International Journal of General Medicine

Dovepress
Taylor & Francis Group

Open Access Full Text Article

ORIGINAL RESEARCH

Integration of 2D Speckle Tracking Strain and Clinical Indicators for Early Prediction of Post-PCI Heart Failure in Patients with STEMI and Type 2 Diabetes

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Background: Patients with ST-segment elevation myocardial infarction (STEMI) and type 2 diabetes mellitus (T2DM) are at increased risk of heart failure after percutaneous coronary intervention (PCI). Early identification of high-risk individuals remains challenging. This study aimed to develop a prediction model integrating two-dimensional speckle tracking imaging (2D-STI) and clinical variables to improve risk stratification.

Methods: A total of 328 T2DM patients with STEMI who underwent PCI were retrospectively analyzed. Clinical, laboratory, and 2D-STI parameters were collected within one week after PCI. Heart failure within one year was the study endpoint. LASSO regression followed by Boruta analysis was used to identify key predictors. A multivariable logistic model was established, visualized by a nomogram, and evaluated using ROC curves, reclassification indices, calibration, and decision curve analysis.

Results: Heart failure occurred in 62 patients (18.9%). Six variables—GLS, HbA1c, BMI, eGFR, hs-CRP, and diabetes duration—were identified as core predictors. GLS showed the highest individual discriminative ability (AUC = 0.798). The combined model achieved an AUC of 0.861, significantly outperforming the base model (AUC = 0.803, $P < 0.001$). Adding GLS improved reclassification (NRI = 0.216; IDI = 0.057). The model demonstrated good calibration and favorable clinical utility.

Conclusion: Integrating GLS with clinical, metabolic, inflammatory, and renal indicators significantly improves early prediction of post-PCI heart failure in T2DM patients with STEMI, offering a practical tool for individualized risk assessment.

Keywords: global longitudinal strain, two-dimensional speckle tracking imaging, ST-segment elevation myocardial infarction, type 2 diabetes mellitus, heart failure

Introduction

ST-segment elevation myocardial infarction (STEMI) remains a major global burden of cardiovascular mortality and heart failure events despite significant advances in reperfusion strategies.[1,2] Although percutaneous coronary intervention (PCI) can rapidly restore blood flow in the infarct-related artery, a subset of patients still develop ventricular remodeling, deterioration of cardiac function, or clinical heart failure after the procedure, which severely affects long-term survival and quality of life.[3,4] This issue is particularly prominent in patients with STEMI complicated by type 2 diabetes mellitus (T2DM), in whom chronic inflammation, microvascular dysfunction, glucotoxicity, and metabolic disturbances may synergistically aggravate reperfusion injury, rendering this population at markedly higher risk for developing heart failure.[5,6]

Traditional prediction methods primarily rely on conventional echocardiographic and biomarker indicators such as left ventricular ejection fraction (LVEF) and N-Terminal pro-brain natriuretic peptide (NT-proBNP). However, these macroscopic parameters often become abnormal only after substantial structural myocardial injury has occurred, limiting their utility for the early detection of post-PCI myocardial dysfunction and heart failure risk.[7–9] In recent years, growing evidence has suggested that two-dimensional speckle tracking imaging (2D-STI), through quantitative assessment of myocardial strain, provides load-

https://doi.org/10.2147/IJGM.S586226
Received: 3 December 2025
Accepted: 23 January 2026
Published: 4 March 2026

independent information on myocardial deformation and has substantial value in identifying early structural and functional abnormalities. It has been applied, for example, in evaluating left atrial remodeling, predicting adverse outcomes in patients with borderline coronary lesions, and assessing the risk of left ventricular remodeling in STEMI patients.[10–12] Furthermore, recent advancements in deep learning and automated ultrasound image analysis have shown promise in enhancing the precision and efficiency of echocardiographic segmentation and feature extraction,[13–15] paving the way for more robust clinical applications. However, systematic studies focusing on the high-risk subgroup of T2DM patients with STEMI remain lacking, particularly regarding whether 2D-STI can reveal subclinical injury shortly after PCI and improve the precision of heart failure risk prediction.

Based on this background, the present study aims to integrate 2D-STI-derived myocardial strain parameters with key clinical characteristics, applying LASSO regression and the Boruta algorithm to identify the most valuable predictive factors and to construct a combined prediction model for heart failure following PCI in patients with T2DM and STEMI. A nomogram was developed to visualize the model, with the goal of providing clinicians with a sensitive, accurate, and practical tool for early risk stratification to support individualized management, reduce adverse events, and improve clinical outcomes.

Materials and Methods

Study Population

This single-center retrospective cohort study consecutively included patients with ST-segment elevation myocardial infarction (STEMI) complicated by type 2 diabetes mellitus (T2DM) who underwent percutaneous coronary intervention (PCI) at the Second Affiliated Hospital of Xuzhou Medical University from January 2021 to December 2023. The study protocol was approved by the Institutional Ethics Committee of the Second Affiliated Hospital of Xuzhou Medical University, with informed consent waived (Approval No.: 2021111801).

Inclusion criteria: ① Age ≥ 18 years; ② Diagnosis of STEMI and treatment with PCI; ③ Established diagnosis of T2DM; ④ Completion of two-dimensional speckle tracking imaging (2D-STI) after PCI.

Exclusion criteria: ① History of heart failure or LVEF < 40% before PCI; ② Concomitant cardiomyopathy, severe valvular heart disease, congenital heart disease, or severe pulmonary hypertension; ③ Severe hepatic or renal dysfunction (eGFR < 30 mL/min/1.73 m^2); ④ Acute or chronic infection (defined as body temperature > 37.3°C, active infectious symptoms, or antibiotic use within 2 weeks), malignancy, or autoimmune disease; ⑤ Previous CABG or PCI; ⑥ Inadequate 2D-STI image quality for strain analysis; ⑦ Missing baseline or follow-up information.

