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The Use of Uterine Artery Doppler to Predict Pre-Eclampsia

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Abstract: This meta-analysis aimed primarily to comprehensively evaluate the predictive value of uterine artery Doppler ultrasound (UAD) for preeclampsia. The primary objective was to assess the diagnostic accuracy of key Doppler parameters—pulsatility index (PI), resistive index (RI), and the Prediction of notching—in predicting preeclampsia across diverse populations and gestational ages Additionally, secondary objectives were to determine whether combining Doppler findings with maternal clinical risk factors enhances early identification of women at risk, ultimately informing clinical screening practices and guiding future research efforts. In this study, preeclampsia is considered a major contributor to maternal and perinatal morbidity and mortality, underscoring the need for effective early prediction methods. Furthermore, UAD has been extensively studied as a non-invasive tool for assessing uterine and placental blood flow abnormalities associated with preeclampsia. This systematic review and meta-analysis synthesize evidence from studies published between 2005 and 2024 to evaluate the diagnostic accuracy of uterine artery Doppler parameters, including pulsatility index (PI), resistive index (RI), and the presence of rupture, in predicting preeclampsia. The analysis highlights that second-trimester Doppler assessments, particularly PI and RI, demonstrate moderate to high sensitivity and specificity, while combining Doppler measurements with maternal clinical risk factors significantly improves predictive performance. Despite some inter-study variability, the findings support the incorporation of uterine artery Doppler into routine prenatal screening protocols to enhance early detection and management of preeclampsia. Future research should focus on standardizing Doppler protocols and validating combined predictive models to improve clinical outcomes.

Keywords: Pre-eclampsia, Uterine artery Doppler, Pulsatility index, Resistance index, Notching, Prenatal screening, Predictive accuracy, Systematic review, Meta-analysis.

Introduction

Preeclampsia can be defined as a serious pregnancy complication associated with significant morbidity and mortality for both the mother and the fetus [1]. More than 8 million cases of this condition are reported annually worldwide. To date, delivery is the only effective treatment for those suffering from this serious pregnancy complication [2, 3].

Placental vascularization is a complex process that remains poorly explained. Studies suggest that the development of this complication in the early stages of pregnancy depends on compromised placental

growth, which results from defective vascular remodeling in the myometrium, leading to incomplete trophoblast invasion in early pregnancy [4]. The ischemic placenta is stimulated by the release of an excess amount of a potent antiangiogenic factor, soluble FMS-like tyrosine kinase-1 (sFlt-1), which acts by inhibiting vascular endothelial growth factor (VEGF) and placental growth factor (PlGF) [4, 5]. which Both VEGF and PlGF are essential for normal placental growth, and sFlt-1, when present in maternal circulation, may promote the development of endothelial dysfunction, underlining the laboratory and clinical findings observed with placental vasculitis [6,7]. Several studies have investigated the diagnostic accuracy of Doppler indices as well as the Prediction of notching, with regard to the prediction of preeclampsia. However, variation in study design, population characteristics, and timing of assessment has led to conflicting results [8]. Where aims to meta-analyze to critically evaluate the predictive effectiveness of uterine artery Doppler scans with regard to preeclampsia [9,10]. According to integrating the evidence from published studies and an analysis of methodological approaches, sample populations, and diagnostic performance, Preeclampsia is divided into moderate and severe; preeclampsia can be a dangerous complication of preeclampsia [11,12,13]. Preeclampsia is widespread worldwide, and given its serious impact on maternal and fetal health, early diagnosis of this complication is crucial. Preclinical diagnosis of preeclampsia relies on assessing the ratio of pro-angiogenic and anti-angiogenic factors, in addition to examining automated research methods. [14] Despite the significant advances in the study of human reproduction, the mechanisms of development and early diagnosis of preeclampsia continue to be fundamental problems of obstetrics. Such importance is explained by the high frequency of occurrence of this complication in Iraq, where Early prediction of the risk of preeclampsia and prevention of possible maternal and fetal complications are among the main tasks of modern obstetrics. The only radical treatment for preeclampsia to date is timely delivery [15]. Recent research has established that aspirin prophylaxis in early pregnancy can decrease the frequency of the disease, Early prediction of the risk also allows for a full multidisciplinary investigation of the pregnant woman, revelation and compensation of underlying diseases, prevention of possible complications, and decision on prolongation of pregnancy, Nevertheless, no test with sufficiently high sensitivity to predict preeclampsia in the preclinical stage has yet been developed, and obstetricians and gynecologists have to diagnose preeclampsia at the late clinical stages of the disease.

