

Original Article

Predictive value of modified early warning score and risk stratification for adverse cardiovascular events in acute chest pain patients

Caihong Hu^{1*}, Dongqiao Zhang^{2*}, Ying Chen³, Xiaojing Zhuang¹, Zhenfa Xian¹, Shaolin Chen⁴

¹Department of Emergency, The People's Hospital of Pingshan Shenzhen (Pingshan Hospital, Southern Medical University), Shenzhen 518100, Guangdong, China; ²Department of Emergency, The Fifth People's Hospital of Longgang District, Shenzhen 518111, Guangdong, China; ³Department of Geriatric Medicine, The People's Hospital of Pingshan Shenzhen (Pingshan Hospital, Southern Medical University), Shenzhen 518100, Guangdong, China; ⁴Department of Emergency, Shenzhen People's Hospital (The First Affiliated Hospital, Southern University of Science and Technology; The Second Clinical Medical College, Jinan University), Shenzhen 518020, Guangdong, China. *Co-first authors.

Received July 9, 2025; Accepted September 20, 2025; Epub October 15, 2025; Published October 30, 2025

Abstract: Objective: To assess the prognostic value of the modified early warning score (MEWS) in predicting major adverse cardiovascular events (MACE) within one month of admission, compared to established cardiac risk scores. Methods: This retrospective study included 565 adults with acute chest pain who visited the Emergency Department between January 2023 and January 2024. Baseline demographics, medical history, vital signs, and clinical scores were collected. Patients were classified based on the occurrence of MACE - defined as cardiac death, ST-segment elevation myocardial infarction (STEMI), non-ST-segment elevation myocardial infarction (NSTEMI), or coronary revascularization - within one month. Results: Of the 565 patients, 112 (19.8%) experienced MACE. Patients in the MACE group had significantly higher clinical scores (all $P < 0.05$). The MEWS score exhibited the strongest association with MACE ($\rho = 0.451$, $P < 0.001$) and remained a significant predictor in multivariate logistic regression (odds ratio = 4.416; 95% CI, 3.006-6.488; $P < 0.001$). MEWS demonstrated the highest discriminative ability (area under the curve [AUC] = 0.826) compared to other scores tested. Random forest analysis confirmed MEWS as the most important predictor of MACE. Conclusion: The MEWS score outperforms traditional cardiac risk assessment tools in early prediction of major adverse cardiovascular events in acute chest pain patients. Its use could enhance risk stratification and inform clinical decision-making in emergency settings.

Keywords: Acute chest pain, modified early warning score, major adverse cardiovascular events, risk stratification, emergency department, prognostic scores

Introduction

Acute chest pain is a common and challenging complaint in the Emergency Department (ED), accounting for approximately 5% to 10% of emergency visits. Many of these patients may be facing life-threatening conditions such as acute coronary syndromes (ACS), pulmonary embolism, aortic dissection, among others [1]. While most chest pain cases are eventually found to be benign, timely and accurate risk stratification is essential for identifying high-risk patients, ensuring they receive appropriate urgent interventions, avoiding unnecessary

hospitalizations, and optimizing resource utilization [2].

Current tools for risk assessment in acute chest pain include widely used scoring systems such as the history, electrocardiogram (ECG), age, risk factors, and troponin (HEART) score, the global registry of acute coronary events (GRACE) score, and the thrombolysis in myocardial infarction (TIMI) score [3, 4]. These scoring systems integrate history, clinical signs, electrocardiographic changes, and cardiac biomarkers to estimate the risk of short-term and long-term adverse cardiovascular outcomes

[5]. However, these tools rely on detailed history-taking, laboratory results, and imaging studies, which can delay initial assessment and treatment decisions, especially in resource-limited or overcrowded EDs [6].

The Modified Early Warning Score (MEWS) is a simple composite scoring system based on vital signs (temperature, heart rate, systolic blood pressure, respiratory rate, and level of consciousness). It does not depend on medical history, laboratory results, or imaging studies [7]. Originally designed to detect early clinical deterioration in hospitalized patients, MEWS alerts healthcare providers to impending physiological decompensation, triggering timely escalation of care [8]. Unlike disease-specific scores, MEWS reflects the patient's overall physiological vulnerability, capturing disturbances caused by various acute insults, such as infections, hypovolemia, cardiac instability, and respiratory insufficiency [9]. Its simplicity and immediate availability make MEWS particularly well-suited for resource-limited settings and busy EDs.

Recent studies have shown that MEWS is effective not only in general hospital populations but also in predicting adverse outcomes across various acute medical and surgical conditions, including sepsis and trauma [10, 11]. However, data on the role of MEWS in acute chest pain, particularly in predicting major adverse cardiovascular events (MACE) - including myocardial infarction, the need for coronary revascularization, or cardiovascular death - remain limited. Additionally, its predictive performance compared to other established cardiac-specific risk scores in this clinical setting has not been fully elucidated [12]. This highlights the need for further investigation into MEWS's utility in acute chest pain, especially concerning its effectiveness in predicting MACE and its comparative performance against existing risk stratification tools.

Given the urgent need for a rapid and widely applicable risk stratification tool in the triage of acute chest pain, evaluating MEWS in this high-risk patient group is both timely and clinically relevant. This study aims to explore the relationship between MEWS scores and disease risk stratification in acute chest pain patients, assessing its predictive value for adverse cardiovascular events. By comparing MEWS with

established cardiac risk scores, this study will clarify the relative performance of a physiology-based, readily accessible scoring system and provide insights into strategies for the early identification and management of high-risk acute cardiac event patients. We aim to demonstrate that MEWS is an effective and user-friendly risk stratification tool, crucial for early management and risk assessment in acute chest pain patients. The unique advantage of MEWS lies in its simplicity and immediate availability, enabling swift application during busy periods in the ED and in resource-limited settings, thereby enhancing the quality and efficiency of clinical decision-making, improving patient outcomes.

Materials and methods

Case selection

This retrospective case-control study included 565 patients with acute chest pain who visited the ED of the People's Hospital of Pingshan Shenzhen between January 2023 and January 2024. Patients were identified through a systematic search of the hospital's electronic medical record (EMR) system using keywords such as "acute chest pain", "emergency visit", and "admission".

Inclusion criteria: (1) Age ≥ 18 years and < 90 years; (2) Symptoms occurred within the past 24 hours and the patient was diagnosed with acute chest pain, including compression, stabbing pain, dullness, burning, or tightness [13]; (3) First occurrence of acute chest pain, lasting more than 30 minutes; (4) Suspected by the attending physician of ACS; (5) Elevated levels of myocardial injury markers (troponin, creatine kinase isoenzyme); (6) Complete case records.

Exclusion criteria: (1) Chest pain related to other clear causes (e.g., emphysema, trauma history, gastroesophageal reflux disease, pneumonia, rheumatic heart disease, aortic dissection, or cancer); (2) Patients whose vital signs were absent upon admission; (3) Patients with missing clinical scoring data; (4) Mental illness patients who are unable to cooperate with research.