A total of 343 patients were initially screened; 15 patients (4.4%) were excluded due to missing baseline or follow-up data. The remaining 328 eligible patients were included in the final analysis and classified into the heart failure (HF) group (n = 62) and non-heart failure (Non-HF) group (n = 266) according to the occurrence of HF within one year after PCI. The study flowchart is shown in Figure 1.

Clinical Data Collection

Baseline clinical data within 24 hours of admission were extracted from the electronic medical record system, including age, sex, BMI, smoking status, drinking status, diabetes duration, and hypertension history. Laboratory parameters collected according to standardized procedures included white blood cells (WBC), red blood cells (RBC), platelets (PLT), neutrophils (NEUT), lymphocytes (LYMPH), eosinophils (EO), basophils (BASO), NT-proBNP, glycated hemoglobin (HbA1c), high-sensitivity C-reactive protein (hs-CRP), estimated glomerular filtration rate (eGFR, CKD-EPI equation), fasting blood glucose (FBG), total cholesterol (TC), triglycerides (TG), and low-density lipoprotein cholesterol (LDL-C). PCI-related information included the number of stents implanted.

2D-STI Examination and Strain Parameter Acquisition

All patients underwent 2D-STI within one week after PCI. A Philips EPIQ5 ultrasound system was used to obtain apical four-chamber, two-chamber, and long-axis views, recording at least three consecutive cardiac cycles. Myocardial speckle tracking was performed using QLAB-aCMQ software to calculate global longitudinal strain (GLS), circumferential strain

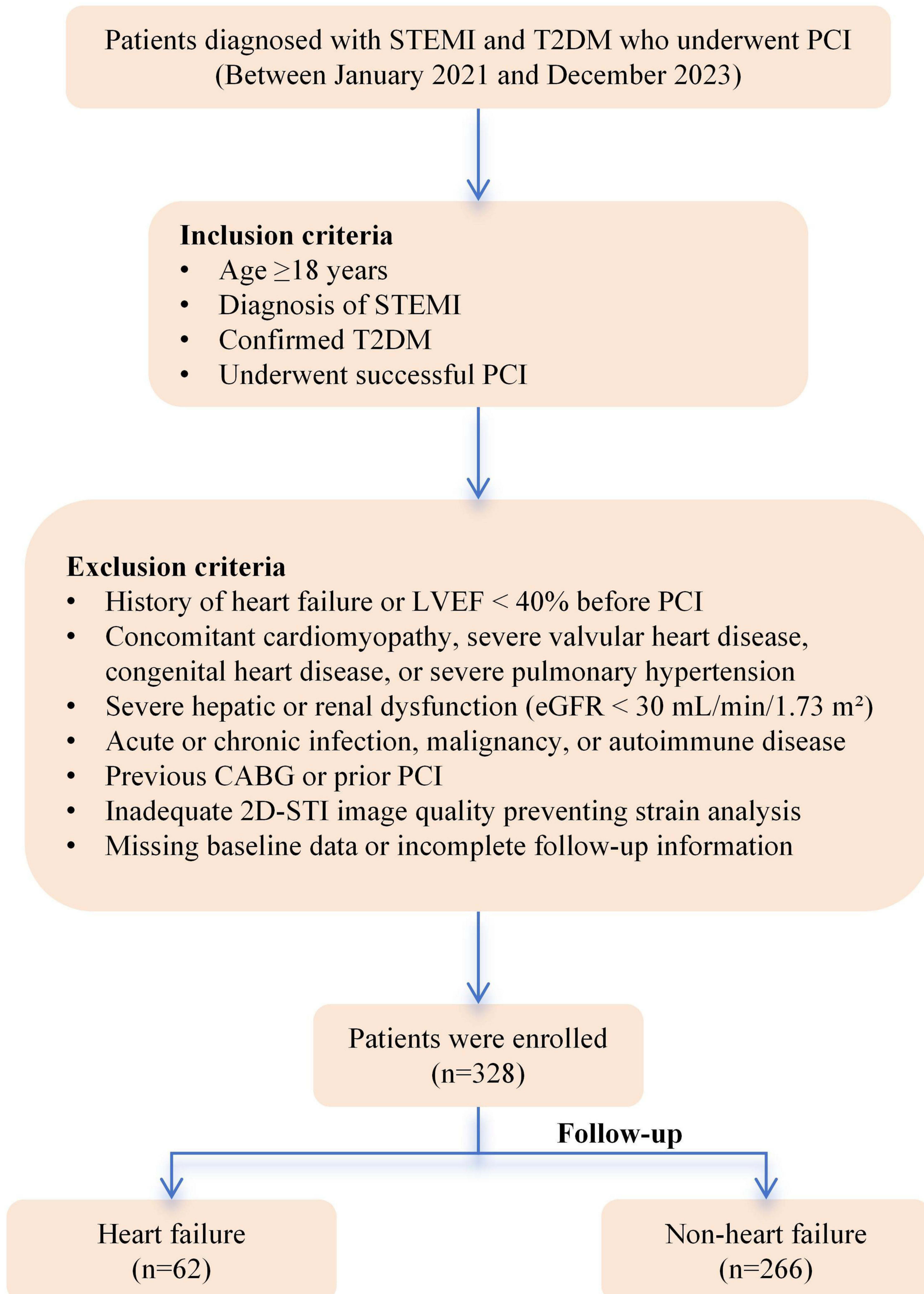

Figure 1 Study flowchart of patient selection and analysis process.

(CS), and radial strain (RS). All analyses were conducted independently by two experienced echocardiographers, and the mean value was used.

