Review Article

http://wjpn.ssu.ac.ir

Integration of Artificial Intelligence, Multi-Omics, and Digital Health for Precision Prevention of Preterm Birth: A Structured Narrative Review

Mahshid Bokaie[1], Roghayeh Ijabi[2*]

[1] Research Center for Nursing and Midwifery Care, Comprehensive Research Institute for Maternal and Child Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran
[2] Student Research Committee, School of Nursing and Midwifery, Shahid Sadoughi University of Medical Sciences, Yazd, Iran

Received: 22 February 2026 **Revised:** 18 July 2026 **Accepted:** 21 July 2026

ARTICLE INFO

Corresponding author:
Roghayeh Ijabi

Email:
ki.ijabi29@gmail.com

Keywords:
Preterm birth;
Precision prevention;
Artificial intelligence;
Machine learning;
Multi-omics;
Digital health

ABSTRACT

Background: Preterm birth (PTB) remains a leading cause of neonatal morbidity and mortality worldwide. Conventional prediction methods have limited accuracy, highlighting the need for precision prevention strategies that integrate molecular, clinical, and digital health data.

Methods: A structured narrative review was conducted using PubMed, Scopus, and Web of Science to identify relevant studies published between 2010 and 2024. A total of 21 relevant studies were included and narratively synthesized into three thematic areas: multi-omics technologies, artificial intelligence (AI)-based prediction models, and digital health approaches for PTB prevention.

Results: Multi-omics technologies, including genomics, transcriptomics, proteomics, metabolomics, and microbiome profiling, improved understanding of PTB pathophysiology and identified biomarkers associated with inflammation, immune dysregulation, oxidative stress, extracellular matrix remodeling, and placental dysfunction. AI models integrating clinical, imaging, laboratory, and molecular data demonstrated promising predictive performance, with reported area under the receiver operating characteristic curve (AUC) values ranging from approximately 0.61 to 0.94 where available. Ensemble machine learning and deep learning algorithms generally outperformed conventional statistical approaches. Digital health technologies, including wearable devices and remote monitoring systems, supported continuous maternal assessment and facilitated earlier identification of women at increased risk. However, limited external validation, heterogeneous datasets, model interpretability, and data privacy remain important challenges to clinical implementation.

Conclusion: The integration of multi-omics technologies, AI, and digital health represents a promising strategy for precision prevention of PTB. Future research should prioritize multicenter validation, standardized data integration, and the development of transparent and clinically applicable AI models to facilitate translation into routine obstetric care.

Introduction

Preterm birth (PTB), defined as delivery before 37 completed weeks of gestation, remains one of the most pressing challenges in modern obstetrics and a leading cause of neonatal mortality worldwide. Infants born preterm are at increased risk of lifelong neurodevelopmental, respiratory, cardiovascular, and metabolic complications, placing a substantial clinical, economic, and societal burden on healthcare systems. Despite advances in prenatal care, the ability to accurately predict and prevent PTB remains limited. Conventional risk assessment strategies-including transvaginal cervical length measurement, fetal fibronectin testing, and maternal clinical risk models-demonstrate only modest predictive performance and often fail to generalize across diverse populations. Consequently, ineffective risk stratification continues to hinder the timely implementation of preventive interventions[1-3].

Recent advances in artificial intelligence (AI) have transformed medical research and clinical practice, particularly in maternal–fetal medicine. By enabling the analysis of large-scale, heterogeneous datasets, AI techniques-including machine learning (ML) and deep learning (DL)-have substantially improved the ability to identify complex patterns associated with adverse pregnancy outcomes. Unlike conventional statistical models, AI algorithms can simultaneously integrate clinical, imaging, molecular, and longitudinal health data to generate individualized risk predictions with greater accuracy[1, 4-7].

Current AI-based prediction models for PTB incorporate a wide range of data sources, including electronic health records, transvaginal cervical ultrasound images, electrohysterography (EHG) signals, maternal and amniotic fluid metabolomic profiles, and multi-omics datasets[4, 8]. Across studies published between 2010 and 2024, reported model performance has ranged from moderate to excellent, with areas under the receiver operating characteristic curve (AUCs) of approximately 0.61–0.94. Ensemble learning methods, such as Random Forest and Extreme Gradient Boosting (XGBoost), together with deep learning architectures including convolutional neural networks (CNNs) and transformer-based models, have consistently outperformed conventional approaches such as logistic regression[9, 10].

