Am J Transl Res 2026;18(6):4802-4812
www.ajtr.org /ISSN:1943-8141/AJTR0173124

Original Article

Predictive value of Index of Cardiac Electrophysiological Balance (ICEB) for ischemia-reperfusion injury following coronary artery angioplasty

Dexian Zhang, Ying Zhou, Lihui Ren

Department of Cardiology, Beijing Shijitan Hospital, Capital Medical University, Beijing 100038, China

Received April 7, 2026; Accepted June 1, 2026; Epub June 15, 2026; Published June 30, 2026

Abstract: Objective: To evaluate the predictive value of the Index of Cardiac Electrophysiological Balance (ICEB) for ischemia-reperfusion injury (IRI) following coronary artery angioplasty. Methods: The retrospective study analyzed data from 138 patients who underwent coronary artery angioplasty from January 2024 and December 2025. ICEB was calculated as the ratio of the QT interval to the QRS duration (QT/QRS). Patients were divided into an IRI (n = 65) and a Non-IRI (n = 73) group based on the presence or absence of clinical and laboratory evidence of IRI following the procedure. Cardiac biomarkers, electrocardiographic findings, renal function indices, coagulation values, inflammatory markers, and ICEB values were compared between the two groups. Logistic regression and receiver operating characteristic (ROC) analyses were conducted to assess the relationship between the measured indicators and the occurrence of IRI. Results: ICEB values, Troponin I, creatine kinase-MB (CK-MB) relative index, ST-segment elevation, serum creatinine, blood urea nitrogen, cystatin C, prothrombin time, D-dimer levels, fibrinogen levels, white blood cell (WBC) levels, neutrophil-to-lymphocyte ratio (NLR), and C-reactive protein (CRP) levels were significantly associated with IRI ($P < 0.05$). ROC analysis showed that ICEB and ST-segment elevation exhibited favorable sensitivity and specificity and were among the strongest predictors of IRI. Conclusion: ICEB, a non-invasive electrocardiographic marker reflecting ventricular repolarization-depolarization balance, may strongly predict IRI following coronary artery angioplasty. Assessment of ICEB may facilitate the early identification of patients at high-risk for IRI, thereby improving risk stratification and potentially guiding perioperative management to reduce IRI-related adverse outcomes.

Keywords: ICEB, predictive value, ischemia-reperfusion injury, following coronary artery angioplasty

Introduction

Coronary artery disease (CAD) remains aprimary contributor to morbidity and mortality worldwide [1, 2]. Percutaneous coronary intervention (PCI), particularly coronary artery angioplasty, has substantially improved the management and prognosis of CAD [3, 4]. However, ischemia-reperfusion injury (IRI) remains a significant complication of PCI, contributing to adverse clinical outcomes [5, 6].

IRI is a well-documented pathologic process that may occur during or after PCI, particularly following coronary artery angioplasty [7, 8]. According to the American College of Cardiology, IRI remains a major clinical challenge in patients undergoing coronary artery angioplasty, affecting approximately 20% to 40% of patients [9]. This occurrence of IRI is associated with increased morbidity and mortality, contributing to unfavorable clinical outcomes after the procedure [10]. Hence, identification of reliable predictors capable of recognizing patients at high risk for IRI following coronary artery angioplasty is of considerable clinical importance [11].

The Index of Cardiac Electrophysiological Balance (ICEB), calculated as the ratio of the QT interval to the QRS duration (QT/QRS), has been increasingly recognized as a novel electrocardiographic marker. ICEB reflects the equilibrium between cardiac repolarization and depolarization and provides insight into myocardial electrophysiological status [12, 13]. Previous stud-

https://doi.org/10.62347/ETYD5477

ies have indicated that alterations in cardiac electrophysiological balance, as reflected by ICEB, may increase myocardial susceptibility to IRI [14].

Despite advancements in PCI techniques and adjunctive pharmacotherapy, the ability to predict accurately and prevent IRI following coronary artery angioplasty remains limited [15, 16]. Consequently, identifying reliable predictors of IRI is essential for improving risk stratification and optimizing patient outcome. This study aimed to investigate the predictive value of ICEB for IRI after coronary artery angioplasty, with the goal of facilitating early risk stratification, and providing evidence to support the development of targeted preventive and therapeutic strategies.

Patients and methods

Study subjects and groups

To investigate the predictive value of ICEB for IRI following coronary artery angioplasty, this retrospective study analyzed data from patients who underwent coronary artery angioplasty at Beijing Shijitan Hospital, Capital Medical University between January 2024 and December 2025. A total of 138 patients met predefined inclusion and exclusion criteria and were included in the study. Participants were divided into an IRI group (n = 65) and a non-IRI group (n = 73) according to the presence or absence of clinical and laboratory evidence of IRI.

Case selection and ethical declaration

Inclusion criteria: Patients who underwent coronary artery angioplasty; aged > 18 years; and with complete clinical and laboratory data available.

Exclusion criteria: Patients with bleeding disorders or a predisposition to bleeding; those with chronic heart failure of New York Heart Association (NYHA) functional classification > II; patients who experienced sudden cardiac arrest or cardiogenic shock; and individuals with acute or chronic concomitant systemic diseases, such as infectious disease, tumors, autoimmune diseases, or severe trauma.

Ethical statement: This study was approved by the Institutional Review Board (IRB) of Beijing Shijitan Hospital, Capital Medical University. As this was a retrospective analysis using anonymized medical records without additional interventions or risk to patients, the IRB determined that informed consent was not required.

All data were handled with strict confidentiality, and measures were taken to ensure the privacy and security of participant information.

ICEB

ICEB was calculated as the ratio of the QT interval to QRS duration (QT/QRS) [17]. ICEB reflects the balance between ventricular depolarization and repolarization [18]. Electrophysiologically, ICEB is considered analogous to the cardiac wavelength (λ), which is defined as the product of conduction velocity and the effective refractory period [19]. One of the key advantages of ICEB is its non-invasive nature and ease of measurement [20].