Demographic information, medical history, vital signs, and other relevant data were collected through the case system. All procedures involv-

MEWS predicts chest pain risk

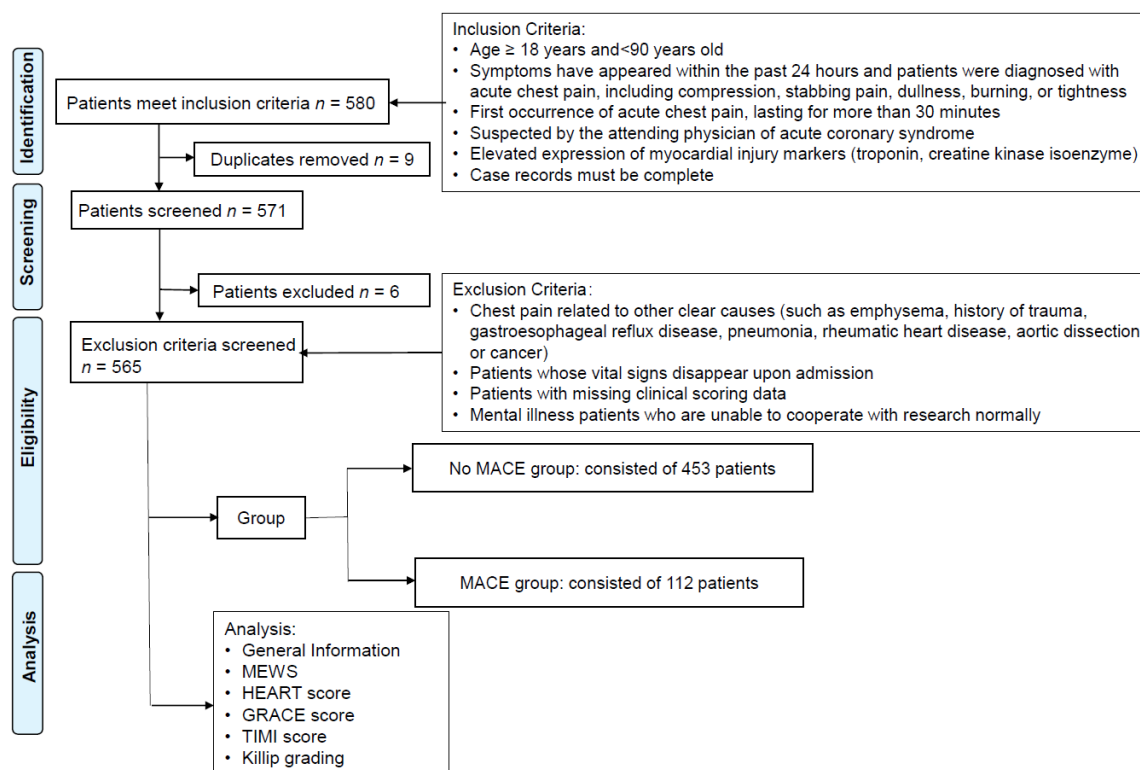


Figure 1. Research and Design Flowchart. Note: MACE: Major Adverse Cardiovascular Events; MEWS: Modified Early Warning Score; HEART: History, ECG, Age, Risk factors, and Troponin; GRACE: Global Registry of Acute Coronary Events; TIMI: Thrombolysis in Myocardial Infarction.

ing human participants followed the ethical guidelines of the Helsinki Declaration. This study was approved by the Ethics Review Committee of the People's Hospital of Ping-shan Shenzhen. Given its retrospective design and use of anonymized patient data, the requirement for informed consent was waived according to relevant regulations (Figure 1).

Grouping criteria

MACE are defined as cardiac death, STEMI, NSTEMI, or coronary revascularization procedures. Coronary revascularization includes percutaneous coronary intervention (PCI) and coronary artery bypass grafting (CABG). Based on the occurrence of MACE within one month after admission, patients were divided into two groups: the No MACE group ($n = 453$) and the MACE group ($n = 112$). Patients who did not experience any adverse cardiovascular events within one month after admission were assigned to the No MACE group, while patients who experienced one or more MACE events

within one month were assigned to the MACE group.

Data collection

Primary index and secondary indexes: The primary index is the MEWS score, while secondary indexes include the HEART score, GRACE score, TIMI score, and their respective risk stratifications, as well as the Killip classification. Vital signs data recorded during the first admission were used to calculate the MEWS score, HEART score, GRACE score, TIMI score, and their respective risk stratifications. The patient's Killip classification was determined by the ED physician at the time of admission.

Baseline data collection: Data extraction was performed by one independent reviewer using a standardized form to ensure consistency and accuracy. All data were cross-verified with the original EMR entries. The collected general information included a medical history questionnaire (covering conditions such as hyper-

tension, diabetes, coronary heart disease, etc.) and demographic details (age, gender). Baseline vital signs upon admission (including fasting blood glucose, blood pressure, pulse rate, blood oxygen saturation, and respiratory rate) were also recorded.

MEWS: The MEWS score is used to assess the severity of a patient's condition. It consists of five physiological indicators: body temperature, systolic blood pressure, heart rate, respiratory rate, and level of consciousness (AVPU) [14]. Each parameter is assigned a score from 0 to 3 based on its deviation from the normal range, with higher scores indicating more severe clinical concern. Specifically, systolic blood pressure scores range from 3 for pressures below 70 mmHg or above 200 mmHg, to 0 for pressures between 101-199 mmHg. Heart rate scoring ranges from 2 for rates below 40 bpm or above 130 bpm, to 0 for rates between 51-100 bpm. Respiratory rate receives a score of 0 for normal values between 9-14 breaths per minute, while temperatures below 35°C or above 38.5°C are flagged with a score of 2. Finally, consciousness level is scored from alert (0) to unresponsive (3). The total MEWS score is the sum of the individual parameter scores, with a higher total indicating a more severe condition. Scores of 0-1 indicate low risk, 2-3 indicate moderate risk, and ≥ 4 indicates high risk. The MEWS tool had a Cronbach's alpha of 0.826 [15].

HEART: The HEART score includes five variables: patient history, electrocardiogram (ECG) findings, age, risk factors, and troponin levels. Each variable is assigned a score of 0 to 2 points, resulting in a maximum total of 10 points. A cumulative score of 0-3 indicates low risk; 4-6 points suggest moderate risk; and 7-10 points denote high risk. The history variable can score up to 2 points for highly suspicious symptoms; ECG abnormalities, such as significant ST depression, score 2 points; age over 65 years scores 2 points; the presence of three or more risk factors or atherosclerotic disease history scores 2 points; and troponin levels $\geq 3\times$ the normal limit score 2 points.

GRACE: The GRACE score is based on several factors, including the patient's age, heart rate, systolic blood pressure, creatinine level, Killip classification, and eight other variables. It is used to assess the risk of patients with acute

chest pain. A total score of less than 108 indicates low risk; a score of 109 to 140 indicates moderate risk; and a score of 140 or above indicates high risk. Age scores range from 0 for patients under 30 years to 100 for those aged 90 years or older. Heart rate scores range from 0 for rates below 50 bpm to 46 for rates above 200 bpm. Systolic blood pressure scores range from 58 for pressures below 80 mmHg to 0 for pressures ≥ 200 mmHg. Creatinine levels are scored from 1 for values up to 35 $\mu\text{mol/L}$ to 28 for levels ≥ 352 $\mu\text{mol/L}$. Killip class scores increase with worsening heart failure, ranging from 0 for class I to 59 for class IV. Additionally, elevated cardiac biomarkers and ST-segment deviations add 14 and 28 points, respectively, while a history of cardiac arrest adds 39 points.

TIMI: The TIMI score consists of seven binary prognostic factors: age ≥ 65 , ≥ 3 CAD risk factors (hypertension, hyperlipidemia, diabetes, family history, smoking), significant coronary artery stenosis, severe angina symptoms, ST-segment deviation, elevated cardiac enzymes, and aspirin use in the last 7 days. Each factor scores 1 if present and 0 if absent. The total score ranges from 0 to 7, with 0 points indicating low risk, 1-2 points indicating moderate risk, and 3-7 points indicating high risk.

Killip grading: Killip grading is used to classify the severity of heart failure in patients with acute myocardial infarction, with mortality rates of 17.7% (Class I), 27.3% (Class II), 30.4% (Class III), and 48.8% (Class IV). At admission, the attending physician in the ED determines the Killip classification. Specifically, Killip Class I indicates no evidence of heart failure; Class II indicates mild heart failure with rales involving up to one-third of the posterior lung fields and a systolic blood pressure ≥ 90 mm Hg; Class III indicates pulmonary edema with rales affecting more than one-third of the posterior lung fields and a systolic blood pressure ≥ 90 mm Hg; and Class IV indicates cardiogenic shock with any rales and a systolic blood pressure < 90 mm Hg [16].

