ORIGINAL RESEARCH ARTICLE

Development and validation of a predictive risk model for placental abruption in women with pre-eclampsia using SMOTE

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Abstract

Placental abruption is a serious complication in pregnant women with preeclampsia. This study investigated the risk factors for placental abruption and developed a predictive model using the Synthetic Minority Over-sampling Technique (SMOTE). A total of 280 pregnant women with preeclampsia treated between September 2020 and September 2025 were enrolled and classified into placental abruption and non-placental abruption groups. Logistic regression showed that parity ≥3, severe preeclampsia, anemia, polyhydramnios, and short umbilical cord were independent risk factors for placental abruption. ROC analysis demonstrated that the SMOTE-based model had better predictive performance than the original model, with a higher AUC (0.863, 95% CI: 0.817–0.901 vs 0.792, 95% CI: 0.739–0.838; z=2.163, P=0.031). The SMOTE-based model also showed higher F-score and positive predictive value, although its true positive rate was lower than that of the original model. These findings indicate that a SMOTE-based predictive model may provide useful support for early risk assessment and prevention of placental abruption in women with preeclampsia. *(Afr J Reprod Health 2026; 30 [14]: 26-34).*

Keywords: preeclampsia; placental abruption; synthetic minority over-sampling technique; predictive model

Résumé

L'hématome rétro-placentaire (ou décollement prématuré du placenta) est une complication grave chez les femmes enceintes atteintes de prééclampsie. Cette étude a examiné les facteurs de risque de cette complication et a élaboré un modèle prédictif utilisant la technique SMOTE (*Synthetic Minority Over-sampling Technique*). Au total, 280 femmes enceintes atteintes de prééclampsie, prises en charge entre septembre 2020 et septembre 2025, ont été incluses et réparties en deux groupes : celles ayant présenté un hématome rétro-placentaire et celles n'en ayant pas présenté. La régression logistique a révélé qu'une parité ≥ 3, la prééclampsie sévère, l'anémie, le hydramnios et un cordon ombilical court constituaient des facteurs de risque indépendants d'hématome rétro-placentaire. L'analyse des courbes ROC a démontré que le modèle basé sur la technique SMOTE offrait de meilleures performances prédictives que le modèle initial, avec une aire sous la courbe (AUC) plus élevée (0,863 ; IC à 95 % : 0,817–0,901 contre 0,792 ; IC à 95 % : 0,739–0,838 ; z = 2,163 ; P = 0,031). Le modèle basé sur SMOTE présentait également un score F (*F-score*) et une valeur prédictive positive plus élevés, bien que son taux de vrais positifs fût inférieur à celui du modèle initial. Ces résultats indiquent qu'un modèle prédictif basé sur la technique SMOTE pourrait constituer un outil utile pour l'évaluation précoce des risques et la prévention de l'hématome rétro-placentaire chez les femmes atteintes de prééclampsie.*(Afr J Reprod Health 2026; 30 [14]: 26-34).*

Mots-clés : prééclampsie ; décollement placentaire ; technique de suréchantillonnage synthétique des minorités ; modèle prédictif

Introduction

Preeclampsia is a relatively common and severe complication during pregnancy, with an incidence of approximately 8%–10%, usually occurring after 20 weeks of gestation and presenting with hypertension, proteinuria, and multiple systemic symptoms.[1–2] Placental abruption, defined as the premature partial or complete separation of a normally implanted placenta after 20 weeks of gestation, is one of the most serious complications associated with preeclampsia.[3–4] It can result in massive maternal hemorrhage, disseminated intravascular coagulation, fetal hypoxia, stillbirth, and other severe adverse outcomes, with preeclampsia accounting for approximately 60% of cases.[5–6] Therefore, early identification of high-risk individuals is crucial for reducing the incidence and improving maternal–fetal outcomes. Previous studies have identified several clinical factors associated with placental abruption in women with preeclampsia, including anemia and abnormalities in amniotic fluid volume.[7–8] However, most of these studies have primarily focused on identifying individual risk factors, rather than constructing comprehensive predictive models for clinical application. Moreover, traditional statistical methods such as logistic regression may have limitations when dealing with imbalanced datasets, as placental abruption occurs relatively infrequently compared with non-abruption cases. This imbalance can lead to biased model performance and reduced predictive accuracy, particularly in identifying high-risk patients.

