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Clinical Application of Combined Measurement of Cardiac Injury Markers and Platelet Parameters in Pregnant Women with Preeclampsia

Background	Preeclampsia (PE) is a severe pregnancy complication characterized by hypertension and organ damage. Recent evidence suggests that cardiac injury and platelet dysfunction may contribute to the progression of PE. This study aimed to evaluate the clinical value of combined detection of cardiac injury markers and platelet parameters in the diagnosis, risk stratification, and prognosis of PE in pregnant women.
Material and methods	This retrospective study included 120 pregnant women with PE (PE group) and 120 healthy pregnant women (control group) hospitalized from January 2020 to December 2022. Serum cardiac injury markers (cardiac troponin I [cTnI], creatine kinase-MB [CK-MB], and N-terminal pro-B-type natriuretic peptide [NT-proBNP]) and platelet parameters (platelet count [PLT], mean platelet volume [MPV], platelet distribution width [PDW], and plateletcrit [PCT]) were measured. Receiver operating characteristic (ROC) curve analysis was used to evaluate the diagnostic efficacy of individual markers and their combinations.
Results	Compared with the control group, PE patients had significantly elevated cTnI, CK-MB, NT-proBNP, MPV, and PDW, and decreased PLT and PCT (all $p<0.01$). The diagnostic performance of a combined detection model (AUC=0.907, 95% CI: 0.867–0.947) was superior to any single marker. In PE patients, elevated cardiac injury markers were positively correlated with PE disease severity, blood pressure, and proteinuria. Patients with both abnormal cardiac markers and platelet parameters had significantly higher rates of maternal and neonatal adverse outcomes ($p<0.001$) and were more likely to require early delivery and intensive care.
Conclusions	Combined detection of cardiac injury markers and platelet parameters provides better diagnostic accuracy for PE and can serve as a valuable tool for risk stratification and prognosis prediction. This approach may facilitate early intervention and individualized management strategies for pregnant women with PE.

Keywords	Preeclampsia; cardiac injury markers; platelet parameters; cardiac troponin i; mean platelet volume; combined detection; risk stratification; pregnancy complications
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Introduction

Preeclampsia (PE) is a pregnancy-specific severe complication characterized by hypertension and organ dysfunction occurring after 20 wks of gestation, and it is one of the major causes of maternal and perinatal mortality worldwide [1]. Statistics show that PE affects 2–8% of pregnancies globally, with higher incidence rates in developing countries, seriously threatening maternal and fetal health [2]. The pathophysiological mechanisms of this disease are complex, involving multiple aspects including abnormal placental vascular development, endothelial dysfunction, inflammatory response, and coagulation disorders, and there is still a lack of method of early detection and treatment [3].

Recent studies have shown that PE patients often present with cardiovascular system damage and platelet dysfunction. Cardiac injury markers such as cardiac troponin I (cTnI), creatine kinase-MB (CK-MB), and N-terminal pro-B-type natriuretic peptide (NT-proBNP) are significantly elevated in PE patients, suggesting the presence of myocardial cell damage and cardiac dysfunction [4]. Meanwhile, changes in platelet parameters, including decreased platelet count, increased mean platelet volume (MPV) and platelet distribution width (PDW), reflect increased platelet activation state and thrombosis risk [5]. These biomarker changes are not only closely related to disease severity but may also predict the occurrence of adverse pregnancy outcomes [6].

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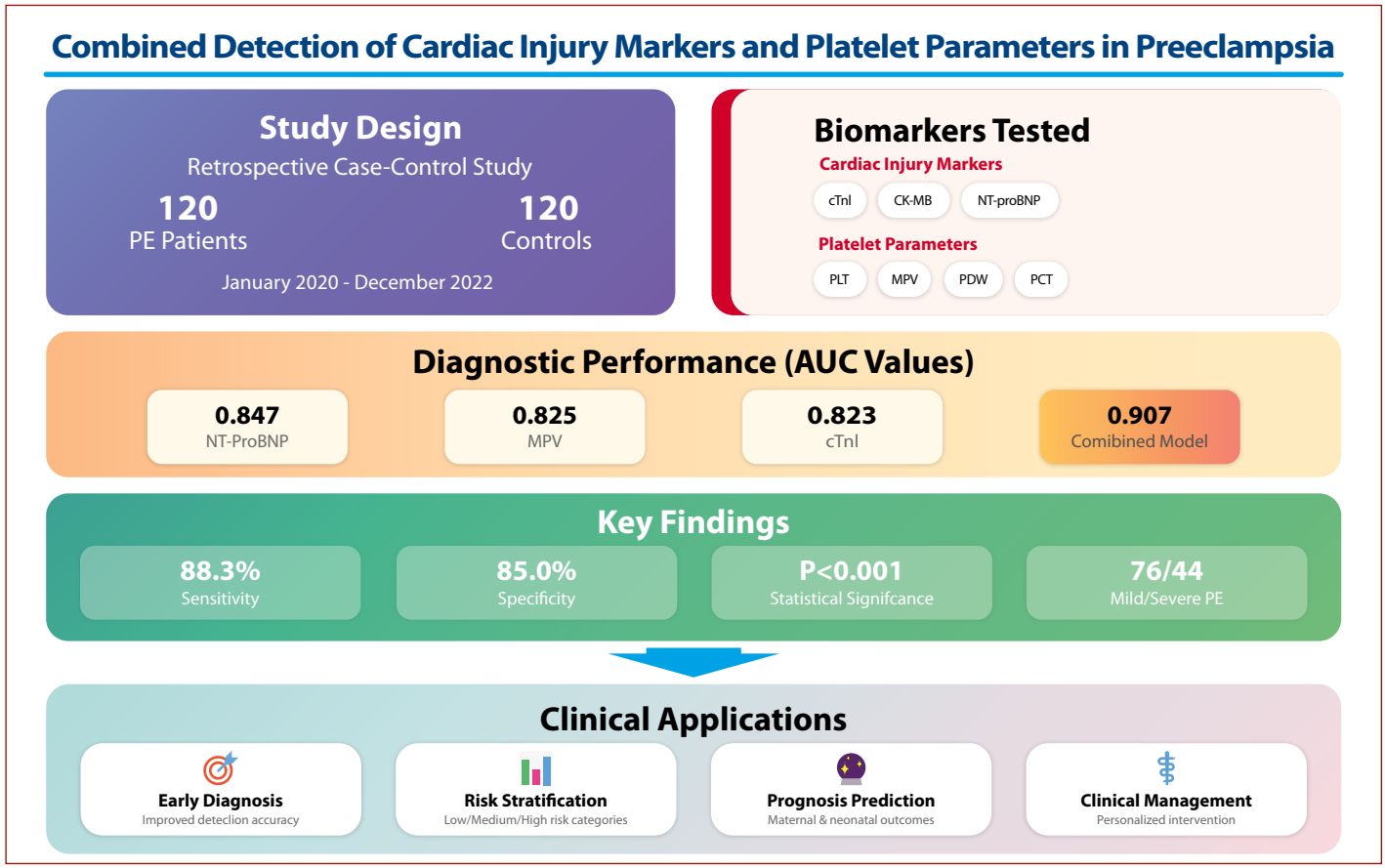
Central illustration. Clinical Application of Combined Measurement of Cardiac Injury Markers and Platelet Parameters in Pregnant Women with Preeclampsia



