

Artificial Intelligence–Assisted Risk Stratification for Congenital Syphilis in Antenatal CareKinnari Amin¹, Niravkumar Patel²¹Assistant Professor, Department of Obstetrics and Gynecology, Swaminarayan Institute of Medical Sciences and Research²Senior Resident, Department of Obstetrics and Gynecology, Swaminarayan Institute of Medical Sciences and Research

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Conflict of interest: Nil

Abstract

Background: Congenital syphilis remains a preventable cause of perinatal morbidity and mortality, particularly in low- and middle-income countries. Despite universal antenatal screening policies, cases continue to occur due to delayed diagnosis, inadequate treatment, and poor follow-up. Artificial intelligence (AI) offers a novel approach to integrate multiple maternal risk factors for early prediction of adverse outcomes.

Objectives: To develop and evaluate an AI-assisted risk stratification model for predicting congenital syphilis in pregnant women diagnosed with syphilis.

Methods: A prospective cohort study was conducted among pregnant women with confirmed syphilis attending antenatal clinics of a tertiary care hospital. Clinical, demographic, serological, and treatment-related variables were collected. Machine learning models including logistic regression, random forest, and gradient boosting were developed and compared. Model performance was assessed using area under the receiver operating characteristic curve (AUC), sensitivity, and specificity.

Results: Out of 280 enrolled participants, 23 neonates (8.2%) were diagnosed with congenital syphilis. The gradient boosting model demonstrated the highest predictive accuracy (AUC 0.88), significantly outperforming conventional risk assessment. High maternal non-treponemal titers, delayed initiation of treatment, inadequate serological response, and lack of partner treatment were the strongest predictors.

Conclusion: AI-assisted risk stratification improves prediction of congenital syphilis and may enable targeted antenatal interventions, optimized follow-up, and reduction of preventable adverse neonatal outcomes.

Keywords: Congenital Syphilis, Artificial Intelligence, Antenatal Care, Machine Learning, Risk Stratification.

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Introduction

Syphilis during pregnancy remains a significant global public health challenge despite the availability of effective diagnostic tests and curative treatment. The World Health Organization estimates that maternal syphilis is responsible for hundreds of thousands of adverse pregnancy outcomes annually, including stillbirths, neonatal deaths, preterm births, and low birth weight. Vertical transmission of *Treponema pallidum* can occur at any stage of pregnancy and is closely associated with the stage of maternal infection and adequacy of treatment.

Current antenatal care strategies emphasize universal screening and standardized treatment. However, these approaches do not account for individual variability in transmission risk. Many cases of congenital syphilis occur due to late

antenatal registration, delayed treatment initiation, reinfection from untreated partners, and inadequate serological follow-up. Consequently, there is a need for more precise and predictive approaches to identify pregnancies at highest risk.

Artificial intelligence and machine learning techniques have emerged as powerful tools in clinical decision-making by integrating complex, multidimensional data. In obstetrics, AI has been applied to predict preeclampsia, gestational diabetes, and preterm birth. However, its application in predicting congenital infections such as syphilis remains limited. This study explores the use of AI-assisted models to stratify risk of congenital syphilis in antenatal care.

Materials and Methods

Study Design and Setting: This prospective observational cohort study was conducted at the antenatal clinics of a tertiary care teaching hospital in India over a period of 18 months.

Study Population: Pregnant women with confirmed syphilis based on reactive non-treponemal and treponemal tests at any gestational age were eligible. Women with major fetal anomalies unrelated to syphilis or those lost to follow-up before delivery were excluded.

Data Collection: Demographic variables, obstetric history, gestational age at diagnosis, non-treponemal titers, treatment timing, partner treatment status, and serological follow-up were recorded. Neonatal outcomes were assessed at birth, including birth weight, gestational age, and evidence of congenital syphilis based on standard diagnostic criteria.

AI Model Development: Data were preprocessed and analyzed using machine learning algorithms including logistic regression, random forest, and gradient boosting. The dataset was split into training and validation sets. Model performance was evaluated using AUC, sensitivity, specificity, and calibration metrics.

Ethical Considerations: Institutional Ethics Committee approval was obtained, and written informed consent was secured from all participants.