Parallel advances in genomics and systems biology have led to the emergence of **precision prevention**, an individualized strategy that integrates multi-omics data with AI to improve prediction and prevention of PTB[4, 9]. Rather than relying on population-based risk estimates, precision prevention combines genomic, transcriptomic, proteomic, metabolomic, microbiome, clinical, and environmental information to generate dynamic, patient-specific risk profiles[5]. This approach enables more accurate identification of women at high risk for spontaneous PTB while reducing unnecessary interventions among low-risk pregnancies[5, 9].

Multi-omics technologies have significantly expanded our understanding of the biological mechanisms underlying PTB. Genomic studies have identified susceptibility variants associated with pregnancy duration and spontaneous PTB, whereas transcriptomic analyses have revealed dysregulated inflammatory and immune pathways in maternal blood and placental tissues[11, 12]. Proteomic and metabolomic investigations have identified candidate biomarkers reflecting extracellular matrix remodeling, oxidative stress, and inflammatory activation, while growing evidence highlights the contribution of vaginal and gut microbiome dysbiosis to PTB pathogenesis[12, 13]. The integration of these complementary molecular layers with clinical and imaging data has further enhanced predictive performance and provided new insights into disease mechanisms[11, 13-15].

The convergence of AI and multi-omics is reshaping not only PTB prediction but also its prevention and future therapeutic strategies. Improved risk stratification enables earlier implementation of evidence-based interventions,

such as progesterone therapy, cervical cerclage, and intensified antenatal surveillance, while minimizing unnecessary treatment in women at low risk[5]. Moreover, molecular characterization of PTB may facilitate the identification of novel therapeutic targets and support the development of precision medicine approaches tailored to an individual's biological profile[16, 17]. Emerging technologies, including federated learning, further enable collaborative development of AI models across multiple institutions while preserving patient privacy and data security[1, 17-20].

Despite these advances, substantial barriers remain before AI- and omics-driven approaches can be routinely implemented in clinical practice. Many published prediction models are limited by small sample sizes, methodological shortcomings, inadequate external validation, and restricted generalizability across diverse populations. Furthermore, algorithmic bias, limited interpretability of complex models, data privacy concerns, and evolving ethical and regulatory frameworks continue to challenge their clinical translation[4, 5, 16, 21].

In this narrative review, we summarize recent advances in AI, multi-omics technologies, and digital health for precision prevention of PTB. We discuss their contributions to risk prediction, prevention, and emerging therapeutic opportunities, critically examine current methodological and implementation challenges, and highlight future directions for translating precision prevention into routine obstetric care.

Materials and Methods

Study Design

This study was conducted as a narrative review to provide a comprehensive overview of current evidence regarding the integration of omics technologies, artificial intelligence (AI), machine learning (ML), and digital health approaches for the precision prevention of preterm birth (PTB). Given the diversity of study designs, populations, technologies, and reported outcomes, a qualitative narrative synthesis was considered the most appropriate approach for summarizing the available evidence and identifying emerging trends, current challenges, and future research directions.

Literature Search

A structured literature search was conducted in the PubMed, Scopus, and Web of Science databases to identify relevant articles published between January 2010 and March 2024. The search strategy combined Medical Subject Headings (MeSH), where available, with free-text keywords related to preterm birth, precision medicine, omics technologies, artificial intelligence, and digital health. Search terms included "preterm birth," "premature birth," "PTB," "precision prevention," "precision medicine," "personalized medicine," "genomics," "transcriptomics," "proteomics," "metabolomics," "multi-omics," "artificial intelligence," "machine learning," "deep learning," "digital health," "mHealth," "mobile health," and "wearable devices." Boolean operators (AND/OR) were used to combine search terms appropriately according to the indexing system of each database. In addition, the reference lists of relevant original articles and review papers were manually screened to identify additional publications of relevance to the topic.

