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First-Trimester Uterine Artery Doppler for Early Risk Prediction of Adverse Maternal and Perinatal Outcomes

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***Abstract*—Because of the frequent occurrence of placental dysfunction in early pregnancy and the lack of recognition until complications occur, adverse maternal and perinatal outcomes continue to be significant challenges in obstetric care. Early detection of high-risk pregnancy is thus gaining importance for better maternal and neonatal health. The proposed study is to present an ACFO, HDRI and XGBoost classifier with the FMF First-Trimester Screening Dataset. Combination of maternal clinical parameters, uterine artery Doppler indices and biochemical markers are being used for predicting adverse outcomes. The results of the experiments are showing an accuracy of 95% for prediction, which shows better identification of HYDR, FGR, preterm birth, and neonatal complications. The proposed framework is helping to enable early decision making in clinical care and personalised antenatal care.**

Keywords—Adverse Maternal Outcomes, Perinatal Outcome Prediction, Adaptive Clinical Feature Optimization (ACFO), XGBoost, First-Trimester Uterine Artery Doppler.

I. INTRODUCTION

Despite improved maternal and perinatal outcomes, adverse outcomes are continuing to be a significant public health problem due to rising rates of hypertensive disorders, placental insufficiency, fetal growth restriction, preterm delivery, and neonatal problems [1]. This disruption of placental development in early pregnancy is creating abnormal blood flow to the placenta and has a negative impact on both the mother and fetus [2]. Therefore, early detection of high-risk pregnancies is becoming increasingly important and a crucial part of antenatal care to enable timely surveillance, preventive interventions, and appropriate clinical management to prevent severe complications [3].

Uterine artery Doppler is a new, non-invasive imaging method to assess uteroplacental circulation by measuring vascular resistance parameters such as the Pulsatility Index (PI), and it is being used effectively in the first trimester [4]. Raised uterine artery resistance is a sign of poor trophoblastic invasion and how insufficient the placental remodeling is, which are leading to poor pregnancy outcomes and placental dysfunction [5]. Doppler assessment is helping to achieve early risk stratification and thereby facilitating optimized prenatal monitoring and evidence-based obstetic decision making [6].

Existing investigations are mostly focused on the estimate of preeclampsia and fetal growth restriction, while further evaluation of other maternal and perinatal outcomes, such as gestational hypertension, SFA neonate, antepartum hemorrhage, preterm delivery, neonatal resuscitation, APGAR score, NICU admission and mode of delivery, are comparatively less studied. Moreover, although there are emerging clinical data about the predictive value for routine use of uterine artery Doppler during first trimester screening is still not well established.

This learning aims to explore the linkages between various first trimester (FT) uterine artery Doppler measurements and bad maternal and perinatal outcomes, using a prospective cohort design. The normal and abnormal Doppler are classified based on the uterine artery (UA) Pulsatility Index, and then longitudinal follow-up of pregnancy is carried out until delivery [8]. Statistical evaluation: Establishing associations between Doppler abnormalities and various obstetric and neonatal outcomes, thus giving comprehensive evidence of the medical value of early valuation of the vascular function of the placenta.

A. Key Contributions

- Building a detailed prediction system for adverse perinatal outcome based on the assessment of uterine artery Doppler in the first trimester of pregnancy.
- An evaluation of the relationship between abnormal uterine artery Doppler and multiple maternal complications such as preeclampsia, gestational hypertension, antepartum bleeding and preterm delivery.
- Perinatal outcome measures such as fetal growth restriction, small-for-gestational-age neonates, APGAR score, neonatal resuscitation, NICU admission and gestational age at delivery.
- To show the clinical importance of the use of UA Doppler in the FT as a non-invasive screening tool for the early detection of high-risk pregnancies.
- Availability of data to support the inclusion of UA Doppler in routine FT antenatal screening for better maternal surveillance and prediction of the outcome of pregnancy.

B. Paper Organization

The remainder of the paper will be divided as follows. In Section II, the literature review on the topic of first trimester uterine artery Doppler evaluation and adverse maternal/fetal outcomes is being presented. The proposed methodology is described in Section III: The Study Design, Participant Selection, Doppler Assessment Procedure, Outcome

Measures and Statistical Analysis. The experimental results are being presented along with a detailed discussion of clinical findings and comparative analysis, in Section IV. Lastly, Section V is offering the end of the study and research directions for the future.