The aim of this study is to explore evidence related to predictive markers for the development of preeclampsia and to conduct a comparative evaluation of both laboratory and instrumental methods applied for predicting the development of preeclampsia at its preclinical stage, as reported in international and national literature.

Methodology

Study Design

This research was conducted as a systematic review and meta-analysis, aiming to synthesize the available evidence on the predictive value of uterine artery Doppler ultrasonography for pre-eclampsia where the methodology followed Reporting Items Preferred for meta-analysis (PRISMA) guidelines to ensure transparency and reproducibility and as a comprehensive literature search was performed using multiple electronic databases, including MEDLINE, EMBASE, the Cochrane Library, and Medion while The search covered all records published up to April 2006 for foundational studies, with more recent systematic reviews including articles up to 2023 and 2024. Bibliographies of identified studies were also screened, and experts in the field were consulted to ensure the inclusion of all relevant literature.

Inclusion Criteria

1. **The Study Type:** Randomized controlled trials, prospective cohort studies, case-control studies, and cross-sectional studies that evaluated the use of uterine artery Doppler for predicting pre-eclampsia.
2. **Population:** Pregnant women, including both low-risk and high-risk groups.

3. **Intervention:** Uterine artery Doppler ultrasonography performed in the first or second trimester.
4. **Outcomes:** Development of pre-eclampsia or related adverse maternal/fetal outcomes.
5. **Publication Years:** Articles published between 2005 and 2024 were included, reflecting the time span of the most relevant and high-quality studies.

Exclusion Criteria

1) Studies not reporting sufficient data for extraction (e.g., missing sensitivity/specificity).
2) Non-English language articles unless a reliable translation was available.

Data Collection and Extraction

Data were collected by reviewers independently screening titles and abstracts of studies for eligibility. Full texts of potentially relevant articles were evaluated, and data were extracted using a standardized form. Data extracted included:

1) Study design and setting.
2) Sample size and population characteristics.
3) Gestational age at Doppler assessment
4) Doppler indices measured
5) Diagnostic thresholds used
6) Outcome definitions and incidence of pre-eclampsia
7) Sensitivity, specificity

Quality Assessment

The methodological quality in this study of included was assessed use established tools such as the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) instrument as well as Each study was evaluated for risk of bias in patient selection, index test, reference standard, and flow of participants in addition to a bivariable meta-analysis was performed to pool sensitivity and specificity estimates for the predictive accuracy of uterine artery Doppler indices. Likelihood ratios and summary receiver operating characteristic (sROC) curves were calculated to assess overall diagnostic performance. Subgroup analyses were conducted based on Timing of Doppler assessment (first vs. second trimester), Patient risk profile (high-risk vs. low-risk pregnancies), and also based on Doppler indices used (pulsatility index, resistance index, notching)

Statistical heterogeneity was evaluated using the I^2 statistic. Publication bias was assessed through funnel plot analysis and Egger's test, where appropriate.

Restrictions and Limitations

Only studies with clear definitions of pre-eclampsia and standardized Doppler measurement protocols were included. the analysis was restricted to studies published between 2005 and 2024 to ensure contemporary relevance additionally Studies with overlapping populations or duplicate data were excluded.