Outcome measures

The primary outcome measure of this study was the occurrence of MACE within one month after admission. Secondary outcomes included the association between the MEWS score and

disease risk stratification, as well as correlations with other clinical scores (HEART, GRACE, TIMI).

Statistical methods

The sample size for this study was calculated using G*Power software, assuming a medium effect size ($d = 0.5$) and a two-tailed significance level ($\alpha = 0.05$). A minimum of 88 patients per group were required to reject the null hypothesis of equal means with 95% statistical power when using a two-sided, two-sample t-test with equal variances. Data analysis was performed using SPSS 29.0 statistical software (SPSS Inc., Chicago, Illinois, USA). Categorical data were expressed as [n (%)] and analyzed with the chi-square test. For continuous data with a normal distribution, results were expressed as ($X \pm sd$) and compared using a t-test. Pearson correlation analysis was applied to continuous variables, and Spearman correlation analysis was used for categorical variables. Logistic regression analyses, both univariate and multivariate, were performed to evaluate the association between the MEWS score and disease risk stratification, as well as adverse cardiovascular events. Univariate logistic regression was used to evaluate the independent effects of MEWS, HEART, GRACE, TIMI, and Killip Class on adverse cardiovascular events. Variables showing statistical significance in univariate analysis were included in a multivariate logistic regression model to adjust for potential confounding factors and identify independent predictors of treatment response. The results of logistic regression analysis were expressed as odds ratios (OR) with 95% confidence intervals (CI) and corresponding p -values. The AUC values were calculated and compared using the Delong test. A p -value <0.05 was considered statistically significant.

Results

Comparison of general information

No significant differences were found between the No MACE and MACE groups in age, sex distribution, BMI, or most comorbid conditions, including ischemic heart disease, diabetes, hypertension, chronic renal failure, congestive heart failure, respiratory disease, myocardial infarction, previous PCI, or CABG (all $P > 0.05$, **Table 1**). Employment status, marital status,

current residence, and smoking and drinking patterns were also similar between the two groups (all $P > 0.05$). However, dyslipidemia was significantly less frequent in the MACE group compared to the No MACE group ($P = 0.019$). These results suggest that baseline demographic and clinical characteristics were comparable, except for dyslipidemia.

Comparison of clinical characteristics

Patients in the MACE group had significantly higher body temperatures and respiratory rates compared to the No MACE group (both $P < 0.05$, **Table 2**). No significant differences were found in pulse rate, blood pressure, or oxygen saturation at admission (all $P > 0.05$). The use of medications, including aspirin, P2Y12 inhibitors, vitamin K antagonists, and other antiplatelet or anticoagulant agents, was comparable between the groups (all $P > 0.05$).

Comparison of various scores

The MACE group had significantly higher mean MEWS, HEART, GRACE, and TIMI scores compared to the No MACE group (all $P < 0.05$, **Tables 3-6**). The proportion of MACE patients classified as high risk by GRACE and TIMI scores was also significantly higher (both $P < 0.05$). However, there were no significant differences in HEART risk stratification between the groups ($P > 0.05$). Killip class IV was more frequent in the MACE group, while other Killip classes showed no significant differences between groups (all $P < 0.05$, **Figure 2**).

Correlation analysis between MEWS score and disease risk stratification

Correlation analysis showed that the MEWS score was strongly positively associated with disease risk stratification ($\rho = 0.889$, $P < 0.001$), indicating that higher MEWS scores correlated with higher levels of risk (**Figure 3**).

Correlation analysis between various scores and MACE in acute chest pain patients

The MEWS score showed the strongest positive correlation with MACE occurrence ($\rho = 0.451$, $P < 0.001$), followed by MEWS disease risk stratification ($\rho = 0.324$, $P < 0.001$). Modest positive correlations were also observed between MACE and higher respiratory

MEWS predicts chest pain risk

Table 1. Comparison of general information between the two groups

Parameters	No MACE group (n = 453)	MACE group (n = 112)	t/ χ^2	p
Age (years)	59.74±6.65	60.86±7.44	1.557	0.120
Male gender [n (%)]	256 (56.51%)	63 (56.25%)	0.003	0.960
BMI [kg/m ²]	23.42±3.00	23.13±3.30	0.915	0.361
Medical history [n (%)]				
Ischemic heart disease	174 (38.41%)	51 (45.54%)	1.902	0.168
Diabetes	82 (18.10%)	23 (20.54%)	0.352	0.553
Hypertension	258 (56.95%)	59 (52.68%)	0.666	0.414
Dyslipidemia	246 (54.30%)	47 (41.96%)	5.478	0.019
Chronic renal failure	67 (14.79%)	25 (22.32%)	3.736	0.053
Congestive heart failure	24 (5.30%)	11 (9.82%)	3.162	0.075
Respiratory disease	12 (2.65%)	1 (0.89%)	0.575	0.448
Myocardial infarction	63 (13.91%)	23 (20.54%)	3.057	0.080
PCI	94 (20.75%)	15 (13.39%)	3.122	0.077
CABG	38 (8.39%)	4 (3.57%)	3.028	0.082
Employment Status [n (%)]			0.571	0.450
Employed	286 (63.13%)	75 (66.96%)		
Unemployed	167 (36.87%)	37 (33.04%)		
Marital Status [n (%)]			1.880	0.170
Married	377 (83.22%)	87 (77.68%)		
Divorced	76 (16.78%)	25 (22.32%)		
Current Residence [n (%)]			0.371	0.543
Rural	216 (47.68%)	57 (50.89%)		
Urban	237 (52.32%)	55 (49.11%)		
Smoking [n (%)]			0.123	0.940
Never	90 (19.87%)	23 (20.54%)		
Former	96 (21.19%)	25 (22.32%)		
Current	267 (58.94%)	64 (57.14%)		
Drinking [n (%)]			3.938	0.140
Never	101 (22.30%)	33 (29.46%)		
Former	88 (19.43%)	25 (22.32%)		
Current	264 (58.28%)	54 (48.21%)		

Note: BMI: Body Mass Index; MACE: Major Adverse Cardiovascular Events; PCI: Percutaneous Coronary Intervention; CABG: Coronary Artery Bypass Graft.

Table 2. Comparison of clinical characteristics between the two groups of patients

Parameters	No MACE group (n = 453)	MACE group (n = 112)	t/ χ^2	P
Temperature (°C)	36.32±0.59	36.48±0.67	2.492	0.013
Pulse rate (beats/minute)	79.45±17.42	81.35±15.22	1.055	0.292
Respiratory rate (breaths/minute)	19.45±3.56	20.68±5.67	2.187	0.030
Systolic BP (mmHg)	142.67±28.57	137.61±31.65	1.639	0.102
Diastolic BP (mmHg)	70.15±15.67	67.56±17.18	1.538	0.125
Oxygen saturation (%)	98.11±4.57	97.35±4.35	1.580	0.115
Medication at presentation [n (%)]				
Aspirin	156 (34.44%)	36 (32.14%)	0.211	0.646
P2Y12-inhibitor (clopidogrel)	28 (6.18%)	7 (6.25%)	0.001	0.978
Vitamin K antagonists (coumarin)	47 (10.38%)	11 (9.82%)	0.030	0.863
Other (Dipyridamol, Ticagrelor, DOAC)	21 (4.64%)	6 (5.36%)	0.103	0.749

Note: MACE: Major Adverse Cardiovascular Events; BP: Blood Pressure; DOAC: Direct Oral Anticoagulant.

