

Role of First-Trimester Mean Arterial Pressure and Second-Trimester Uterine Artery Pulsatility Index in Prediction of Preeclampsia in High-Risk Pregnant Women

Maryam Bashar, Maliha Sadaf, Humera Noreen, Khansa Iqbal, Fouzia Naheed, Amna Abbasi

ABSTRACT

Objective: To compare the predictive performance of first-trimester mean arterial pressure (MAP) and second-trimester uterine artery pulsatility index (UtA-PI) for subsequent preeclampsia in high-risk pregnant women.

Study Design and Setting: Validation study at Department of Obstetrics and Gynaecology, Holy Family Hospital, Rawalpindi.

Methodology: This validation study included 202 high-risk singleton pregnancies enrolled by non-probability consecutive sampling. MAP was measured in the first trimester and was considered abnormal when >100 mmHg. Uterine artery Doppler was performed at 22+6 to 24+6 weeks of gestation; UtA-PI >1.45 was considered abnormal. Participants were followed after 20 weeks for development of preeclampsia. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy were calculated against the final clinical prediction of preeclampsia.

Result: Preeclampsia developed in 75/202 (37.1%) participants. For MAP, sensitivity was 92.0% (95% CI 83.6–96.3), specificity 89.0% (82.3–93.3), PPV 83.1% (73.7–89.7), NPV 95.0% (89.4–97.7), and overall accuracy 90.1% (85.2–93.5). For second-trimester UtA-PI, sensitivity was 76.0% (65.2–84.2), specificity 79.5% (71.7–85.6), PPV 68.7% (58.1–77.6), NPV 84.9% (77.4–90.2), and overall accuracy 78.2% (72.0–83.4).

Conclusion: In this selected high-risk cohort, first-trimester MAP showed higher predictive accuracy than second-trimester UtA-PI for subsequent preeclampsia. These findings support MAP as a practical component of risk assessment, but they should not be interpreted as establishing MAP as a stand-alone screening strategy for all pregnant women.

Keywords: Preeclampsia, mean arterial pressure, uterine artery Doppler, pulsatility index, high-risk pregnancy.

How to cite this Article:

Bashar M, Sadaf M, Noreen H, Iqbal K, Naheed F, Abbasi A. Role of First-Trimester Mean Arterial Pressure and Second-Trimester Uterine Artery Pulsatility Index in Prediction of Preeclampsia in High-Risk Pregnant Women. *J Bahria Uni Med Dental Coll.* 2026;16(4):915-20 DOI: <https://doi.org/10.51985/JBUMDC20261039>

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non Commercial License (<http://creativecommons.org/licenses/by-nc/4.0>) which permits unrestricted non commercial use, distribution and reproduction in any medium, provided the original work is properly cited.

Maryam Bashar

Post Graduate Resident, Department of Obstetrics & Gynecology
Holy Family Hospital, Rawalpindi
Email: drbasharmaryam@gmail.com

Maliha Sadaf

Assistant Professor, Department of Obstetrics & Gynecology
Holy Family Hospital, Rawalpindi
Email: drmalihah1978@gmail.com

Humera Noreen

Professor, Department of Obstetrics & Gynecology
Holy Family Hospital, Rawalpindi
Email: humeranoreen@ymail.com

Khansa Iqbal

Assistant Professor, Department of Obstetrics & Gynecology
Holy Family Hospital, Rawalpindi
Email: iqbalkhansa78@gmail.com

Fouzia Naheed

Post Graduate Resident, Department of Obstetrics & Gynecology
Holy Family Hospital, Rawalpindi
Email: zenithcuba1986@gmail.com

Amna Abbasi

Post Graduate Resident, Department of Obstetrics & Gynecology
Holy Family Hospital, Rawalpindi
Email: dramnahabbasi87@gmail.com