Traditional PE diagnosis mainly relies on clinical manifestations and routine laboratory tests, but these indicators often show abnormalities only in the late stage of the disease, thus missing the optimal timing for early intervention. The diagnostic efficacy of single biomarkers is limited [7], whereas multi-marker combined detection might provide higher diagnostic accuracy and predictive value. However, research on the clinical application value of combined measurement of cardiac injury markers and platelet parameters in PE diagnosis, risk stratification, and prognosis assessment remains limited [8]. Therefore, this study aimed to explore the clinical application value of combined measurement of cardiac injury markers and platelet parameters in pregnant women with PE, and to provide new laboratory evidence for early identification, risk assessment, and individualized management of this disease.

Material and methods

Patient selection

This report describes a single-center retrospective cohort study. The hospital ethics committee approved the study protocol, and all patients signed informed consent forms.

The study adopted a case-control design, continuously recruiting eligible pregnant women through the hospital information system. The sample size calculation was based on pilot data, with test power set at 80%, α level at 0.05, expected Area Under the Curve (AUC) of combined detection at 0.90, and AUC of the single best indicator at 0.80, This calculation showed that at least 108 patients were needed in each group. Considering a 10% dropout rate, 120 patients at West China Second University Hospital, Sichuan University, from January 2020 to December 2022, were included in each group.

The inclusion criteria for the PE group were strictly formulated according to the American College of Obstetricians and Gynecologists (ACOG) 2019 guidelines: Hypertension occurring after 20 wks of pregnancy, defined as systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg, confirmed by two measurements at least 4 h apart; and combined with proteinuria (24-h urinary protein ≥300 mg or protein/creatinine ratio ≥0.3); or with evidence of any of the following organ dysfunction: thrombocytopenia (<100×10^9/l), liver dysfunction (transaminase elevation to more than twice normal values), renal dysfunction (serum creatinine >1.1 mg/dl or doubling from baseline), pulmonary edema, or cerebral or visual symptoms.

The control group consisted of healthy pregnant women undergoing routine prenatal care during the same period. *Inclusion criteria* were:

1) Singleton pregnancy;
2) Normal blood pressure (<140/90 mmHg);

3) No proteinuria;
4) No pregnancy complications;
5) Normal fetal development.
6) Patients in both groups were matched according to maternal age (±2 yrs), gestational age (±1 wk), and body mass index (±1 kg/m^2).

Exclusion criteria included:

1) Age <18 yrs or >45 yrs;
2) Multiple pregnancy;
3) History of cardiovascular disease, including cardiomyopathy, coronary heart disease, arrhythmia, congenital heart disease;
4) Hematological disease such as thrombocytopenic purpura, hemophilia, coagulation dysfunction;
5) Chronic kidney disease or renal dysfunction;
6) Autoimmune diseases such as systemic lupus erythematosus, antiphospholipid syndrome;
7) Chronic hypertension or diabetes;
8) Malignancy;
9) Recent use of drugs affecting cardiac markers or platelet function (except low-dose aspirin for PE prevention);
10) Acute infection at the time of blood collection;
11) Incomplete clinical data.

The included PE patients were further classified according to disease severity into mild PE (n=76) and severe PE (n=44) groups. Diagnostic criteria for severe PE required the presence of one or more of the following:

1) Blood pressure ≥160/110 mmHg;
2) Proteinuria ≥5 g/24h;
3) Platelet count <100×10^9/l;
4) Liver enzymes elevated to more than twice normal values;
5) Serum creatinine >1.1 mg/dl;
6) Pulmonary edema, or neurological symptoms.

Laboratory methods

After admission, patients fasted for 12 h, and 5 ml of venous blood was collected during the morning. The blood was collected into ethylenediaminetetraacetic acid anticoagulant tubes for measuring platelet parameters and into coagulation-promoting tubes for detecting cardiac injury markers. These samples were tested within 2 h of collection, and all tests were performed by trained laboratory technicians who were blinded to the patient clinical information.

Cardiac injury markers were detected using chemiluminescent immunoassay (cTnI), immunoinhibition (CK-MB), and electrochemiluminescence immunoassay (NT-proBNP). Platelet count, mean platelet volume, platelet distribution width, and plateletcrit were measured with an automated blood cell analyzer. All detection methods were performed strictly according to the manufacturers' instructions, with regular quality control.

