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Poor clinical outcome despite successful recanalisation in patients with acute myocardial infarction undergoing direct percutaneous coronary intervention: a retrospective cohort study

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ABSTRACT

Background ST-segment elevation myocardial infarction (STEMI) remains a major cause of morbidity and mortality. Primary percutaneous coronary intervention (PPCI) is the preferred treatment, yet some patients experience major adverse cardiac events (MACE) within a year despite successful recanalisation. Identifying predictors of futile recanalisation—defined as achieving thrombolysis in myocardial infarction grade III flow after PPCI but still developing MACE—is essential for improving outcomes.

Research design and methods This single-centre, retrospective study included patients with STEMI treated with PPCI from January 2019 to January 2023. The primary outcome was futile recanalisation. Least absolute shrinkage and selection operator (LASSO) regression and logistic regression were used to identify independent predictors of futile recanalisation.

Results Of the 489 consecutive patients who achieved successful recanalisation, 20.9% met the criteria for futile recanalisation within 1 year. Multivariable analysis identified several independent predictors: heart rate at admission (OR 1.32, 95% CI 1.02 to 1.71), reduced left ventricular ejection fraction (LVEF; OR 0.30, 95% CI 0.22 to 0.41), advanced left ventricular diastolic dysfunction (OR 1.44, 95% CI 1.02 to 2.15), elevated cardiac troponin I (CTnI) levels (OR 1.42, 95% CI 1.08 to 1.90), high Selvester QRS scores (OR 1.59, 95% CI 1.20 to 2.13) and increased homocysteine (HCY) levels (OR 1.37, 95% CI 1.07 to 1.77).

Conclusion Despite successful recanalisation, certain factors—high admission heart rate, low LVEF, advanced left ventricular diastolic dysfunction, elevated CTnI levels, high Selvester QRS scores, and increased HCY levels—are associated with futile recanalisation in patients with STEMI. These findings highlight the need for targeted monitoring and management strategies to reduce long-term MACE risks in this population.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This study included detailed assessments of cardiac function parameters and biochemical markers to identify predictors of major adverse cardiac events.
⇒ Least absolute shrinkage and selection operator regression and multivariable logistic regression were applied to select independent risk factors while minimising multicollinearity.
⇒ The retrospective single-centre design may introduce selection bias, limiting the generalisability of the findings.
⇒ The study population consisted exclusively of Chinese patients, which may restrict applicability to other ethnic groups.
⇒ Only baseline biomarker levels were analysed without evaluating their dynamic changes over time.

INTRODUCTION

ST-segment elevation myocardial infarction (STEMI) remains a critical cardiovascular emergency, posing a substantial burden on global public health due to its high mortality and morbidity rates.[1 2] Globally, acute myocardial infarction (AMI) affects approximately 7–9 million people annually,[3] with STEMI accounting for nearly 30% of cases.[4] In China, the incidence of AMI continues to rise, with an estimated 2.5 million new cases each year and in-hospital mortality rates ranging from 4.6% to 10.2%.[5] Despite advancements in primary percutaneous coronary intervention (PPCI), up to 20%–30% of patients with STEMI experience major adverse cardiovascular events (MACE) within 1 year.[2] This underscores the persistent challenges in optimising post-STEMI outcomes and highlights the need for a deeper understanding of the factors influencing long-term prognosis.

Despite achieving successful recanalisation through PPCI, a considerable proportion of patients with STEMI still face adverse events such as heart failure (HF), malignant arrhythmias and recurrent myocardial infarction within 1 year.[4 6] This phenomenon suggests that the effectiveness of PPCI may be limited by factors beyond procedural success.[7]

Identifying these predictors is essential for improving risk stratification, guiding individualised management and reducing the burden of long-term complications.

Previous studies have investigated various predictors of outcomes in patients with STEMI, such as age, diabetes and hypertension, but many have focused on short-term endpoints or overall populations without differentiating those who achieved successful recanalisation.[8 9] Moreover, the role of factors such as systemic inflammation and myocardial injury biomarkers in determining long-term MACE remains underexplored in this specific subgroup.

This study aims to address these gaps by investigating the incidence and predictors of 1 year MACE in patients with STEMI who have undergone successful recanalisation. By elucidating the key determinants of adverse outcomes in this population, the findings of this study may provide critical insights to guide clinicians in identifying high-risk patients, implementing targeted interventions and ultimately improving long-term outcomes for STEMI survivors.