Received: 05-06-2026

Accepted: 29-09-2026

1st Revision: 19-06-2026

2nd Revision: 25-09-2026

INTRODUCTION

Preeclampsia is a multisystem, pregnancy-related hypertension disorder and remains one of the leading causes of morbidity and mortality in mothers and new babies all over the world. It is usually defined by the onset of hypertension or proteinuria after 20 weeks of gestation and/or maternal organ failure, i.e. renal failure, hepatic, nervous system, hematologic and/or placental under-perfusion. Even with the augmented antenatal care, preeclampsia remains an immense burden of the obstetric practice given its risk of polite manifestation in the initial stages and its occurrence after a short interval of time to severe eclampsia, retarded fetal growth, placental abruption, preterm birth and maternal or fetal mortality.¹ The pathophysiology of preeclampsia is very complex and is associated with abnormal placenta, failure of the normal invasion of the trophoblastic proliferation of the spiral arteries, endothelial dysfunction, over-reaction of the inflammatory response and the imbalance between the proliferation of the angiogenic factors and the anti-angiogenic factors. In normal pregnancy, the spiral arteries of the uterus undergo remodelling to make low resistance uteroplacental circulation. The augmentation of such remodeling occurs

through a faulty mechanism occurring during pregnancies that are likely to have preeclampsia due to augmented vascular resistance, placental hypoxia, oxidative stress and the discharge of anti-angiogenic cytokines to the maternal blood vessels. It is the processes of these that have made maternal cardiovascular parameters and uteroplacental Doppler indices significant to the early diagnosis of preeclampsia.² The clinical relevance of the early prediction is that the preventive measures will be the most effective when implemented prior to the development of the disease. First-trimester screening enables women to be identified as being at a high risk so that preventive measures, including low-dose aspirin, more frequent monitoring and tailored antenatal care, can be implemented to mitigate the risk of preterm preeclampsia and associated adverse events.³⁻⁵ Screening directed by maternal history and clinical risk factors alone has not proven to be an effective predictor of risk, especially since not all women at risk develop visible risk factors. As such, integrated screening approaches that include maternal factors, mean blood pressure, uterine artery Doppler and aerobic biomarkers have been progressively explored.^{6,7}

Mean arterial pressure is an inexpensive, non-invasive, simple, and reproducible parameter, which measures hemodynamic adjustments in the mother during pregnancy. High MAP during early pregnancy can imply augmented vascular resistance at the systemic stage and compromise of cardiovascular adaptation, which have been recognized to be related to preeclampsia development in the future. Female longitudinal cohort study in the Asian female population indicated a beneficial predictive quality of MAP during pregnancy which confirms its applicability as a human screening instrument in the reproductive care association during pregnancy.³ Since it can be done with accurate blood pressure measurement alone, MAP can be particularly useful in low-resource locations where state-of-the-art biochemical or Doppler facilities are not ubiquitous. Another valuable screening marker is the uterine artery pulsatility index. High-resistance uteroplacental blood flow indicates increased UtA-PI, and is an indirect indicator of poor placentation. Doppler studies of the uterine artery carried out during the first trimester have revealed that abnormal UtA-PI is linked to subsequent occurrence of preeclampsia, especially at an early age and preterm conditions.⁴ Nonetheless, Doppler evaluation necessitates professional sonologists, standardized method, and ultrasound gadgets which might restrict its usage in certain clinical settings. Also, UtA-PI characteristics have been shown to depend on population features, period of gestation at the time of assessment, and the presence or absence of other screening algorithms.^{8,9} Recent studies of implementation have demonstrated that first-trimester screening programs that are structured may be implemented into regular maternity care, and could potentially enhance risk detection and prevention of preterm preeclampsia.^{7,8,10}

Thus, it is clinically relevant to compare first-trimester MAP and uterine artery pulsatility index. In case MAP shows as accurate in diagnosis as UtA-PI does, it can be used as a cost-efficient and readily-implemented screening factor. On the other hand, when UtA-PI demonstrates better predictive ability, it can be accepted to be used in high-risk pregnancies in spite of the extra cost and technical consideration. The current research aims at comparing and contrasting the diagnostic accuracy of first-trimester MAP and uterine artery pulsatility index to predict the occurrence of preeclampsia in pregnant women who are at high risks.

METHODOLOGY

This validation study was conducted from 12 April 2025 to 11 October 2025 in the outpatient Department of Obstetrics and Gynaecology, Holy Family Hospital, Rawalpindi, after approval from the institutional ethical review committee (Ref. No. 709/4/IREF/RMU/2024, dated 30 May 2024). A total of 202 high-risk women with singleton pregnancies were enrolled by non-probability consecutive sampling after application of prespecified eligibility criteria. High-risk status was defined by the presence of one or more of the following: previous preeclampsia, chronic hypertension, diabetes mellitus, renal disease, autoimmune disease, clotting disorder, first-degree family history of preeclampsia, or BMI >30 kg/m². Women with preeclampsia at enrolment or multiple pregnancy were excluded. Written informed consent was obtained before enrolment. Demographic characteristics, obstetric history, medical risk factors and family history were recorded on a structured proforma. Gestational age was determined from the last menstrual period and confirmed by first-trimester crown-rump length where appropriate. Maternal height and weight were measured and BMI was calculated as weight in kilograms divided by height in metres squared.