Endpoints

Primary and secondary endpoints were evaluated to comprehensively assess the clinical utility of combined application of cardiac injury markers and platelet parameters. Primary endpoints focused on diagnostic efficacy. This was evaluated from sensitivity, specificity, positive and negative predictive values, ROC curve analysis and AUC calculation, and by comparing individual marker prediction with a combined prediction model. Secondary endpoints examined correlations between biomarker concentrations and PE severity, as well as their associations with maternal complications. These complications included eclampsia, hemolysis, elevated liver enzymes, low platelet count [HELLP] syndrome, pulmonary edema, acute kidney injury, need for antihypertensive treatment, and maternal Intensive Care Unit [ICU] admission and adverse fetal/neonatal outcomes (including preterm birth <37 wk, intrauterine growth restriction, low birth weight <2500 g, 5-min Apgar score <7, admission to the neonatal intensive care unit, and stillbirth or neonatal death).

Statistical analysis

Statistical analyses were performed using SPSS 26.0 software. The normality of continuous variables was assessed using the Shapiro-Wilk test. Continuous variables with normal distribution were compared using Student's t-test, while those with non-normal distribution were analyzed using Mann-Whitney U test. Categorical variables were analyzed using chi-square test or Fisher's exact test when expected cell counts were less than 5. Multivariate logistic regression analysis evaluated independent associations between biomarkers and adverse outcomes. Correlations between biomarkers and clinical parameters were assessed using Pearson correlation coefficient for normally distributed variables and Spearman rank correlation for non-normally distributed variables. Fisher's Z-transformation was used to statistically compare the strength of correlation coefficients between different biomarkers. ROC curve analysis was performed to evaluate diagnostic performance, and optimal cutoff points were determined using the Youden index (J = sensitivity + specificity – 1), which identifies the point on the ROC curve with maximum diagnostic accuracy by equally weighting sensitivity and specificity. Logistic regression was used to construct prediction models and to calculate AUC, with Net Reclassification Improvement (NRI) and Integrated Discrimination Improvement (IDI) quantifying improvements in risk prediction. Model calibration was assessed using the Hosmer-Lemeshow goodness-of-fit test to evaluate the agreement between predicted probabilities and observed outcomes. Statistical significance was set at $p<0.05$. Continuous data are presented as mean ± standard deviation (SD) for normally distributed variables and median (interquartile range) for non-normally distributed variables. Categorical data are presented as frequencies and percentages.

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Table 1. Comparison of baseline characteristics, myocardial injury markers and platelet parameters between the PE and control groups

Variable	PE Group (n=120)	Control Group (n=120)	Statistical Value	p-Value
Demographic and Clinical Characteristics				
Maternal age (yrs)	29.7±4.8	30.2±4.5	t=0.822	0.413
Body mass index (kg/m²)	28.3±3.9	27.6±3.7	t=1.414	0.159
Gestational age at sampling (wks)	33.4±3.6	33.8±3.3	t=0.914	0.362
Primipara (%)	63.3	60.0	χ^2=0.281	0.597
Blood Pressure and Proteinuria				
Systolic blood pressure (mmHg)	158.6±18.4	116.3±10.2	t=22.152	<0.001
Diastolic blood pressure (mmHg)	97.3±11.2	74.8±8.6	t=17.726	<0.001
24-hour urinary protein (g/24h)	2.42 (1.68–3.89)	0.13 (0.09–0.16)	z=13.287*	<0.001
Serum Indicators				
Serum uric acid (mg/dl)	6.82±1.43	4.21±0.87	t=17.539	<0.001
Myocardial Injury Markers				
cTnI (ng/ml)	0.024 (0.018–0.035)	0.007 (0.006–0.010)	z=12.735*	<0.001
CK-MB (ng/ml)	5.8±1.7	2.3±0.9	t=20.432	<0.001
NT-proBNP (pg/ml)	342.6±98.4	115.2±42.7	t=24.174	<0.001
Platelet Parameters				
Platelet count (×10⁹/l)	156.3±45.7	234.8±52.1	t=12.453	<0.001
Plateletcrit (%)	0.138±0.037	0.214±0.042	t=15.216	<0.001
Mean platelet volume (fl)	11.2±1.3	9.1±0.8	t=15.849	<0.001
Platelet distribution width (%)	17.4±2.6	12.5±1.8	t=17.173	<0.001

Data are mean±SD or median (interquartile range). *Mann-Whitney U test was used for non-normally distributed variables. PE, preeclampsia; cTnI, cardiac troponin I; CK-MB, creatine kinase-MB; NT-proBNP, N-terminal pro-B-type natriuretic peptide; PLT, platelet count; MPV, mean platelet volume; PDW, platelet distribution width; PCT, plateletcrit.

Results

Baseline demographic and clinical data

Demographic characteristics of the PE and control groups were comparable (Table 1). Women with PE had significantly elevated concentrations of all cardiac injury markers compared with the healthy pregnant control group (all p<0.001). For platelet parameters, PE patients had significantly decreased platelet count and plateletcrit compared with the control group, while MPV and PDW were significantly elevated (all p<0.001).

Comparison between mild and severe PE

Compared with mild PE patients, women with severe PE showed more pronounced clinical manifestations and bio-

Table 2. Comparison of clinical characteristics and laboratory parameters between severe and mild PE groups.