Evidence Synthesis

The retrieved literature was reviewed and synthesized narratively to summarize current evidence on molecular biomarkers, artificial intelligence–based prediction models, and digital health technologies for the precision prevention of preterm birth. Because of the considerable heterogeneity in study objectives, methodologies, study populations, outcome measures, and analytical approaches, quantitative synthesis or meta-analysis was not considered appropriate. Instead, the evidence was organized into three broad thematic areas: (1) omics technologies for biomarker discovery, (2) artificial intelligence and machine learning for risk prediction, and (3)

digital health technologies for continuous monitoring and personalized prevention of preterm birth.

Results

A structured literature search of PubMed, Scopus, and Web of Science identified relevant studies published between 2010 and 2024 investigating the application of artificial intelligence (AI), multi-omics technologies, and digital health approaches for the precision prevention of preterm birth (PTB). Following relevance screening, the retrieved evidence was narratively synthesized into three major thematic domains: (1) multi-omics technologies for biomarker discovery, (2) AI-based prediction models for PTB risk assessment, and (3) digital health technologies for continuous maternal monitoring and personalized prevention.

Artificial Intelligence Improves PTB Risk Prediction

The reviewed studies demonstrated that AI models incorporated diverse data sources, including electronic health records, cervical ultrasound images, electrohysterography (EHG), routine laboratory biomarkers, and multi-omics datasets[4, 8]. Reported predictive performance varied across studies, with available area under the receiver operating characteristic curve (AUC) values ranging from approximately 0.61 to 0.94 [4, 9, 10]. Ensemble machine learning algorithms, particularly Random Forest and XGBoost, together with deep learning architectures such as convolutional neural networks (CNNs), generally demonstrated superior predictive performance compared with conventional statistical approaches. Table 1 presents the characteristics of representative AI studies.

Multi-omics Technologies for Precision Prediction of PTB

The reviewed studies investigated the application of genomics, transcriptomics, proteomics, metabolomics, and microbiome profiling to improve understanding of the molecular mechanisms underlying PTB11-15. These complementary omics approaches identified biomarkers associated with inflammation, immune dysregulation, oxidative stress, extracellular matrix remodeling, placental dysfunction, and alterations in the vaginal microbiome. Overall, integrated multi-omics approaches provided a more comprehensive assessment of PTB risk than single-omics analyses and highlighted their potential for individualized risk stratification. The characteristics of representative multi-omics studies are summarized in Table 2.

Table 1. Characteristics of studies evaluating AI for prediction of preterm birth

Study	Design	Population/ Sample	Data source	AI algorithm	Main findings	Performance	Limitation
Akazawa & Hashimot, 2022	Systematic review	22 studies	Clinical datasets	ML/DL	AI generally outperformed conventional statistical models (4)	AUC: 0.61–0.94 (4)	High heterogeneity (4)
Zuo et al., 2024	Comparative study	Not specified	Ultrasound + clinical	CNN, RF, XGBoost	CNN achieved the highest predictive performance (10)	Not reported	Single-center (10)
Teng et al., 2025	Retrospective cohort	Not specified	Routine biomarkers	XGBoost	Routine biomarkers effectively predicted PTB (16)	Not reported	External validation limited (16)
Kang et al., 2025	External validation study	Not specified	Clinical variables	Explainable ML	Good calibration after validation (18)	Not reported	Limited population diversity (18)
Lee, 2026	Narrative review	—	AI studies	Multiple algorithms	Summarized clinical applicability of AI (5)	—	Narrative review (5)