MEWS predicts chest pain risk

Table 3. Average MEWS score between the two groups of patients

Parameters	No MACE group (n = 453)	MACE group (n = 112)	t/ χ^2	P
MEWS (score)	2.02±0.87	3.42±1.18	11.801	<0.001
MEWS disease risk stratification [n (%)]			65.249	<0.001
low risk	210 (46.36%)	17 (33.04%)		
moderate risk	179 (39.51%)	44 (39.29%)		
high risk	64 (14.13%)	51 (27.68%)		

Note: MEWS: Modified Early Warning Score; MACE: Major Adverse Cardiovascular Events.

Table 4. Average HEART score between the two groups of patients

Parameters	No MACE group (n = 453)	MACE group (n = 112)	t/ χ^2	P
HEART (score)	3.14±1.24	3.55±1.17	3.201	0.001
HEART disease risk stratification [n (%)]			2.075	0.354
low risk	204 (45.03%)	42 (37.5%)		
moderate risk	175 (38.63%)	49 (43.75%)		
high risk	74 (16.34%)	21 (18.75%)		

Note: HEART: History, ECG, Age, Risk factors, and Troponin; MACE: Major Adverse Cardiovascular Events.

Table 5. Average GRACE score between the two groups of patients

Parameters	No MACE group (n = 453)	MACE group (n = 112)	t/ χ^2	p
GRACE (score)	107.63±33.35	116.78±37.26	2.540	0.011
GRACE disease risk stratification [n (%)]			6.616	0.037
low risk	201 (44.37%)	41 (36.61%)		
moderate risk	151 (33.33%)	33 (29.46%)		
high risk	101 (22.3%)	38 (33.93%)		

Note: GRACE: Global Registry of Acute Coronary Events; MACE: Major Adverse Cardiovascular Events.

Table 6. Average TIMI score between the two groups of patients

Parameters	No MACE group (n = 453)	MACE group (n = 112)	t/ χ^2	p
TIMI (score)	1.74±0.78	2.02±0.82	3.371	<0.001
TIMI disease risk stratification [n (%)]			11.360	0.003
low risk	177 (39.07%)	34 (30.36%)		
moderate risk	192 (42.38%)	41 (36.61%)		
high risk	84 (18.54%)	37 (33.04%)		

Note: TIMI: Thrombolysis in Myocardial Infarction; MACE: Major Adverse Cardiovascular Events.

rate, temperature, HEART, GRACE, TIMI scores, and Killip class IV (all $P < 0.05$) (**Table 7**). Additionally, dyslipidemia showed a weak negative correlation with MACE ($\rho = -0.098$, $P = 0.019$).

Feature selection via LASSO regression for prognostic modeling

LASSO regression was used for variable selection. **Figure 4** illustrates the coefficient path of the MEWS score as a function of the L1 norm (**Figure 4A**). This visualization provides in-

sight into how the coefficients of the MEWS score change with varying levels of regularization. The optimal lambda value was determined through cross-validation (**Figure 4B**), aiming to minimize the mean squared error and select non-zero coefficient predictors.

Regression analysis of MACE in acute chest pain patients

Univariate logistic regression identified MEWS score, MEWS disease risk stratification, HEART, GRACE, TIMI scores, and Killip class IV as sig-

MEWS predicts chest pain risk

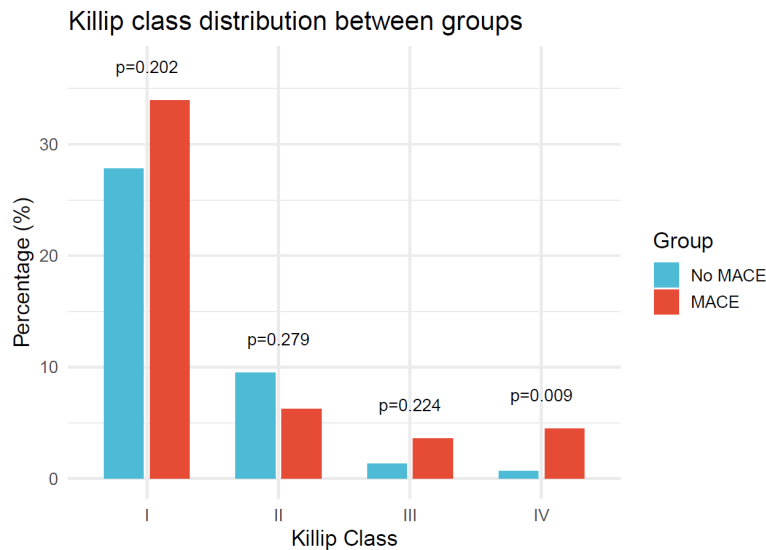


Figure 2. Killip class between the two groups of patients. Note: MACE: Major Adverse Cardiovascular Events.

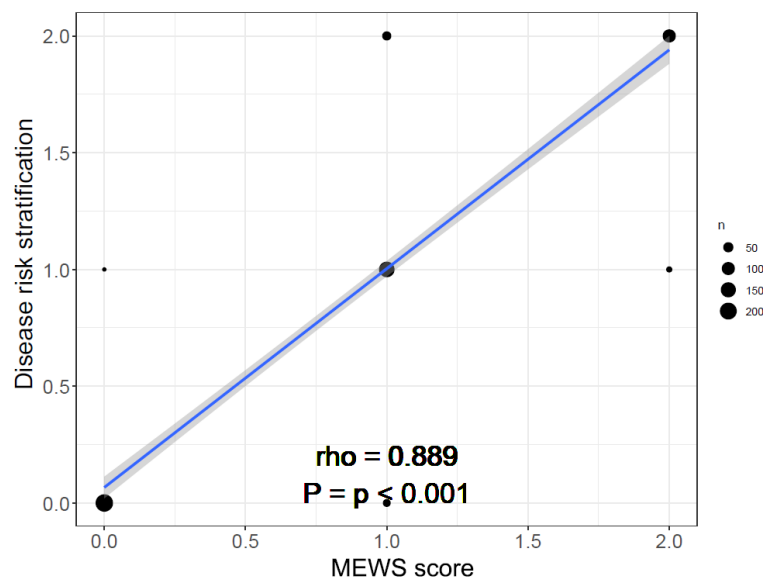


Figure 3. Correlation analysis between MEWS score and disease risk stratification. Note: MEWS: Modified Early Warning Score.

nificant predictors of MACE (all $P < 0.05$) (**Table 8**). Multivariate logistic regression revealed that only the MEWS score remained an independent predictor of MACE (OR = 4.416; 95% CI, 3.006-6.488; $P < 0.001$), while associations observed for other variables, including MEWS disease risk stratification, HEART, GRACE, and TIMI scores, dyslipidemia, temperature, respiratory rate, and Killip class IV, were no longer statistically significant (all $P > 0.05$).

ROC curve analysis of key indicators

ROC curve analysis showed that the MEWS score had the highest discriminative ability for predicting MACE among acute chest pain patients (**Figure 5**). The AUC for HEART, GRACE, and TIMI scores was notably lower.

The predictive role of MEWS score

Random forest analysis confirmed that the MEWS score was the most important predictor of MACE (**Figure 6**). These findings highlight that the MEWS score provides superior sensitivity and specificity in risk stratification for adverse cardiovascular events compared to other conventional scoring systems. In order to further validate the superiority of the combined model over individual parameters, DeLong's test was conducted for each of 4 scoring systems (**Table 9**).

Discussion

The findings of this study highlight the clinical value of the MEWS in the initial risk assessment of patients with acute chest pain and its predictive role for MACE. In modern emergency and cardiology practice, rapid, accurate risk prediction tools that synthe-

size vital physiological parameters are essential for guiding management decisions and improving patient outcomes [17]. While established cardiac risk scores such as HEART, GRACE, and TIMI incorporate patient history, biomarkers, and electrocardiographic parameters, MEWS uniquely relies on immediate, basic clinical data - vital signs and observations - which may explain its particular utility in high-acuity settings [18].