Electrocardiographic measurement

A standard 12-lead electrocardiogram (ECG) was obtained from all patients in a resting and clinically stable state before coronary artery angioplasty using a MAC 5500 HD electrocardiograph (GE Healthcare, USA). Two cardiologists, who were blinded to the group allocation, manually measured the values including QT interval, QRS duration, and PR interval. The average value of the two measurements was used for subsequent analyses. ICEB was calculated as the ratio of the QT interval to QRS duration (QT/QRS). The degree of ST-segment elevation was automatically determined using the ECG system software and subsequently confirmed by the cardiologists. The presence of T-wave inversion was also assessed and recorded for analysis.

Blood sample testing

A 5 ml venous blood sample was collected from the antecubital vein of all patients after an overnight fast on the morning of the procedure.

(1) Cardiac biomarkers: After centrifugation, Troponin I levels were measured using a chemiluminescent immunoassay analyzer (ADVIA Centaur XP, Siemens Healthineers, Germany). Creatine Kinase-MB (CK-MB) activity was assessed using an automated biochemical ana-

lyzer (Cobas c 503, Roche Diagnostics, Switzerland), and the CK-MB Relative Index was calculated. N-terminal pro-brain natriuretic peptide (NT-proBNP) was quantified using an electrochemiluminescence immunoassay on a Cobas e 601 analyzer (Roche Diagnostics, Switzerland). Myoglobin and Ischemia Modified Albumin (IMA) levels were determined using a colorimetric method and an albumin-cobalt binding test, respectively, on the Cobas c 503 analyzer.

(2) Renal function markers: Serum creatinine, blood urea nitrogen (BUN), and cystatin C were measured using the automated biochemical analyzer (Cobas c 503, Roche Diagnostics, Switzerland). The estimated glomerular filtration rate (eGFR) was calculated using the CKD-EPI formula.

(3) Coagulation values: Blood samples were collected into citrate-anticoagulated tubes, gently inverted for mixing, and analyzed within 2 hours using a fully automated coagulation analyzer (CS-5100, Sysmex Corporation, Japan) to determine prothrombin time (PT), activated partial thromboplastin time (APTT), fibrinogen, and D-dimer levels.

(4) Inflammatory markers: White blood cell count (WBC) was determined using an automated hematology analyzer (DxH 800, Beckman Coulter, USA). The differential WBC count was used to calculate the neutrophil-to-lymphocyte ratio (NLR). C-reactive protein (CRP) levels were measured using an immunoturbidimetric assay on the automated biochemical analyzer (Cobas c 503, Roche Diagnostics, Switzerland).

Statistical analysis

Statistical analyses were performed using SPSS 29.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics were used to summarize the baseline characteristics, cardiac biomarkers, electrocardiographic findings, renal function indices, coagulation values, inflammatory markers, and ICEB values of the study participants. Continuous variables were reported as means ± standard deviations (SD), whereas categorical variables were summarized as frequencies and percentages.

Inter-group comparisons for continuous variables were conducted using t-tests, and chi-square tests were employed for categorical variables. Correlation analysis and logistic regression analysis were conducted to assess the relationship between the investigated variables and IRI occurrence following coronary artery angioplasty. Receiver operating characteristic (ROC) curve analysis was performed to assess the predictive performance of the indicators, and the area under the curve (AUC) was calculated to determine their discriminatory ability. A two-sided P value < 0.05 was considered significant.

Results

Baseline characteristics

No significant differences were observed between the IRI and non-IRI groups in terms of age (60.23±5.37 vs. 59.81±4.79, P = 0.628), gender distribution, BMI (26.12±2.55 vs. 25.84±2.39, P = 0.498), smoking status, hypertension, diabetes, hyperlipidemia, previous MI, previous PCI, or previous CABG (all P > 0.05). These findings indicate that the baseline characteristics were comparable between the two groups, thereby minimizing potential confounding effects in the subsequent analyses (**Table 1**).

Cardiac biomarkers levels

Comparison of cardiac biomarkers between the IRI and Non-IRI groups presented in (**Figure 1**). Patients in the IRI group exhibited significantly higher Troponin I levels (2.92±1.13 ng/mL vs. 2.12±0.98 ng/mL, P < 0.001) and CK-MB Relative Index values (3.85±0.83 vs. 3.08±0.79, P < 0.001) than those in the non-IRI group. However, no significant differences were observed between the two groups in CK-MB, NT-proBNP, myoglobin, or IMA levels (all P > 0.05).

Electrocardiographic findings

ECG values were compared between patients with and without IRI (**Figure 2**). Compared to the Non-IRI group, patients in the IRI group exhibited significantly higher ST-segment elevation (3.78±0.97 mm vs. 2.18±0.72 mm, P < 0.001), longer QRS duration (100.25±15.34 ms vs. 92.74±13.23 ms, P = 0.003), prolonged PR interval (165.89±20.79 ms vs. 155.58±18.49 ms, P = 0.003), prolonged QT interval

Table 1. Baseline characteristics of study population

Item	IRI group (n = 65)	Non-IRI group (n = 73)	t/x^2	*p* Value
Age (years)	60.23±5.37	59.81±4.79	0.485	0.628
Gender (M/F)	40/25	44/29	0.023	0.879
Body Mass Index (kg/m^2)	26.12±2.55	25.84±2.39	0.680	0.498
Smoking [n (%)]	24 (36.9%)	28 (38.4%)	0.03	0.862
Hypertension [n (%)]	32 (49.2%)	34 (46.6%)	0.020	0.888
Diabetes [n (%)]	18 (27.7%)	20 (27.4%)	0.002	0.969
Hyperlipidemia [n (%)]	28 (43.1%)	30 (41.1%)	0.004	0.95
Previous MI [n (%)]	12 (18.5%)	10 (13.7%)	0.281	0.596
Previous PCI [n (%)]	8 (12.3%)	7 (9.6%)	0.057	0.812
Previous CABG [n (%)]	5 (7.7%)	4 (5.5%)	0.032	0.857

MI: Myocardial Infarction; PCI: Percutaneous Coronary Intervention; CABG: Coronary Artery Bypass Grafting.