Definition of Outcomes and Follow-Up

The study endpoint was the occurrence of heart failure within one year after PCI, defined as: hospitalization due to heart failure; marked elevation of NT-proBNP accompanied by clinical signs of heart failure; or imaging evidence of new or worsening left ventricular dysfunction. Follow-up was conducted through outpatient visits and telephone interviews.

https://doi.org/10.2147/IJGM.S586226

Statistical Analysis

The sample size was determined by including all consecutive eligible patients during the study period. Based on the 62 observed heart failure events and 6 predictors in the final model, the events per variable (EPV) ratio was greater than 10, satisfying the recommended sample size requirements for logistic regression modeling. All statistical analyses were performed using R version 4.2.3. Continuous variables with normal distribution were expressed as mean ± standard deviation and compared using independent-sample t-tests; non-normally distributed variables were presented as median (interquartile range) and compared using the Mann–Whitney *U*-test. Categorical variables were expressed as frequencies (%) and compared using χ^2 or Fisher's exact test. To construct the prediction model for post-PCI heart failure, occurrence of HF within one year was used as the outcome variable. Baseline clinical characteristics and 2D-STI parameters were first subjected to univariate analysis, and variables with $P < 0.05$ were considered candidates. LASSO regression using the glmnet package with 10-fold cross-validation was then applied to reduce redundancy and minimize multicollinearity. To further enhance the robustness of feature selection, the Boruta package was used within a random forest framework to determine variable importance and identify core predictors. A multivariable logistic regression model was built using the selected predictors, and a nomogram was constructed to visualize the prediction model. Model discrimination was assessed using ROC curves and area under the curve (AUC), with DeLong's test used to compare AUC differences between models. Improvement in model performance after adding GLS was quantified by calculating the net reclassification improvement (NRI) and integrated discrimination improvement (IDI) using the nricens package. Model calibration was evaluated using the Hosmer-Lemeshow goodness-of-fit test and bootstrap calibration curves (1000 replications). Clinical utility was examined using decision curve analysis (DCA) to assess net benefit across a range of threshold probabilities. All statistical tests were two-sided, and $P < 0.05$ was considered statistically significant.

Results

Baseline Characteristics

A total of 328 patients with T2DM and STEMI were included, of whom 62 (18.9%) developed heart failure within one year after PCI, while 266 (81.1%) did not. Baseline characteristics of the two groups are shown in Table 1. Compared with the non-HF group, patients in the HF group were older, had higher BMI, longer diabetes duration, and a higher prevalence of hypertension (all $P < 0.05$). Regarding laboratory findings, HbA1c, NT-proBNP, hs-CRP, and FBG levels were significantly elevated in the HF group, whereas eGFR was markedly reduced (all $P < 0.05$). Among the 2D-STI parameters, GLS, CS, and RS were all significantly lower in the HF group than in the non-HF group (all $P < 0.001$), indicating more prominent myocardial deformation impairment.

Feature Selection

To further identify key predictors of post-PCI heart failure in T2DM patients with STEMI, 12 significantly different baseline variables were included in the LASSO regression analysis. Using 10-fold cross-validation to determine the optimal penalty parameter λ, eight variables were retained: HbA1c, GLS, diabetes duration, hs-CRP, BMI, eGFR, age, and hypertension history (Figure 2A–C). The Boruta algorithm was then applied to reassess variable importance and exclude factors with limited contribution. Six variables—HbA1c, GLS, BMI, eGFR, hs-CRP, and diabetes duration—were ultimately identified as core predictors and included in the multivariable model, whereas age and hypertension history were removed due to insufficient predictive value (Figure 2D).

ROC Curve and Model Performance Analysis

Single-predictor ROC analysis (Figure 3A) showed that GLS had the strongest predictive performance, with an AUC of 0.798, outperforming HbA1c (0.743), eGFR (0.757), BMI (0.748), hs-CRP (0.690), and diabetes duration (0.598). In the multivariable prediction model (Figure 3B), the base model (Model 1: HbA1c + BMI + eGFR + hs-CRP + diabetes duration) achieved an AUC of 0.803 (95% CI: 0.743–0.862). After adding GLS (Model 2: HbA1c + BMI + eGFR + hs-CRP + diabetes duration + GLS), the AUC increased to 0.861 (95% CI: 0.811–0.911), and the improvement was statistically significant based on DeLong's test ($P < 0.001$).

Table 1 Baseline Characteristics of Patients with and without Heart Failure After PCI

Variables	Non-HF (n=266)	HF (n=62)	*P*
Age, years	58.9 ± 9.2	65.3 ± 8.7	0.012
Male, n (%)	198 (74.4%)	45 (72.6%)	0.600
BMI, kg/m^2	24.1 ± 2.9	26.8 ± 3.5	<0.001
Smoking, n (%)	145 (54.5%)	38 (61.3%)	0.215
Drinking, n (%)	103 (38.7%)	21 (33.9%)	0.182
Hypertension, n (%)	182 (68.4%)	50 (80.6%)	0.048
Diabetes duration, years	7.0 (4.0–10.0)	12.5 (8.0–16.0)	<0.001
Number of implants, n	1 (1, 2)	2 (1, 3)	0.640
WBC, ×10^9/L	5.88 (4.26, 8.53)	5.68 (4.17, 9.37)	0.601
RBC, ×10^{12}/L	4.36 (3.79, 4.77)	4.15 (3.11, 4.65)	0.216
PLT, ×10^9/L	163.00 (122.00, 203.00)	180.00 (142.00, 216.25)	0.372
NEUT, ×10^9/L	3.72 (2.36, 7.58)	4.20 (2.26, 7.63)	0.157
LYMPH, ×10^9/L	1.60 (1.06, 2.64)	2.28 (1.54, 5.22)	0.265
EO, ×10^9/L	0.09 (0.03, 0.32)	0.12 (0.08, 0.64)	0.173
BASO, ×10^9/L	0.18 (0.11, 0.27)	0.14 (0.06, 0.26)	0.436
NT-proBNP, pg/mL	450 (300–600)	1000 (700–1500)	<0.001
HbA1c, %	7.2 ± 0.8	8.0 ± 1.0	<0.001
hs-CRP, mg/L	2.5 (1.8–3.2)	4.0 (3.1–5.0)	0.001
eGFR, mL/min/1.73m^2	90.0 ± 15.0	75.0 ± 18.0	<0.001
FBG, mmol/L	7.8 ± 1.5	8.4 ± 1.7	0.015
TC, mmol/L	4.5 ± 1.0	4.8 ± 1.2	0.064
TG, mmol/L	1.8 (1.3–2.2)	1.9 (1.4–2.3)	0.317
LDLC, mmol/L	2.7 ± 0.8	2.8 ± 0.9	0.384
GLS, %	−16.5 ± 3.1	−13.2 ± 2.8	<0.001
CS, %	−18.2 ± 4.0	−14.6 ± 3.5	<0.001
RS, %	35.2 ± 7.3	28.4 ± 6.7	<0.001