METHOD

Study population

This study was a single-centre study that included patients with AMI treated with PPCI from January 2019 to January 2023. Patients meeting the following criteria were included in this study: age ≥18 years, time from symptom onset to hospital visit (onset-to-door time) ≤12 hour, meeting the diagnostic criteria for acute ST-elevation myocardial infarction (STEMI) and receiving PPCI treatment. The exclusion criteria consisted of (1) prior history of myocardial infarction; (2) severe liver or kidney dysfunction (defined as Child-Pugh class C liver disease or estimated glomerular filtration rate ((eGFR) <30 mL/min/1.73 m²), severe infection (defined as an active infection requiring intravenous antibiotics or associated with sepsis) or malignancy; (3) coexisting valvular heart disease, pulmonary heart disease or cardiomyopathy; (4) in-hospital mortality and (5) incomplete baseline data with missing rates exceeding 5%. In this study, we further excluded patients with final thrombolysis in myocardial infarction (TIMI) grading evaluation criteria 0-II.

Data collection

During hospitalisation, demographic, clinical and laboratory data were retrospectively collected. Body mass index was calculated as weight in kilograms divided by height squared in metres (kg/m^2).[10] Killip classification was determined based on clinical signs of HF at admission, including blood pressure, rales, pulmonary oedema and cardiogenic shock.[11] The TIMI grading evaluation criteria were assessed after PPCI as follows: Class 0 indicated no blood perfusion in the infarct-related artery (IRA) with occlusion of distal vessels and no blood flow; Class I showed contrast medium partially going through the IRA with distal stenosis of the coronary artery without blood flow; Class II displayed distal stenosis of the coronary artery that could be completely filled in, but with slow development and slow elimination of the contrast agent; Class III demonstrated the contrast agent rapidly filling the distal coronary artery and being completely eliminated, similar to normal coronary artery blood flow. Vascular mechanical obstruction eradication was confirmed, with no artery dissection or spasm.[12 13] A TIMI grading of II or less indicated no reflow in AMI. Two qualified operators, who were blinded to the clinical findings, examined the angiographic recordings. Left ventricular ejection fraction (LVEF), left ventricular posterior wall thickness, interventricular septum thickness and left ventricular diastolic function (LVDF) grading were assessed using two-dimensional echocardiography. This assessment was performed during the postprocedure recovery period, within 3–6 days after PPCI, to allow for stabilisation and minimise acute procedural effects on cardiac function. The Selvester score, evaluated in ECGs and also measured within 3–6 days post-PPCI, was calculated according to the 2011 guidelines, which uses 54 criteria, including the assessment of Q wave duration, R wave duration and the R/Q and R/S amplitude ratios in leads I, II, Left Arm Lead (aVL), Foot Lead (aVF) and V1–V6 of a standard 12-lead ECG.[14] The SYNTAX score, derived from coronary angiography, evaluates the complexity of coronary artery disease in 16 coronary segments. The total score was computed using a dedicated online system (http://www.syntaxscore.com/) created for this specific task.[15]

We also collected laboratory data including cardiac troponin I (CTnI) level, peak creatine kinase myocardial band, N-terminal probrain natriuretic peptide, total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, serum creatinine, C reactive protein, homocysteine (HCY), platelet distribution width and neutrophil-to-lymphocyte ratio (NLR). These tests were conducted before PPCI.

Treatment

All patients received antiplatelet therapy prior to PPCI, including aspirin (300 mg), clopidogrel (600 mg) or ticagrelor (180 mg) orally. Coronary angiography was performed using the percutaneous method to identify the IRA. Based on angiographic findings, all patients underwent vascular interventional therapy, with drug-eluting stents implanted whenever feasible using direct techniques.

To enhance reperfusion, thrombus aspiration was followed by balloon inflation at the proximal lesion site, set at a pressure of 4–6 atm for 60 s, with subsequent post-dilation to optimise vessel patency. This approach minimised the risk of embolisation from ruptured plaques. The inflation–deflation sequence was tailored to the surgeon's intraoperative assessment. Additionally, the administration of IIb/IIIa inhibitors (abciximab or eptifibatide) was guided by the thrombotic load and disease severity observed during the procedure. Informed consent for treatment was obtained from all patients prior to intervention.