(400.69±30.34 ms vs. 380.98±25.79 ms, P < 0.001), and increased ICEB (QT/QRS) value (4.92±0.83 vs. 3.21±0.64, P < 0.001). No significant difference was observed in T-wave inversion between the two groups (35.55±5.78% vs. 34.46±6.38%, P = 0.296).

Renal function markers

Comparisons of renal function markers between the IRI and non-IRI groups are shown in **Table 2**. The IRI group demonstrated significantly higher mean serum creatinine levels than the non-IRI group (1.77±0.23 mg/dL vs. 1.49±0.35 mg/dL; t = 5.573, P < 0.001). Similar trends were observed in the levels of BUN (26.65±5.32 mg/dL vs. 22.18±4.67 mg/dL; t = 5.212, P < 0.001). Cystatin C levels were also significantly higher in patients with IRI than in those without IRI (1.08±0.27 mg/L vs. 0.96±0.15 mg/L, *t* = 3.097, *P* = 0.003). In contrast, no significant differences were observed between the two groups in terms of eGFR (P = 0.081).

Coagulation values

A comparative analysis of coagulation values between the IRI and non-IRI groups is shown in **Figure 3**. Patients in the IRI group demonstrated a significantly prolonged PT (12.57±1.09 s vs. 12.09±0.81 s, P = 0.004), elevated D-dimer levels (0.69±0.24 mg/L vs. 0.58±0.15 mg/L, P = 0.002) and fibrinogen levels (3.58±0.52 g/L vs. 3.27±0.43 g/L, P < 0.001) compared to the non-IRI group. However, no significant difference in APTT was noted between the two groups (30.12±2.59 s vs. 29.56±2.07 s, P = 0.165).

Inflammatory marker levels

A comparison of inflammatory markers between the two groups is shown in **Table 3**. The IRI group exhibited significantly higher WBC counts (9.22±2.01 × 10^9/L vs. 7.85±1.82 × 10^9/L, P < 0.001), NLR (5.21±1.87 vs. 3.85±1.42, P < 0.001), and CRP levels (12.38±4.24 mg/L vs. 8.92±2.67 mg/L, P < 0.001) compared to the non-IRI group.

Correlation analysis

As shown in **Table 4**, correlation analysis revealed significant associations between various indicators and the occurrence of IRI following coronary artery angioplasty. Noteworthy positive correlations were observed for troponin I (r = 0.354, R^2 = 0.125), CK-MB Relative Index (r = 0.434, R^2 = 0.188), ST-segment elevation (r = 0.688, R^2 = 0.473), QRS duration (r = 0.256, R^2 = 0.065), PR interval (r = 0.256, R^2 = 0.065), QT interval (r = 0.333, R^2 = 0.111), ICEB (QT/QRS) (r = 0.76, R^2 = 0.577), serum creatinine (r = 0.436, R^2 = 0.19), BUN (r = 0.411, R^2 = 0.169), Cystatin C (r = 0.264, R^2 = 0.07), PT (r = 0.245, R^2 = 0.06), D-dimer levels (r = 0.269, R^2 = 0.073), Fibrinogen levels (r = 0.316, R^2 = 0.1), WBC (r = 0.521, R^2 = 0.271), NLR (r = 0.598, R^2 = 0.358), and CRP (r = 0.563, R^2 = 0.317) (all P < 0.05). These findings emphasize the potential value of these indicators for predicting the risk of IRI following coronary angioplasty.

Logistic regression analysis

The results of the logistic regression analysis are summarized in **Table 5**. Among the evaluated indicators, ICEB (QT/QRS) showed the strongest association with IRI (coef = 3.087, odds ratio [OR] = 21.903, BIC = 90.413), followed by ST-segment elevation (coef = 2.430, OR = 11.358, BIC = 111.879) and D-dimer levels (coef = 2.885, OR = 17.890, BIC = 190.267). Troponin I (coef = 0.714, OR = 2.042, BIC = 158.235), CK-MB Relative Index (coef = 1.184, OR = 3.268, BIC = 142.279), and cystatin C (coef = 2.576, OR = 13.150, BIC = 190.731)