Table 2. Characteristics of studies evaluating omics biomarkers for PTB

Study	Omics platform	Specimen	Biomarkers	Main findings	Clinical implication
Cheng et al., 2025 (11)	Microbiome	Vaginal swab	Multi-omics biomarkers	Dysbiosis associated with spontaneous PTB	Risk stratification
Couture et al., 2023 (12)	Transcriptomics	Placenta	Inflammatory genes	Identified inflammatory pathways	Early diagnosis
Gupta & Alfirevic, 2022 (13)	Multi-omics	Maternal/pregnancy specimens	Genomic, transcriptomic, proteomic, metabolomic markers	Integrated omics improved understanding of PTB biomarkers	Precision prediction
Alikamali et al., 2025 (14)	Microbiome	Vaginal microbiome	Lactobacillus and dysbiotic taxa	Microbiome alterations associated with PPROM	Biomarker discovery
Powell et al., 2024(15)	Microbiome	Pregnancy microbiome	Microbial communities	Microbiome influences PTB susceptibility	Future biomarker

Table 3. Challenges and future directions identified across the reviewed studies

Challenge identified in reviewed studies	Evidence from reviewed literature	Potential solution
Limited external validation	Most prediction models were developed and tested in single-center cohorts (4, 5, 16, 21)	Large multicenter validation studies (4, 5, 16, 21)
Small sample sizes	Several AI and omics studies included relatively small datasets (4, 5, 16, 21)	Larger prospective cohorts (4, 5, 16, 21)
Heterogeneous datasets	Different outcome definitions and input variables (4, 5, 16, 21)	Standardized reporting and harmonized datasets (4, 5, 16, 21)
Black-box AI models	Limited model interpretability (4, 5, 16, 21)	Explainable AI approaches (4, 5, 16, 21)
Data privacy	Difficulty sharing multicenter data (1, 17-20)	Federated learning (1, 17-20)
Clinical implementation	Few models have been prospectively evaluated (4, 5, 16, 21)	Clinical impact studies and implementation trials (4, 5, 16, 21)

Digital Health Technologies Enable Continuous Monitoring

The reviewed literature highlighted the growing role of digital health technologies, including wearable devices, mobile health applications, telemonitoring systems, and remote monitoring platforms, in supporting precision prevention of PTB[1,5, 17-20]. These technologies enable continuous assessment of maternal physiological parameters throughout pregnancy, facilitating earlier identification of women at increased risk while improving access to prenatal care and supporting timely preventive interventions.

Current Challenges and Future Translation

Despite encouraging advances, the reviewed studies consistently identified several barriers to the clinical implementation of AI-driven precision prevention. Common limitations included relatively small study populations, inadequate external validation, heterogeneous datasets, methodological variability, and limited interpretability of complex AI models[4,5,16,21]. Ethical and regulatory considerations, including data privacy, transparency, algorithmic fairness, and governance of healthcare data, remain important challenges for the successful translation of these technologies into routine obstetric practice. The major challenges and potential future directions identified across the reviewed studies are summarized in Table 3.

Discussion

This structured narrative review highlights the growing potential of integrating multi-omics technologies, artificial intelligence (AI), and digital health approaches to advance the

precision prevention of preterm birth (PTB). Collectively, the reviewed evidence suggests that combining molecular biomarkers with advanced computational models enables more individualized risk assessment than conventional prediction methods based solely on clinical characteristics[1-3]. Rather than relying on a single predictor, precision prevention incorporates multiple biological and clinical dimensions, offering a more comprehensive understanding of the complex mechanisms underlying PTB[5,9].

One of the most important findings across the reviewed studies is the increasing contribution of multi-omics technologies to PTB research. Genomics, transcriptomics, proteomics, metabolomics, and microbiome profiling have identified biological pathways involved in inflammation, immune dysregulation, oxidative stress, extracellular matrix remodeling, and placental dysfunction, all of which are recognized contributors to spontaneous PTB[11,12]. Importantly, integrating these complementary molecular datasets provides a more comprehensive representation of disease biology than individual omics platforms alone, supporting the development of personalized risk profiles and improving opportunities for early intervention[13-15].

Artificial intelligence represents another major advancement in precision obstetrics. Unlike conventional statistical models, AI algorithms can simultaneously analyze large, heterogeneous datasets that include clinical characteristics, laboratory biomarkers, medical imaging, and molecular information[4,8]. Across the reviewed studies, ensemble learning algorithms such as Random Forest and XGBoost, together with deep learning models including convolutional neural networks, generally demonstrated superior predictive performance compared with traditional regression-based approaches[9,10]. These findings support the growing role of AI as a clinical decision-support tool capable of improving risk stratification and facilitating earlier preventive interventions in women at increased risk of PTB[4,5].