In China, the management of AMI, particularly STEMI, follows a standardised prehospital and in-hospital care system. The prehospital phase involves an emergency medical service (EMS) network that facilitates early diagnosis and rapid transportation to PPCI-capable hospitals. In Anhui province, a regional STEMI network integrates EMS with tertiary hospitals, enabling prehospital ECG transmission and direct activation of catheterisation labs for PPCI. In-hospital management follows the China Chest Pain Center guidelines. All patients enrolled in this study received standard in-hospital care per these national guidelines.

Outcome

Patients were followed up from the time of discharge through outpatient visits and/or telephone contacts using a standard questionnaire. MACE included a composite of all-cause mortality, non-fatal reinfarction, hospitalisation for HF and non-fatal ischaemic stroke. The primary outcome of this study was futile recanalisation, defined as achieving a TIMI grade III classification after PPCI treatment, but experiencing MACE within 1 year.

Statistical analysis

In the study, continuous variables were presented as means±SD or medians (IQR), while categorical variables were displayed as frequencies (percentages). T-tests or Mann-Whitney U tests were employed to compare continuous variables, and χ^2 or Fisher's exact tests were used for comparing categorical variables. To address multicollinearity, we employed the least absolute shrinkage and selection operator (LASSO) regression method. Variables with a p value <0.10 in the univariate analysis were included in the LASSO regression to identify the factors associated with futile recanalisation. LASSO introduces a penalty term to the regression coefficient, allowing it to shrink towards zero as the penalty term increases.

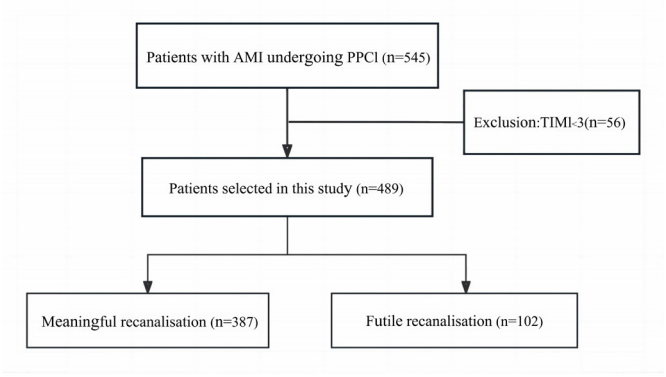

Figure 2 Flowchart. AMI, acute myocardial infarction; PPCI, primary percutaneous coronary intervention; TIMI, thrombolysis in myocardial infarction.

Figure 1A illustrates the coefficient shrinkage with rising lambda (the penalty term's coefficient). Figure 1B demonstrates how we determined the optimal lambda. Subsequently, a backward stepwise regression analysis was performed to establish a final model containing variables that best explained the outcome. The statistical analysis was carried out using R (V.4.1.3). A significance level of p <0.05 (two sided) was considered statistically significant.

RESULTS

In this study, we included 489 patients with STEMI who underwent PPCI and achieved successful recanalisation (figure 2). Successful recanalisation improved the prognosis of 79.1% of patients, but 20.9% of patients still experienced MACE at 1 year. Among all patients, 77.3% were men, with a median age of 61 (IQR, 51–70) years. 26.8% of patients had Killip classification >I, with LVEF at 57 (IQR, 49–62).

