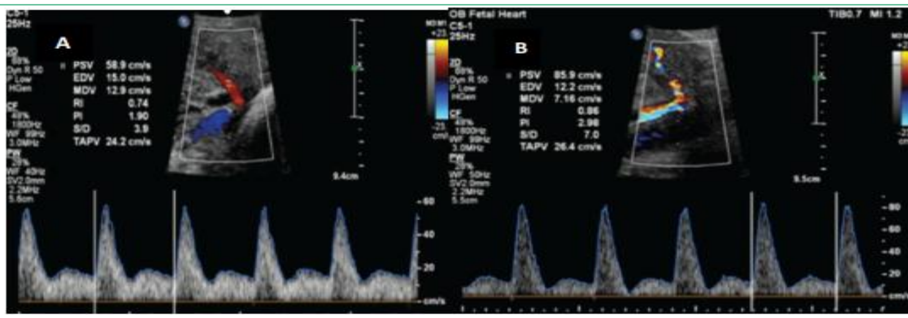

Fig. (2):Abnormal second trimester uterine artery Doppler waveforms on the right (A) and left (B) sides characterized by a mean PI of 2.44 and bilateral diastolic notches (Quoted from Oloyede et al., 2013)

The combined approach is also supported by mechanistic work explaining how uterine artery waveform changes arise from both placental bed resistance and broader uteroplacental vascular characteristics. Advanced physiologic frameworks demonstrate that the Doppler waveform is influenced by spiral artery remodeling, placental vascular architecture, and maternal systemic factors. Placental laterality provides context about regional uterine perfusion reliance, thereby improving interpretation of unilateral versus bilateral Doppler abnormalities. [59]

However, the magnitude of benefit gained from combining laterality with uterine artery Doppler varies across studies, largely due to methodological heterogeneity. Differences in how laterality is defined, timing of assessment, Doppler thresholds, and whether unilateral or mean uterine artery indices are used can significantly affect performance metrics. Standardization of protocols and definitions is therefore essential before this combined strategy can be widely generalized and adopted across diverse clinical settings. [60]

From a radiology-driven protocol perspective, incorporating placental laterality into routine reporting is simple, but it must be done consistently and with awareness of confounders such as uterine rotation, placental migration, and multifocal placentation. When combined with guideline-concordant uterine artery Doppler velocimetry, placental laterality may contribute incremental value to prediction models, particularly in environments where biochemical markers are unavailable or cost-prohibitive. [61]

Clinical Performance: Sensitivity, Specificity, and Risk Prediction Metrics

The clinical performance of placental laterality as a predictor of preeclampsia is generally modest when used alone, with variability across studies driven by differences in definition, population risk profile, and timing of ultrasound assessment. Most reports suggest that laterality may identify a subgroup with increased risk, but sensitivity is limited because many cases of preeclampsia occur in pregnancies with centrally located placentas. Therefore, placental laterality is best regarded as a risk-enhancing marker rather than a standalone screening test. [62]

Uterine artery Doppler velocimetry demonstrates stronger predictive performance than placental laterality, particularly for early-onset and severe preeclampsia. Elevated uterine artery pulsatility index and persistent early diastolic notching correlate with impaired placental vascular remodeling, and prediction improves when Doppler indices are interpreted relative to gestational age–specific reference ranges. However, even uterine artery Doppler alone has limited sensitivity for late-onset preeclampsia, which is more influenced by maternal cardiovascular and metabolic factors. [63]

Performance metrics depend strongly on whether assessment focuses on early-onset versus all preeclampsia, and whether the outcome includes placental insufficiency phenotypes such as fetal growth restriction. Studies show that uterine artery Doppler is most informative when the endpoint is early delivery for preeclampsia or growth restriction, because these phenotypes are most tightly linked to abnormal placentation. This explains why Doppler screening often performs better in predicting preeclampsia associated with small-for-gestational-age infants than in predicting term preeclampsia. [64]

Combined strategies that integrate uterine artery Doppler with maternal factors and additional markers yield the highest screening performance. Large prospective screening work has demonstrated that algorithms incorporating maternal characteristics with biophysical markers such as uterine artery Doppler can substantially improve detection of preterm preeclampsia compared with single-parameter approaches.

From a practical imaging standpoint, uterine artery Doppler provides an important biophysical component of such models and remains a cornerstone of ultrasound-based risk stratification where biochemical markers are unavailable. [65]

The incremental value of placental laterality within combined models is less extensively quantified but may be clinically meaningful in specific contexts. Placental laterality can contextualize unilateral Doppler abnormalities and may enhance risk interpretation in populations where Doppler acquisition is variable or where a single-sided abnormality could otherwise be dismissed. This is particularly relevant for pragmatic screening in routine mid-trimester ultrasound where placental site is already documented and can be leveraged without additional cost. [66]

For clinicians and radiologists, it is essential to interpret predictive metrics with attention to disease prevalence and pretest probability. Even tests with good specificity may have limited positive predictive value in low-risk populations, while negative predictive value tends to be high. Therefore, the main clinical utility of placental laterality and uterine artery Doppler lies in identifying women who benefit from intensified surveillance and preventive strategies, rather than definitively ruling in disease. [67]

Clinical Pitfalls and Limitations: Definition Variability, Measurement Errors, and Confounders