Aspirin prophylaxis: Participants received standard antenatal care, including aspirin 150 mg when clinically indicated according to the treating obstetric team's risk assessment. Aspirin was prescribed to [INSERT n/202, %] participants. Because aspirin can reduce the subsequent risk of preeclampsia, aspirin exposure should be reported in the final analysis and considered when interpreting the predictive performance of MAP and UtA-PI. First-trimester MAP was measured using calibrated digital oscillometric blood-pressure devices. After the participant had rested in a seated position with feet supported, legs uncrossed and arms supported at heart level, blood pressure was measured in both upper arms and repeated after at least one minute. MAP was calculated as: $MAP = DBP + (SBP - DBP)/3$, where SBP is systolic blood pressure and DBP is diastolic blood pressure. MAP >100 mmHg was classified as abnormal. All participants underwent routine obstetric ultrasonography. The first-trimester scan was performed at 11+0 to 13+6 weeks for pregnancy dating and fetal assessment. Uterine artery Doppler was performed at 22+6 to 24+6 weeks by a senior

sonographer with at least five years of post-fellowship experience. Flow-velocity waveforms were obtained from both uterine arteries. For this study, second-trimester UtA-PI >1.45 was classified as abnormal; resistance index >0.70 or a unilateral/bilateral diastolic notch was also considered an abnormal uterine artery Doppler finding. UtA-PI is dimensionless. Participants were followed after 20 weeks of gestation for development of preeclampsia during routine antenatal care. Preeclampsia was defined as blood pressure $\geq 140/90$ mmHg on two occasions at least four hours apart after 20 weeks of gestation together with proteinuria of ≥ 300 mg in a 24-hour urine collection. The final clinical prediction of preeclampsia was used as the reference standard for evaluation of MAP and UtA-PI. Data were entered and analyzed using SPSS version 23.0. Continuous variables were summarized as mean $\pm$ standard deviation and categorical variables as frequency and percentage. Separate 2×2 tables were constructed for MAP and UtA-PI against the final preeclampsia outcome. Sensitivity, specificity, PPV, NPV and overall accuracy were calculated with 95% confidence intervals. Associations between test status and preeclampsia were assessed using the chi-square test, with $p < 0.05$ considered statistically significant.

RESULTS

The mean maternal age was 28.6 ± 4.7 years (range 19–40 years), mean gestational age at enrolment was 12.4 ± 1.1 weeks, mean parity was 2.1 ± 1.3 , and mean BMI was 29.8 ± 4.6 kg/m². Mean first-trimester MAP was 96.7 ± 9.4 mmHg. Mean second-trimester UtA-PI was 1.39 ± 0.31 ; UtA-PI is a dimensionless index. Of the 202 participants, 118 (58.4%) were urban residents and 84 (41.6%) were rural residents. Socioeconomic status was upper in 32 (15.8%), middle in 106 (52.5%) and lower in 64 (31.7%). Educational status was illiterate in 28 (13.9%), primary in 34 (16.8%), middle in 41 (20.3%), matriculation in 45 (22.3%), higher secondary in 31 (15.3%), and graduate/postgraduate in 23 (11.4%). Recorded high-risk factors included previous preeclampsia in 46 (22.8%), chronic hypertension in 39 (19.3%), diabetes mellitus in 31 (15.3%), renal disease in 13 (6.4%), autoimmune disease in 10 (5.0%), clotting disorder in 8 (4.0%), family history of preeclampsia/hypertension in 54 (26.7%), and BMI >30 kg/m² in 71 (35.1%). Some participants had more than one risk factor.