Abbreviations: BMI, Body mass index; WBC, White blood cells; RBC, Red blood cells; PLT, Platelets; NEUT, Neutrophils; LYMPH, Lymphocytes; EO, Eosinophils; BASO, Basophils; NT-proBNP, N-Terminal pro-brain natriuretic peptide; HbA1c, Glycated hemoglobin; hs-CRP, High-sensitivity C-reactive protein; eGFR, Estimated glomerular filtration rate; FBG, Fasting blood glucose; TC, Total cholesterol; TG, Triglycerides; LDL-C, Low-density lipoprotein cholesterol; GLS, Global longitudinal strain; CS, Circumferential strain; RS, Radial strain.

Reclassification analysis (Table 2) further confirmed the incremental value of GLS. When GLS was added, the NRI was 0.216 (95% CI: 0.107–0.605, $P < 0.001$), and the IDI was 0.057 (95% CI: 0.015–0.078, $P < 0.001$). These results indicate that GLS not only enhances overall model discrimination but also significantly improves individual risk

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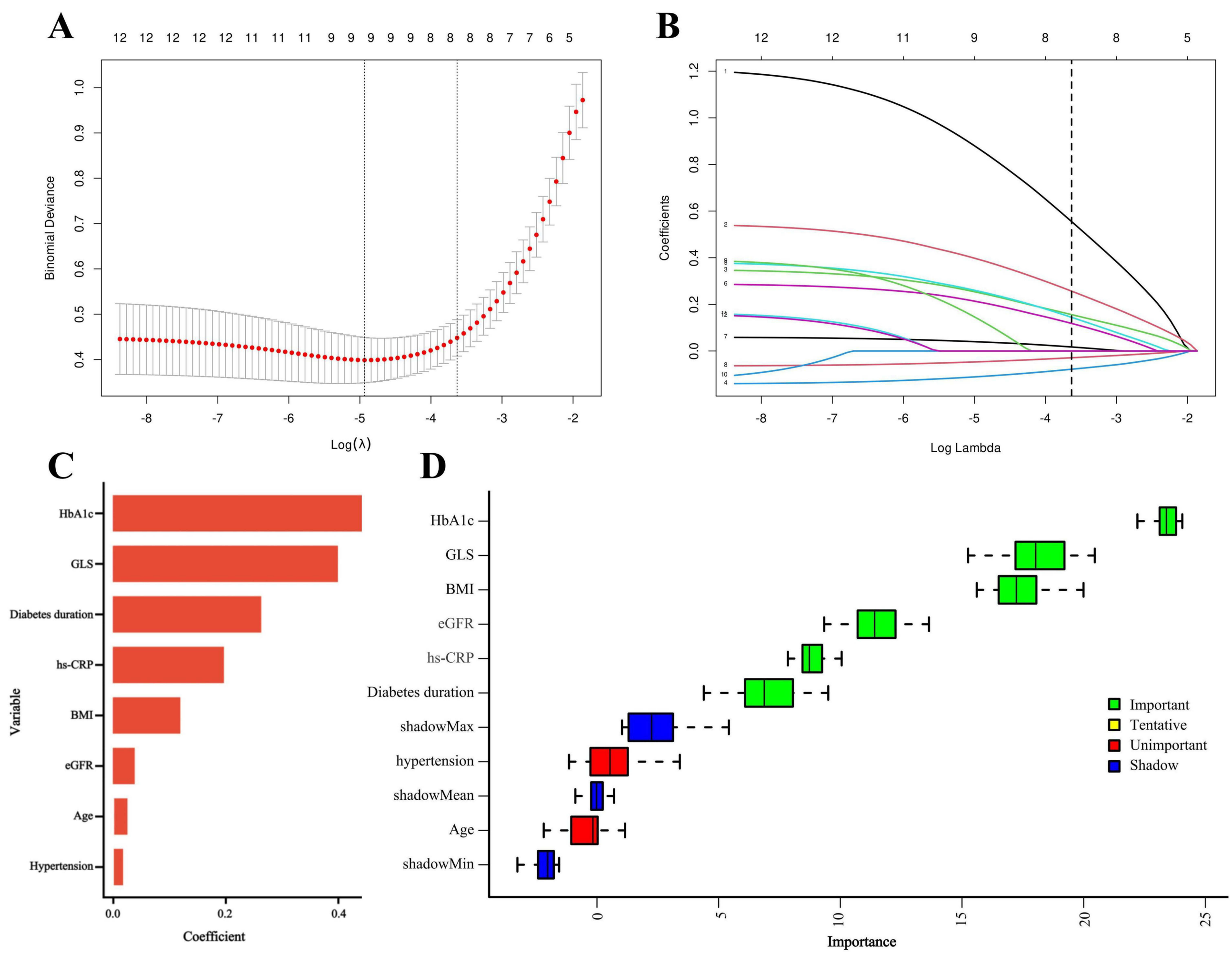

Figure 2 Feature selection using LASSO regression and Boruta algorithm. (**A**) LASSO coefficient profiles of candidate variables; (**B**) Ten-fold cross-validation for selecting the optimal λ; (**C**) LASSO feature ranking; (**D**) Variable importance ranking based on the Boruta algorithm.

reclassification accuracy, providing important added value in assessing post-PCI heart failure risk in T2DM patients with STEMI.