The Synthetic Minority Over-sampling Technique (SMOTE) is an effective approach for handling imbalanced data by generating synthetic samples for the minority class, thereby improving model performance and reducing classification bias [9]. It has been increasingly applied in medical prediction studies, including adverse event analysis [9]. However, to date, few studies have incorporated SMOTE into predictive modeling for placental abruption in women with preeclampsia.

Therefore, this study aimed to develop and validate a predictive model for placental abruption in women with preeclampsia based on the SMOTE algorithm. By addressing the issue of data imbalance and improving model performance, this study seeks to provide a more accurate tool for early risk assessment and prevention.

Methods

General information

A total of 280 pregnant women with preeclampsia admitted for treatment between September 2020 and September 2025 were enrolled in this study. The study was conducted in the Department of Obstetrics of the First Affiliated Hospital of Bengbu Medical University, Bengbu City, Anhui Province, China. This hospital is a tertiary teaching hospital and a regional referral center for high-risk pregnancies. Eligible participants were consecutively enrolled during the study period. The inclusion criteria included the following: ① age ≥21 years, singleton pregnancy; ② meeting the diagnostic criteria for preeclampsia confirmed by hospital examination [10]; ③ no mental disorders and able to communicate normally; ④ gestational age >20 weeks; ⑤ participated in this study voluntarily and signed the informed consent.

The exclusion criteria were: ① infectious diseases or immunodeficiency; ② malignant tumors or severe infectious diseases; ③ accompanied by ketoacidosis or hyperosmolar coma; ④ reproductive organ malformations. This was a retrospective observational study, and all eligible patients meeting the inclusion criteria during the study period were consecutively included. Therefore, no formal sample size calculation was performed.

Grouping and data collection

Participants were classified into two groups according to the occurrence of placental abruption: a placental abruption group (case group) and a non-placental abruption group (control group). Given the retrospective nature of the study, this classification was based on observed clinical outcomes rather than random assignment. The diagnosis of placental abruption was based on the criteria recommended by the Chinese Medical Association[11], including ultrasound findings of a hypoechoic area between the placenta and uterine wall or beneath the placenta, or placental thickening; clinical manifestations such as unexplained abdominal pain accompanied by vaginal bleeding, low back pain, uterine contractions, or uterine tenderness; and abnormal fetal heart monitoring findings.

The data collected included age, gestational age, history of vaginal bleeding, history of cesarean section, history of abortion, parity, pre-delivery body mass index (BMI), severity of preeclampsia, anemia, polyhydramnios, and short umbilical cord. The severity of preeclampsia was assessed with systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg with proteinuria (random urine protein ≥+ or 24-hour urine protein ≥0.3 g) was defined as mild preeclampsia; any of the following conditions in pregnant women with preeclampsia was defined as severe preeclampsia: ① fetal growth restriction; ② heart failure; ③ hematologic abnormalities; ④ hypoalbuminemia with pleural or abdominal effusion; ⑤ renal dysfunction; ⑥ abnormal liver enzymes; ⑦ neurological symptoms; ⑧ 24-hour urine protein ≥2.0 g; ⑨ persistent hypertension. Anemia: hemoglobin <100g/L. Polyhydramnios: ultrasound showing the maximum vertical pocket of amniotic fluid >8 cm.

SMOTE-based data resampling

Because placental abruption occurred in only 30 of the 280 women included in this study, the original dataset was imbalanced, comprising 30 cases in the placental abruption group and 250 cases in the non-placental abruption group. To address this imbalance, the Synthetic Minority Over-sampling Technique (SMOTE) was applied according to the method described by Blagus et al. [12] The placental abruption group was treated as the minority class, and the number of nearest neighbors was set at 8 (k=8). Synthetic samples were generated from the minority class until the class distribution became approximately balanced. After resampling, the placental abruption group increased from 30 to 240 cases, while the non-placental abruption group remained at 250 cases, resulting in a final class ratio of 0.96. The resampled dataset was then used for logistic regression analysis to construct the SMOTE-based predictive model.