Digital health technologies further complement precision prevention by enabling continuous maternal monitoring throughout pregnancy. Wearable sensors, mobile health applications, and remote monitoring platforms provide opportunities for longitudinal assessment of maternal physiological changes outside conventional clinical settings[1, 17-20]. Such technologies may improve access to prenatal care, particularly for women living in underserved or geographically remote areas, while allowing earlier identification of clinical deterioration that may precede spontaneous PTB[5].

Despite these promising developments, several important challenges continue to limit clinical implementation. Most published AI models have been developed using relatively small or single-center datasets, reducing their generalizability across different populations [4,5,16,21]. Variability in PTB definitions, inclusion criteria, biomarker panels, data preprocessing methods, and model evaluation strategies further complicates comparisons between studies and limits reproducibility [4,5]. In addition, many AI algorithms function as "black-box" models, creating concerns regarding transparency, interpretability, and clinician trust [4,5,16,21]. Ethical considerations, including patient privacy, data governance, algorithmic fairness, and regulatory approval, also remain important barriers to routine clinical adoption[1, 17-20].

Addressing these limitations will require multicenter prospective studies with standardized data collection and external validation across diverse populations[4,5,16,21]. Future research should emphasize harmonized reporting standards, integration of multi-omics and longitudinal clinical data, explainable AI techniques, and privacy-preserving collaborative approaches such as federated learning[1, 17-20]. Prospective implementation studies evaluating clinical effectiveness, cost-effectiveness, and patient-centered outcomes will also be essential before these technologies can be routinely incorporated into obstetric practice[4, 5, 16, 21].

This review has several limitations. As a narrative review, the evidence was synthesized qualitatively rather than quantitatively, and no formal meta-analysis was performed because of the substantial heterogeneity in study designs, populations, data sources, and outcome measures[4]. In addition, only studies indexed in PubMed, Scopus, and Web of Science and published in English between 2010 and 2024 were considered, which may have resulted in the omission of relevant evidence.

Conclusion

The convergence of multi-omics technologies, AI, and digital health has the potential to transform PTB prevention from a reactive to a predictive and personalized model of care[5,9]. Although significant methodological and implementation challenges remain, continued advances in data integration, model validation, and ethical governance are expected to accelerate the translation of precision prevention into routine obstetric practice[4, 5, 16, 21].

Conflict of Interest

The authors declare no conflicts of interest.

Acknowledgments

The authors thank the Research Center for Nursing and Midwifery Care at Shahid Sadoughi University of Medical Sciences for administrative support.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethical Considerations

As this study is a narrative review of published literature, no ethical approval was required. All data were extracted from publicly available peer-reviewed articles.

AI Disclosure

Artificial intelligence tools were used solely for language editing and manuscript refinement; all scientific content, interpretation, and final decisions were made by the authors.

Author's Contribution

Contributing to the study conception, literature review, manuscript drafting, critical revision, and final approval of the submitted version: M. B. and R. I.

How to Cite: Bokaie M, Ijabi R. Integration of Artificial Intelligence, Multi-Omics, and Digital Health for Precision Prevention of Preterm Birth: A Structured Narrative Review. World J Peri & Neonatol 2025; 8(2): 74- 81.
DOI: 10.18502/wjpn.v8i2.22103