Nomogram Construction and Model Evaluation

A prediction model incorporating six core predictors—HbA1c, GLS, BMI, eGFR, hs-CRP, and diabetes duration—was constructed and visualized using a nomogram (Figure 4A). The nomogram provides a visual tool for clinical use. To calculate the predicted risk, locate the patient's value for each variable on its respective axis and draw a vertical line upwards to the "Points" axis to determine the score. Sum the scores for all variables to obtain the "Total Points," then draw a vertical line downwards from the total points axis to the "Risk of Y" axis to obtain the individual probability of heart failure.[16] Calibration analysis demonstrated good agreement between predicted and observed probabilities, with satisfactory calibration performance (Hosmer–Lemeshow P = 0.425) (Figure 4B). Decision curve analysis showed that the combined model yielded greater net clinical benefit across a wide range of threshold probabilities (Figure 4C), suggesting its potential utility for early risk stratification in T2DM patients with STEMI after PCI.

Discussion

This study focused on a very high-risk population—patients with T2DM complicated by STEMI—and systematically evaluated the predictive value of integrating 2D-STI parameters with multidimensional clinical features for assessing

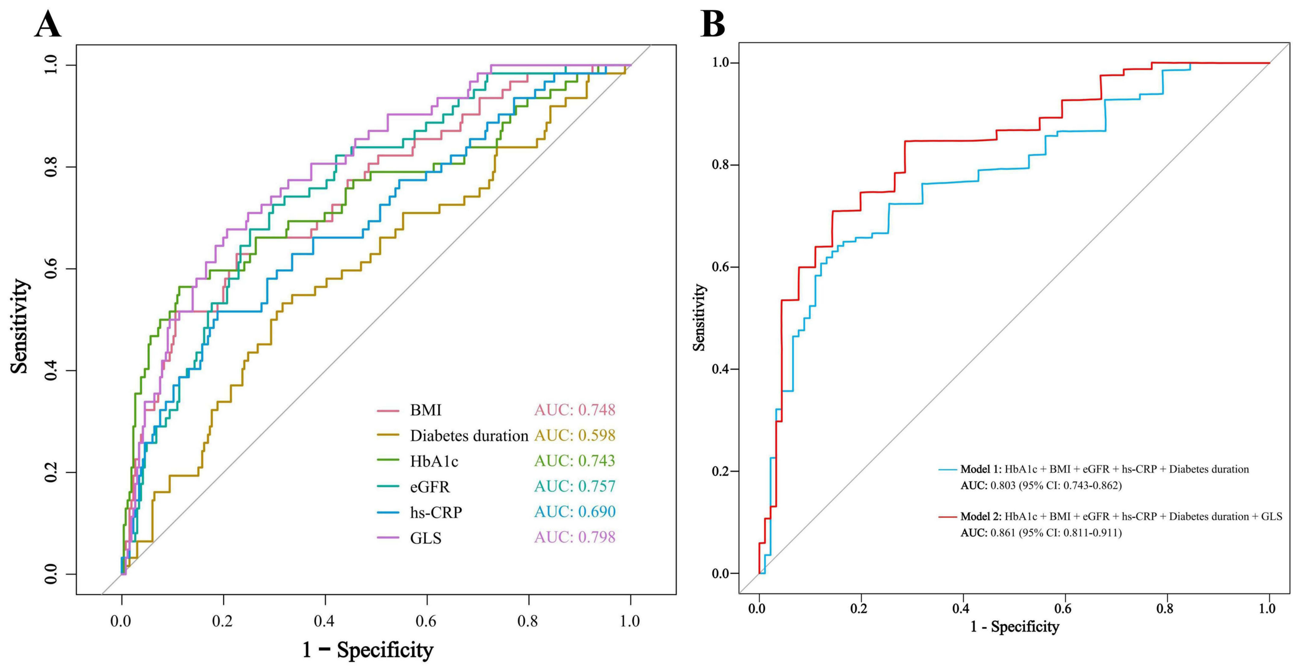

Figure 3 ROC curves and model performance comparison. (**A**) ROC curves for individual predictors. (**B**) Comparison of ROC curves between the base model (Model 1) and the GLS-enhanced model (Model 2).

post-PCI heart failure. The results demonstrated that GLS, HbA1c, BMI, eGFR, hs-CRP, and diabetes duration were key factors closely associated with postoperative heart failure. The combined prediction model constructed from these variables exhibited favorable discrimination, calibration, and clinical net benefit, indicating that incorporating information on myocardial deformation, metabolic status, inflammation, and renal function can substantially improve early identification of high-risk individuals. This may support more precise postoperative follow-up and individualized management. Unlike previous studies that focused solely on STEMI or general diabetic populations, this study specifically targeted the high-risk phenotype of T2DM combined with STEMI. Furthermore, we integrated mechanical strain (GLS) with metabolic and inflammatory markers, providing a more holistic prediction model than those relying on hemodynamic parameters alone.

T2DM profoundly alters the pathophysiological processes of myocardial injury and repair after STEMI and represents a central driver of the high incidence of postoperative heart failure.[17] In this study, patients who developed heart failure exhibited markedly elevated HbA1c levels, longer diabetes duration, and higher hs-CRP levels, suggesting that chronic metabolic imbalance and inflammatory activation jointly contribute to the progressive deterioration of myocardial injury. Persistent hyperglycemia induces mitochondrial dysfunction, lipotoxicity, and microvascular perfusion abnormalities, making ischemic myocardium more prone to apoptosis and fibrosis while impairing the ability to recover after reperfusion.[18,19] These findings are consistent with prior studies in stable coronary artery disease and acute coronary

Table 2 Improvement in Reclassification Performance After Adding GLS to the Prediction Model

Model	NRI		IDI		C-Statistics	
	Index (95% CI)	*P*	Index (95% CI)	*P*	Index (95% CI)	*P*
Model 1		Ref		Ref	0.803 (0.743–0.862)	<0.001
Model 2	0.216 (0.107–0.605)	<0.001	0.057 (0.015–0.078)	<0.001	0.861 (0.811–0.911)	<0.001

Notes: Model 1: HbA1c + BMI + eGFR + hs-CRP + Diabetes duration. Model 2: HbA1c + BMI + eGFR + hs-CRP + Diabetes duration + GLS.