During follow-up, 75/202 participants (37.1%) developed preeclampsia and 127 (62.9%) did not. Secondary adverse outcomes included intrauterine growth restriction in 29 (14.4%), preterm delivery in 36 (17.8%), and placental abruption in 7 (3.5%). An abnormal first-trimester MAP was present in 83 (41.1%) participants: 69 developed preeclampsia and 14 did not. Among the 119 participants with normal MAP, 6 developed preeclampsia and 113 did not. MAP sensitivity was 92.0% (95% CI 83.6–96.3), specificity 89.0% (82.3–93.3), PPV 83.1% (73.7–89.7), NPV 95.0% (89.4–97.7), and overall accuracy 90.1%

(85.2–93.5). Second-trimester UtA-PI was abnormal in 83 (41.1%) participants: 57 developed preeclampsia and 26 did not. UtA-PI was normal in 119 participants, of whom 18 developed preeclampsia and 101 did not. UtA-PI sensitivity was 76.0% (95% CI 65.2–84.2), specificity 79.5% (71.7–85.6), PPV 68.7% (58.1–77.6), NPV 84.9% (77.4–90.2), and overall accuracy 78.2% (72.0–83.4).

DISCUSSION:

This validation study compared first-trimester MAP with second-trimester UtA-PI for prediction of subsequent preeclampsia in 202 high-risk pregnant women. Preeclampsia developed in 75 (37.1%). MAP showed higher sensitivity, specificity and overall accuracy than UtA-PI in this cohort. However, the comparison should be interpreted within a selected high-risk population receiving routine antenatal care rather than as evidence that MAP should replace established multivariable screening approaches.

The relatively high preeclampsia frequency was expected because recruitment was restricted to women with recognized high-risk characteristics. Predictive values are prevalence-dependent, so the PPV and NPV observed here should not be extrapolated directly to unselected obstetric populations. Current international guidance emphasizes maternal risk profile and assessment when feasible.^{11–13}

The study population had a mean age of 28.6 ± 4.7 years and mean BMI of 29.8 ± 4.6 kg/m². Obesity, family history, previous preeclampsia, chronic hypertension and diabetes were common risk factors. These characteristics are clinically important because baseline maternal risk contributes to the probability of preeclampsia and to the performance of screening strategies.¹¹ First-trimester MAP identified 69 of 75 women who subsequently developed preeclampsia, giving a sensitivity of 92.0% and an overall accuracy of 90.1%. Contemporary prediction models frequently retain MAP as an important maternal biophysical marker, although the best-performing strategies generally combine maternal characteristics, MAP, UtA-PI and biochemical markers rather than relying on MAP alone.^{14,15} Machine-learning and multivariable prediction studies further support the contribution of maternal clinical characteristics and biophysical markers to risk stratification.^{16,17} These studies are more complex than the present single-marker comparison and should not be interpreted as direct validation of the MAP >100 mmHg threshold used here.

Second-trimester UtA-PI showed a sensitivity of 76.0%, specificity of 79.5% and overall accuracy of 78.2%. Published meta-analyses and cohort studies confirm that uterine artery Doppler is associated with later preeclampsia, but its performance varies according to gestational age, technique, population and threshold.^{18–20} A Pakistani study has also reported an association between first-trimester uterine artery PI and subsequent preeclampsia, supporting the relevance of uterine artery Doppler in local obstetric populations.²¹ In

Table 1. Baseline demographic, clinical and high-risk characteristics of study participants

Variable	Frequency / Mean	Percentage / SD
Total participants	202	100.0%
Age, years	28.6	± 4.7
Gestational age at enrollment, weeks	12.4	± 1.1
Parity	2.1	± 1.3
Body mass index, kg/m ²	29.8	± 4.6
Mean arterial pressure, mmHg	96.7	± 9.4
Uterine artery PI	1.39	± 0.31
High-risk factors (participants could have more than one factor)		
Previous history of preeclampsia	46	22.8%
Chronic hypertension	39	19.3%
Diabetes mellitus	31	15.3%
Renal disease	13	6.4%
Autoimmune disease	10	5.0%
Clotting disorder	8	4.0%
Family history of preeclampsia / hypertension	54	26.7%
BMI >30 kg/m ²	71	35.1%

Table 2. Distribution of demographic categories among study participants

Variable	Frequency	Percentage
Age group		
≤25 years	51	25.2%
26–30 years	82	40.6%
31–35 years	49	24.3%
>35 years	20	9.9%
Residential status		
Urban	118	58.4%
Rural	84	41.6%
Socioeconomic status		
Upper class	32	15.8%
Middle class	106	52.5%
Lower class	64	31.7%
Educational status		
Illiterate	28	13.9%
Primary	34	16.8%
Middle	41	20.3%
Matric	45	22.3%
Higher secondary	31	15.3%
Graduate / postgraduate	23	11.4%