II. Literature Review

Adekanmi et al. [9] are studying the accuracy of predicting adverse maternal and perinatal outcome using uterine and umbilical artery Doppler exams in the additional and tertiary trimesters. Doppler indices such as Pulsatility index and Resistance index are being studied to evaluate placental perfusion and fetal circulation. There are important links that are emerging between abnormal Doppler findings and difficulties with preeclampsia, fetal growth restriction, preterm labor and neonatal morbidity. The improvement of Doppler's performance is showing combined Doppler's ability to improve the diagnostic performance in identifying pregnancies that need more clinical monitoring. Doppler assessment is only being done in the additional and third base trimesters, which reduces the chances of making a first trimester diagnosis of risk and initiating early preventive intervention.

Sengupta et al. [10] are assessing the feasibility of using UAD for expecting adversative maternal results in the second trimester of pregnancy (18-24 weeks) of pregnancy. It is suggested that there is increased resistance in the uterine arteries that correlates with the presence of hypertensive disorders in pregnancy and placental insufficiency. Doppler abnormalities are showing moderate predictive value to identify pregnancies with increased risk of maternal complications. The results are contributing to the integration of Doppler assessment into the normal antenatal assessment for better obstetric care. Prediction is mainly being directed towards the mother, while comprehensive evaluation of the neonatal and perinatal complications remains restricted.

Duncan et al. [11] are measuring third trimester Doppler parameters of the uterine artery in relation to adverse perinatal outcomes. Higher Doppler indices have been linked to fetal growth restriction, preterm delivery, low birth weight and higher rates of neonatal intensive care admission. Monitoring fetal well-being and the optimum timing of delivery in high-risk pregnancy is showing clinical usefulness with third trimester Doppler assessment. A lack of late pregnancy assessment is limiting the ability to detect placental dysfunction early and to implement early therapeutic preventive measures.

Adan et al. [12] are investigating association of early gestational serum levels of progesterone with spiral artery Doppler and poor perinatal outcomes. The use of biochemical markers and Doppler indices in combination is better to predict fetal growth restriction, preeclampsia and preterm delivery than using individual markers. The incorporation of laboratory biomarkers with ultrasound results is helping to more fully evaluate placental function in the early pregnancy. Relying on extra biochemical tests is elevating the range of diagnostic expenses and thereby reducing its use in healthcare settings with constrained laboratory resources.

Balkoğlu et al. [13] are studying the effects of first trimester vaginal bleeding on uterine artery Doppler indices, first trimester screening parameters and pregnancy outcomes. Early bleeding pregnancies are showing increased uterine artery resistance and increased risk of placental dysfunction, hypertension and poor neonatal outcomes. Research outcomes are being limited to pregnancies with vaginal bleeding, thereby limiting the generalizability to the whole obstetric population.

Albakoush et al. [14] are working on building a predictive model from early pregnancy maternal clinical parameters, biochemical markers and uterine artery Doppler measurements for preeclampsia. Combining several predictive variables is demonstrating greater sensitivity and specificity than single screening variables. The combined risk assessment is helping to identify women for preventive interventions and increased antenatal monitoring earlier. Prediction is focussed mainly on preeclampsia, while a number of important maternal and perinatal outcomes are not being fully assessed.

A. Research Gap

In the present research there is an emphasis on the Doppler assessment of the uterine artery in the second and third trimesters and there are limited opportunities for early identification of pregnancies with adverse maternal and perinatal outcomes. While Doppler evaluation in the first trimester is showing promise for predicting placental dysfunction, current studies have focused on individual problems (preeclampsia and fetal growth restriction) instead of a broader evaluation of multiple maternal and neonatal outcomes. In addition, some studies are using biochemical markers and maternal clinical data together, which leads to greater complexity and expense of screening and limits the use of these markers in the routine clinical setting. There are also limited reports of the effectiveness of first trimester uterine artery Doppler as a screening tool alone for a wide range of maternal and perinatal outcomes such as gestational hypertension, preterm delivery, small for gestational age neonate, antepartum hemorrhage, neonate resuscitation, NICU admission, and APGAR status. Thus, the use of prospective Doppler evaluation of uterine arteries from the first trimester of pregnancy for early identification of various fetal and maternal complications remains inadequately studied and is a key gap in modern obstetric studies.