Table 7. Correlation analysis between various scores and MACE in patients with acute chest pain

Variable	Rho	p
Medical history [n (%)]-Dyslipidemia	-0.098	0.019
Temperature (°C)	0.101	0.016
Respiratory rate (breaths/minute)	0.115	0.006
MEWS (score)	0.451	<0.001
MEWS disease risk stratification [n (%)]	0.324	<0.001
HEART (score)	0.126	0.003
GRACE (score)	0.087	0.039
GRACE disease risk stratification [n (%)]	0.092	0.028
TIMI (score)	0.130	0.002
TIMI disease risk stratification [n (%)]	0.118	0.005
Killip class [n (%)]-IV	0.128	0.002

Note: MACE: Major Adverse Cardiovascular Events; MEWS: Modified Early Warning Score; HEART: History, ECG, Age, Risk factors, and Troponin; GRACE: Global Registry of Acute Coronary Events; TIMI: Thrombolysis in Myocardial Infarction.

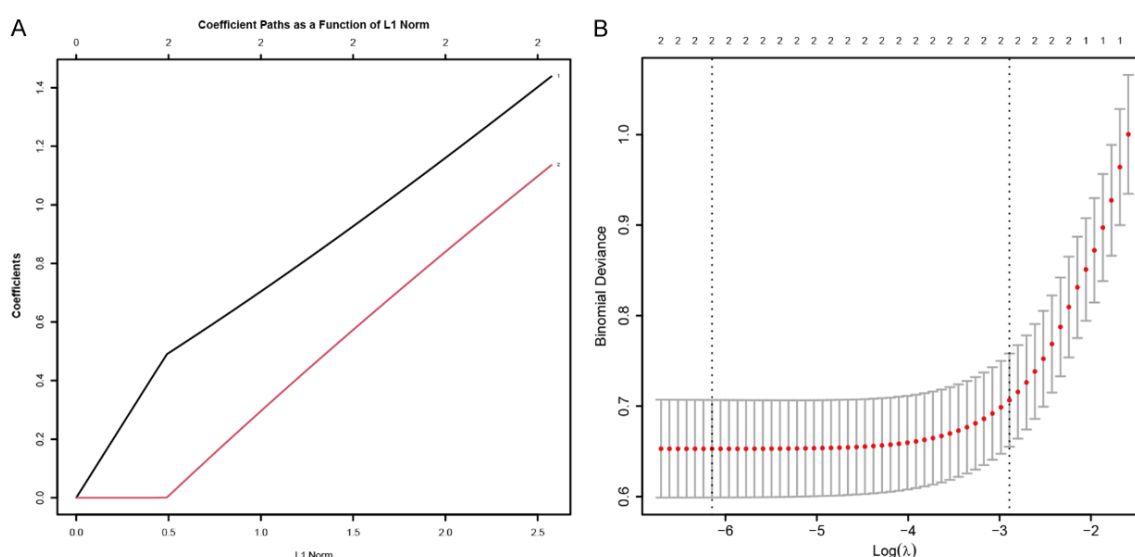


Figure 4. Feature Selection via LASSO Regression for Prognostic Modeling. A. Coefficient Profiles Across the L1 Norm Spectrum; B. Optimal-Lambda Determination via Cross-Validation for LASSO Model. Note: LASSO: Least Absolute Shrinkage and Selection Operator.

Several mechanisms may explain why MEWS outperforms more cardiac-specific risk scores. MEWS integrates temperature, pulse rate, systolic blood pressure, respiratory rate, and level of consciousness - parameters that not only indicate hemodynamic instability but also reflect the body's overall response to acute pathophysiological processes [19]. Acute chest pain is a symptom with a broad differential diagnosis, ranging from ACSs to pulmonary embolism, aortic dissection, sepsis, and non-cardiac causes such as metabolic and stress-induced syndromes [20]. Many life-threatening

conditions presenting with chest pain share a final common pathway of systemic compromise, reflected in abnormal vital signs [21]. Therefore, a scoring system like MEWS, which is independent of etiology, may be more sensitive in identifying patients at greatest risk, regardless of specific clinical diagnoses [22].

Pathophysiologically, abnormalities in vital signs, such as tachypnea, tachycardia, hypotension, and altered mental status, represent signs of impaired oxygen delivery, poor perfusion, and metabolic stress [23]. These abnor-

MEWS predicts chest pain risk

Table 8. Regression analysis of MACE in acute chest pain patients

Parameters	Assignment of values	Univariate analysis			Multivariate analysis		
		P	OR	95% CI	P	OR	95% CI
Medical history [n (%)]-Dyslipidemia	0: Yes; 1: No	0.020	0.608	0.399-0.922	0.875	0.949	0.494-1.822
Temperature (°C)	actual score	0.014	1.547	1.097-2.176	0.276	1.358	0.783-2.357
Respiratory rate (breaths/minute)	actual score	0.005	1.077	1.023-1.134	0.054	1.081	0.999-1.169
MEWS (score)	actual score	<0.001	4.244	3.229-5.734	<0.001	4.416	3.006-6.488
MEWS disease risk stratification [n (%)]	0: low risk; 1: moderate risk; 2: high risk	<0.001	3.151	2.342-4.301	0.985	3.563	0.000-7.567
HEART (score)	actual score	0.002	1.310	1.112-1.571	0.083	1.262	0.970-1.642
GRACE (score)	actual score	0.012	1.008	1.002-1.014	0.091	1.008	0.999-1.018
GRACE disease risk stratification [n (%)]	0: low risk; 1: moderate risk; 2: high risk	0.022	1.347	1.043-1.742	0.989	0.000	0.000-8.633
TIMI (score)	actual score	<0.001	1.568	1.204-2.055	0.060	1.510	0.982-2.322
TIMI disease risk stratification [n (%)]	0: low risk; 1: moderate risk; 2: high risk	0.004	1.506	1.144-1.988	0.990	0.000	0.000-6.744
Killip class [n (%)]-IV	0: Yes; 1: No	0.008	7.009	1.694-34.600	0.768	1.475	0.111-19.543

Note: MACE: Major Adverse Cardiovascular Events; MEWS: Modified Early Warning Score; HEART: History, ECG, Age, Risk factors, and Troponin; GRACE: Global Registry of Acute Coronary Events; TIMI: Thrombolysis in Myocardial Infarction; OR: Odds Ratio; CI, Confidence Interval.