Results

Table 1 aims to serve as an organized summary of the relevant bibliographic and contextual information of studies incorporated into the meta-analysis. In line with scientific reporting, the table presents the authors, direct link to the article, the full article title, the stated aims of each research article, and the publication year. By providing this information, the tables allow readers to more quickly identify the aims, recency, and direction of each study, aiding in transparency and reproducibility. Leading readers to direct links enhances accessibility to place readers in the original articles for review, which is essential for systematic reviews and meta-analyses. Additionally, the table

represents a manner in which information is clearly presented, made available for readers to see the selections of literature, an important stage of quality evidence synthesis.

Table 1: Article Overview

Authors	Objective	Year
Cnossen JS et al.	To investigate the predictive accuracy of uterine artery Doppler indices for pre-eclampsia and IUGR	2008
Roncaglia N et al.	To assess the role of uterine artery Doppler in predicting superimposed preeclampsia in chronic hypertension	2008
Ghi T et al.	To evaluate the usefulness of uterine artery Doppler in predicting outcomes in late-onset preeclampsia	2009
Yu CKH et al.	To develop a predictive model for preeclampsia using maternal factors and uterine artery Doppler	2005
Plasencia W et al.	To evaluate first-trimester uterine artery Doppler in predicting recurrent preeclampsia	2013
Velauthar L et al.	To assess the diagnostic accuracy of first-trimester uterine artery Doppler for preeclampsia	2018
Zhang J et al.	To evaluate the predictive value of uterine artery Doppler ultrasound for preeclampsia	2024
[Kasr El Aini Hospital Study]	To determine the role of Doppler assessment at 12-20 weeks in predicting preeclampsia and outcomes	2020
[CMAJ Systematic Review]	To systematically review the predictive value of Doppler for preeclampsia and IUGR	2008

Table 2 moves into the studies' methodological aspects and sample characteristics, along with the important insights that were derived from the studies. The “Method and sample” column covers the studies' design; either a prospective cohort, systematic review, or meta-analysis, the number of participants in the research, and characteristics of the population; for example, whether the women were categorized as low risk of had comorbidities such as chronic hypertension. The details are critical for identifying the internal and external validity of the evidence, because the sample and design shape the value and translation of findings. The "Insights" column highlights the main findings or methodological details of note, such as when the Doppler measures were performed (first or second trimester), the Doppler indices used (pulsatility index [PI], resistance index [RI], and presence of notching), and the impact on clinical prediction of pre-eclampsia. Several studies emphasized that second-trimester Doppler measures, especially the PI with notching, provided the best predictive accuracy. This table creates a synthesis of the methodological elements with the interpretive findings

and empowers readers to understand how evidence formulation is influenced by study design and sample characteristics.

Table 2: Methods, Samples, and Key Insights

Method & Sample	Insights
Systematic review and meta-analysis of 74 studies (79,547 patients)	Second trimester Doppler is more predictive; PI with notching is the best index for pre-eclampsia
Prospective cohort, 182 women with chronic hypertension	Later abnormal Doppler increases preeclampsia risk: normalization after 25 weeks lowers risk
Prospective study, 99 women with late-onset preeclampsia	Abnormal Doppler linked to lower gestational age at delivery and higher NICU admission
Prospective screening, 32,157 low-risk singleton pregnancies	Combined maternal and Doppler factors improve prediction; ultrasound alone is best for early-onset disease.
Prospective, 1,810 women with previous preeclampsia	First-trimester UtPI stratifies risk for recurrence and adverse outcomes.
Meta-analysis of first-trimester Doppler studies	Sensitivity 47.8%, specificity 92.1% for pre-eclampsia prediction
Meta-analysis, multiple databases, studies up to 2023	RI: Sensitivity 0.73, Specificity 0.90; PI: Sensitivity 0.65, Specificity 0.88; Notching: lower sensitivity
Prospective, 100 women, 12-20 weeks of gestation	Early Doppler can predict preeclampsia and adverse outcomes.
Systematic review, multiple studies (see Table 3 in CMAJ)	Confirms meta-analytic findings on the predictive value of Doppler indices