III. Proposed Methodology

The proposed methodology provides an overall approach to the first trimester prediction of adverse maternal and perinatal outcomes with Doppler assessment of the uterine artery. To improve pregnancy risk stratification, maternal clinical parameters, Doppler measures and biochemical markers are being combined in Adaptive Clinical Feature Optimization (ACFO) and the Hybrid Doppler Risk Index (HDRI). The optimized feature set is then being evaluated for a correct classification of high-risk pregnancies using an Extreme Gradient Boosting (XGBoost) classifier.The optimized feature set is then undergoing analysis with the Extreme Gradient Boosting (XGBoost) classifier to correctly classify high risk pregnancies. The big picture is that they're enabling clinical decision making at an early stage, based on

a reliable prediction of many different maternal and fetal complications and issues.

A. Dataset Acquisition

The proposed study is using the FMF. FTScreening Dataset, which includes detailed maternal clinical data, first trimester uterine artery Doppler data, biochemical screening markers, and pregnancy outcome data from 11-14 weeks gestation. The data is being supplied for standardized fetal and maternal screening parameters to assess placental function and to predict poor pregnancy outcomes. Demographic characteristics of the mother, obstetric history, physiological measurements, uterine artery Doppler indices, biochemical markers and pregnancy outcomes will be added to provide a comprehensive risk assessment.

B. Dataset Preprocessing

The acquired data is currently preprocessed for better quality data prior to predictive data analysis. Duplicated records are being deleted and missing records are being addressed by appropriate imputation methods according to the nature of the variables. Physiological and Doppler measurements are being cleaned of outliers, and the interquartile range method is used to identify them.

Firstly, a duplicate patient records are being eliminated because they will not impact the learning process if they are observed multiple times. Because of the reduction in the influence of extreme observations with the median estimation, missing numerical values will be replaced by the median value. Missing categories are being replaced with the most common category.

Then, continuous variables are being normalized using Min-Max normalization technique to keep all the features in the same range, from 0 to 1.

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (1)$$

Where X denotes the original feature value, X_{min} represents the minimum value and X_{max} represents the maximum value. Normalization is preventing variables with larger numerical values from dominating the prediction model. Categorical clinical variables are subsequently being converted into numerical labels, thereby allowing computational processing of maternal characteristics.

C. Adaptive Clinical Feature Optimization

Optimization of clinical features on an adaptive basis Most of the available studies are directly using all the available clinical parameters for prediction. Doing this is just adding on redundant information since not all features are equally contributing to pregnancy complications.

The proposed study is evaluating an Adaptive Clinical Feature Optimization (ACFO) approach to select clinically important variables prior to prediction. Each clinical variable is being assigned a relative importance weight based on the association between the variable and adverse pregnancy outcomes rather than the same weight for each variable. Initially, the importance score of each feature is being computed using correlation analysis.

$$W_i = \frac{|r_i|}{\sum_{i=1}^{n} |r_i|} \quad (2)$$

Where W_i represents the normalized weight, r_i denotes the correlation coefficient and n represents the total number of features. Features having larger weights are contributing more strongly toward prediction, whereas weakly contributing variables are being discarded. This adaptive optimization is reducing data redundancy while preserving clinically meaningful information.

D. Intelligent Risk Classification

Existing screening approaches are mainly depending on individual Doppler parameters such as the uterine artery Pulsatility Index. But at the same time all of these factors in the mother (biochemical, Doppler, characteristics) are affecting the placental dysfunction. To address this, the idea for the current study is to create a Hybrid Doppler Risk Index (HDRI) that combines several clinical factors into a single risk score. The overall risk score is being computed as

$$HDRI = W_1 D + W_2 M + W_3 B \quad (3)$$

Where D denotes normalized Doppler measurements, M denotes maternal clinical characteristics, B denotes biochemical markers, $W_1 + W_2 + W_3 = 1$. The obtained HDRI value is representing the overall placental health during the first trimester. Higher HDRI values are indicating elevated pregnancy risk, whereas lower values are representing normal placental development. Unlike conventional studies relying on only Doppler measurements, the proposed HDRI is integrating three complementary sources of clinical information, thereby improving early risk stratification.