Abbreviations: HbA1c, Glycated hemoglobin; BMI, Body mass index; eGFR, Estimated glomerular filtration rate; hs-CRP, High-sensitivity C-reactive protein; GLS, Global longitudinal strain.

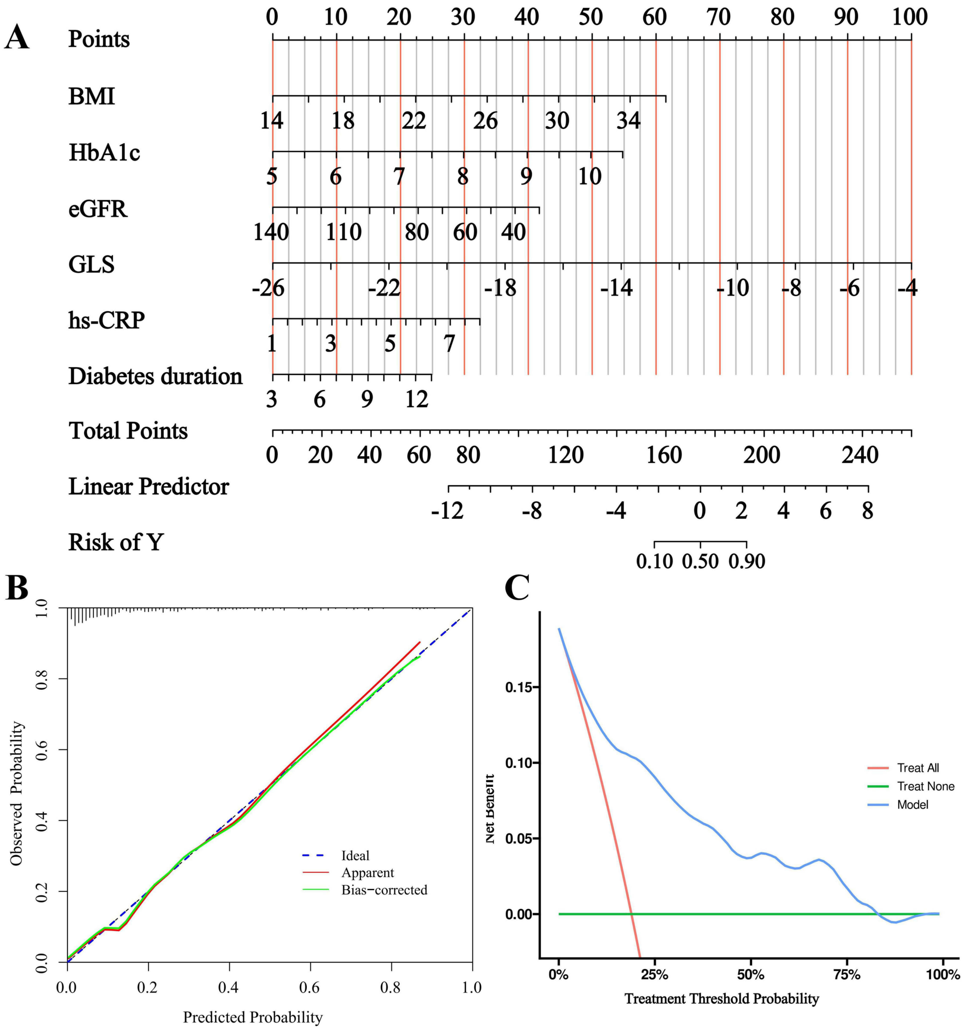

Figure 4 Nomogram, calibration curve, and decision curve analysis of the prediction model. (**A**) Nomogram constructed using six core predictors. (**B**) Calibration curve showing agreement between predicted and observed risk. (**C**) Decision curve analysis showing net clinical benefit across threshold probabilities.

syndrome populations.[20,21] The present study further confirms that under the combined background of STEMI and T2DM, metabolic and inflammatory factors exert a more pronounced and independent influence on the development of heart failure.

Regarding myocardial function assessment, strain parameters derived from 2D-STI provide high sensitivity in detecting subclinical myocardial injury, surpassing conventional echocardiographic indicators.[22,23] This study identified a significant reduction in GLS as a major predictor of postoperative heart failure, reflecting its ability to detect early impairment of longitudinal myocardial fiber contraction. Previous research has shown that GLS can identify myocardial mechanical dysfunction before LVEF decline becomes apparent and is strongly associated with ventricular remodeling and long-term outcomes.[24,25] In STEMI patients with concomitant diabetes, glucotoxic cardiomyopathy, microvascular rarefaction, and chronic inflammation further weaken myocardial integrity, making longitudinal strain impairment more pronounced and earlier in onset.[26,27] Therefore, the particularly strong predictive value of GLS in this study highlights the necessity of incorporating strain assessment into routine post-PCI evaluation to enable earlier and more precise risk stratification.

The interaction among metabolic, inflammatory, and organ function abnormalities further shapes the complex mechanisms underlying the development of heart failure.[28] In this study, higher BMI significantly increased post-operative heart failure risk, likely due to obesity-related increases in volume load, exacerbation of insulin resistance, and chronic low-grade inflammation, thereby promoting myocardial hypertrophy, diastolic dysfunction, and adverse ventricular remodeling.[29,30] Additionally, decreased eGFR was independently associated with heart failure. Renal impairment not only contributes to fluid retention but also promotes the accumulation of toxic metabolites and systemic inflammation, further deteriorating myocardial compliance and cardiac compensatory capacity.[31,32] Given the chronic renal injury associated with diabetes, this mechanism is more prominent in the studied population.[33] Elevated hs-CRP also correlated positively with heart failure risk, reinforcing the notion that inflammation plays a continuous and central role in ischemia–reperfusion injury, myocardial apoptosis, and fibrosis, and becomes even more pronounced in the diabetic context—supporting the "inflammation–remodeling–heart failure" pathological continuum.