References

1. van Zijl MD, Koullali B, Mol BW, Pajkrt E, Oudijk MA. Prevention of preterm delivery: current challenges and future prospects. Int J Womens Health 2016; 8: 633-45.
2. Samuel TM, Sakwinska O, Makinen K, Burdge GC, Godfrey KM, Silva-Zolezzi I. Preterm Birth: A Narrative Review of the Current Evidence on Nutritional and Bioactive Solutions for Risk Reduction. Nutrients 2019; 11(8): 1811.
3. Creswell L, Rolnik DL, Lindow SW, O'Gorman N. Preterm Birth: Screening and Prediction. Int J Womens Health 2023; 15: 1981-97.
4. Akazawa M, Hashimoto K. Prediction of preterm birth using artificial intelligence: a systematic review. J Obstet Gynaecol 2022; 42(6): 1662-8.
5. Lee Y. Artificial intelligence in preterm birth prediction: a narrative review of current approaches and clinical applicability. Obstet Gynecol Sci 2026; 69(2): 94-102.
6. Bradley E, Blencowe H, Moller AB, Okwaraji YB, Sadler F, Gruending A, et al. Born too soon: global epidemiology of preterm birth and drivers for change. Reprod Health 2025; 22(Suppl 2): 105.
7. Medjedovic E, Stanojevic M, Jonuzovic-Prosic S, Ribic E, Begic Z, Cerovac A, et al. Artificial intelligence as a new answer to old challenges in maternal-fetal medicine and obstetrics. Technology and Health Care 2024; 32(3): 1273-87.
8. Seong D, Espinosa C, Aghaeepour N. Computational Approaches for Predicting

Preterm Birth and Newborn Outcomes. Clin Perinatol 2024; 51(2): 461-73.
9. Wu Y. Machine Learning-Based Risk Prediction Models for Pregnancy-Related Syndromes. Birth Defects Res 2026; 118(3): e70038.
10. Zuo R, Zhang F, Shi C, Wang L, Wang Y, Tong L. Deep Learning in Predicting Preterm Birth: A Comparative Study of Machine Learning Algorithms. Matern Fetal Med 2024; 6(3): 141-6.
11. Cheng D, Li N, Sun Q, Wang K, Gao F. Vaginal microbiome and preterm birth: Composition, mechanisms and microbiota-directed therapies (Review). Int J Mol Med 2025;56(6): 203.
12. Couture C, Brien ME, Boufaied I, Duval C, Soglio DD, Enninga EAL, et al. Proinflammatory changes in the maternal circulation, maternal-fetal interface, and placental transcriptome in preterm birth. Am J Obstet Gynecol 2023; 228(3): 332.e1-.e17.
13. Gupta JK, Alfirevic A. Systematic review of preterm birth multi-omic biomarker studies. Expert Rev Mol Med 2022; 24:1-24.
14. Alikamali M, Mohammad-Alizadeh-Charandabi S, Ahmadi S, Memar MY, Shahnazi M. The role of the vaginal microbiome in preterm premature rupture of membranes: a comprehensive review of mechanisms and clinical implications. Health Sci Rep 2025; 8(12): e71484.
15. Powell AM, Khan FZA, Ravel J, Elovitz MA. Untangling Associations of Microbiomes of Pregnancy and Preterm Birth. Clin Perinatol. 2024; 51(2): 425-39.
16. Teng X, Liu M, Wang Z, Dong X. Machine learning prediction of preterm birth in women under 35 using routine biomarkers in a retrospective cohort study. Sci Rep 2025; 15(1): 10213.
17. Deuster E, Khalil A. Artificial Intelligence in Obstetrics: Current Applications, Opportunities, and Clinical Implementation Challenges. Clin Obstet Gynecol 2026; 69(1): 54-61.
18. Kang L, Luo D, Xie W, Luo X, Mei J, He J. An explainable machine learning model for predicting preterm birth in pregnant women with gestational diabetes mellitus and hypertensive disorders of pregnancy: development and external validation. Front Endocrinol (Lausanne) 2025: 16: 1665935.
19. Correia V, Mascarenhas T, Mascarenhas M. Smart Pregnancy: AI-Driven Approaches to Personalised Maternal and Foetal Health-A Scoping Review. J Clin Med 2025; 14(19): 6974.
20. Khalid N, Qayyum A, Bilal M, Al-Fuqaha A, Qadir J. Privacy-preserving artificial intelligence in healthcare: Techniques and applications. Computers in Biology and Medicine 2023; 158: 106848.
21. Liu L, Zhu Q, Zong Y, Chen X, Zhang W, Wang J. Machine Learning Prediction Models for Preeclampsia: Systematic Review and Meta-Analysis. J Med Internet Res 2026; 28: e78714.