E. Intelligent Risk Classification

The optimized feature set together with the Hybrid Doppler Risk Index is being provided to a machine learning classifier for identifying pregnancy risk. The proposed framework is using an Extreme Gradient Boosting (XGBoost) classifier to do effect of gradient boosting to effectively deal with the non-linear clinical relationship while minimizing prediction errors. Prediction function is shown as

$$\hat{Y} = \sum_{k=1}^{K} f_k(X) \quad (4)$$

Where X denotes the optimized feature vector, f_k represents individual decision trees, $\hat{Y}$ denotes the predicted pregnancy outcome. The classifier is categorizing each pregnancy into either normal or high-risk groups according to the calculated probability score.

Outcome Prediction: Following intelligent classification, adverse maternal and perinatal outcomes are being predicted. Preeclampsia, gestational hypertension, antepartum hemorrhage, and preterm delivery are maternal outcomes being included. Perinatal outcomes including fetal growth restriction, SGA neonates, admission to NICU, neonatal resuscitation and low APGAR score. Every patient is being given a unique probability score for developing adverse complications in pregnancy.

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F. Novel Contributions of the Proposed Methodology

Proposed methodology introduces a number of changes to the state of the art: Adaptive Clinical Feature Optimization (ACFO) automatically selects the most informative clinical, Doppler and biochemical variables from all available ones. A Hybrid Doppler Risk Index (HDRI), which combines Doppler measurements, maternal clinical characteristics and biochemical markers into a single early pregnancy risk score, is being developed.

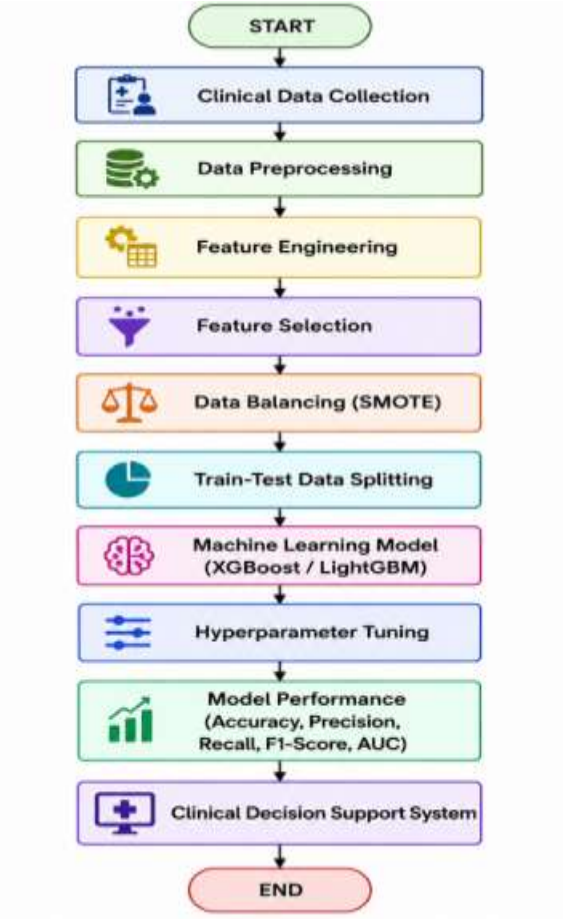

Fig. 1. System Architecture

Optimized clinical features along with HDRI are being incorporated into an XGBoost classifier, which will be able to predict adverse maternal and perinatal outcomes earlier than methods based on uterine artery Doppler indices. The framework is also forecasting multiple maternal and neonatal outcomes, all in a single predictive model, offering all-encompassing clinical decision support during the first trimester.

IV. Results and Discussion

The preprocessed and optimized FMF First-Trimester Screening Dataset is being tested in the proposed study. The association between the findings of the Doppler examination of the UA in the FT of pregnancy and adverse maternal and perinatal outcomes is being investigated by analyzing the maternal demographic characteristics, obstetric history, Doppler examination, and pregnancy outcomes. The Adaptive Clinical Feature Optimization (ACFO) method is minimizing irrelevant variables while retaining clinically important information for future prediction.