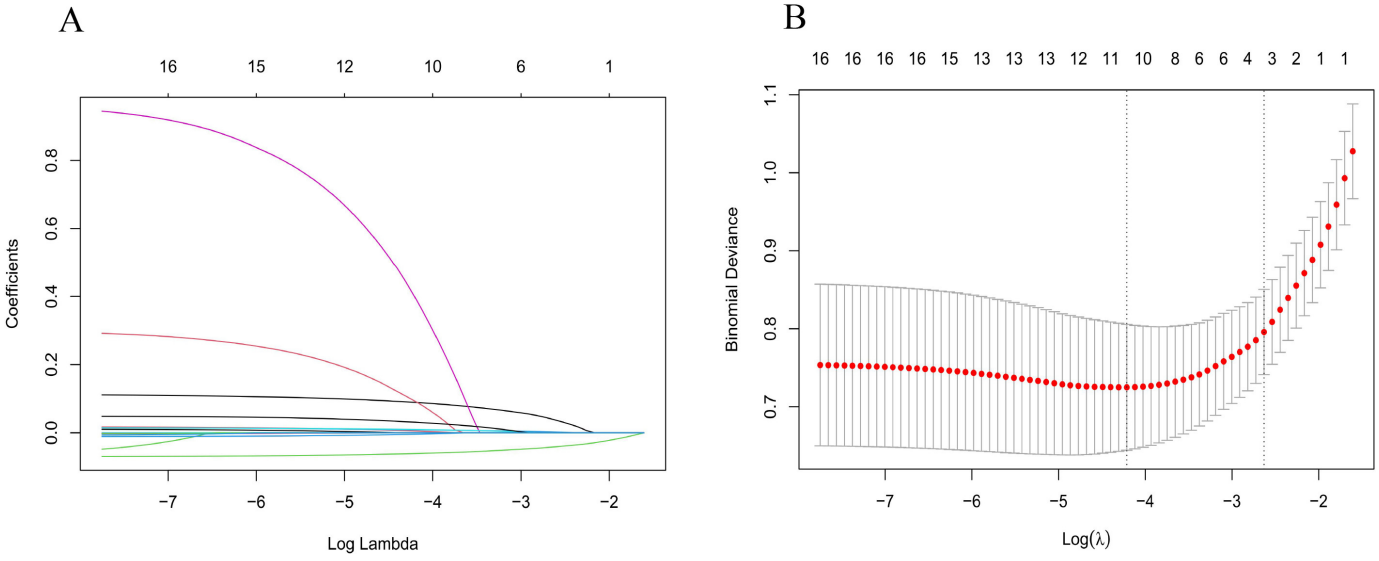

Figure 1 Least absolute shrinkage and selection operator regression analysis employing 10-fold cross-validation to identify predictors of futile recanalisation in patients with acute myocardial infarction who underwent primary percutaneous coronary intervention.

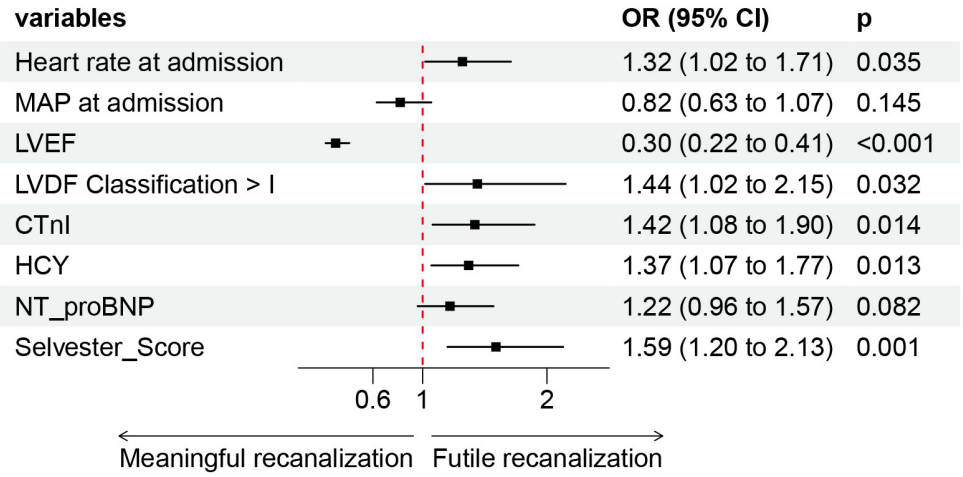

Figure 3 The predictors of futile recanalisation in patients with acute myocardial infarction who underwent primary percutaneous coronary intervention. CTnI, cardiac troponin I; HCY, homocysteine; LVDF, left ventricular diastolic function; LVEF, left ventricular ejection fraction; MAP, mean arterial pressure; NT-proBNP, N-terminal probrain natriuretic peptide

Compared with the meaningful recanalisation group, patients in the futile recanalisation group were older (median age 64 vs 59 years, p=0.009), had higher admission heart rates (median 88 bpm vs 78 bpm, p<0.001), lower mean arterial pressures (median 96 mm Hg vs 100.7 mm Hg, p=0.015) and a higher proportion of Killip classification >I (48% vs 21.2%, p<0.001) (online supplemental table S1).