MEWS predicts chest pain risk

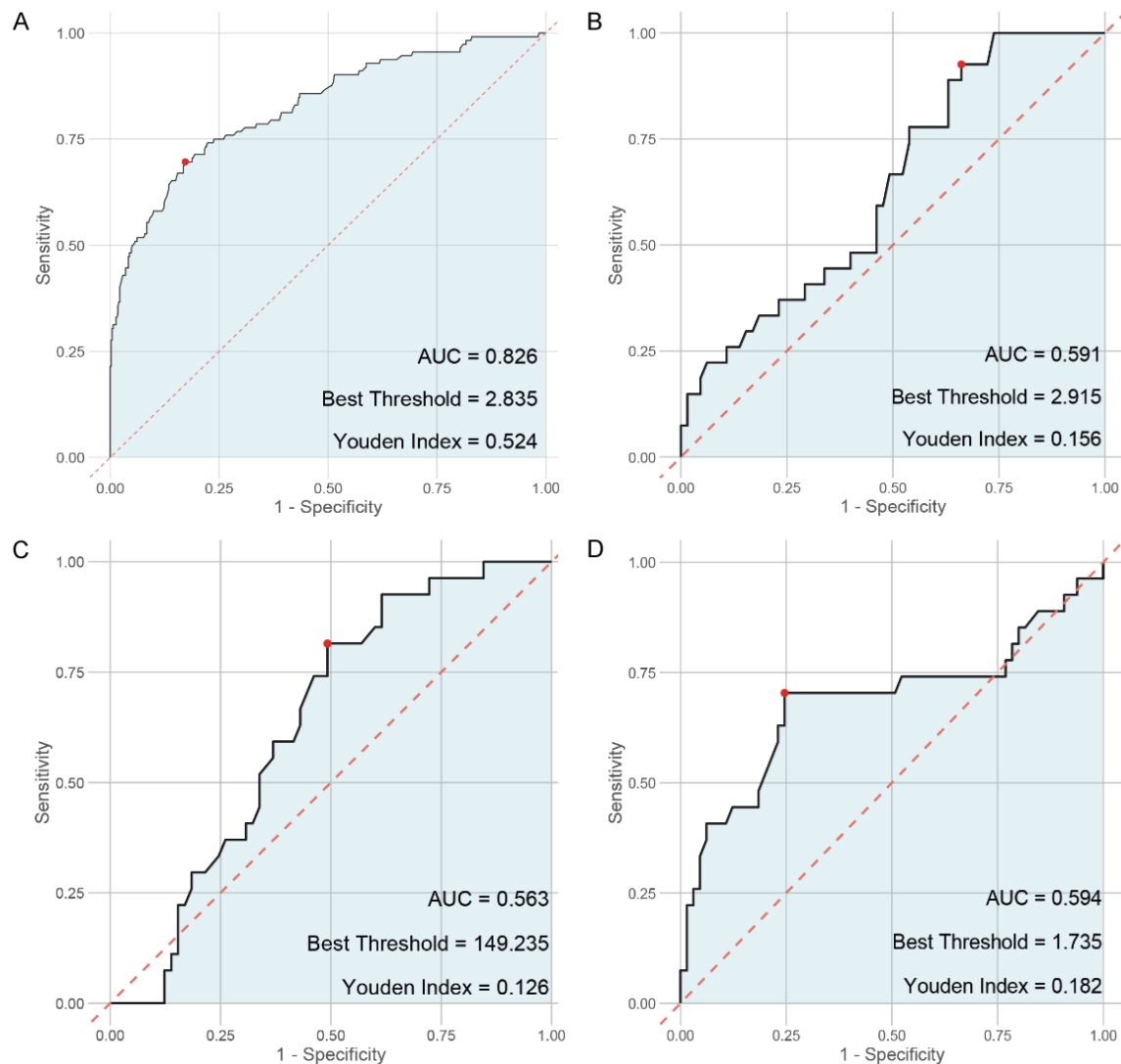


Figure 5. ROC curve analysis of MEWS, HEART, GRACE and TIMI scores on MACE in Patients with Acute Chest Pain. A: MEWS; B: HEART; C: GRACE; D: TIMI. Note: ROC: Receiver Operating Characteristic curve; MEWS: Modified Early Warning Score; HEART: History, ECG, Age, Risk factors, and Troponin; GRACE: Global Registry of Acute Coronary Events; TIMI: Thrombolysis in Myocardial Infarction; AUC: Area Under the Curve.

malities signal the failure of compensatory mechanisms and impending decompensation [24]. For instance, elevated respiratory rate reflects respiratory and cardiovascular stress, increased work of breathing, metabolic acidosis, or impaired cardiac output [25]. Tachycardia and hypotension reflect sympathetic activation due to reduced stroke volume and blood volume [25]. Temperature changes may signal systemic inflammation or infection, worsening the prognosis of acute cardiovascular disease by increasing myocardial oxygen demand and amplifying prothrombotic states [26].

This broad sensitivity to physiological instability may explain why MEWS more effectively identifies patients at risk for MACE than cardiac-specific scores that prioritize electrocardiographic changes, biomarkers, or coronary risk factors - elements that, while specific to ACS, may not fully capture the imminent risk of concurrent non-cardiac conditions [27]. For example, a patient with modest troponin elevation but significant hemodynamic instability may be at greater short-term risk than a stable patient with more pronounced biomarkers [27].

MEWS predicts chest pain risk

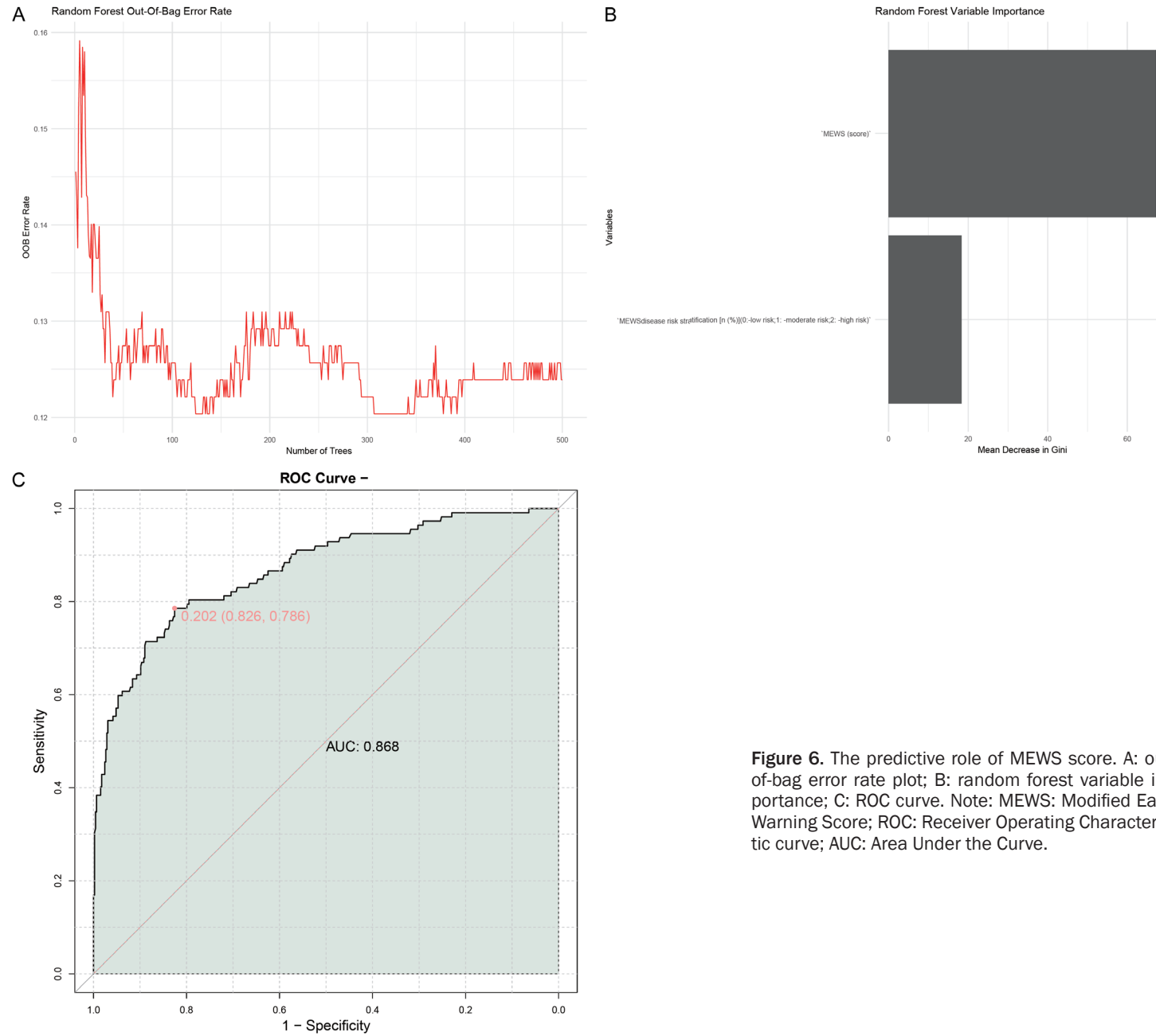


Figure 6. The predictive role of MEWS score. A: out-of-bag error rate plot; B: random forest variable importance; C: ROC curve. Note: MEWS: Modified Early Warning Score; ROC: Receiver Operating Characteristic curve; AUC: Area Under the Curve.