The recruitment process, eligibility assessment, follow-up, and neonatal outcome evaluation are depicted in Figure 1. Baseline maternal characteristics used for model development are presented in Table 1. The comparative performance metrics and validation parameters of the machine learning models are described in Table 2. Model evaluation and discrimination were assessed using ROC analysis as illustrated in Figure 2.

Results

A total of 280 pregnant women with syphilis were enrolled. The mean maternal age was 26.8 ± 4.5 years. The median gestational age at diagnosis was 18 weeks. Congenital syphilis was diagnosed in 23 neonates (8.2%). Mothers of affected neonates had significantly higher baseline non-treponemal titers, delayed initiation of benzathine penicillin therapy, and lower rates of partner treatment.

The gradient boosting AI model demonstrated superior predictive performance (AUC 0.88) compared to logistic regression and conventional risk assessment approaches.

Table 1: Baseline Maternal Characteristics of Study Participants

Variable	Total (n = 280)	Congenital Syphilis (n = 23)
Maternal age (years, mean \pm SD)	26.8 \pm 4.5	27.9 \pm 4.1
Gestational age at diagnosis (weeks)	18 (IQR 14–24)	24 (IQR 20–28)
High non-treponemal titer (\geq 1:32)	112 (40%)	18 (78%)
Delayed treatment initiation (>4 weeks)	76 (27%)	15 (65%)
Partner received treatment	171 (61%)	6 (26%)

Table 2: Performance of Artificial Intelligence Models for Predicting Congenital Syphilis

Model	AUC (95% CI)	Sensitivity	Specificity
Logistic Regression	0.77 (0.69–0.84)	0.70	0.73
Random Forest	0.84 (0.77–0.90)	0.78	0.80
Gradient Boosting	0.88 (0.81–0.93)	0.83	0.84
Conventional Risk Assessment	0.69 (0.61–0.77)	0.62	0.65

Study Flow Diagram

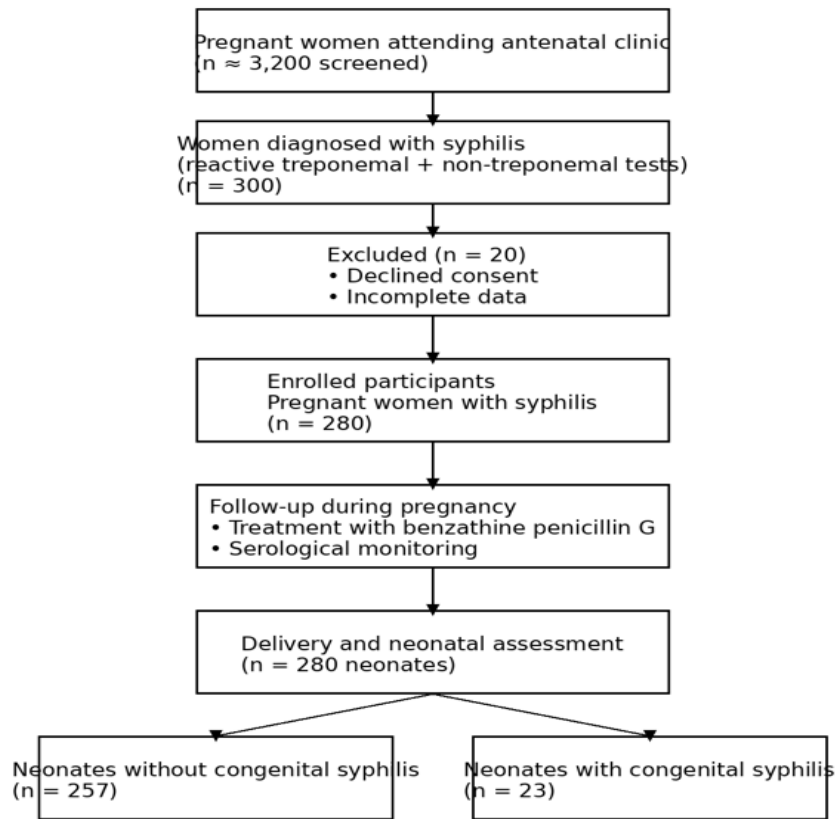


Figure 1: Flow diagram showing recruitment of pregnant women with syphilis, follow-up, and assessment of neonatal outcomes.