Several limitations should be noted. First, as a single-center retrospective study with a relatively small sample size, selection bias and residual confounding (eg, medication adherence) cannot be entirely excluded. Second, predictors were assessed only at baseline; thus, the potential impact of dynamic fluctuations in metabolic or inflammatory markers (eg, HbA1c, hs-CRP) during follow-up was not accounted for. Future studies incorporating serial measurements may provide additional prognostic granularity. Third, the exclusion of patients with severe renal dysfunction (eGFR < 30 mL/min/1.73 m^2) to avoid volume overload confounding limits the generalizability of our findings to the end-stage renal disease population. Finally, despite dual-operator analysis, 2D-STI remains subject to image quality and technical limitations. Large-scale multicenter prospective studies are needed to validate these findings and enhance clinical applicability.

Conclusion

In summary, this study confirmed that GLS serves as a robust individual indicator for predicting post-PCI heart failure. We constructed a multidimensional prediction model integrating six core variables—GLS, HbA1c, BMI, eGFR, hs-CRP, and diabetes duration. This combined model significantly outperformed the clinical-only model in terms of discrimination, reclassification improvement, and clinical net benefit. These findings provide a more powerful tool for the early identification and individualized management of this high-risk population.

Data Sharing Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Ethics Approval and Consent to Participate

This study adheres to the principles outlined in the Declaration of Helsinki and was approved by the Institutional Ethics Committee of the Second Affiliated Hospital of Xuzhou Medical University, with informed consent waived (Approval No.: 2021110101).

Acknowledgments

We are very grateful to all the people who participated in this study.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

There is no funding to report.

Disclosure

The authors declare that they have no competing interests in this work.