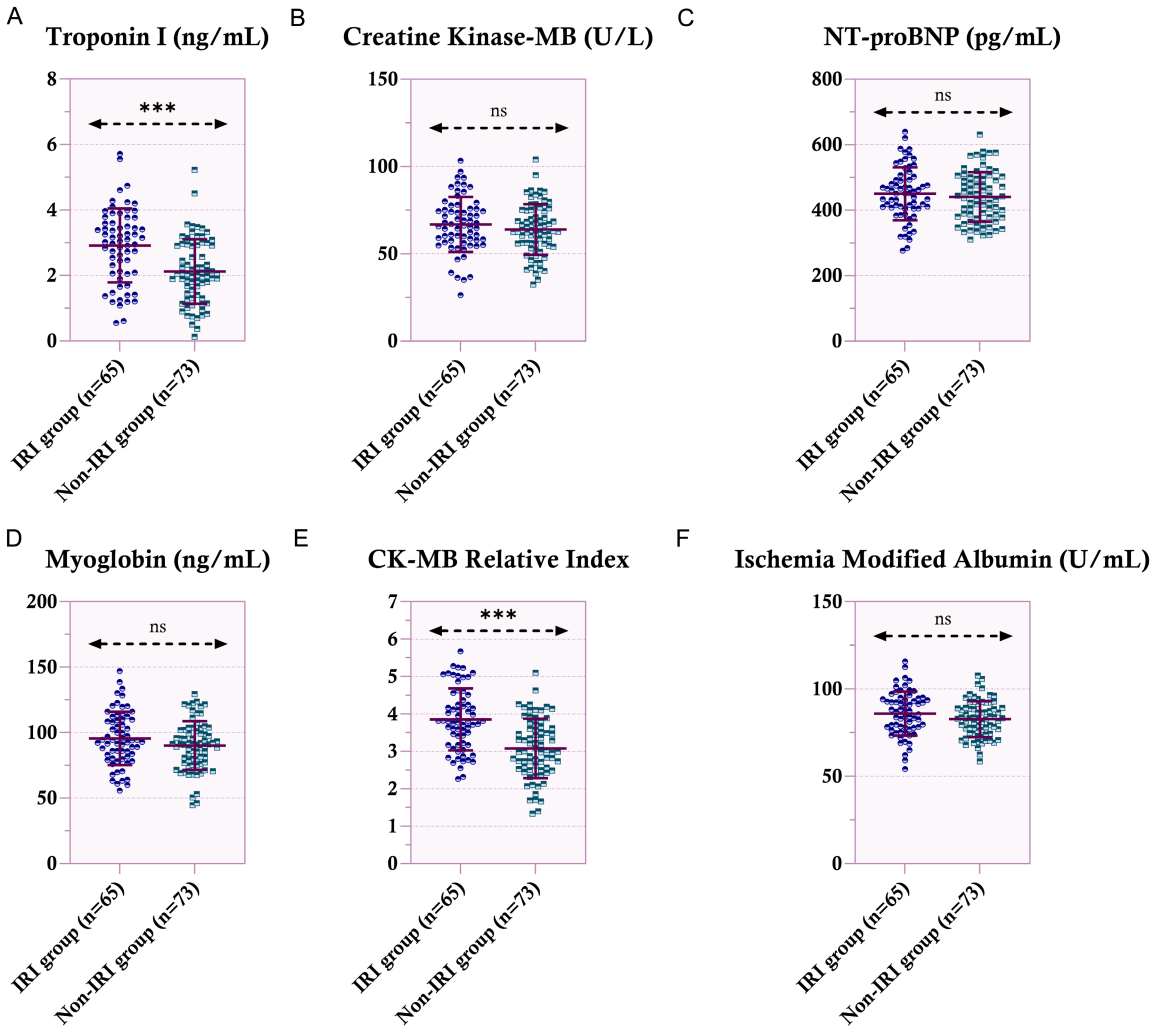

Figure 1. Comparison of cardiac biomarkers between the IRI and non-IRI groups. A: Troponin I (ng/mL); B: Creatine Kinase-MB (U/L); C: NT-proBNP (pg/mL); D: Myoglobin (ng/mL); E: CK-MB Relative Index; F: Ischemia Modified Albumin (U/mL). NT-proBNP: N-terminal pro-brain natriuretic peptide; CK-MB: Creatine Kinase-MB. ns: no significant difference; ***: $P < 0.001$.

were also strongly associated with IRI. In addition, QRS duration, PR interval, QT interval, BUN, PT, fibrinogen levels, WBC, NLR, and CRP were significantly associated with IRI (all $P < 0.05$). Serum creatinine was also a significant risk factor (coef = 0.527, OR = 1.694, BIC = 172.075, $P < 0.001$), consistent with its higher levels in the IRI group.

ROC

The predictive performance of the indicators for IRI after coronary artery angioplasty was assessed using an ROC analysis (**Table 6**). The indicators illustrated varying sensitivities and specificities. ST-segment elevation demonstrated excellent predictive performance, with a sensitivity of 0.89, a specificity of 0.8, an AUC of 0.907, and a Youden index of 0.69. Other ICEB (QT/QRS) showed the highest sensitivity (0.932), with a specificity of 0.831, an AUC of 0.944, and a Youden index of 0.763.

Other indicators, including Troponin I, CK-MB Relative Index, QRS duration, PR interval, QT interval, serum creatinine, BUN, cystatin C, PT, D-dimer levels, fibrinogen levels, WBC count, NLR, and CRP levels exhibited varying degrees of predictive performance. However, their AUC values were lower than those of ST-segment elevation and ICEB (QT/QRS).