Table 9. DeLong test results for comparing AUCs of individual parameters with the combined model

Parameters	AUC	P-value (vs. Combined Model)
Combined Model	0.868	-
MEWS (score)	0.826	0.133
MEWS disease risk stratification [n (%)]	0.718	0.112
HEART (score)	0.591	0.008
GRACE (score)	0.563	0.011
GRACE disease risk stratification [n (%)]	0.563	0.010
TIMI (score)	0.594	0.009
TIMI disease risk stratification [n (%)]	0.580	0.007
Killip class [n (%)]-IV	0.519	0.005

Note: MEWS: Modified Early Warning Score; HEART: History, ECG, Age, Risk factors, and Troponin; GRACE: Global Registry of Acute Coronary Events; TIMI: Thrombolysis in Myocardial Infarction; AUC: Area Under the Curve.

The real-world usability of MEWS in acute care is another key advantage. MEWS can be applied immediately, requiring only basic vital signs without advanced laboratory or imaging data. In emergency settings, where timely identification of high-risk patients is critical [28, 29], MEWS enables rapid risk identification even before a confirmatory diagnosis is made [30]. Its dynamic nature also allows for continuous reassessment as the patient's condition evolves, making it particularly useful for monitoring and detecting clinical deterioration early [31].

Furthermore, MEWS, by identifying physiological deterioration, may prompt earlier intervention and escalation of care. In other populations, such as those with sepsis or trauma, early warning scores have been shown to activate rapid response teams, shorten the time to critical interventions, and ultimately reduce morbidity and mortality [32]. In the context of acute chest pain, timely recognition of instability can expedite decisions to initiate advanced monitoring, transfer to intensive care, or prioritize emergent interventions, all contributing to improved outcomes.

The observed dissociation between MEWS's predictive power and that of cardiac-specific scores calls for reflection on the limitations of relying solely on disease-specific indicators in multi-morbid patient populations. Many acute chest pain patients, especially older adults or those with co-existing systemic diseases, present with overlapping cardiovascular and medical complications [3, 33]. Conditions like infec-

tion, electrolyte disturbances, or occult bleeding are common in patients with suspected ACSs and can independently increase the risk of adverse outcomes. Thus, a flexible risk tool that recognizes a range of life-threatening etiologies may improve triage and treatment decisions.

These findings do not diminish the value of established scores like HEART, GRACE, and TIMI, which remain essential in predicting ischemic events, guiding invasive management, and estimating long-term cardiovascular risk. These scores synthesize detailed clinical data that are integral to assessing cardiac risk.

Rather, MEWS should be considered a complementary tool, especially in the early evaluation phase when decisions about resource allocation and care escalation are being made. Integrating MEWS into clinical workflows could bridge the gap before complete diagnostic data is available, serving as an effective trigger for the use of more specialized tools and protocols.

It is important to note that while MEWS was independently predictive of MACE, the findings should be interpreted with caution due to the inherent limitations of retrospective cohort studies. Patient population specifics, local clinical pathways, and intervention thresholds may influence both the frequency of physiological derangements and the definition of adverse events. Additionally, while powerful in its simplicity, MEWS lacks specificity, as elevated scores can result from non-cardiac conditions that may not ultimately drive cardiovascular morbidity. Therefore, combining MEWS with disease-specific risk scores, imaging, biomarkers, and careful diagnostic reasoning is crucial.

Conclusion

In summary, the MEWS score captures acute physiological disruption in patients with acute chest pain and outperforms cardiac-specific risk assessments for early identification of MACE. By focusing on global clinical instability, MEWS provides an efficient, sensitive, and immediately accessible tool for rapid risk strati-

fication. Its routine use can facilitate earlier intervention and resource allocation in high-risk patients, supplementing established scoring systems and enhancing the safety and quality of acute cardiovascular care. Future research should explore MEWS's prospective validation across diverse patient cohorts, its integration with digital health and electronic medical record systems, and its role in guiding interventions to mitigate acute cardiac risk.

Acknowledgements

This study was supported by the Shenzhen Pingshan District Health System Research Project (No. 2023326).

Disclosure of conflict of interest

None.

Address correspondence to: Caihong Hu, Department of Emergency, The People's Hospital of Pingshan Shenzhen (Pingshan Hospital, Southern Medical University), No. 19 Renmin Street, Pingshan Street, Pingshan District, Shenzhen 518100, Guangdong, China. E-mail: hucaihongzhang@126.com; Shaolin Chen, Department of Emergency, Shenzhen People's Hospital (The First Affiliated Hospital, Southern University of Science and Technology; The Second Clinical Medical College, Jinan University), No. 1017 Dongmenbei Road, Luohu District, Shenzhen 518020, Guangdong, China. E-mail: csl000@163.com

References

- [1] Nomura O, Hashiba K, Kikuchi M, Kojima S, Hanada H, Mano T, Yamamoto T, Nakashima T, Tanaka A, Nakayama N, Yamaguchi J, Matsuo K, Matoba T, Tahara Y and Nonogi H; Japan Resuscitation Council (JRC) Acute Coronary Syndrome (ACS) Task Force and the Guideline Editorial Committee on behalf of the Japanese Circulation Society (JCS) Emergency and Critical Care Committee. Performance of the 0-Hour/1-hour algorithm for diagnosing myocardial infarction in patients with chest pain in the emergency department - a systematic review and meta-analysis. *Circ Rep* 2022; 4: 241-247.
- [2] Dawson LP, Nehme E, Nehme Z, Zomer E, Bloom J, Cox S, Anderson D, Stephenson M, Ball J, Zhou J, Lefkovits J, Taylor AJ, Horrigan M, Chew DP, Kaye D, Cullen L, Mihalopoulos C, Smith K and Stub D. Chest pain management using prehospital point-of-care troponin and paramedic risk assessment. *JAMA Intern Med* 2023; 183: 203-211.
- [3] Sarto G, Simeone B, Spadafora L, Bernardi M, Rocco E, Pelle G, Liberati Q, Forte M, Schirone L, Versaci F, Piaz RD, Palmerio S, Barberi A, Frati G, Bellini D, Rengo M, Carbone I, Sciarretta S and Valenti V. Management of acute chest pain in the Emergency Department: benefits of coronary computed tomography angiography. *Int J Cardiovasc Imaging* 2024; 40: 2447-2457.
- [4] Weizman O, Hamzi K, Henry P, Schurtz G, Hauguel-Moreau M, Trimaille A, Bedossa M, Dib JC, Attou S, Boukertouta T, Boccara F, Pommier T, Lim P, Bochaton T, Millischer D, Merat B, Picard F, Grinberg N, Sulman D, Pasdeloup B, El Ouahidi Y, Gonçalves T, Vicaut E, Dillinger JG, Toupin S and Pezel T; ADDICT-ICCU Investigators. Machine learning score to predict in-hospital outcomes in patients hospitalized in cardiac intensive care unit. *Eur Heart J Digit Health* 2024; 6: 218-227.
- [5] Sharma R, Shah B, Verma S, Pathak V, Sharma S, Meena P and Kunal S. Risk stratification in non-ST-elevation myocardial infarction: evaluating the predictive accuracy of various risk scores in an Indian population. *Monaldi Arch Chest Dis* 2025; [Epub ahead of print].
- [6] Perez-Vicencio D, Thurston AJF, Doudesis D, O'Brien R, Ferry A, Fujisawa T, Williams MC, Gray AJ, Mills NL and Lee KK. Risk scores and coronary artery disease in patients with suspected acute coronary syndrome and intermediate cardiac troponin concentrations. *Open Heart* 2024; 11: e002755.
- [7] Gerry S, Bedford J, Redfern OC, Rutter H, Chester-Jones M, Knight M, Kelly T and Watkinson PJ. Development of a national maternity early warning score: centile based score development and Delphi informed escalation pathways. *BMJ Med* 2024; 3: e000748.
- [8] Guan G, Lee CMY, Begg S, Crombie A and Mnataganian G. The use of early warning system scores in prehospital and emergency department settings to predict clinical deterioration: a systematic review and meta-analysis. *PLoS One* 2022; 17: e0265559.
- [9] Wu PH, Hung SK, Ko CA, Chang CP, Hsiao CT, Chung JY, Kou HW, Chen WH, Hsieh CH, Ku KH and Wu KH. Performance of six clinical physiological scoring systems in predicting in-hospital mortality in elderly and very elderly patients with acute upper gastrointestinal bleeding in emergency department. *Medicina (Kaunas)* 2023; 59: 556.
- [10] Ko RE, Kwon O, Cho KJ, Lee YJ, Kwon JM, Park J, Kim JS, Kim AJ, Jo YH, Lee Y and Jeon K. Quick sequential organ failure assessment score and the modified early warning score for predicting clinical deterioration in general