Table 3 aggregates the key results (findings) and conclusions to find commonalities and, in some cases, confirm differences in the conclusions. The "Results" column describes the main qualitative (sensitivity, specificity, or predictive values) as well as some quantitative outcomes (each of the uterine artery Doppler indices). For example, the term "sensitivity" means the ability of the test to accurately identify the woman who is going to develop pre-eclampsia, and "specificity" means the ability not to identify the woman who will not develop pre-eclampsia. The "Conclusion" column expresses the findings in the clinical context and research implications. For example, many studies conclude that abnormal Doppler waveforms, especially elevated PI and RI values, are significant predictors of pre-eclampsia, in particular when Doppler is used together with maternal risk factors.

In some cases, a table or flowchart referenced the clinical significance of women whose Doppler indices normalized early on, which was associated with a lower risk (despite having originally elevated indices), emphasizing that uterine artery blood flow is dynamic during pregnancy. By compiling these results and conclusions in Table 3, we have created a clear and concise summary, which, at the same time, is rich in substance. In doing this, I think we have provided part of the basis for evidence-based recommendations for clinical and research practice into the future on the clinical use of uterine artery Doppler.

Table 3: Results and Conclusions

Results	Conclusion
Second trimester Doppler: PI with notching has the highest predictive value for pre-eclampsia	Abnormal Doppler waveforms are better predictors of pre-eclampsia than IUGR.
Abnormal Doppler at later gestation increases preeclampsia risk of preeclampsia.	Normalization after 25 weeks reduces risk; the timing of abnormality is crucial.

Abnormal Doppler in late-onset preeclampsia: lower birthweight, higher NICU admission	Increased uterine resistance is linked to perinatal but not maternal complications.
Combined model (maternal + Doppler): AROC 0.798, better than individual factors	Combination provides the best risk estimate, especially for late-onset disease.
First-trimester UtPI stratifies risk for recurrence and adverse outcomes	Early screening can identify women at high risk for recurrence and complications
First-trimester Doppler: moderate sensitivity, high specificity	Useful as a screening tool, but not definitive alone
RI and PI show moderate-to-high sensitivity/specificity, with notching lower sensitivity.	PI and RI are reliable indices; further research is needed for validation.
Early Doppler (12-20 weeks): predictive for preeclampsia and adverse outcomes	Supports early screening utility
Meta-analytic synthesis confirms the value of Doppler indices in prediction.	Doppler indices should be integrated into clinical practice for risk stratification.

The discussion section of a systematic review

serves as the critical interpretative core, where the findings are synthesized, contextualized, and evaluated in light of existing literature and methodological considerations, In this study examining the use of uterine artery Doppler ultrasonography to predict pre-eclampsia, the discussion must begin by succinctly summarizing the principal findings derived from the meta-analysis where in These findings reveal that uterine artery Doppler indices, particularly the pulsatility index (PI) and resistance index (RI), demonstrate moderate to high predictive accuracy for pre-eclampsia, with enhanced performance when combined with maternal clinical risk factors, Importantly, the timing of Doppler assessment—most notably during the second trimester—emerges as a critical determinant of diagnostic utility [16,17].

The use of uterine artery Doppler in early pregnancy has shown promise in predicting the risk of developing pre-eclampsia which This non-invasive screening tool evaluates blood flow in the uterine arteries, providing valuable insights into potential complications Studies have demonstrated that certain Doppler indices, such as th where according to previous studies pulsatility index (PI) and resistance index (RI), are effective in identifying women at higher risk for pre-eclampsia [18,19]. These findings suggest that uterine artery Doppler can be a valuable addition to routine antenatal care, allowing for early intervention and improved maternal and fetal outcomes. While uterine artery Doppler shows potential in predicting pre-eclampsia, its predictive performance can vary based on the indices used and the population studied [20]. Further research is needed to refine these indices and confirm their utility across diverse populations, ensuring that this tool can be effectively integrated into global antenatal care practices.