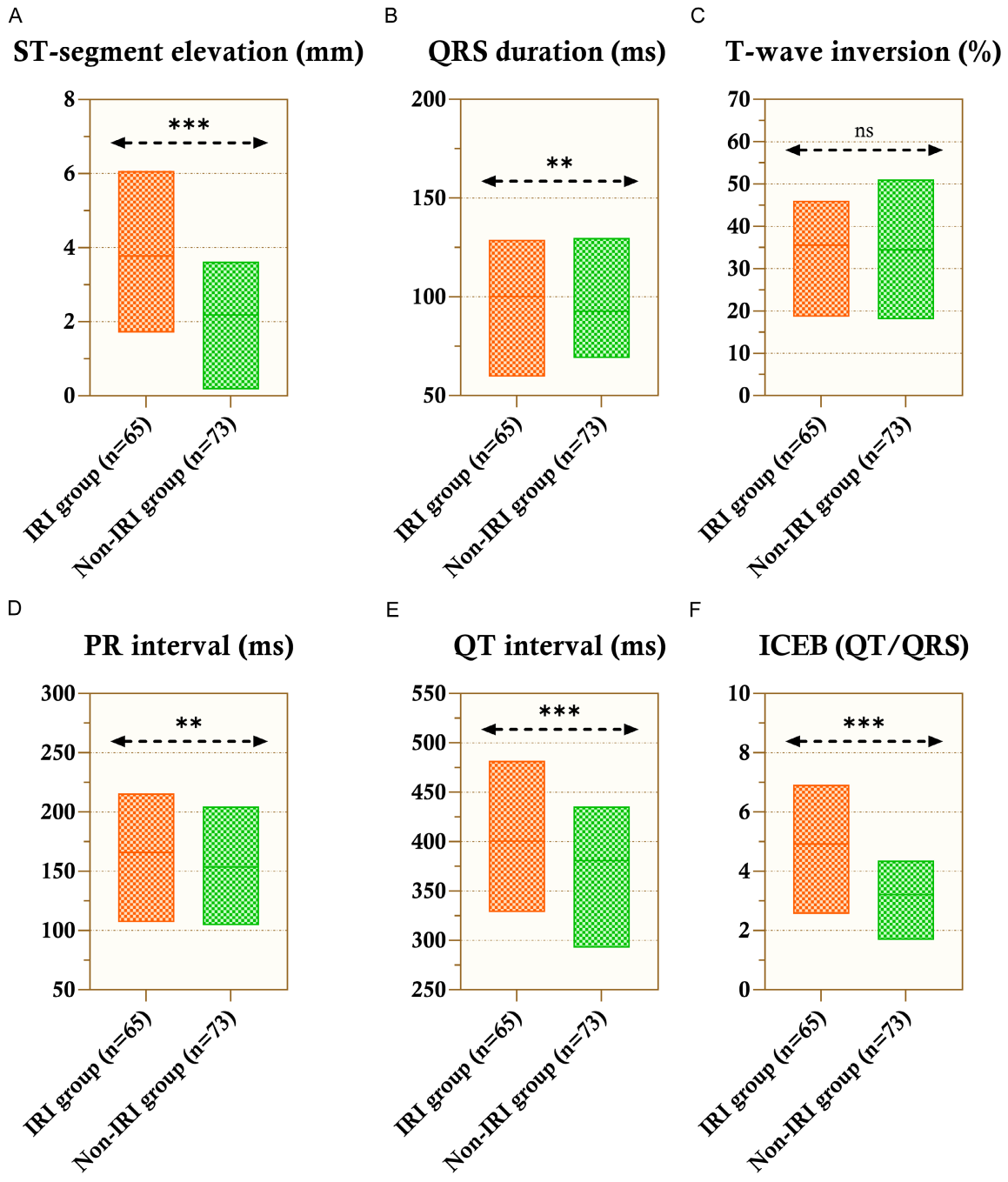

Figure 2. Comparison of ECG findings between the IRI and non-IRI groups. A: ST-segment elevation (mm); B: QRS duration (ms); C: T-wave inversion (%); D: PR interval (ms); E: QT interval (ms); F: ICEB (QT/QRS). ECG: Electrocardiogram; ICEB: Index of Cardiac Electrophysiological Balance. ns: no significant difference; **: $P < 0.01$; ***: $P < 0.001$.

Discussion

The present study highlights the potential use of the ICEB as a predictive marker for IRI following coronary artery angioplasty. IRI remains a significant complication in the context of PCI, contributing to adverse clinical outcomes [21]. Identification of reliable predictive markers for IRI is essential for risk stratification and reduction, guiding tailored interventions [22].

Table 2. Comparison of renal function indexes between the two groups

Values	IRI group (n = 65)	Non-IRI group (n = 73)	t	*p*-value
Serum creatinine (mg/dL)	1.77±0.23	1.49±0.35	5.573	P < 0.001
Blood urea nitrogen (mg/dL)	26.65±5.32	22.18±4.67	5.212	P < 0.001
Glomerular filtration rate (mL/min/1.73 m^2)	91.22±15.41	95.23±10.62	1.759	0.081
Cystatin C (mg/L)	1.08±0.27	0.96±0.15	3.097	0.003

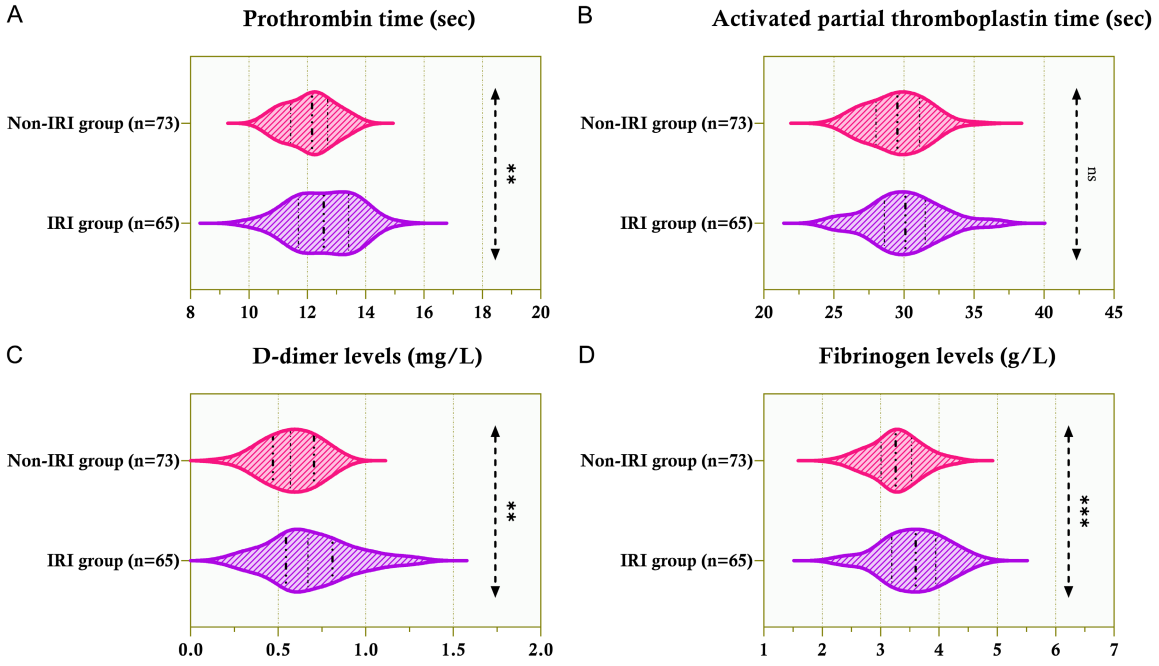

Figure 3. Comparison of coagulation values between the IRI and non-IRI groups. A: Prothrombin time (sec); B: Activated partial thromboplastin time (sec); C: D-dimer levels (mg/L); D: Fibrinogen levels (g/L). ns: no significant difference; **: P < 0.01; ***: P < 0.001.

Table 3. Comparison of inflammatory markers between the two groups

Values	IRI group (n = 65)	Non-IRI group (n = 73)	t	*p*-value
WBC (×10^9/L)	9.22±2.01	7.85±1.82	4.182	P < 0.001
NLR	5.21±1.87	3.85±1.42	4.779	P < 0.001
CRP (mg/L)	12.38±4.24	8.92±2.67	5.667	P < 0.001

WBC: White Blood Cell count; NLR: Neutrophil-to-Lymphocyte Ratio; CRP: C-Reactive Protein.