Statistical analysis

The data were analyzed with SPSS 26.0, with t-test for comparison of measurement data and χ^2 test for comparison of count data, and the factors for placental abruption risks in pregnant women who suffer from preeclampsia were selected with logistic regression analysis. We plotted the ROC (receiver operating characteristic) curve with MedCalc software, and TPR (true positive rate), PPV (positive predictive value), and F-score were used to evaluate model accuracy, while the Hosmer–Lemeshow (H-L) test was used to assess model calibration. $P<0.05$ was considered statistically significant.

Ethical considerations

This study was approved by the Ethics Committee of The First Affiliated Hospital of Bengbu Medical University (Approval No. 2020-011; approved on 1st September 2020. The study was conducted in accordance with the principles of the Declaration of Helsinki. All participants voluntarily took part in the study and provided written informed consent prior to inclusion. All personal information was kept confidential, and the data were anonymized before analysis.

Results

Univariate analysis of placental abruption in pregnant women with preeclampsia

As shown in Table 1, there were no significant differences between the two groups in age, gestational age, history of vaginal bleeding, history of cesarean section, history of abortion, or pre-delivery BMI (all $P > 0.05$). However, parity, severity of preeclampsia, anemia, polyhydramnios, and short umbilical cord differed significantly between the two groups (all $P < 0.05$).

Logistic regression analysis of placental abruption in pregnant women with preeclampsia

Parity, severity of preeclampsia, anemia, polyhydramnios, and short umbilical cord were used as independent variables, and the placental abruption occurrence in pregnant women who suffer from preeclampsia was used as the dependent variable to perform Logistic regression analysis. Based on the findings, parity ≥3, severe preeclampsia, anemia, polyhydramnios, and short umbilical cord were all factors for placental abruption risks in pregnant women who suffer from preeclampsia. On the basis of the regression coefficients of the risk factors, the original predictive model was obtained as Logit (P1)= 1.349 parity +1.133 severity of preeclampsia +1.731 anemia +1.439 polyhydramnios +1.351 short umbilical cord −3.750, and the H-L test results (coefficient of determination R^2=0.269, P=0.718)

Table 1: Univariate analysis of factors associated with placental abruption in women with preeclampsia

Variable	Placental abruption group (n=30)	Non-placental abruption group (n=250)	t/χ^2	P value
Age (years)	28.4±3.1	28.2±2.6	0.4	0.684
Gestational age (weeks)	37.2±2.2	37.6±2.1	1.0	0.341
History of vaginal bleeding, n (%)	8 (26.7)	44 (17.6)	1.5	0.228
History of cesarean section, n (%)	14 (46.7)	108 (43.2)	0.1	0.717
History of abortion, n (%)	5 (16.7)	29 (11.6)	0.6	0.422
Parity ≥3, n (%)	11 (36.7)	38 (15.2)	8.5	0.003
Pre-delivery BMI (kg/m^2)	25.1±2.0	24.9±1.7	0.7	0.479
Severe preeclampsia, n (%)	14 (46.7)	52 (20.8)	9.9	0.002
Anemia, n (%)	9 (30.0)	23 (9.2)	11.4	0.001
Polyhydramnios, n (%)	12 (40.0)	39 (15.6)	10.7	0.001
Short umbilical cord, n (%)	8 (26.7)	21 (8.4)	9.6	0.002

Table 2: Multivariable logistic regression analysis of placental abruption in women with preeclampsia

Variable	β	SE	Wald χ^2	P value	OR	95% CI
Parity ≥3	1.3	0.5	7.7	0.005	3.9	1.5–10.0
Severe preeclampsia	1.1	0.4	6.5	0.011	3.1	1.3–7.4
Anemia	1.7	0.5	10.7	0.001	5.6	2.0–15.9
Polyhydramnios	1.4	0.5	9.2	0.002	4.2	1.7–10.7
Short umbilical cord	1.4	0.5	6.1	0.013	3.9	1.3–11.2
Constant	-3.8	0.4	77.2	<0.001	0.0	—