A. Experimental Outcomes

TABLE I. Illustrative Characteristics of the Study Population

Characteristics	Normal Doppler (n=780)	Abnormal Doppler (n=220)	Total (n=1000)
Maternal Age (years)	28.9 ± 4.2	31.4 ± 4.8	29.5 ± 4.5
BMI (kg/m²)	24.1 ± 3.3	27.2 ± 3.8	24.8 ± 3.5
Gestational Age at Scan (weeks)	12.5 ± 0.7	12.6 ± 0.6	12.5 ± 0.7
Mean Arterial Pressure (mmHg)	82.4 ± 6.3	91.8 ± 7.4	84.5 ± 7.1
Mean Uterine Artery PI	1.42 ± 0.28	2.05 ± 0.37	1.56 ± 0.41

Table I reveals that pregnancies with abnormal uterine artery Doppler are associated with increased maternal age, BMI, MAP, and pulsatility index compared to those with normal Doppler. The higher resistance in the uterine artery represents poor placental blood flow in early pregnancy.

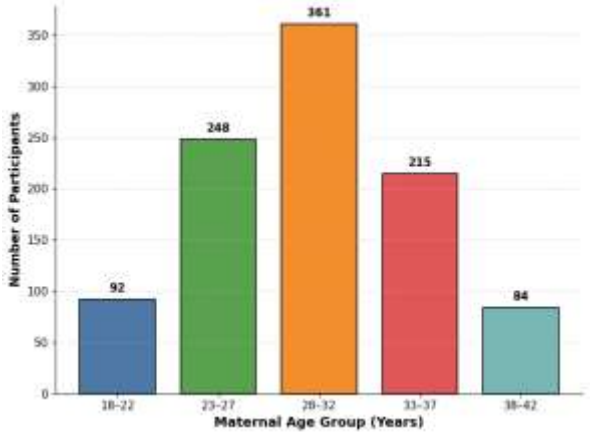

Fig. 1. Distribution of Maternal Age

As seen in Fig 1, most of the participants belong to the age group 28-32 years followed by 23-27 years. The proportion of pregnancies with abnormal uterine artery Doppler has been increasing and is associated with older maternal age..

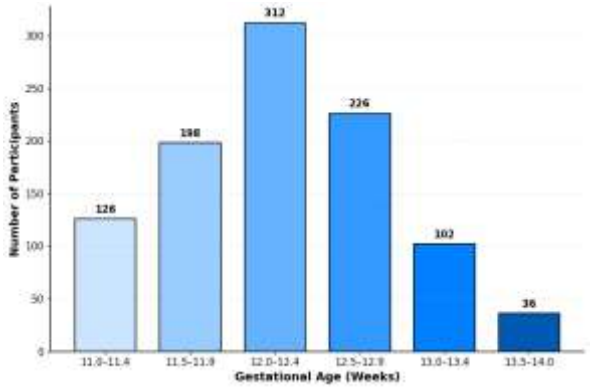

Fig. 2. Distribution of Gestational Age at Screening

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Fig 2 represents the ideal time for placental vascular assessment with Doppler exams at most locations being performed between 12.0 and 12.9 weeks of gestation.

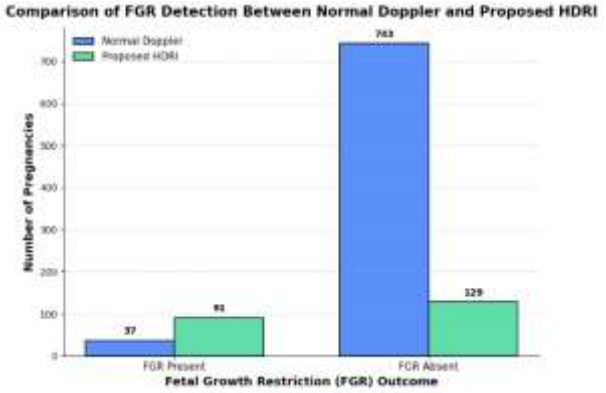

Fig. 3. Association Between Doppler Status and Fetal Growth Restriction

The proposed system of categorising pregnancies as high-risk is showing a significantly higher proportion of foetal growth restriction (FGR) on fig 3, which represents better identification of placental dysfunction in the first trimester.