References

1. Rao SV, O'Donoghue ML, Ruel M, et al. 2025 ACC/AHA/ACEP/NAEMSP/SCAI guideline for the management of patients with acute coronary syndromes: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. *Circulation*. 2025;151(13):e771–e862. doi:10.1161/CIR.0000000000001328
2. Welt FGP, Batchelor W, Spears JR, et al. Reperfusion injury in patients with acute myocardial infarction: JACC scientific statement. *J Am Coll Cardiol*. 2024;83(22):2196–2213. doi:10.1016/j.jacc.2024.02.056
3. Cocco M, Campo G, Guiducci V, et al. Complete vs culprit-only revascularization in older patients with myocardial infarction with or without ST-segment elevation. *J Am Coll Cardiol*. 2024;84(20):2014–2022. doi:10.1016/j.jacc.2024.07.028
4. Elbadawi A, Hamed M, Gad M, et al. Immediate versus staged complete revascularization for patients with ST-segment-elevation myocardial infarction and multivessel disease: a network meta-analysis of randomized trials. *J Am Heart Assoc*. 2024;13(21):e035535. doi:10.1161/JAHA.124.035535
5. Wu Y, Liu J, Du X, et al. Prognostic value of angiography-derived index of microcirculatory resistance in patients with diabetes and ST-segment elevation myocardial infarction. *Can J Cardiol*. 2025;41(10):2041–2051. doi:10.1016/j.cjca.2025.05.001
6. Li N, Zhou J, Chen R, et al. Prognostic impacts of diabetes status and lipoprotein(a) levels in patients with ST-segment elevation myocardial infarction: a prospective cohort study. *Cardiovasc Diabetol*. 2023;22(1):151. doi:10.1186/s12933-023-01881-w
7. Butler J, Hammonds K, Talha KM, et al. Incident heart failure and recurrent coronary events following acute myocardial infarction. *Eur Heart J*. 2025;46(16):1540–1550. doi:10.1093/eurheartj/ehae885
8. Ibanez B, Latini R, Rossello X, et al. Beta-blockers after myocardial infarction without reduced ejection fraction. *N Engl J Med*. 2025;393(19):1889–1900. doi:10.1056/NEJMoa2504735
9. Liang J, Zhang Z. Predictors of in-hospital heart failure in patients with acute anterior wall ST-segment elevation myocardial infarction. *Int J Cardiol*. 2023;375:104–109. doi:10.1016/j.ijcard.2023.01.002
10. Mashayekhi B, Mohseni-Badalabadi R, Hosseinsabet A, Ahmadian T. Correlation between Heart rate recovery and Left Atrial phasic functions evaluated by 2D speckle-tracking Echocardiography after Acute Myocardial infarction. *BMC Cardiovasc Disord*. 2023;23(1):164. doi:10.1186/s12872-023-03194-y
11. Arnautu DA, Gheorghiu A, Arnautu SF, et al. Subtle changes in myocardial work indices assessed by 2D-speckle tracking echocardiography are linked with pathological LV remodeling and MACEs following an acute myocardial infarction treated by primary percutaneous coronary intervention. *Diagnostics*. 2023;13(19):3108. doi:10.3390/diagnostics13193108
12. Zhang R, Liang S, Zhao F, et al. Association between segmental noninvasive longitudinal strain and quantitative microvascular perfusion in ST-segment elevation myocardial infarction: implications for clinical outcomes. *BMC Cardiovasc Disord*. 2025;25(1):109. doi:10.1186/s12872-025-04547-5
13. Zhang Z, Zhang H, Zeng T, et al. Bridging multi-level gaps: bidirectional reciprocal cycle framework for text-guided label-efficient segmentation in echocardiography. *Med Image Anal*. 2025;102:103536. doi:10.1016/j.media.2025.103536
14. Zhang Z, Yu C, Zhang H, et al. Embedding tasks into the latent space: cross-space consistency for multi-dimensional analysis in echocardiography. *IEEE Trans Med Imaging*. 2024;43(6):2215–2228. doi:10.1109/TMI.2024.3362964
15. Wang Y, Ding W, Lin W, et al. FedHNR: federated hierarchical resilient learning for echocardiogram segmentation with annotation noise. *Expert Syst Appl*. 2025;273:126841. doi:10.1016/j.eswa.2025.126841
16. Wu Z, Wang D, Tang C. A novel nomogram for predicting the risk of coronary atherosclerosis in patients with gastroesophageal reflux disease. *Arab J Gastroenterol*. 2025;26(2):176–184. doi:10.1016/j.ajg.2025.02.003
17. Chen P, Wang B, Zhao L, et al. Machine learning for predicting intrahospital mortality in ST-elevation myocardial infarction patients with type 2 diabetes mellitus. *BMC Cardiovasc Disord*. 2023;23(1):585. doi:10.1186/s12872-023-03626-9
18. Rokicka D, Hudzik B, Wróbel M, et al. The prognostic impact of insulin resistance surrogates in patients with acute myocardial infarction with and without type 2 diabetes. *Cardiovasc Diabetol*. 2024;23(1):147. doi:10.1186/s12933-024-02240-z
19. Cole A, Weight N, Wijeysundera HC, et al. Association of quality of care and long-term mortality risk for individuals presenting with ST-segment myocardial infarction (STEMI) by diabetes mellitus status: a nationwide cohort study. *Diabet Res Clin Pract*. 2025;222:112092. doi:10.1016/j.diabres.2025.112092
20. Singh YS, Wada H, Ogita M, et al. Clinical outcomes of ST elevation myocardial infarction patients without standard modifiable risk factors. *J Cardiol*. 2024;84(1):41–46. doi:10.1016/j.jjcc.2023.11.007
21. Guo W, Zhu J, Liu W. Stress hyperglycemia ratio: an independent predictor for in-hospital major adverse cardiovascular and cerebrovascular events in patients with st-segment elevation myocardial infarction. *BMC Cardiovasc Disord*. 2023;23(1):195. doi:10.1186/s12872-023-03219-6
22. Radwan HI, Alhoseeny AMA, Ghoniem SM, Nashy BNE, Shehata IE. Early right ventricular dysfunction after primary percutaneous coronary intervention in anterior versus isolated inferior myocardial infarction assessed by tissue Doppler imaging and speckle tracking echocardiography. *Heart Fail Rev*. 2023;28(2):407–417. doi:10.1007/s10741-022-10278-y
23. Chiang HP, Aguiar MOD, Tavares BG, et al. The impact of sonothrombolysis on left ventricular diastolic function and left atrial mechanics preventing left atrial remodeling in patients with ST elevation acute myocardial infarction. *J Am Soc Echocardiogr*. 2023;36(5):504–513. doi:10.1016/j.echo.2022.12.010
24. Shao C, Zhu J, Chen J, Xu W. Independent prognostic value of left atrial function by two-dimensional speckle tracking imaging in patients with non-ST-segment-elevation acute myocardial infarction. *BMC Cardiovasc Disord*. 2015;15:145. doi:10.1186/s12872-015-0135-9
25. Antoni ML, Ten Brinke EA, Marsan NA, et al. Comprehensive assessment of changes in left atrial volumes and function after ST-segment elevation acute myocardial infarction: role of two-dimensional speckle-tracking strain imaging. *J Am Soc Echocardiogr*. 2011;24(10):1126–1133. doi:10.1016/j.echo.2011.06.017
26. El-Naggar HM, Osman AS, Ahmed MA, Youssef AA, Ahmed TAN. Three-dimensional echocardiographic assessment of left ventricular geometric changes following acute myocardial infarction. *Int J Cardiovasc Imaging*. 2023;39(3):607–620. doi:10.1007/s10554-022-02764-z
27. Yu F, Tang G, Chen YA, et al. Number of segments with motion abnormalities is better correlated with infarct size in acute myocardial infarction. *Coron Artery Dis*. 2023;34(7):489–495. doi:10.1097/MCA.0000000000001266

28. Martin J. Persistent mortality and heart failure burden of anterior ST-segment elevation myocardial infarction following primary percutaneous coronary intervention: real-world evidence from the US Medicare Data Set. *BMJ Open*. 2023;13(6):e070210. doi:10.1136/bmjopen-2022-070210
29. Wei P, Hou J, Yu R, et al. Development and validation of an LDH-focused nomogram for the early prediction of heart failure in patients with acute ST-elevation myocardial infarction after percutaneous coronary intervention. *Lipids Health Dis*. 2025;24(1):233. doi:10.1186/s12944-025-02649-9
30. Zhou Z, Liu Q, Zheng M, et al. Comparative study on the predictive value of TG/HDL-C, TyG and TyG-BMI indices for 5-year mortality in critically ill patients with chronic heart failure: a retrospective study. *Cardiovasc Diabetol*. 2024;23(1):213. doi:10.1186/s12933-024-02308-w
31. Chatur S, Beldhuis IE, Claggett BL, et al. Sacubitril/Valsartan in patients with heart failure and deterioration in eGFR to <30 mL/min/1.73 m^2. *JACC Heart Fail*. 2024;12(10):1692–1703. doi:10.1016/j.jchf.2024.03.014
32. Neuen BL, Vaduganathan M, Claggett BL, et al. Natriuretic peptides, kidney function, and clinical outcomes in heart failure with preserved ejection fraction. *JACC Heart Fail*. 2025;13(1):28–39. doi:10.1016/j.jchf.2024.08.009
33. Madsen JM, Kjaer AK, Lønborg JT, et al. Long-term prognostic impact of glucagon-like peptide-1 receptor agonist before ST-segment elevation myocardial infarction in patients with type 2 diabetes: a nationwide cohort study. *Cardiovasc Diabetol*. 2025;24(1):4. doi:10.1186/s12933-024-02548-w