Table 3: Multivariable logistic regression analysis after SMOTE resampling

Variable	β	SE	Wald χ^2	P value	OR	95% CI
Parity ≥3	1.3	0.3	24.6	<0.001	3.5	2.1–5.8
Severe preeclampsia	0.9	0.2	14.7	<0.001	2.4	1.5–3.8
Anemia	1.5	0.3	28.0	<0.001	4.7	2.6–8.3
Polyhydramnios	1.4	0.2	33.3	<0.001	4.2	2.6–6.8
Short umbilical cord	1.3	0.3	16.3	<0.001	3.5	1.9–6.4
Constant	-1.5	0.2	73.9	<0.001	0.2	—

indicated that the Logistic regression model had a good fit. See Table 2.

Predictive model based on the SMOTE algorithm

Based on the factors included in the Logistic regression analysis, the SMOTE algorithm was applied for 8-fold oversampling to make the ratio of the placental abruption group to the non-placental abruption group approximately 1:1 (actual ratio 0.96), and Logistic regression analysis was performed on the resampled data. The results showed that the predictive model based on the SMOTE algorithm was Logit (P2)=1.263 parity +0.887 severity of preeclampsia +1.544 anemia +1.436 polyhydramnios +1.254 short umbilical cord −1.514, and the H-L test results (coefficient of determination R^2=0.347, P=0.319) indicated that the model based on the SMOTE algorithm had a good fit. See Table 3.

Evaluation of predictive model performance

According to ROC curve analysis, the area under the ROC curve of the predictive model based on the SMOTE algorithm was 0.863 (95% CI: 0.817–0.901), which was higher than that of the original predictive model 0.792 (95% CI: 0.739–0.838) (z=2.163, P=0.031). The F-score and PPV of the SMOTE-based predictive model were both higher than those of the original predictive model, while the

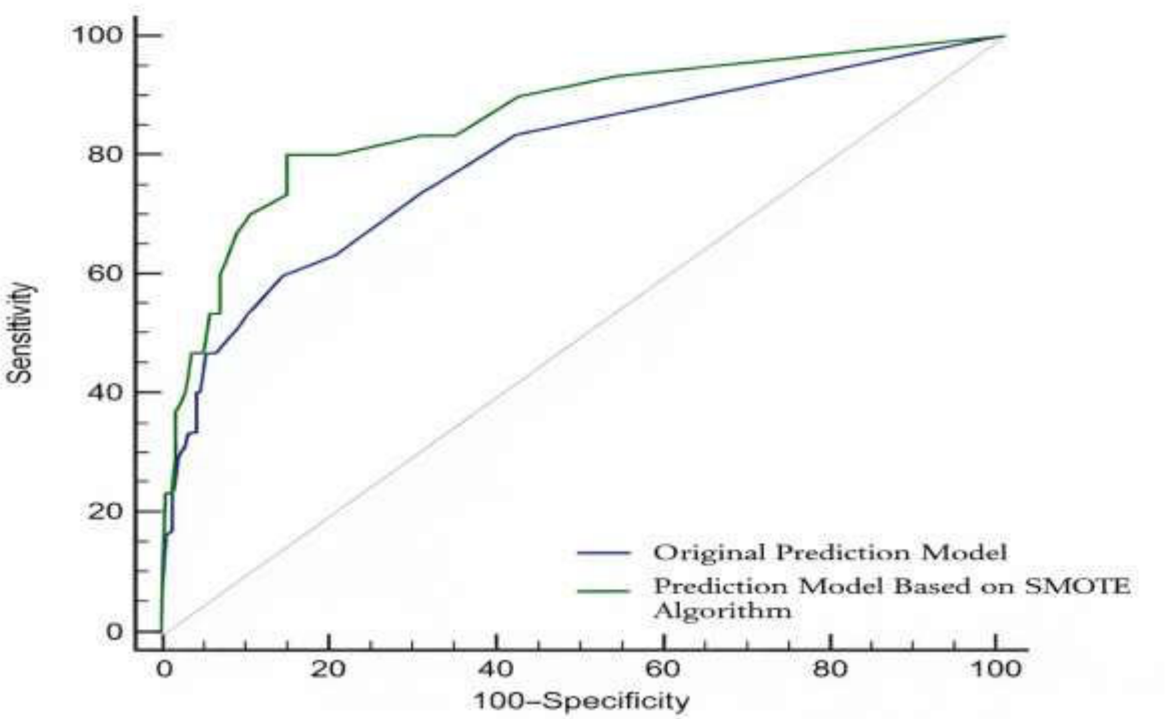

Figure 1 ROC curves of the two predictive models

Table 4: Performance comparison of the original and SMOTE-based predictive models