Table 4. Predictive performance of first-trimester MAP and second-trimester uterine artery PI

Predictive parameter	MAP	Second-trimester UtA-PI
True positive	69	57
False positive	14	26
False negative	6	18
True negative	113	101
Sensitivity	92.0% (83.6–96.3)	76.0% (65.2–84.2)
Specificity	89.0% (82.3–93.3)	79.5% (71.7–85.6)
Positive predictive value	83.1% (73.7–89.7)	68.7% (58.1–77.6)
Negative predictive value	95.0% (89.4–97.7)	84.9% (77.4–90.2)
Overall accuracy	90.1% (85.2–93.5)	78.2% (72.0–83.4)

Table 3. Association of MAP and second-trimester uterine artery PI with development of preeclampsia

Screening test	Preeclampsia present	Preeclampsia absent	Total	p-value
MAP abnormal	69	14	83	<0.001
MAP normal	6	113	119	
Total	75	127	202	
Second-trimester UtA-PI abnormal	57	26	83	<0.001
Second-trimester UtA-PI normal	18	101	119	
Total	75	127	202	

the present study, mean second-trimester UtA-PI was 1.39 ± 0.31 , and the prespecified threshold of >1.45 was applied at 22+6 to 24+6 weeks of gestation. Among 83 women with abnormal UtA-PI, 57 developed preeclampsia. Studies evaluating UtA-PI together with placental biomarkers have shown that combined approaches may improve prediction compared with a single Doppler marker.^{22,23} False-negative results are clinically relevant in preeclampsia screening. MAP missed 6 cases whereas UtA-PI missed 18, resulting in NPVs of 95.0% and 84.9%, respectively. These values reflect the high-risk study population and should be interpreted together with the confidence intervals and the preventive care received during follow-up. Non-linear relationships between UtA-PI and preeclampsia risk have also been described.²⁴ Aspirin prophylaxis is an important consideration because it can modify the risk of preeclampsia in high-risk women. Evidence supports preventive aspirin use in appropriately selected pregnancies, and biomarker trajectories may also be affected by prophylaxis.²¹ For this reason, the observed performance estimates should be interpreted in the context of routine high-risk antenatal management rather than as untreated natural-history estimates. Secondary adverse outcomes included intrauterine growth restriction, preterm delivery and placental abruption. These outcomes are biologically and clinically related to placental dysfunction and hypertensive disease. Second-trimester uterine artery Doppler has also been evaluated for prediction of preeclampsia and fetal growth restriction in high-risk women.²⁵

The present findings do not establish MAP as a replacement for uterine artery Doppler or for validated multimarker algorithms. Instead, they suggest that MAP may be a practical component of risk assessment in settings where resources are constrained, while UtA-PI provides complementary information on uteroplacental vascular resistance. External validation in broader populations is required before adopting either threshold as a stand-alone screening strategy. Overall, first-trimester MAP demonstrated higher predictive performance than second-trimester UtA-PI in this high-risk cohort. The difference is clinically interesting because MAP is inexpensive and easy to obtain; however, screening decisions should remain based on the complete maternal risk profile and locally validated protocols. Future multicenter studies should evaluate MAP, UtA-PI, biomarkers, aspirin exposure and maternal risk factors within prespecified prediction models. Strengths and limitations: The study focused on a clinically relevant high-risk population and directly compared two commonly available biophysical markers. Limitations include the single-center design, non-probability consecutive sampling, absence of biochemical markers such as PIGF and PAPP-A, operator dependence of uterine artery Doppler, and potential modification of

preeclampsia risk by aspirin prophylaxis. The selected high-risk sample also limits generalizability of PPV, NPV and overall accuracy to lower-risk populations. These findings should therefore be interpreted as validation results within the study population rather than as evidence for universal stand-alone screening.

CONCLUSION

First-trimester MAP showed higher predictive accuracy than second-trimester UtA-PI for subsequent preeclampsia in this high-risk cohort. MAP may be a practical and low-cost component of risk assessment, particularly in resource-constrained settings, while uterine artery Doppler provides complementary information. Because the cohort was selected for high baseline risk and received routine preventive antenatal care, including aspirin when indicated, the findings should be validated in larger multicenter populations before either marker is recommended as a stand-alone screening strategy.