- ward patients regardless of suspected infection. *J Korean Med Sci* 2022; 37: e122.
- [11] Kuit M, Veldhuis LI, Hollmann M, Nanayakkara P and Ridderikhof M. Recognition of critically ill patients by acute healthcare providers: a multicenter observational study. *Crit Care Med* 2023; 51: 697-705.
 - [12] Song SY, Choi WK and Kwak S. A model study for the classification of high-risk groups for cardiac arrest in general ward patients using simulation techniques. *Medicine (Baltimore)* 2023; 102: e35057.
 - [13] Huang Z, Wang K, Yang D, Gu Q, Wei Q, Yang Z and Zhan H. The predictive value of the HEART and GRACE scores for major adverse cardiac events in patients with acute chest pain. *Intern Emerg Med* 2021; 16: 193-200.
 - [14] Tan ADA, Permejo CC and Torres MCD. Modified early warning score vs cardiac arrest risk triage score for prediction of cardiopulmonary arrest: a case-control study. *Indian J Crit Care Med* 2022; 26: 780-785.
 - [15] Aksoy ŞG, Aksoy UM and Semerci B. Linguistic equivalence, validity and reliability study of the mind excessively wandering scale. *Noro Psikiyatr Ars* 2022; 59: 201-209.
 - [16] Khot UN, Jia G, Moliterno DJ, Lincoff AM, Khot MB, Harrington RA and Topol EJ. Prognostic importance of physical examination for heart failure in non-ST-elevation acute coronary syndromes: the enduring value of Killip classification. *JAMA* 2003; 290: 2174-2181.
 - [17] Bunney G, Sundaram V, Graber-Naidich A, Miller K, Brown I, McCoy AB, Freeze B, Berger D, Wright A and Yiadom MYAB. Beyond chest pain: Incremental value of other variables to identify patients for an early ECG. *Am J Emerg Med* 2023; 67: 70-78.
 - [18] Brooks SC, Sivilotti MLA, Héту MF, Norman PA, Day AG, O'Callaghan N, Latiu V, Newbigging J, Hill B and Johri AM. Focused carotid ultrasound to predict major adverse cardiac events among emergency department patients with chest pain. *CJEM* 2023; 25: 81-89.
 - [19] Huang L, Zhang J, Huang Q, Cui R and Chen J. In-hospital major adverse cardiovascular events after primary percutaneous coronary intervention in patients with acute ST-segment elevation myocardial infarction: a retrospective study under the China chest pain center (standard center) treatment system. *BMC Cardiovasc Disord* 2023; 23: 198.
 - [20] Dasari M, Arun Kumar P, Singh Y and Ramsaran E. New scoring system for acute chest pain risk stratification: is it worth SVEAT-ing it? *World J Cardiol* 2023; 15: 200-204.
 - [21] Ihdayhid AR, Lan NSR, Figtree GA, Patel S, Arnott C, Hamilton-Craig C, Psaltis PJ, Leipsic J, Fairbairn T, Wahi S, Hillis GS, Rankin JM, Dwivedi G and Nicholls SJ. Contemporary chest pain evaluation: the Australian case for cardiac CT. *Heart Lung Circ* 2023; 32: 297-306.
 - [22] O' Rielly CM, Harrison TG, Andruchow JE, Ronksley PE, Sajobi T, Robertson HL, Lorenzetti D and McRae AD. Risk scores for clinical risk stratification of emergency department patients with chest pain but no acute myocardial infarction: a systematic review. *Can J Cardiol* 2023; 39: 304-310.
 - [23] Braumann S, Faber-Zameitat C, Macherey-Meyer S, Tichelbäcker T, Meertens M, Heyne S, Nießen F, Nies RJ, Nettersheim F, Reuter H, Pfister R, Hellmich M, Burst V, Baldus S, Lee S and Adler C. Acute chest pain - diagnostic accuracy and pre-hospital use of anticoagulants and platelet aggregation inhibitors. *Dtsch Arztebl Int* 2023; 120: 317-323.
 - [24] van den Bulk S, Manten A, Bonten TN and Harskamp RE. Chest pain in primary care: a systematic review of risk stratification tools to rule out acute coronary syndrome. *Ann Fam Med* 2024; 22: 426-436.
 - [25] Tavoosi A, Kadoya Y, Chong AY, Small GR and Chow BJW. Utility of FFRCT in patients with chest pain. *Curr Atheroscler Rep* 2023; 25: 427-434.
 - [26] Cayley WE Jr. Noninvasive cardiac testing. *Am Fam Physician* 2024; 110: 577-584.
 - [27] Chidambaran V, Duan Q, Pilipenko V, Glynn SM, Sproles A, Martin LJ, Lacagnina MJ, King CD and Ding L. The role of cytokines in acute and chronic postsurgical pain after major musculoskeletal surgeries in a quaternary pediatric center. *Brain Behav Immun* 2024; 122: 596-603.
 - [28] Zheng ZC, Yuan W, Wang N, Jiang B, Ma CP, Ai H, Wang X and Nie SP. Exploring the feasibility of machine learning to predict risk stratification within 3 months in chest pain patients with suspected NSTEMI-ACS. *Biomed Environ Sci* 2023; 36: 625-634.
 - [29] Myrmetel GMS, Steiro OT, Tjora HL, Langørgen J, Bjørneklett R, Skadberg Ø, Bonarjee VVS, Mjelva ØR, Pedersen EKR, Vikenes K, Omland T and Aakre KM. Growth differentiation factor 15: a prognostic marker in patients with acute chest pain without acute myocardial infarction. *Clin Chem* 2023; 69: 649-660.
 - [30] Saeed N, Steiro OT, Langørgen J, Tjora HL, Bjørneklett RO, Skadberg Ø, Bonarjee VVS, Mjelva ØR, Norekvål TM, Steinsvik T, Vikenes K, Omland T and Aakre KM. Diagnosing myocardial injury in an acute chest pain cohort; long-term prognostic implications of cardiac troponin T and I. *Clin Chem* 2024; 70: 1241-1255.

- [31] Greer C, Williams MC, Newby DE and Adamson PD. Role of computed tomography cardiac angiography in acute chest pain syndromes. *Heart* 2023; 109: 1350-1356.
- [32] Guo B, Jiang M, Guo X, Tang C, Zhong J, Lu M, Liu C, Zhang X, Qiao H, Zhou F, Xu P, Xue Y, Zheng M, Hou Y, Wang Y, Zhang J, Zhang B, Zhang D, Xu L, Hu X, Zhou C, Li J, Yang Z, Mao X, Lu G and Zhang L. Diagnostic and prognostic performance of artificial intelligence-based fully-automated on-site CT-FFR in patients with CAD. *Sci Bull (Beijing)* 2024; 69: 1472-1485.
- [33] D'Ascenzo F and De Filippo O. Novel risk score to predict ischaemic and bleeding risk after acute coronary syndrome: new tools for an upcoming new era? *Heart* 2023; 109: 1805-1807.