Model	AUC	95% CI	TPR	F-score	PPV
Original predictive model	0.80	0.74–0.84	0.82	0.70	0.76
Predictive model based on the SMOTE algorithm	0.86	0.82–0.90	0.78	0.73	0.80

TPR was lower than that of the original predictive model. See Figure 1 and Table 4.

Discussion

At present, the exact etiology and pathogenesis of preeclampsia remain unclear, and its occurrence and development may be related to multiple factors involving the placenta, the mother, and the fetus.[13-14] Placental abruption is a common complication of preeclampsia, with two core pathological mechanisms: on the one hand, preeclampsia leads to insufficient placental perfusion and trophoblast ischemia; on the other hand, spasm of the spiral arterioles in the decidua basalis causes bleeding, forming and enlarging a retroplacental hematoma that ultimately forces placental separation.[15] Placental abruption often has an insidious onset but progresses rapidly, and due to its unclear etiology and mechanism, it can lead to a series of serious complications such as disseminated intravascular coagulation, fetal death, and even hysterectomy.[16] Early detection and timely intervention are key to reducing the placental abruption occurrence in pregnant women who suffer from preeclampsia.

This study found that parity ≥3 is a factor for placental abruption risks in pregnant women who suffer from preeclampsia. Zhang Yi et al.[17] found that parity ≥3 increases the placental abruption risks in pregnant women who suffer from preeclampsia.

The reason may be that multiple pregnancies reduce the elasticity of the uterine myometrium, making it unable to effectively buffer intrauterine pressure fluctuations caused by preeclampsia. When intrauterine pressure rises sharply, the stiff myometrium cannot disperse the pressure, resulting in uneven stress on the placental attachment surface and ultimately leading to abruption. This study found that severe preeclampsia is a factor for placental abruption risks in pregnant women who suffer from preeclampsia. In normal pregnancy, maternal spiral arteries undergo physiological remodeling to ensure placental blood flow. However, in severe preeclampsia, the high rate of poor remodeling of spiral arteries leads to narrowed lumen and poor elasticity, resulting in insufficient placental perfusion. Ischemic villi then undergo infarction and necrosis, and local bleeding forms a retroplacental hematoma, which ultimately exceeds the attachment threshold and causes abruption.

This study found that anemia is a factor for placental abruption risks in pregnant women who suffer from preeclampsia, which aligns with the findings of Wang Runfang *et al.*[18] The reason may be that under normal conditions, the placenta can compensate for mild ischemia through vasodilation and redistribution of blood flow.

However, in pregnant women with preeclampsia, due to endothelial damage, the placenta is already in a state of high resistance and low elasticity, losing its ability to dilate. At this time, if anemia further reduces oxygen supply, the compensatory mechanism collapses directly, and local tissues initiate anaerobic metabolism due to hypoxia, leading to the accumulation of a large amount of lactic acid, further damaging vascular endothelium and significantly increasing the risk of rupture, thereby inducing placental abruption. This study showed that polyhydramnios is a risk factor for placental abruption in pregnant women with preeclampsia, consistent with the findings of Chen Lincui et al.[19]. It may be because when polyhydramnios occurs, the uterine volume increases significantly, leading to excessive stretching of the uterine wall myometrium, thereby increasing the tension at the placental attachment site, and excessive traction can tear small blood vessels at the site, causing spot-like bleeding; if not treated in time, the bleeding accumulates to form a hematoma, ultimately leading to placental abruption. This study found that a short umbilical cord is a risk factor for placental abruption in pregnant women with preeclampsia, which is consistent with the findings of Tang Ping et al. [20]. It may be because when the umbilical cord is too short and taut, it mechanically compresses the umbilical arteries and veins, narrowing the lumen and further reducing placental blood flow, leading to extensive hypoxic infarction of villi, and rupture may cause massive hemorrhage; in addition, obstruction of umbilical venous return increases placental venous pressure, jointly aggravating the risk of vascular rupture and ultimately leading to placental abruption.