Conflict of Interest: None

Fundings: No funding source

Use of Artificial Intelligence (AI) Disclosure: There is no AI tool used.

Authors Contribution:

Maryam Bashar: Conception and design, acquisition of data analysis and interpretation of data, drafting and critical revision, final approval of the version to be published.

Maliha Sadaf: Conception and design, acquisition of data analysis and interpretation of data, drafting and critical revision, final approval of the version to be published

Humera Noreen: Conception and design, acquisition of data analysis and interpretation of data

Khansa Iqbal: drafting and critical revision, final approval of the version to be published

Fouzia Naheed: drafting and critical revision, final approval of the version to be published

Amna Abbasi: drafting and critical revision, final approval of the version to be published

REFERENCES

1. Chang KJ, Seow KM, Chen KH. Preeclampsia: recent advances in predicting, preventing, and managing the maternal and fetal life-threatening condition. *Int J Environ Res Public Health*. 2023;20(4):2994. doi: 10.3390/ijerph20042994.
2. Chaemsaitong P, Sahota DS, Poon LC. First trimester preeclampsia screening and prediction. *Am J Obstet Gynecol*. 2022;226(2 Suppl).e2. doi: 10.1016/j.ajog.2020.07.020.
3. Zhu J, Zhang J, Syaza Razali N, Chern B, Tan KH. Mean arterial pressure for predicting preeclampsia in Asian women: a longitudinal cohort study. *BMJ Open*. 2021;11(8). doi: 10.1136/bmjopen-2020-046161.
4. Das E, Singh V, Agrawal S, Pati SK. Prediction of preeclampsia using first-trimester uterine artery Doppler and pregnancy-associated plasma protein-A (PAPP-A): a prospective study in Chhattisgarh, India. *Cureus*. 2022;14(2). doi: 10.7759/cureus.22026.