In this study, ICEB, calculated as QT/QRS from a standard 12-lead ECG, was proven to be a valuable non-invasive indicator reflecting ventricular electrical stability. A higher ICEB value suggested a relative prolongation of repolarization compared to depolarization, which may predispose the myocardium to arrhythmias and increased myocardial vulnerability to reperfusion injury [23, 24]. These findings support the use of ICEB, a marker of the balance between cardiac repolarization and depolarization, for early identification of patients at high risk of IRI.

Our results revealed a cluster of predictors that held significant associations with IRI. Among these, ICEB demonstrated the strongest predictive capability, with the highest sensitivity and specificity by ROC analysis. This finding underscores the potential of ICEB as an effective and accessible tool for pre-procedural risk stratification in patients undergoing coronary artery angioplasty [25].

In addition to ICEB, we also assessed other clinical findings, including cardiac biomarkers, renal function markers, coagulation values, electrocardiographic findings, and inflammato-

Table 4. Correlation analysis of investigated indicators and IRI occurrence

Values	r	R^2	P
Troponin I	0.354	0.125	P < 0.001
CK-MB Relative Index	0.434	0.188	P < 0.001
ST-segment elevation	0.688	0.473	P < 0.001
QRS duration	0.256	0.065	0.002
PR interval	0.256	0.065	0.002
QT interval	0.333	0.111	P < 0.001
ICEB (QT/QRS)	0.76	0.577	P < 0.001
Serum creatinine	0.436	0.19	P < 0.001
Blood urea nitrogen	0.411	0.169	P < 0.001
Cystatin C	0.264	0.07	0.002
Prothrombin time	0.245	0.06	0.004
D-dimer levels	0.269	0.073	0.001
Fibrinogen levels	0.316	0.1	P < 0.001
WBC	0.521	0.271	P < 0.001
NLR	0.598	0.358	P < 0.001
CRP	0.563	0.317	P < 0.001

CK-MB: Creatine Kinase-MB; ICEB: Index of Cardiac Electrophysiological Balance; WBC: White Blood Cell count; NLR: Neutrophil-to-Lymphocyte Ratio; CRP: C-Reactive Protein.

ry markers. Troponin I and CK-MB Relative Index levels were significantly elevated in patients of the IRI group, confirming their potential role as specific biomarkers for post-angioplasty IRI. Renal function biomarkers, including serum creatinine, BUN, and cystatin C, were significantly higher in the IRI group, providing a more comprehensive characterization of the clinical profile of affected patients [26]. These findings are consistent with prior research linking renal dysfunction to adverse outcomes in patients with coronary arterial diseases [27, 28], and suggest that these renal markers may reflect the pathophysiologic processes underlying IRI. Coagulation values also played a role in IRI [29]. In our study, prothrombin time, D-dimer, and fibrinogen levels were significantly higher in the IRI group, indicating a close association between ischemia-reperfusion and the coagulation system, casting coagulation values as emerging markers to predict IRI post-angioplasty [30, 31].

ECG results revealed that ST-segment elevation, QT interval, ICEB were significantly associated with IRI. ST-segment elevation, a classical marker of myocardial ischemia, was markedly increased in the IRI group, consistent with previous reports [32]. ICEB and QT interval were also elevated, with ICEB demonstrating strong predictive value [33]. These findings suggest a relationship between ventricular electrical instability and susceptibility to IRI, echoing the concept that repolarization abnormalities may predispose the myocardium to susceptibility to IRI [34].

Furthermore, inflammatory markers were significantly elevated in the IRI group, including WBC, NLR, and CRP. This observation aligns with the well-established pathophysiology that IRI triggers a robust inflammatory cascade, characterized by neutrophil activation and pro-inflammatory cytokine release [35, 36]. In particular, NLR exhibited a strong correlation with IRI, underscoring the interplay between innate immune activation and cardiac injury following reperfusion. The incorporation of inflammatory markers provides a more holistic view of the IRI pathology, bridging electrophysiological, ischemic, and inflammatory pathways. While ICEB remains the strongest predictor, the additive value of inflammatory indices such as NLR could be explored in future multi-marker predictive models.

From a clinical perspective, incorporating ICEB assessment into pre-procedural risk evaluation offers a simple, low-cost, and reproducible approach for identifying patients at heightened risk of IRI following coronary angioplasty. Early risk stratification could facilitate personalized perioperative management, including optimization of anti-ischemic therapies and closer monitoring during reperfusion, thereby reducing the incidence and severity of IRI-associated adverse events.

Several limitations of this study should be acknowledged. First, the retrospective, single-center design may have introduced selection bias, and the relatively small sample size may limit the generalizability of our findings. Second, although we identified several independent predictors, causal relationships cannot be established because of the observational nature of the study. Third, the study population was relatively limited, and external validation was not performed. Therefore, large-scale, prospective multicenter studies are warranted to validate the predictive value of ICEB for IRI.

Table 5. Logistic regression analysis of factors associated with IRI after coronary artery angioplasty

Values	coef	Odds ratio	BIC	*P* Value
Troponin I	0.714	2.042 (1.477-2.822)	158.235	< 0.001
CK-MB Relative Index	1.184	3.268 (2.157-4.951)	142.279	< 0.001
ST-segment elevation	2.430	11.358 (6.885-18.735)	111.879	< 0.001
QRS duration	0.037	1.038 (1.014-1.062)	191.438	0.003
PR interval	0.027	1.027 (1.009-1.046)	191.340	0.004
QT interval	0.026	1.026 (1.015-1.038)	184.193	< 0.001
ICEB (QT/QRS)	3.087	21.903 (13.251-36.198)	90.413	< 0.001
Serum creatinine	0.527	1.694 (1.299-2.208)	172.075	< 0.001
Blood urea nitrogen	0.183	1.201 (1.102-1.309)	175.235	< 0.001
Cystatin C	2.576	13.150 (4.211-41.060)	190.731	0.003
Prothrombin time	0.529	1.698 (1.180-2.443)	192.171	0.005
D-dimer levels	2.885	17.890 (3.980-80.411)	190.267	0.002
Fibrinogen levels	1.403	4.070 (2.160-7.660)	186.244	< 0.001
WBC	0.412	1.510 (1.220-1.869)	188.521	< 0.001
NLR	0.785	2.193 (1.640-2.932)	180.326	< 0.001
CRP	0.184	1.202 (1.068-1.353)	191.876	0.003

CK-MB: Creatine Kinase-MB; ICEB: Index of Cardiac Electrophysiological Balance; WBC: White Blood Cell count; NLR: Neutrophil-to-Lymphocyte Ratio; CRP: C-Reactive Protein.