Class imbalance in data can cause traditional models to be biased toward the majority class, resulting in accurate identification of majority class events but severely sacrificing the prediction accuracy for minority class events [21]. SMOTE is a classical oversampling method for addressing imbalanced classification problems, which balances class proportions so that the model can pay equal attention to minority and majority classes during training, thereby improving the recognition ability for minority classes [22]. Based on the study findings, the area under the ROC curve of the predictive model based on the SMOTE algorithm was 0.863 (95% CI: 0.817–0.901), which was higher than that of the original predictive model 0.792 (95% CI: 0.739–0.838); the F-score and PPV of the SMOTE-based predictive model were higher than those of the original model, while the TPR was lower, indicating that the predictive model for placental abruption in pregnant women with preeclampsia based on the SMOTE algorithm has good predictive accuracy.

Strengths and limitations

This study has several strengths. First, it focused specifically on placental abruption in women with preeclampsia, a clinically important but relatively underexplored subgroup in obstetric risk prediction. Second, the study not only identified independent risk factors, but also developed a predictive model, thereby extending the findings from simple association analysis to a more clinically applicable risk assessment tool. Third, by applying the SMOTE algorithm to address class imbalance, this study improved the identification of minority events and demonstrated better predictive performance than the original model, which may enhance early clinical recognition of high-risk patients.

However, several limitations should also be acknowledged. First, this was a single-center retrospective study, which may limit the generalizability of the findings to other populations and healthcare settings. Second, the sample size of the placental abruption group in the original dataset was relatively small, and although SMOTE improved class balance, synthetic resampling cannot fully substitute for larger real-world datasets. Third, the variables included in the model were limited to routinely available clinical characteristics, and some potentially relevant biomarkers or imaging indicators were not assessed. Finally, external validation was not performed; therefore, the model should be interpreted cautiously until confirmed in multicenter prospective studies.

Implications for policy and practice

The findings of this study have potential implications for both clinical practice and maternal health management. In clinical settings, the identification of parity ≥3, severe preeclampsia, anemia, polyhydramnios, and short umbilical cord as important predictors may help obstetricians and nurses strengthen surveillance and individualized management for women at high risk of placental abruption. In particular, the SMOTE-based predictive model may serve as a practical supplementary tool for early risk stratification in routine obstetric care. From a policy perspective, these findings support the need for improved risk screening protocols for pregnant women with preeclampsia, especially in tertiary referral centers managing high-risk pregnancies. Early identification and timely intervention may contribute to reducing maternal and fetal adverse outcomes and optimizing resource allocation in obstetric care.

In conclusion, this study achieved its objective of identifying independent risk factors and developing a predictive model for placental abruption in women with preeclampsia. Parity ≥3, severe preeclampsia, anemia, polyhydramnios, and short umbilical cord were identified as important predictors, and the SMOTE-based model showed better predictive performance than the original model. These findings suggest that the proposed model may provide useful support for early risk assessment and targeted clinical management in high-risk obstetric populations.

Conclusion

A SMOTE-based predictive model may improve the early identification of placental abruption risk in women with preeclampsia. The integration of key clinical factors into a predictive framework may facilitate timely intervention and contribute to improved maternal and fetal outcomes.

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Conflicting interests

The authors declare no competing interests.

Authors' contributions

F.F.W. and R.Y. conceived and designed the study. F.F.W. and Z.J.R. performed data collection and analysis.F.F.W. drafted the manuscript. R.Y. , as the corresponding author, supervised the study and critically revised the manuscript for important intellectual content. Z.J.R. contributed to data interpretation and manuscript revision. All authors reviewed and approved the final manuscript.

Data availability

The data used and/or analysed during the current study are available from the corresponding author on reasonable request. The data are not publicly available because they contain information that could compromise the privacy of research participants.

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