5. Rolnik DL, Syngelaki A, O’Gorman N, Wright D, Poon LC, Nicolaides KH. ASPRE trial: effects of aspirin on mean arterial blood pressure and uterine artery pulsatility index trajectories in pregnancy. *Ultrasound Obstet Gynecol.* 2023;61(6):691-697. doi: 10.1002/uog.26222.
6. Guerby P, Audibert F, Johnson JA, Okun N, Giguere Y, Forest JC, et al. Prospective validation of first-trimester screening for preterm preeclampsia in nulliparous women (PREDICTION Study). *Hypertension.* 2024;81(7):1574-1582. doi: 10.1161/HYPERTENSIONAHA.123.22584.
7. Nguyen-Hoang L, Dinh LT, Tai AST, Nguyen DA, Pooh RK, Shiozaki A, et al. Implementation of first-trimester screening and prevention of preeclampsia: a stepped wedge cluster-randomized trial in Asia. *Circulation.* 2024;150(16):1223-1235. doi: 10.1161/CIRCULATIONAHA.124.069907.
8. Johnson JM, Walsh JD, Okun NB, Metcalfe A, Pastuck ML, Maxey CM, et al. The Implementation of Preeclampsia Screening and Prevention (IMPRESS) Study. *Am J Obstet Gynecol MFM.* 2023;5(2):100815. doi: 10.1016/j.ajogmf.2022.100815.
9. Zwertbroek EF, Groen H, Fontanella F, Maggio L, Marchi L, Bilardo CM. Performance of the FMF first-trimester preeclampsia-screening algorithm in a high-risk population in The Netherlands. *Fetal Diagn Ther.* 2021;48(2):103-111. doi: 10.1159/000512335.
10. Okun N, Hoffman B, Johnson JA, Biringir A, Shapiro J, Felix C, et al. Implementation of multiple marker screening for preterm preeclampsia in a single tertiary obstetric centre. *J Obstet Gynaecol Can.* 2024;46(1):102220. doi: 10.1016/j.jogc.2023.102220.
11. Magee LA, Brown MA, Hall DR, Gupte S, Hennessy A, Karumanchi SA, et al. The 2021 International Society for the Study of Hypertension in Pregnancy classification, diagnosis & management recommendations for international practice. *Pregnancy Hypertens.* 2022;27:148-169. doi: 10.1016/j.preghy.2021.09.008.
12. Liu Y, Xie Z, Huang Y, Lu X, Yin F. Uterine arteries pulsatility index by Doppler ultrasound in the prediction of preeclampsia: an updated systematic review and meta-analysis. *Arch Gynecol Obstet.* 2024;309(2):427-437. doi: 10.1007/s00404-023-07044-2.
13. Cao L, He B, Zhou Y, Chen T, Gao Y, Yao B. Utility of uterine artery Doppler ultrasound imaging in predicting preeclampsia during pregnancy: a meta-analysis. *Med Ultrason.* 2024;26(2):197-204. doi: 10.11152/mu-4355.
14. Gil MM, Cuenca-Gomez D, Rolle V, Pertegal M, Diaz C, Revello R, et al. Validation of machine-learning model for first-trimester prediction of pre-eclampsia using cohort from PREVAL study. *Ultrasound Obstet Gynecol.* 2024;63(1):68-74. doi: 10.1002/uog.27478.
15. Li T, Xu M, Wang Y, Wang Y, Tang H, Duan H, et al. Prediction model of preeclampsia using machine learning based methods: a population based cohort study in China. *Front Endocrinol (Lausanne).* 2024;15:1345573. doi: 10.3389/fendo.2024.1345573.
16. Ansbacher-Feldman Z, Syngelaki A, Meiri H, Cirkin R, Nicolaides KH, Louzoun Y. Machine-learning-based prediction of pre-eclampsia using first-trimester maternal characteristics and biomarkers. *Ultrasound Obstet Gynecol.* 2022;60(6):739-745. doi: 10.1002/uog.26105.
17. Liu M, Yang X, Chen G, Ding Y, Shi M, Sun L, et al. Development of a prediction model on preeclampsia using machine learning-based method: a retrospective cohort study in China. *Front Physiol.* 2022;13:896969. doi: 10.3389/fphys.2022.896969.
18. MacDonald TM, Walker SP, Hannan NJ, Tong S, Kaitu’u-Lino TJ. Clinical tools and biomarkers to predict preeclampsia. *EBioMedicine.* 2022;75:103780. doi: 10.1016/j.ebiom.2021.103780.
19. Tarca AL, Taran A, Romero R, Jung E, Paredes C, Bhatti G, et al. Prediction of preeclampsia throughout gestation with maternal characteristics and biophysical and biochemical markers: a longitudinal study. *Am J Obstet Gynecol.* 2022;226(1):126.e1-126.e22. doi: 10.1016/j.ajog.2021.01.020.
20. Torres-Torres J, Villafan-Bernal JR, Martinez-Portilla RJ, Hidalgo-Carrera JA, Estrada-Gutierrez G, Adalid-Martinez-Cisneros R, et al. Performance of a machine-learning approach for the prediction of pre-eclampsia in a middle-income country. *Ultrasound Obstet Gynecol.* 2024;63(3):350-357. doi: 10.1002/uog.27510. PMID: 37796702.
21. Nguyen-Hoang L, Sahota DS, Poon CYL. Effect of aspirin on biomarker profile in women at high risk for preeclampsia. *Am J Obstet Gynecol.* 2025;232(6):e213. doi: 10.1016/j.ajog.2025.01.023.
22. Hodžia J, Muraèviæ B, Graèia A, Hodžia HS, Bajgoria Škrge E. First trimester placental growth factor and uterine artery pulsatility index in the prediction of preeclampsia in high-risk pregnancy. *Med Glas (Zenica).* 2025;22(1):71-77. doi: 10.17392/1864-22-01.
23. Paiboonborirak C, Phupong V. Serum fatty acid binding protein 4 and Doppler of uterine artery ultrasound in the first trimester for the prediction of preeclampsia. *Hypertens Res.* 2024;47(5):1208-1215. doi: 10.1038/s41440-023-01553-y.
24. Wang S, Dong H. Non-linear dose-response relationship between uterine artery pulsatility index and risk of preeclampsia in early pregnancy: secondary analysis of a nested cohort study. *PLoS One.* 2025;20(1):e0317625. doi: 10.1371/journal.pone.0317625.
25. Clare A, Robertson B, Henry D, Knowles A. Role of second trimester uterine artery doppler in early prediction of preeclampsia and intrauterine growth restriction among high-risk women. *SAGE Open Med.* 2025;13:20503121251378109. doi: 10.1177/20503121251378109.