Variable	Severe PE (n=44)	Mild PE (n=76)	Statistical Value	p-Value
Clinical Characteristics				
Systolic blood pressure (mmHg)	173.8 ± 15.2	149.7 ± 13.9	t = 8.914	<0.001
Diastolic blood pressure (mmHg)	106.5 ± 9.7	92.1 ± 8.3	t = 8.647	<0.001
24-hour urinary protein (g/24h)	5.12 (3.45–6.89)	1.58 (1.12–2.24)	z = 10.142*	<0.001
Serum uric acid (mg/dL)	7.89 ± 1.31	6.18 ± 1.14	t = 7.534	<0.001
AST (U/l)	62.5 (41.2–89.7)	28.3 (22.1–36.8)	z = 6.237*	<0.001
ALT (U/l)	52.8 (35.6–74.2)	24.9 (19.7–32.5)	z = 6.129*	<0.001
Myocardial Injury Markers				
cTnI (ng/ml)	0.041 (0.028–0.056)	0.019 (0.015–0.025)	z = 7.826*	<0.001
CK-MB (ng/ml)	7.2 ± 1.9	4.9 ± 1.3	t = 7.853	<0.001
NT-proBNP (pg/ml)	487.3 ± 112.6	263.7 ± 82.9	t = 12.614	<0.001
Platelet Parameters				
Platelet count (×10^9/l)	124.5 ± 38.2	174.6 ± 41.3	t = 6.627	<0.001
Plateletcrit (%)	0.112 ± 0.029	0.153 ± 0.032	t = 7.084	<0.001
MPV (fl)	12.1 ± 1.5	10.7 ± 1.1	t = 5.913	<0.001
PDW (%)	19.3 ± 2.4	16.4 ± 2.1	t = 6.937	<0.001

Data are mean ± SD or median (interquartile range). *Mann-Whitney U test used for non-normally distributed variables. PE, preeclampsia; AST, aspartate aminotransferase; ALT, alanine aminotransferase; cTnI, cardiac troponin I; CK-MB, creatine kinase-MB; NT-proBNP, N-terminal pro-B-type natriuretic peptide; MPV, mean platelet volume; PDW, platelet distribution width.

Figure 1. ROC curves of individual biomarkers in PE diagnosis

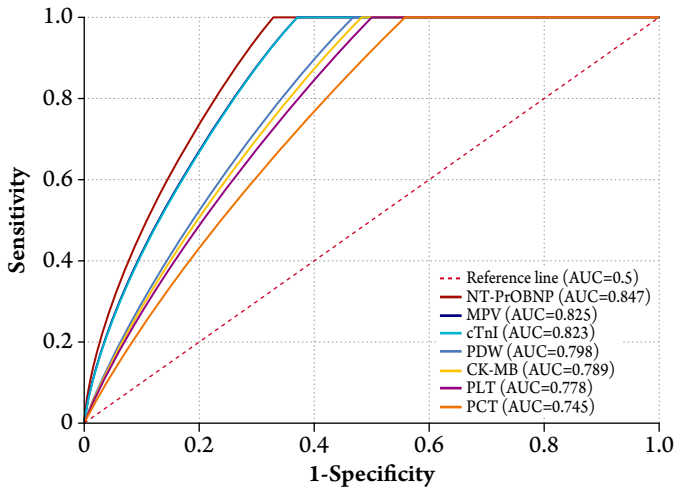
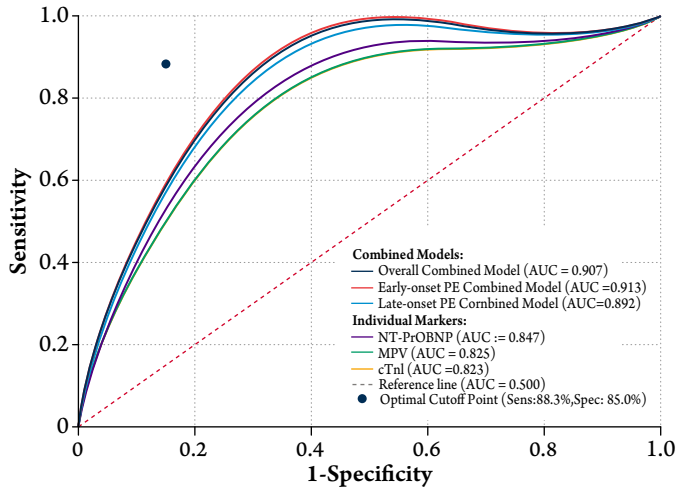


Figure 2. ROC curves showing combined biomarker model versus individual markers.



marker abnormalities (Table 2). Severe PE patients had significantly worse blood pressure control, more severe proteinuria, higher serum uric acid, and worse liver function (all p<0.001). Regarding cardiac injury markers, women with severe PE had significantly higher values of all three indicators compared with the mild PE group (all p<0.001). Severe PE patients also had more pronounced platelet abnormalities as manifested by significantly decreased platelet count and plateletcrit, while MPV and PDW were significantly elevated (all p<0.001).

Diagnostic performance of individual markers

ROC curve analysis of individual biomarkers showed their varying diagnostic performance (Figure 1). ROC curves of individual biomarkers in PE diagnosis show different diagnostic performances, with NT-proBNP showing the highest diagnostic value among cardiac injury markers (AUC=0.847), followed by cTnI (AUC=0.823) and CK-MB (AUC=0.789), while among platelet parameters, MPV performed best (AUC=0.825), followed by PDW (AUC=0.798) and platelet count (AUC=0.778). Notably, the combined detection model, developed using logistic regression analysis incorporating all three cardiac injury markers (cTnI, CK-MB, NT-proBNP) and four platelet parameters (platelet count, MPV, PDW, PCT), showed superior diagnostic efficacy compared that of any individual marker (AUC=0.907) (Figure 2). This was evident from higher sensitivity (88.3%) and specificity (85.0%), thus demonstrating excellent performance in both early-onset and late-onset PE.