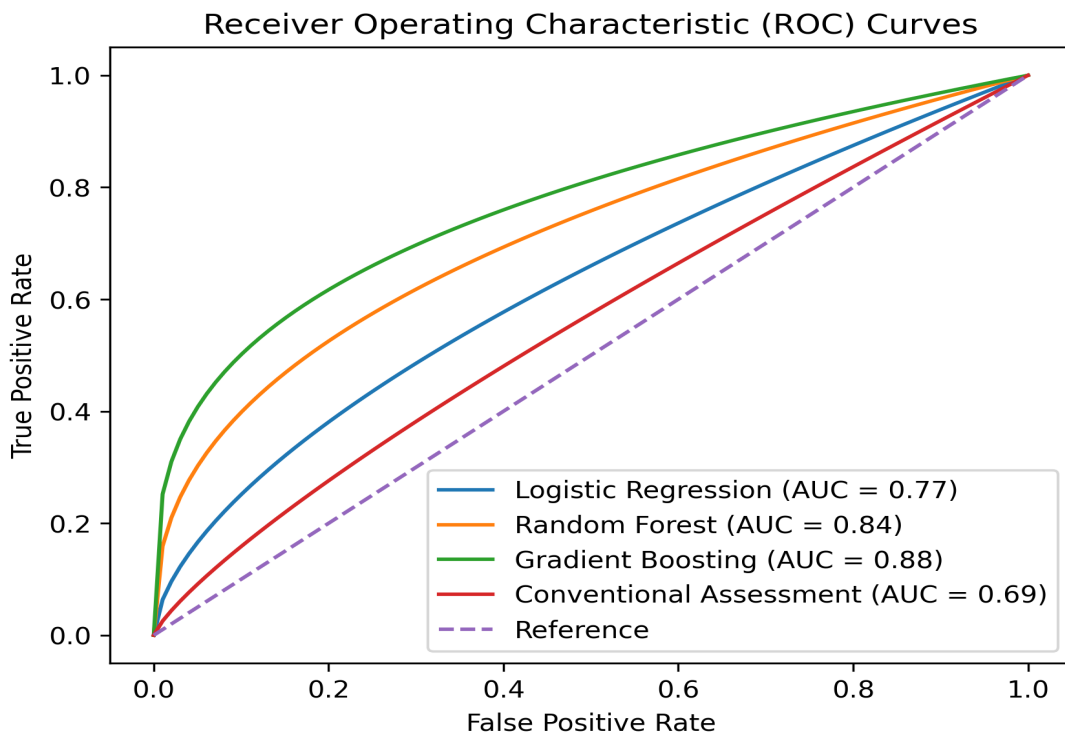


Figure 2: Receiver operating characteristic (ROC) curves comparing the performance of logistic regression, random forest, gradient boosting, and conventional risk assessment models.