Table 6. Predictive performance of various values for IRI occurrence after coronary artery predictive value

Values	Sensitivities	Specificities	AUC	Youden index
Troponin I	0.822	0.585	0.71	0.407
CK-MB Relative Index	0.616	0.815	0.755	0.431
ST-segment elevation	0.89	0.8	0.907	0.69
QRS duration	0.548	0.754	0.658	0.302
PR interval	0.603	0.6	0.632	0.203
QT interval	0.712	0.662	0.685	0.374
ICEB (QT/QRS)	0.932	0.831	0.944	0.763
Serum creatinine	0.908	0.548	0.749	0.456
Blood urea nitrogen	0.863	0.462	0.725	0.325
Cystatin C	0.877	0.477	0.637	0.354
Prothrombin time	0.767	0.569	0.664	0.336
D-dimer levels	0.836	0.492	0.652	0.328
Fibrinogen levels	0.808	0.569	0.684	0.377
WBC	0.692	0.644	0.694	0.336
NLR	0.569	0.849	0.716	0.418
CRP	0.723	0.767	0.761	0.490

CK-MB: Creatine Kinase-MB; ICEB: Index of Cardiac Electrophysiological Balance; WBC: White Blood Cell count; NLR: Neutrophil-to-Lymphocyte Ratio; CRP: C-Reactive Protein.

Conclusion

The current study demonstrated that ICEB was a potent predictor of IRI in patients undergoing coronary artery angioplasty. In addition, cardiac biomarkers, renal function markers, coagulation values, and inflammatory markers were also associated with IRI to varying degrees. Evaluating ICEB before coronary angioplasty may facilitate early identification of high-risk patients, potentially informing perioperative management strategies. These findings provide further insight into clinical management of IRI and may guide refinement of therapeutic strategies. Future prospective investigations ought to focus on validating these outcomes and identifying other predictive factors that may serve as reliable predictors of IRI following coronary artery angioplasty.

Disclosure of conflict of interest

None.

Address correspondence to: Lihui Ren, Department of Cardiology, Beijing Shijitan Hospital, Capital Medical University, No. 10 Tieyi Road, Yangfangdian, Haidian District, Beijing 100038, China. E-mail: renlh@bjsjth.cn

References

[1] Al-Lamee RK. Angina pectoris 2023: with and without obstructive coronary artery disease: epidemiology, diagnosis, prognosis, and treatment. Vascul Pharmacol 2024; 155: 107285.

[2] Sucato V, Coppola G, Manno G, Vadalà G, Novo G, Corrado E and Galassi AR. Coronary artery disease in south Asian patients: cardiovascular risk factors, pathogenesis and treatments. Curr Probl Cardiol 2023; 48: 101228.

[3] Ogawa T, Sakakura K, Sumitsuji S, Hyodo M, Yamaguchi J, Hirase H, Yamashita T, Kadota K, Kobayashi Y and Kozuma K. Clinical expert consensus document on bailout algorithms for complications in percutaneous coronary intervention from the Japanese Association of Cardiovascular Intervention and Therapeutics. Cardiovasc Interv Ther 2025; 40: 1-32.

[4] Tao S, Tang X, Yu L, Li L, Zhang G, Zhang L, Huang L and Wu J. Prognosis of coronary heart disease after percutaneous coronary intervention: a bibliometric analysis over the period 2004-2022. Eur J Med Res 2023; 28: 311.

[5] Ilyas M, Noor M, Khan HS, Haroon S, Farhat K and Ali S. Cardio protective effect of nicorandil in reperfusion injury among patients undergoing primary percutaneous coronary intervention. Pak J Med Sci 2023; 39: 177-181.

[6] Al-Ogaili A, Gill GS and Brilakis ES. Complications of percutaneous coronary intervention. Prog Cardiovasc Dis 2025; 88: 80-93.

[7] Ndrepepa G and Kastrati A. Coronary no-reflow after primary percutaneous coronary intervention-current knowledge on pathophysiology, diagnosis, clinical impact and therapy. J Clin Med 2023; 12: 5592.

[8] Algoet M, Janssens S, Himmelreich U, Gsell W, Pusovnik M, Van den Eynde J and Oosterlinck W. Myocardial ischemia-reperfusion injury and the influence of inflammation. Trends Cardiovasc Med 2023; 33: 357-366.

[9] Zang X, Zhou J, Zhang X, Han Y and Chen X. Ischemia reperfusion injury: opportunities for nanoparticles. ACS Biomater Sci Eng 2020; 6: 6528-6539.

[10] Li X, Ma N, Xu J, Zhang Y, Yang P, Su X, Xing Y, An N, Yang F, Zhang G, Zhang L and Xing Y. Targeting ferroptosis: pathological mechanism and treatment of ischemia-reperfusion injury. Oxid Med Cell Longev 2021; 2021: 1587922.

[11] Liu Y, Li L, Wang Z, Zhang J and Zhou Z. Myocardial ischemia-reperfusion injury; molecular mechanisms and prevention. Microvasc Res 2023; 149: 104565.

[12] Lin Y, Zhou F, Wang X, Guo Y and Chen W. Effect of the index of cardiac electrophysiological balance on major adverse cardiovascular events in patients with diabetes complicated with coronary heart disease. PeerJ 2023; 11: e15969.