Diagnostic performance of combined detection

The combined detection model incorporating all three cardiac injury markers and four platelet parameters showed superior diagnostic performance compared with any individual marker (all p<0.05; Figure 2). This combined model achieved good sensitivity and specificity, as well as positive and negative predictive values at the optimal cutoff point. Subgroup analysis showed that the combined model maintained high diagnostic efficacy in both early-onset and late-onset PE (Figure 2). Comparison of the ROC curves between the combined biomarker model and individual markers in PE diagnosis illustrated the superior diagnostic performance of the comprehensive approach, achieving excellent AUC 0.907 (95% CI: 0.867–0.947), sensitivity 88.3%, and specificity of 85.0% at the optimal cutoff point. This combined model incorporating three cardiac injury markers and four platelet parameters significantly outperformed even the best individual biomarkers (NT-proBNP, AUC=0.847; MPV, AUC=0.825) and maintained excellent diagnostic efficacy in both early-onset (AUC=0.913) and late-onset (AUC=0.892) PE subgroups.

Correlation with disease severity markers

Cardiac injury markers and platelet parameters showed significant correlations with clinical markers of PE severity (Figure 3). Scatter plots showed significant positive correlations between biomarkers and PE severity indicators, with NT-proBNP showing relatively high correlations with systolic blood pressure (r=0.674, p<0.001) and proteinuria (r=0.618, p<0.001), followed by moderate correlations of MPV with the same clinical parameters (r=0.563 and r=0.541, respectively). These relationships highlight the potential clinical utility of cardiac injury markers and platelet parameters in assessing PE severity, indicating their value for risk stratification in clinical practice. Among platelet parameters, MPV showed notable correlations with systolic blood pressure and proteinuria. Statistical comparison of correlation coefficients using Fisher's Z-transformation confirmed that NT-proBNP demonstrated significantly stronger correlations with both clinical parameters compared to other biomarkers (all p<0.05).

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Figure 3. Correlation between biomarkers and PE severity markers