A major limitation in the literature on placental laterality is inconsistency in how laterality is defined and measured. Some studies define laterality based on the site of maximal placental thickness, others on the proportion of placental mass relative to the uterine midline, and some rely on simplified anterior/posterior descriptors that do not reliably capture lateral implantation. This heterogeneity reduces comparability across studies and can substantially alter reported associations with preeclampsia risk, emphasizing the need for standardized, reproducible definitions in imaging protocols. [68]

Gestational age at assessment is another important confounder, because placental position appears to “migrate” as the uterus expands, and early placental localization may not reflect mid-trimester position. Misclassification can occur if laterality is recorded too early or if follow-up scans are not considered. This is particularly relevant when screening programs use first-trimester scans for early prediction while laterality may be more stable and accurately characterized in the second trimester. [69]

Uterine artery Doppler is highly operator-dependent, and technical errors can lead to false abnormal or false reassuring results. Insonation angle errors, inappropriate sampling location, failure to standardize wall filter and pulse repetition frequency, and incorrect identification of the uterine artery (sampling arcuate arteries instead) are common pitfalls. Such technical variation can inflate interobserver variability and weaken the reliability of Doppler indices for prediction unless rigorous acquisition standards are maintained. [70]

Physiological and anatomical factors can also influence uterine artery Doppler measurements independent of placental pathology. Maternal heart rate, blood pressure, uterine contractions, and systemic vascular tone can transiently alter waveform morphology. In addition, anatomical variations in uterine artery branching and anastomotic patterns may contribute to unilateral differences in Doppler indices, which can be misinterpreted as placental disease if placental laterality and uterine anatomy are not considered. [71]

Interpretation pitfalls arise when abnormal Doppler findings are treated as diagnostic rather than probabilistic. Uterine artery Doppler abnormalities indicate increased risk but do not confirm that preeclampsia will occur, and a normal Doppler does not exclude late-onset preeclampsia driven by maternal constitutional risk factors. Overreliance on Doppler can therefore lead to unnecessary anxiety and over-surveillance, while underappreciation of its limitations may cause missed opportunities for prevention in truly high-risk cases. [72]

Finally, across both placental laterality and uterine artery Doppler, the absence of harmonized reporting standards limits clinical translation. Predictive performance depends not only on measurement accuracy but also on consistent thresholds (e.g., percentile-based PI cutoffs), clear documentation of unilateral versus bilateral abnormalities, and use of gestational age–appropriate reference ranges. Addressing these limitations through standardized protocols is essential if these imaging markers are to be reliably integrated into routine screening pathways for preeclampsia. [73]

Standardized Imaging Protocols and Reporting (Placental Laterality and Uterine Artery Doppler)

Standardization of imaging protocols is essential to improve the reliability and clinical applicability of placental laterality and uterine artery Doppler in preeclampsia prediction. Placental location should be assessed systematically during routine obstetric ultrasound, with clear identification of the uterine midline and classification of placentation as central or lateral based on the predominant placental mass. Consistent documentation of placental site reduces interobserver variability and enhances comparability across examinations and studies. [74]

Uterine artery Doppler acquisition should follow established technical guidelines to ensure reproducible and accurate measurements. The uterine arteries should be sampled at the level of the internal cervical os using color Doppler guidance, with attention to insonation angle, pulse repetition frequency, and wall filter settings. Both right and left uterine arteries must be evaluated, and mean pulsatility index values should be reported alongside qualitative assessment for early diastolic notching. [75]

Interpretation of Doppler findings must rely on gestational age–specific reference ranges, as uterine artery resistance decreases physiologically with advancing gestation. Abnormal results should be expressed using percentile-based thresholds rather than absolute cutoffs to minimize population bias. Clear differentiation between unilateral and bilateral abnormalities should be included in reports, particularly in pregnancies with lateral placentation. [76]

Structured reporting that integrates placental laterality with uterine artery Doppler findings facilitates clinical decision-making. Radiology reports should contextualize Doppler abnormalities in relation to placental site and emphasize that findings represent increased risk rather than definitive diagnosis. Adoption of standardized terminology and reporting templates supports effective communication between radiologists and obstetric care providers. [76]

Conclusion

Placental laterality and uterine artery Doppler velocimetry provide complementary structural and functional insights into the placental pathology underlying preeclampsia. Placental laterality reflects implantation-related asymmetry in uterine perfusion, while uterine artery Doppler abnormalities represent the hemodynamic consequences of impaired spiral artery remodeling. When interpreted together, these imaging markers offer a biologically plausible and clinically accessible approach to early risk stratification.

Although uterine artery Doppler has a stronger and more established predictive role, particularly for early-onset and severe preeclampsia, placental laterality adds contextual value that may improve interpretation of unilateral Doppler abnormalities and enhance risk assessment in routine obstetric ultrasound. Neither parameter is sufficient as a standalone screening tool, but their combined use aligns with the multifactorial nature of preeclampsia and supports integrated imaging-based prediction models.

The clinical utility of these markers depends heavily on standardized acquisition techniques, consistent definitions, and gestational age–appropriate interpretation. Awareness of technical pitfalls and physiological confounders is essential to avoid misclassification and overinterpretation. From a radiology perspective, structured reporting that integrates placental location with uterine artery Doppler findings can strengthen multidisciplinary communication and guide appropriate surveillance strategies.

In summary, placental laterality and uterine artery Doppler represent valuable, low-cost, and widely available imaging tools that, when used judiciously and in combination, contribute meaningfully to the prediction of preeclampsia. Ongoing refinement of imaging protocols and integration into multimodal screening frameworks will be critical to maximizing their impact on maternal and perinatal outcomes.

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