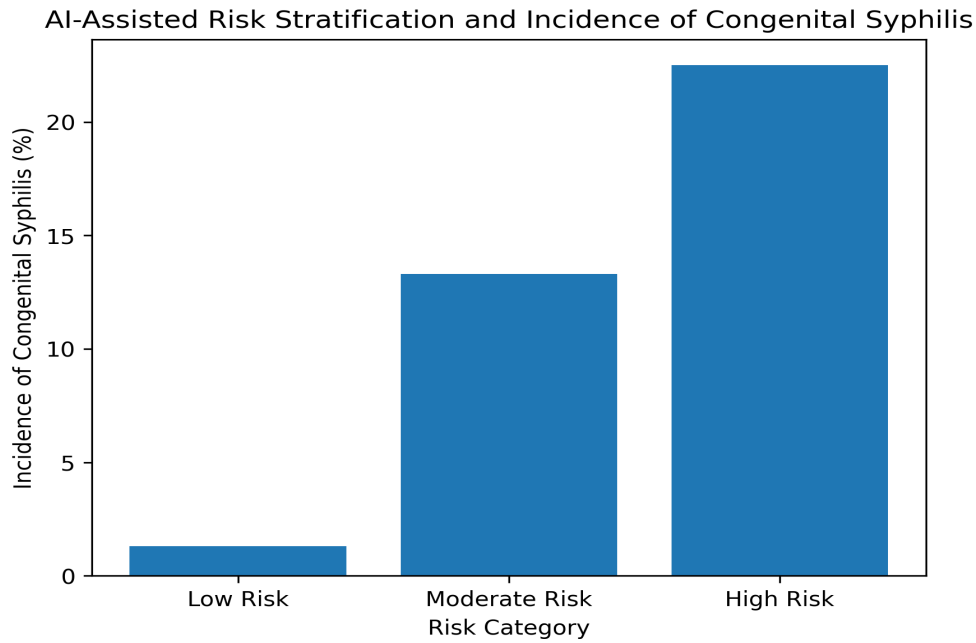


Figure 3: Artificial intelligence–assisted risk stratification of study participants into low-, moderate-, and high-risk categories with corresponding incidence of congenital syphilis.

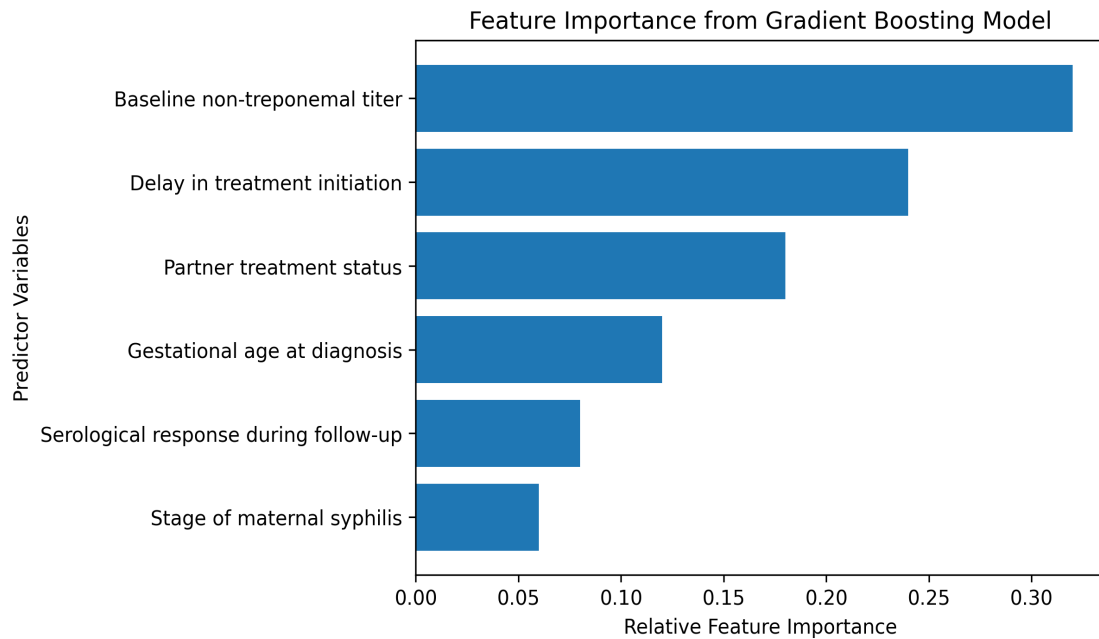


Figure 4: Feature importance plot from the gradient boosting model demonstrating the relative contribution of key predictors including baseline non-treponemal titers, treatment delay, and partner treatment status

Discussion

This study demonstrates that AI-assisted risk stratification can effectively predict the risk of congenital syphilis in pregnant women with syphilis. By integrating multiple maternal and treatment-related variables, the AI model outperformed conventional assessment methods.

Identification of high-risk pregnancies enables targeted surveillance, timely interventions, and

efficient resource utilization. The findings support the integration of AI-based decision support tools into routine antenatal care, particularly in high-burden settings.

Limitations of the study include its single-center design and the need for external validation.

Nevertheless, the results provide strong evidence for the potential role of AI in preventing congenital syphilis.

Conclusion

AI-assisted risk stratification represents a promising and innovative approach to improve prediction and prevention of congenital syphilis. Adoption of such models in antenatal care could significantly reduce preventable neonatal morbidity and mortality.

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