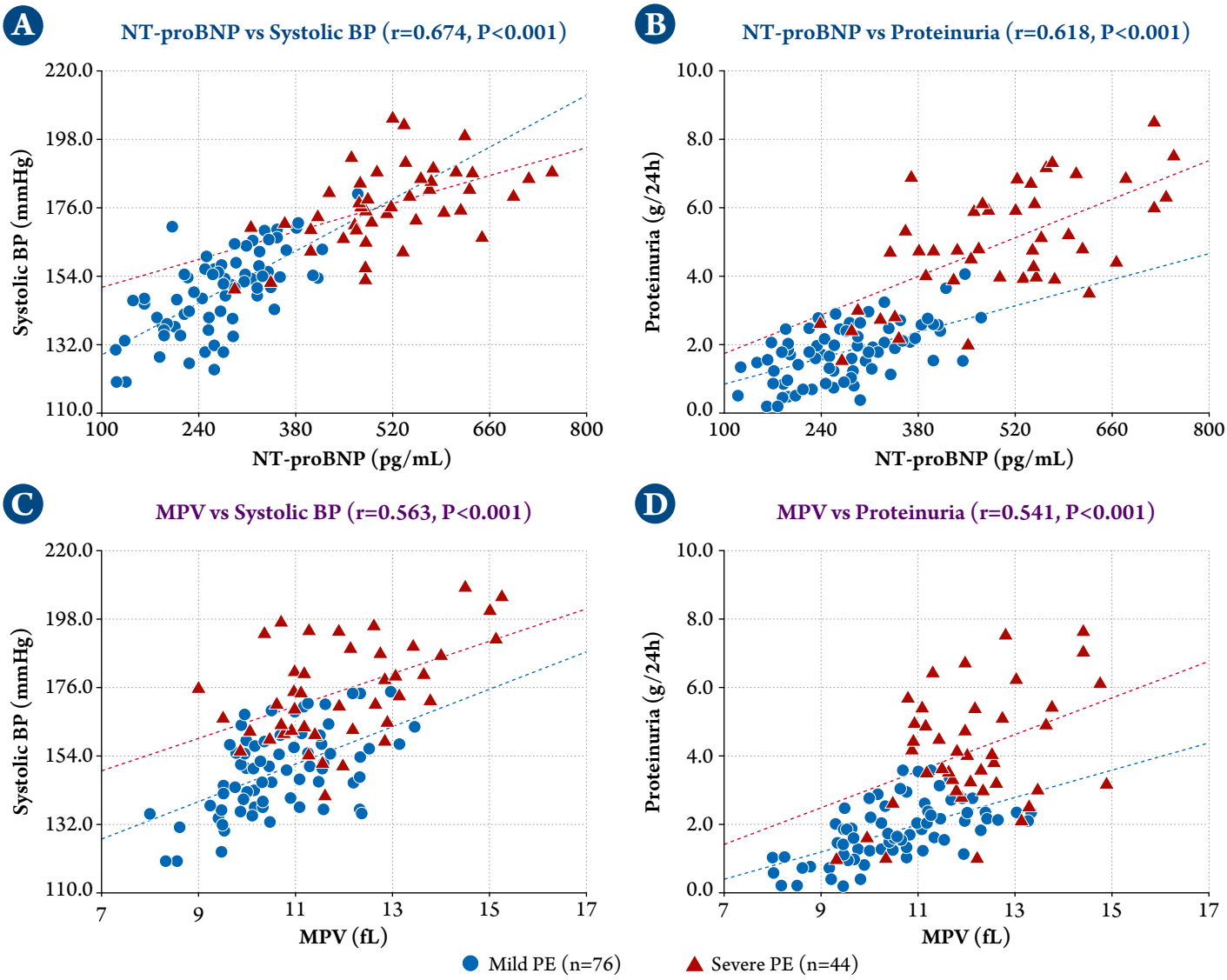


Figure 4. Forest plot of multivariate analysis for severe PE predictors

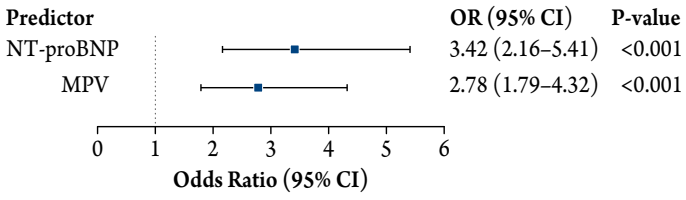
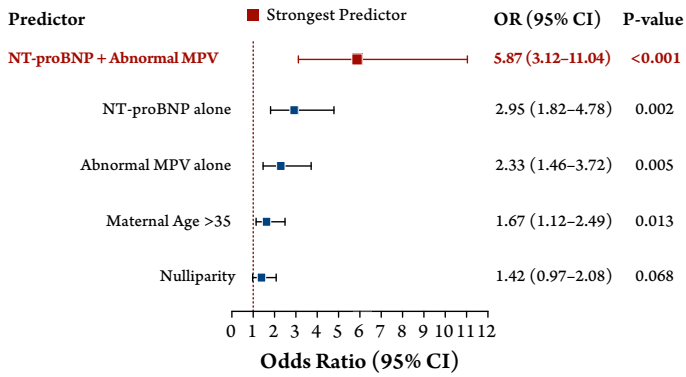


Figure 5. Forest plot: Predictors of composite maternal adverse outcomes in PE



Multivariate analysis identified NT-proBNP and MPV as independent predictors of severe PE (Figure 4). The forest plot shows NT-proBNP and MPV as independent predictors of severe PE, with NT-proBNP having an adjusted odds ratio of 3.42 (95% CI: 2.16–5.41, p<0.001) and MPV having an adjusted odds ratio of 2.78 (95% CI: 1.79–4.32, p<0.001). Neither confidence intervals crossed the reference line (OR=1), indicating their statistically significant role in predicting severe PE.

Association with maternal complications

Women with both elevated cardiac injury markers (above 75th percentile) and with abnormal platelet parameters had significantly higher rates of maternal complications compared with women with normal biomarkers (all p<0.001).

Table 3. Comparison of maternal complications between abnormal and normal biomarker groups.

Complication	Abnormal Biomarkers (%)	Normal Biomarkers (%)	p-Value	Risk Ratio	Absolute Risk Difference (%)	NNH
Eclampsia	13.6	1.2	<0.001	11.33	12.4	8
HELLP Syndrome	22.7	3.5	<0.001	6.49	19.2	5
Pulmonary Edema	9.1	0	0.002	∞	9.1	11
Maternal ICU Admission	31.8	5.8	<0.001	5.48	26.0	4
Severe Hypertension	78.3	45.2	<0.001	1.73	33.1	3
Acute Kidney Injury	17.2	3.8	<0.001	4.53	13.4	8
Placental Abruption	12.5	2.3	0.003	5.43	10.2	10
Thrombocytopenia	42.9	11.7	<0.001	3.67	31.2	4
Liver Dysfunction	35.4	8.2	<0.001	4.32	27.2	–

HELLP, hemolysis, elevated liver enzymes, low platelet count syndrome; ICU, intensive care unit; NNH, number needed to harm (the number of patients who need to be exposed to a risk factor for one additional patient to be harmed compared to those not exposed to the risk factor). Abnormal biomarkers were defined as cardiac injury markers above the 75th percentile and abnormal platelet parameters. Risk ratio represents the ratio of the probability of an event occurring in the abnormal biomarker group versus the normal biomarker group. Absolute risk difference represents the difference in event rates between the two groups expressed as a percentage.

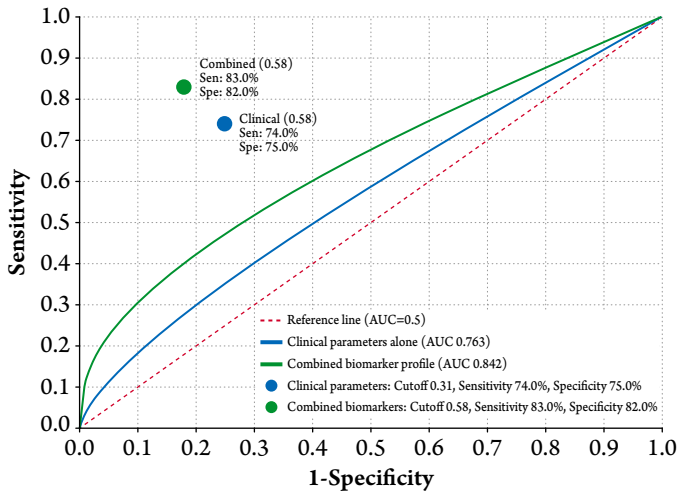
The combined abnormal biomarker group showed higher incidence rates for various severe complications (all p<0.001; Table 3).

Multivariate logistic regression identified the combination of elevated NT-proBNP and abnormal MPV as the strongest predictor of composite maternal adverse outcomes, suggesting these biomarkers may serve as valuable early warning indicators for the development of severe PE complications requiring prompt intervention (Figure 5). The forest plot illustrates multiple risk factors for predicting adverse pregnancy outcomes in women with PE, with the combination of NT-proBNP and abnormal MPV being the strongest predictor (adjusted odds ratio 5.87, 95% confidence interval: 3.12–11.04, p<0.001). This biomarker combination is highlighted in red in the figure, showing that its predictive value was significantly higher than other potential predictors, such as NT-proBNP alone, abnormal MPV alone, maternal age >35 years, and primiparity.

Association with fetal/neonatal outcomes

Elevated cardiac injury markers and abnormal platelet parameters were also associated with adverse fetal/neonatal outcomes. Women with elevations in both marker types had higher incidence rates for multiple adverse neonatal outcomes. The combined biomarker profile showed better predictive value for adverse neonatal outcomes than clinical parameters alone (Figure 6). The combined biomarker profile (AUC=0.842, 95% CI: 0.787–0.897) significantly outperformed clinical parameters alone (AUC=0.763, 95% CI: 0.698–0.828, p=0.014) in predicting adverse neonatal outcomes in pregnant women with PE. At the optimal cutoff point, the combined approach achieved superior sensitivity (83.0% vs. 74.0%) and specificity (82.0% vs. 75.0%), highlighting its potential clinical utility in identifying high-risk pregnancies requiring intensive monitoring and management.