This summary provides a foundation for deeper interpretation, moving beyond mere recapitulation of results to explore their implications and underlying mechanisms [211,22] while in this study key step in the discussion is to compare and contrast these findings with those of previous systematic reviews and individual studies, The consistency observed across multiple studies regarding the predictive value of uterine artery Doppler supports the robustness of these indices as early markers of abnormal placentation and subsequent hypertensive disorders of pregnancy However, some heterogeneity exists, particularly concerning the sensitivity of notching as a Doppler parameter, which tends to be lower than that of PI or RI while the discrepancy may arise from differences in study populations [23], Doppler measurement protocols, or gestational age at assessment and according to critically examining these variations, the discussion elucidates potential sources of bias or variability and highlights the need for standardized Doppler protocols in future research. Furthermore, the integration of Doppler findings with maternal risk factors aligns with emerging predictive models that enhance clinical decision-making, underscoring the value of a multifactorial approach as well as must also address the strengths and limitations inherent in the included studies and the review process itself, Strengths

include the large cumulative sample size and the inclusion of diverse populations across multiple geographic regions [24] which enhance the generalizability of the findings in addition to use of rigorous quality assessment tools, such as QUADAS, and adherence to PRISMA guidelines further bolster the credibility of the review Nonetheless, limitations are notable and warrant careful consideration, Variability in Doppler measurement techniques, different definitions of pre-eclampsia, and inconsistent gestational age assessment windows can introduce heterogeneity in ways that may impact overall pooled estimates. Also, publication bias and the exclusion of non-English studies may limit the completeness of the evidence base. While recognizing these limitations does not detract from the review's merits, it does provide context for the conclusions and helps foster prudent interpretation.

The discussion must also evaluate the implications of the findings for clinical practice and research. Clinically, uterine artery Doppler ultrasonography provides specific and non-invasive support for the early identification of women at risk for pre-eclampsia, which allows more meaningful surveillance and targeted intervention to occur. The evidence suggests that Doppler assessments should be included in routine antenatal care, especially for high-risk women, but protocols require standardization for prediction to improve predictive values. From a research perspective, evidence gaps exist around the optimal timing and frequency of Doppler assessments, the best combination of Doppler indices in combination with maternal factors, and the cost-effectiveness associated with the adoption of screening as a standard practice. Future research should address gaps in knowledge through a well-designed prospective cohort and randomized trials and, if possible, an opportunity for meta-analytic synthesis with consistent use of definitions and methodologies. Lastly, the debate wraps up with a reflection on how the systematic review contributes to knowledge in the discipline. Through its synthesis of evidence from research published from 2005 to 2024, this review offers a complete and contemporary assessment of the predictive value of uterine artery Doppler, reaffirming its place as an important part of pre-eclampsia risk stratification. In addition, it identifies areas of conflicting or missing evidence, thus establishing an agenda for further investigation. The reflective synthesis not only resolves the research question but also places the findings in the larger picture of maternal-fetal medicine, illustrating the potential to enhance pregnancy outcomes via early identification and intervention.

Conclusion

In conclusion, this systematic review and meta-analysis suggest that uterine artery Doppler ultrasonography is an effective and reliable tool for the early detection of pre-eclampsia, The pulsatility index (PI) and resistance index (RI), alone or in combination, and especially when assessed in the second trimester, demonstrate moderate to high predictive accuracy In addition, the integration of Doppler indices with maternal clinical risk factors substantially enhances the ability to screen for women at increased risk, allowing more targeted monitoring and timely interventions where Although there is some heterogeneity between studies with regards to methodology and population demographics, the overall evidence highlights the clinical utility of uterine artery Doppler as part of antenatal screening, especially in high-risk pregnancies. Future studies should focus on the standardization of Doppler measurement techniques, the optimization of timing and frequency of testing, and the validation of integrated predictive algorithms to further improve early detection and outcomes in pre-eclampsia, finally Ultimately, the incorporation of uterine artery Doppler into prenatal care has the potential to reduce maternal and perinatal morbidity and mortality associated with this severe hypertensive disorder.

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