Laboratory findings revealed significantly elevated levels of CTnI (median 16.98 vs 2.72, p<0.001) and HCY (median 15.70 vs 13.30, p<0.001) in the futile recanalisation group, along with higher Selvester scores (median 11.5 vs 6.0, p<0.001) and a greater prevalence of advanced LVDF classification (94.1% vs 83.5%, p=0.01) (online supplemental table S1).

Using LASSO regression followed by multivariable logistic regression analysis (figure 3), we identified six independent predictors of futile recanalisation: elevated admission heart rate (OR 1.32, 95% CI 1.02 to 1.71), reduced LVEF (OR 0.30, 95% CI 0.22 to 0.41), advanced LVDF classification (OR 1.44, 95% CI 1.02 to 2.15), increased CTnI (OR 1.42, 95% CI 1.08 to 1.90), higher Selvester scores (OR 1.59, 95% CI 1.20 to 2.13) and elevated HCY levels (OR 1.37, 95% CI 1.07 to 1.77]).

DISCUSSION

In this study, we investigated the incidence and predictors of MACE within 1 year in patients with AMI who underwent successful PPCI recanalisation. Despite achieving angiographic success, ~20.9% of patients still experienced MACE during follow-up, underscoring that successful recanalisation alone may not ensure favourable long-term outcomes for all patients with AMI. Our findings emphasise the importance of identifying additional risk factors associated with adverse outcomes to guide personalised management in this population.

Several factors were found to independently predict poor clinical outcomes despite successful recanalisation. Notably, increased heart rate at admission, reduced LVEF, advanced LVDF classification, elevated Selvester scores, high CTnI and HCY levels were associated with an elevated risk of futile recanalisation. These predictors provide valuable insights into the pathophysiological mechanisms that may underlie poor prognosis in successfully recanalised patients.

The observed relationship between high admission heart rate and futile recanalisation aligns with previous research linking elevated heart rate to adverse cardiovascular outcomes.[16 17] An elevated heart rate is a well-established marker of increased cardiovascular risk and may indicate heightened sympathetic nervous system activation or an acute stress response.[18 19] This increase in sympathetic tone is associated with several detrimental effects on the myocardium, particularly in patients recovering from AMI. This may be related to the following mechanisms: (1) a higher heart rate directly raises myocardial oxygen consumption as the heart needs to work harder and faster. This increased demand for oxygen, especially in the setting of compromised coronary blood flow or partial myocardial injury, may create an imbalance between oxygen supply and demand.[20 21] This imbalance can exacerbate ischaemia, particularly in areas of the myocardium already affected by infarction. (2) Elevated heart rate shortens the diastolic phase of the cardiac cycle, during which coronary perfusion primarily occurs.[22] Reduced diastolic time limits blood flow to the coronary arteries, diminishing oxygen delivery to the myocardium precisely when demand is high.[22] This mechanism can worsen ischaemia and impede recovery of injured myocardial tissue, leading to adverse remodelling. (3) Sympathetic activation and elevated HR are associated with heightened electrical instability within the myocardium, predisposing patients to arrhythmias. Conditions such as ventricular tachycardia and fibrillation are particularly concerning in the post-AMI setting as they significantly increase the risk of sudden cardiac death.

Additionally, recurrent arrhythmias place further strain on myocardial tissue, worsening damage and reducing cardiac efficiency. (4) Increased sympathetic activity can stimulate proinflammatory and oxidative stress pathways, further contributing to myocardial injury and adverse remodelling.[23] Elevated levels of inflammatory cytokines and oxidative stress markers in patients with higher HR may indicate ongoing damage to myocardial tissue, even after successful PPCI, increasing the risk of HF and other MACE. (5) Persistent tachycardia and sympathetic overdrive can lead to maladaptive left ventricular remodelling, characterised by increased wall stress, fibrosis and ventricular dilation. This process gradually reduces left ventricular function, worsening ejection fraction and contributing to the development of HF. Poor ventricular function is strongly linked to higher long-term mortality and morbidity in post-AMI patients.