Figure 6. ROC curves showing predictive value for adverse neonatal outcomes



Performance of a risk stratification model

Based on multivariate logistic regression analysis, the final model included four variables: NT-proBNP (β=1.847, OR=6.34, 95% CI: 3.21–12.53, p<0.001), MPV (β=1.265, OR=3.54, 95% CI: 2.18–5.75, p<0.001), platelet count (β=–0.892, OR=0.41, 95% CI: 0.24–0.69, p=0.001), and CK-MB (β=0.734, OR=2.08, 95% CI: 1.33–3.26, p=0.001). The risk scoring formula was Risk score = 1.847×NT-proBNP (standardized value) + 1.265×MPV (standardized value) – 0.892 × platelet count (standardized value) + 0.734 × CK-MB (standardized value).

Based on tertile cutoff values of the risk scores (<2.5 for low-risk, 2.5–4.8 for moderate-risk, >4.8 for high-risk), 120 PE patients were stratified into low-risk (n=41, 34.2%), moderate-risk (n=39, 32.5%), and high-risk (n=40, 33.3%) groups.

Clinical outcomes differed significantly among the three risk groups. The incidence of maternal complications in the high-risk group was 72.5% (29/40), significantly high-

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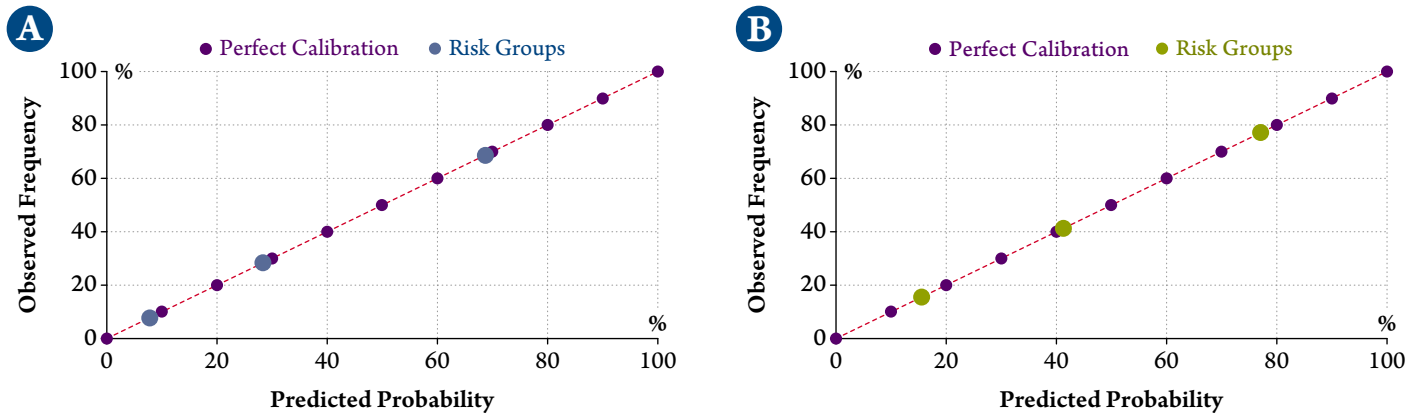
Figure 7. Calibration curves for PE risk stratification model



Panel A: Maternal complications. **Panel B**: Neonatal adverse outcomes.

er than in the moderate-risk group 35.9% (14/39), and in the low-risk group 7.3% (3/41) (p<0.001). The incidence of adverse neonatal outcomes in the high-risk group was 70.0% (28/40), significantly higher than in the moderate-risk group 28.2% (11/39) and low-risk group 4.9% (2/41) (p<0.001). Blood pressure values, proteinuria severity, and hepatic and renal function indicators all showed clear risk gradient distributions among the risk groups (all p<0.001).

The Hosmer-Lemeshow goodness-of-fit test demonstrated good model calibration. For predicting maternal complications: χ^2=5.23, df=8, p=0.731; for predicting neonatal adverse outcomes: χ^2=6.47, df=8, p=0.595. Calibration curves showed high concordance between predicted and actual probabilities, closely approximating the ideal 45° diagonal line (Figure 7). Bootstrap internal validation (1000 resamples) showed calibration intercepts close to 0 (maternal complications: – 0.024, neonatal adverse outcomes: – 0.018) and calibration slopes close to 1 (maternal complications: 0.987, neonatal adverse outcomes: 0.992), indicating stable model calibration.

The risk stratification model showed excellent performance in distinguishing adverse outcomes. The AUC for predicting maternal complications was 0.895 (95% CI: 0.854–0.936), with sensitivity of 82.6% and specificity of 89.3%. The AUC for predicting neonatal adverse outcomes was 0.887 (95% CI: 0.844–0.930), with sensitivity of 80.5% and specificity of 88.8%. Bootstrap-corrected AUCs were 0.889 and 0.881, respectively, demonstrating good internal consistency of the model.

Compared with the basic model containing only traditional clinical risk factors (maternal age, body mass index, systolic blood pressure, diastolic blood pressure, proteinuria), the risk stratification model incorporating biomarkers significantly improved predictive performance. For predicting maternal complications, NRI was 0.423 (95% CI: 0.287–0.559, p<0.001), indicating that the new model could correctly reclassify 42.3% of patients; IDI was 0.186 (95% CI: 0.124–0.248, p<0.001), indicating an 18.6% improvement in discriminative ability compared to the basic model. For predicting neonatal adverse outcomes, NRI was 0.401 (95% CI: 0.265–0.537, p<0.001), and IDI was 0.172 (95% CI: 0.115–0.229, p<0.001).