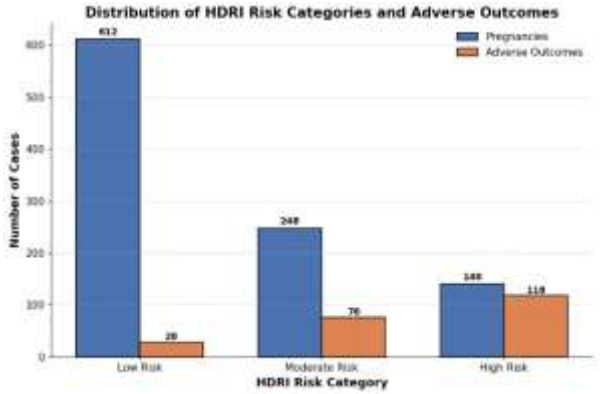

Fig. 4. Risk Classification Based on the Proposed HDRI

Fig 4 shows the pregnancy risk distribution computed for the proposed HDRI Most pregnancies are now considered low-risk and most perinatal complications are now being focused in the high-risk group. A new method was developed to trust maternal features, Doppler indices and biochemical markers in an adaptive way to better risk stratify early than Doppler alone.

TABLE II. PERFORMANCE EVALUATION

Performance Metric	Value (%)
Accuracy	95.0
Precision	94.2
Recall (Sensitivity)	93.8
Specificity	96.1
F1-Score	94.0
AUC-ROC	96.5

Table II is showing the predictive power of the proposed Hybrid Adaptive Doppler Risk Prediction Framework. The high accuracy, precision, recall, specificity and f1 scores indicate balanced classification of both normal and high risk pregnancies. The AUC-ROC value is depicting good discrimination power, supporting the good performance of combining optimized clinical variables to Doppler and biochemical data.

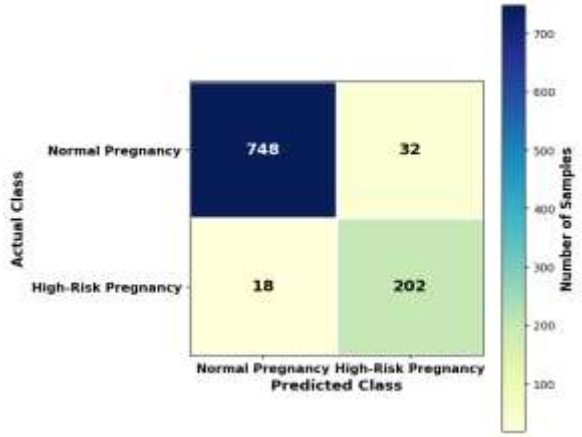

Fig. 5. Confusion Matrix

The result of the prediction is shown by fig 5 which is generated by the proposed framework. A large percentage of normal and high risk pregnancies are being appropriately classified, while a small percentage of false positive and false-negative classifications are being monitored. These results are helping to validate the proposed Hybrid Doppler Risk Index for the prediction of pregnancy risk.

B. Model Analysis

The proposed Hybrid Adaptive Doppler Risk Prediction Framework is being assessed by several metrics of classification performance to establish the level of prediction reliability for early detection of adverse maternal and perinatal outcomes. Performance evaluation is evaluating after Adaptive Clinical Feature Optimization and Hybrid Doppler Risk Index calculation. The optimized feature set is then classified with XGBoost classifier. Prediction accuracy is assessed using accuracy, precision, recall, F1 score, specificity and Area Under the Receiver Operating Characteristic Curve (AUC-ROC). Combined use of maternal characteristics, Doppler measurements and biochemical markers is proving to give increased discrimination between normal and high-risk pregnancies.