Our study also identified reduced LVEF as a strong predictor of MACE, consistent with its established role as a key indicator of myocardial function and prognosis in patients with AMI.[24] Low LVEF may signify extensive myocardial injury, decreased myocardial contractility and elevated risk of HF, which can negatively impact recovery even after successful PPCI.[25] The significance of advanced LVDF classification further highlights the impact of impaired cardiac function on long-term outcomes, as LVDF is a critical factor in diastolic HF and myocardial stiffness, both of which contribute to adverse remodelling.[26]

The Selvester score, which estimates the extent of myocardial scarring through QRS complex alterations on the ECG, was an independent predictor of MACE in our study. A higher Selvester score indicates a greater burden of myocardial scarring, reflecting fibrotic remodelling and structural changes that can impair ventricular function and increase susceptibility to arrhythmias.[27] These findings suggest that quantifying myocardial scarring may offer valuable prognostic insights into the likelihood of adverse events following successful PPCI.

Elevated levels of CTnI and HCY were similarly associated with an increased risk of MACE. CTnI, a well-established biomarker of myocardial injury, reflects the extent of cardiac muscle damage. Even after successful revascularisation in patients with STEMI, persistent low-level elevations in CTnI suggest ongoing subclinical myocardial injury, especially when microvascular recovery is incomplete or microvascular dysfunction persists.[28] Elevated HCY levels are associated with vascular damage, promoting atherosclerosis and thrombogenesis through oxidative stress and inflammation.[29 30] In the context of STEMI, elevated HCY further underscores the ongoing vascular stress and its contribution to adverse cardiovascular outcomes.

This study's results have several clinical implications. First, the identification of these risk factors allows clinicians to stratify patients more effectively based on their risk of MACE following PPCI. Variables such as high admission heart rate, reduced LVEF, advanced LVDF classification, elevated CTnI levels, high Selvester QRS scores and increased HCY levels can be integrated into routine clinical assessments to identify high-risk individuals. These patients may benefit from closer postdischarge monitoring, personalised pharmacological strategies (eg, beta-blockers for heart rate control, statins for lipid management and ACE inhibitors to improve cardiac remodelling), or more intensive lifestyle interventions such as smoking cessation and dietary adjustments. Moreover, our findings highlight the importance of a holistic and comprehensive approach to post-PPCI management that extends beyond achieving angiographic success. Functional markers, such as LVEF and LVDF classification, haemodynamic parameters like admission heart rate, and biochemical markers, including CTnI and HCY, should all be considered as part of a multidimensional evaluation framework. This integrative strategy enables healthcare providers to address both residual ischaemic risk and secondary prevention needs, optimising long-term outcomes for patients with STEMI. Additionally, the incorporation of these predictors into existing risk stratification tools or clinical algorithms could aid in the early identification of patients at elevated risk for adverse outcomes, facilitating timely interventions. Future research should focus on validating these predictors in diverse populations and investigating targeted interventions aimed at mitigating the risks identified in high-risk groups.

This study has several limitations. First, being a single-centre, retrospective cohort study, it may be subject to selection bias and inherent biases. Second, we only assessed baseline levels of key biomarkers, such as CTnI and HCY, without examining their dynamic changes over time. This limitation reduces the comprehensiveness of our analysis and prevents a more nuanced understanding of their role in long-term outcomes. Finally, the study was conducted in a specific cohort of patients with STEMI, and the results may not apply to different ethnic groups or healthcare contexts. To enhance the generalisability of these findings, further multicentre studies involving diverse populations are needed. Additionally, future prospective trials should evaluate the impact of targeted interventions based on these identified predictors to determine their clinical value in improving patient outcomes.

Conclusion

In conclusion, our study highlights that successful PPCI recanalisation does not uniformly prevent adverse outcomes in patients with AMI, and several clinical and biochemical factors significantly influence prognosis. Identifying these high-risk patients early can lead to more tailored and effective post-PPCI management strategies, potentially improving long-term survival and quality of life in this vulnerable patient group.

Contributors XP, WD and ZL designed the study and initial analysis plan. XP, WD and ZL contributed to the statistical analysis, performed the data analysis and wrote the draft of the manuscript. All authors contributed to revision of the manuscript. All authors participated in data collection, analysis and interpretation. All authors critically reviewed this and subsequent drafts. All authors approved the final draft for submission. ZL is the guarantor.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Consent obtained directly from patient(s)

Ethics approval This study involves human participants and was approved by the Ethics Committee of the Second Affiliated Hospital of Anhui Medical University (Approval No. YX2022-001). Due to its retrospective nature, informed consent from patients was waived.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request.

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