Ten-fold cross-validation demonstrated good generalizability of the model, with mean AUCs of 0.884±0.032 (maternal complications) and 0.878±0.028 (neonatal adverse outcomes). Sensitivity analysis showed that model performance remained stable (all AUCs >0.85) when excluding extreme values, using different cutoff points for grouping, or in different subgroups (early-onset vs. late-onset PE, primiparous vs. multiparous), demonstrating the robustness and clinical utility of the risk stratification model.

Discussion

This study systematically evaluated the clinical value of combined measurement of cardiac injury markers and platelet parameters in PE diagnosis and prognosis assessment. The study revealed that the combined detection model demonstrated excellent performance in PE diagnosis, with an AUC of 0.907, significantly superior to the diagnostic efficacy of any single marker. More importantly, we further discovered that this combined detection approach not only improved diagnostic accuracy but also demonstrated superior performance in disease severity stratification and prognostic prediction. This result is consistent with previous evidence of limited diagnostic efficacy of single biomarkers [9]. Specifically, our data indicated that the combination of elevated NT-proBNP and abnormal MPV was the strongest predictor of severe PE complications (adjusted OR=5.87), providing clinicians with a powerful tool for identifying high-risk patients. Thus, the results of the present study emphasize the important value of multiple biomarkers in detection of PE and in improving diagnostic accuracy.

The significant elevation of cardiac injury markers in PE patients reflects the severe impact of this disease on the car-

diovascular system. This study found that NT-proBNP showed the highest diagnostic value among cardiac injury markers (AUC=0.847), which is consistent with recent research results, and confirming the important role of NT-proBNP as a sensitive indicator that reflects cardiac function status and increased volume load in PE [10]. The elevation of the cTnI and CK-MB values further confirmed the presence of myocardial cell damage in PE patients, which is likely related to disease-associated vascular endothelial dysfunction, microvascular lesions, and increased cardiac load.

The abnormal changes in platelet parameters also have important clinical significance. This study observed that MPV and PDW were significantly elevated in PE patients, while platelet count and PCT were markedly decreased, reflecting the pathological processes of increased platelet activation and consumption [11]. Elevation of MPV, as an indicator of platelet volume size, usually suggests enhanced platelet activation and increased thrombosis risk, which is closely related to coagulation dysfunction and microvascular lesions in PE [12]. Studies have shown that changes in platelet parameters may precede abnormalities in traditional coagulation indicators, thus having potential value in early detection of PE [13].

The risk stratification model established in this study demonstrated good clinical utility. By incorporating four key variables, NT-proBNP, MPV, platelet count, and CK-MB, this model could effectively distinguish among PE patients with different risk levels. The incidence of maternal complications in the high-risk group reached 72.5%, and the incidence of adverse neonatal outcomes was 70.0%, significantly higher than the moderate and low-risk groups. This new information, has important significance for guiding clinical decision-making and resource allocation [14]. The good calibration and stability of the model further support its application in clinical practice [15].

Correlation analysis between biomarkers and disease severity revealed important pathophysiological connections. The strong correlation of NT-proBNP with systolic blood pressure and proteinuria (r=0.674 and r=0.618) shows that the degree of cardiac function impairment is closely related to disease severity [16]. This correlation may reflect the pathological processes of increased circulating blood volume, increased cardiac preload, and elevated ventricular wall tension in PE patients [17]. The moderate correlation of MPV with clinical severity indicators further supports the role of platelet activation in the progression of the disease [18].

The superiority of combined biomarker detection in predicting maternal complications deserves attention. This study found that patients with combined abnormalities of NT-proBNP and MPV had significantly increased risk of composite adverse maternal outcomes (OR=5.87), providing clinicians with a powerful tool for identifying high-risk patients [19]. The high incidence of severe complications, such as hemolysis, elevated liver enzymes, low platelet count (HELLP) syndrome, eclampsia, and pulmonary edema in the abnormal biomarker group, emphasizes the importance of early identification and treatment of PE [20].

In terms of neonatal outcome prediction, the combined biomarker model also performed excellently, with an AUC of 0.842, superior to traditional clinical parameters (AUC=0.763). This finding is an important reference value for obstetricians in formulating delivery timing and neonatal monitoring strategies [21]. Prediction of adverse neonatal outcomes such as preterm birth, intrauterine growth restriction, and low birth weight helps clinicians optimize perinatal management and improve maternal and neonatal prognosis [22].

Despite the positive results achieved in this study, some limitations exist. First, as a single-center retrospective study, the generalizability of results may be somewhat limited, requiring further validation through multicenter prospective studies [23]. Second, this study did not include other, emerging biomarkers, such as soluble fts-like tyrosine kinase-1/placental growth factor (sFlt-1/PlGF) ratio, that also have important value in PE diagnosis [24]. Additionally, the lack of long-term follow-up data limits an in-depth analysis and assessment of long-term cardiovascular risk [25].

Future research directions should include the expanding sample size in multi-center validation, exploring combined application of more biomarkers, establishing dynamic monitoring models to reflect disease progression, and evaluating the impact of biomarker-guided intervention strategies on clinical outcomes. With the continuous development of precision medicine concepts, comprehensive risk assessment models based on multi-omics data are expected to bring further breakthroughs in PE management.

Conclusions

This study confirmed the important value of combined measurement of cardiac injury markers and platelet parameters in PE diagnosis and risk stratification. The combined detection model not only improved diagnostic accuracy, but it also effectively predicted maternal and neonatal adverse outcomes, thus providing valuable information for clinical decision making. The established risk stratification model has good discrimination and calibration, and it is expected to be widely applicable in clinical practice. Thus, these findings provide new scientific evidence for improving management strategies and clinical outcomes for PE patients, and they point the direction for future related research.

No conflict of interest is reported.

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