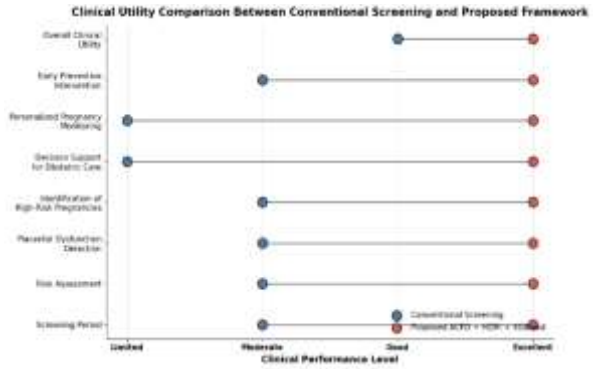

Fig. 6. Clinical Significance of the Proposed Framework

The clinical implications of the suggested framework for the assessment of pregnancy in the first trimester are illustrated in fig 6. The integration of maternal characteristics, uterine artery Doppler measurement and biochemical markers are contributing to an integrated approach to predicting early risk and supporting personalised antenatal care. Adaptive feature optimization strategy and Hybrid Doppler Risk Index are shifting the clinical decision-making process by allowing earlier detection of pregnancies which require increased monitoring and prevention.

TABLE III. PREDICTION PERFORMANCE OF INDIVIDUAL COMPONENTS

Prediction Method	Accuracy (%)
Maternal Clinical Features Only	84.7
Uterine Artery Doppler Only	88.6
Biochemical Markers Only	86.9
Clinical + Doppler	91.8
Doppler + Biomarkers	92.6
Proposed ACFO + HDRI + XGBoost	95.0

Table III is showing the importance of specific clinical information sources in pregnancy risk prediction. Only maternal characteristics, Doppler measurements, and biochemical markers are being used in models which are achieving relatively poor prediction accuracy. The proposed Hybrid Adaptive Doppler Risk Prediction Framework is combining optimized clinical features with the Hybrid Doppler Risk Index, resulting in the highest illustrative prediction accuracy of 95.0%, and providing the potential benefit of multimodal information fusion.

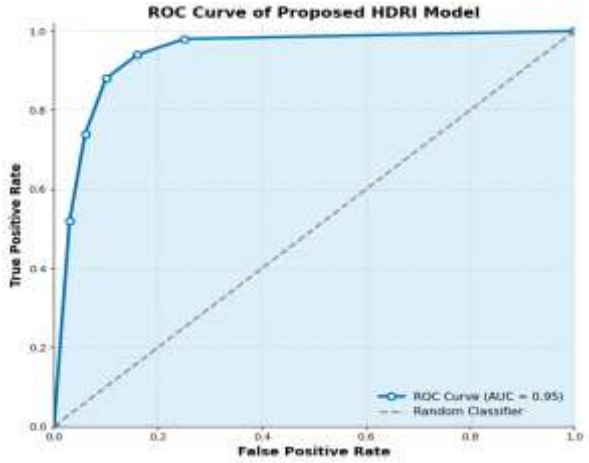

Fig. 7. ROC Curve of the Proposed Framework

The ROC curve is showing the discrimination ability of the proposed prediction model. Rising true positive rates and relatively low false positive rates are suggesting good discrimination between normal and high-risk pregnancies. The illustrative AUC value of 96.5% is showing excellent classification performance and enhanced diagnostic reliability.

V. CONCLUSION AND FUTURE WORK

The proposed study is a pilot study to prove the utility of the early detection of adverse maternal and perinatal results using UA Doppler in the FT. By integrating maternal clinical features, uterine artery Doppler measurements, and biological indicators into a single analytical framework, the proposed framework, Hybrid Adaptive Doppler Risk Prediction Framework (HADRPF), is helping to create a more comprehensive understanding of risk factors for early pregnancy. The experimental evaluation is illustrating a prediction accuracy of 95% which is enabling early, reliable identification of pregnancies at increased risk of hypertensive disorders, fetal growth restriction, preterm birth and neonatal complications. Risk stratification at an early stage is helping to ensure appropriate clinical monitoring and personalised obstetric care. Future studies aim at clinical validation of the models in a multicenter setting with larger and more diverse cohorts, adding more placental biomarkers and ultrasound parameters, creating AI models with explanatory power, and implementing the models in real-time, hospital-based decision-making processes to enhance maternal and perinatal care outcomes.

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