[13] Yücetas SC, Kaya H, Kafadar S, Kafadar H, Tibilli H and Akcay A. Evaluation of index of cardiac-electrophysiological balance in patients with subarachnoid hemorrhage. BMC Cardiovasc Disord 2022; 22: 477.

[14] Askin L and Tanrıverdi O. Evaluation of index of cardio-electrophysiological balance in patients with coronary slow flow. Acta Cardiol 2022; 77: 337-341.

[15] Hoole SP and Bambrough P. Recent advances in percutaneous coronary intervention. Heart 2020; 106: 1380-1386.

[16] Kandan SR and Johnson TW. Management of percutaneous coronary intervention complications. Heart 2019; 105: 75-86.

[17] Sivri S and Çelik M. Evaluation of index of cardiac-electrophysiological balance before and after hemodialysis in patients with end-stage renal disease. J Electrocardiol 2019; 54: 72-75.

[18] Ozturk U and Ozturk O. Index of cardio-electrophysiological balance and Parkinson disease. Medicine (Baltimore) 2023; 102: e35075.

[19] Kaya H, Suner A, Koparal M, Yucetas SC and Kafadar S. Evaluation of Tp-e interval, Tp-e/QT ratio and index of cardiac-electrophysiological balance in patients with tinnitus. BMC Cardiovasc Disord 2021; 21: 415.

[20] Özdemir L and Sökmen E. Effect of habitual cigarette smoking on the index of cardiac electrophysiological balance in apparently healthy individuals. J Electrocardiol 2020; 59: 41-44.

[21] Panconesi R, Widmer J, Carvalho MF, Eden J, Dondossola D, Dutkowski P and Schlegel A. Mitochondria and ischemia reperfusion injury. Curr Opin Organ Transplant 2022; 27: 434-445.

[22] Huet F, Delbaere Q, Aguilhon S, Dupasquier V, Delseny D, Gervasoni R, Macia JC, Leclercq F, Jammoul N, Kahlouche S, Soltani S, Cardon F, Dupuy AM, Cristol JP, Mariano-Goulart D, Akodad M, Nagot N and Roubille F. Colchicine to prevent sympathetic denervation after an acute myocardial infarction: the COLD-MI trial protocol. Medicina (Kaunas) 2021; 57: 1047.

[23] Afsin A, Asoglu R, Kobat MA, Asoglu E and Suner A. Evaluation of index of cardio-electrophysiological balance in patients with atrial fibrillation on antiarrhythmic-drug therapy. Cardiol Res 2021; 12: 37-46.

[24] Zhang YT, Li HY, Sun XT, Tong XW, Shan YY, Xu YX, Pu SD and Gao XY. Relationship between index of cardiac electrophysiological balance, frontal QRS-T angle and retinopathy in people with type 2 diabetes. Diabetes Metab Syndr Obes 2023; 16: 861-871.

[25] Pan YJ, Chen R, Xu Y, Xia H, Xu C and Yuan W. Association between CD137 and ischemia-reperfusion injury in patients with acute ST-segment elevation myocardial infarction. Zhonghua Xin Xue Guan Bing Za Zhi 2021; 49: 1198-1205.
[26] Oikonomou E, Zografos T, Papamikroulis GA, Siasos G, Vogiatzi G, Theofilis P, Briasoulis A, Papaioannou S, Vavuranakis M, Gennimata V and Tousoulis D. Biomarkers in atrial fibrillation and heart failure. Curr Med Chem 2019; 26: 873-887.
[27] Zanoli L, Lentini P, Briet M, Castellino P, House AA, London GM, Malatino L, McCullough PA, Mikhailidis DP and Boutouyrie P. Arterial stiffness in the heart disease of CKD. J Am Soc Nephrol 2019; 30: 918-928.
[28] Nørgård M and Svenningsen P. Acute kidney injury by ischemia/reperfusion and extracellular vesicles. Int J Mol Sci 2023; 24: 15312.
[29] Wang SS, Xu H, Ge AQ, Yang KL, He Q and Ge JW. Bombyx batryticatus extract activates coagulation factor XII to promote angiogenesis in rats with cerebral ischemia/reperfusion injury. J Ethnopharmacol 2024; 319: 117081.
[30] Guzzardo GM and Regling K. Developmental hemostasis: the evolution of our coagulation system. Neoreviews 2022; 23: e82-e95.
[31] Sachetto ATA and Mackman N. Modulation of the mammalian coagulation system by venoms and other proteins from snakes, arthropods, nematodes and insects. Thromb Res 2019; 178: 145-154.
[32] He JF, Yang YX, Li JY, Liang L, Xu L, Liu Y, Guo ZS, Yang Q, Jiang T, Lin XM, Yang XC, Chen ML, Su PX, Zhong JC and Wang LF. A novel reperfusion strategy for primary percutaneous coronary intervention in patients with acute ST-segment elevation myocardial infarction: a prospective case series. J Clin Med 2023; 12: 433.
[33] Chen X, Wang Z, Liu L, Zhang W, Tang Z, Liu B, Zhang X, Wei N, Wang J, Liu F and Ma M. Prognostic value of index of cardiac electrophysiological balance among US middle-aged adults. Front Cardiovasc Med 2023; 10: 1139967.
[34] Zhang L, Wang L, Tao L, Chen C, Ren S and Zhang Y. Risk factors of ischemia reperfusion injury after PCI in patients with acute ST-segment elevation myocardial infarction and its influence on prognosis. Front Surg 2022; 9: 891047.
[35] He T, Luo Y, Wan J, Hou L, Su K, Zhao J and Li Y. Analysis of the correlation between the systemic inflammatory response index and the severity of coronary vasculopathy. Biomol Biomed 2024; 24: 1726-1734.
[36] Wang Z and Peng J. The predictive value of the nomogram model of clinical risk factors for ischemia-reperfusion injury after primary percutaneous coronary intervention. Sci Rep 2023; 13: 5084.