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Modified Early-Warning Score combined with early-warning symptoms and electrocardiographic findings in predicting in-hospital cardiac arrest in critically ill patients: a retrospective cohort study

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Abstract

Background: We aimed to investigate the clinical value of the Modified Early-Warning Score (MEWS) combined with early-warning symptoms and electrocardiogram (ECG) findings in predicting in-hospital cardiac arrest (IHCA) in critically ill patients, to assess and reduce the occurrence of IHCA.

Methods: This retrospective cohort study examined critically ill patients who were enrolled in a hospital from January 2019 to March 2023 and divided into an IHCA group and NO-IHCA group. The critically ill patients were randomly divided into 2 sets at the ratio of 7:3, for the training set and test set. The training set used to develop the model and the test set used to test the model. Univariate and multivariate logistic regressions were used to determine the independent predictors. The generated prediction models were evaluated using 10-fold cross verification, and the areas under the curve (AUCs), accuracy, sensitivity, and specificity were reported. Hosmer-Lemeshow goodness of fit test was used to compare the calibration degree of the model and Delong test was used to compare the AUC.

Results: Multivariate logistic analysis showed that MEWS, early-warning symptoms, and ECG findings were independent risk factors for IHCA in critically ill patients ($P < 0.05$). The AUC values for MEWS, early-warning symptoms, and ECG findings were 0.671, 0.527, and 0.723, respectively. The AUC value for the combination of MEWS, early-warning symptoms, and ECG findings was 0.902 ($P < 0.001$), which was higher than MEWS.

Conclusion: MEWS combined with early-warning symptoms and ECG findings can predict IHCA in critically ill patients, which may help reduce IHCA in this population.

Keywords: Early-warning symptoms, In-hospital cardiac arrest, Modified Early-Warning Score

Introduction

In-hospital cardiac arrest (IHCA) is a major clinical event with a high mortality rate.[1] The incidence of IHCA is 8.4 per 1000 admissions in Chinese adults. Among these victims, 41.1% achieve return of spontaneous circulation, with an overall survival to hospital discharge of 9.4%. A good 30-day neurological outcome has been reported in 6.7% of patients discharged from the hospital.[2] Changes might occur in the body before the occurrence of cardiac arrest (CA). Clinical symptoms typically arise from alterations in the patient's physiological state, such as changes in respiratory, cardiac, or brain function, which may result in the onset of CA.[3]

The Modified Early-Warning Score (MEWS) is a widely used clinical tool for assessing changes in disease status. It consists of five physiological variables, including systolic blood pressure, heart rate, respiratory rate, body temperature, and level of consciousness. Each variable is scored according to its specific levels, and a higher sum score indicates a greater probability of IHCA. Although MEWS is currently the most commonly used tool for predicting IHCA, it can only determine whether a patient requires admission to the hospital or intensive care unit via assessment of vital signs.[4] However, vital signs alone may lead to inaccurate judgment of disease severity. Consequently, MEWS fails to precisely ascertain disease status. Although the *2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care*[5] incorporates MEWS as an early-warning instrument for CA, the recommendation level is low (level C). A recent study revealed that 45.3% of patients still had a MEWS of only 1–2 points 8 hours before the onset of CA, and these scores showed no upward trend despite potential changes in ECG findings or the emergence of early-warning symptoms.[6] Early-warning symptoms often appear before CA onset, timely identification of these early-warning symptoms helps predict CA, thus enabling the timely initiation of interventions and improved prognosis.[7,8] Electrocardiogram (ECG) detects disease progression; therefore, ECG also has a role in predicting the occurrence of IHCA in critically ill patients,

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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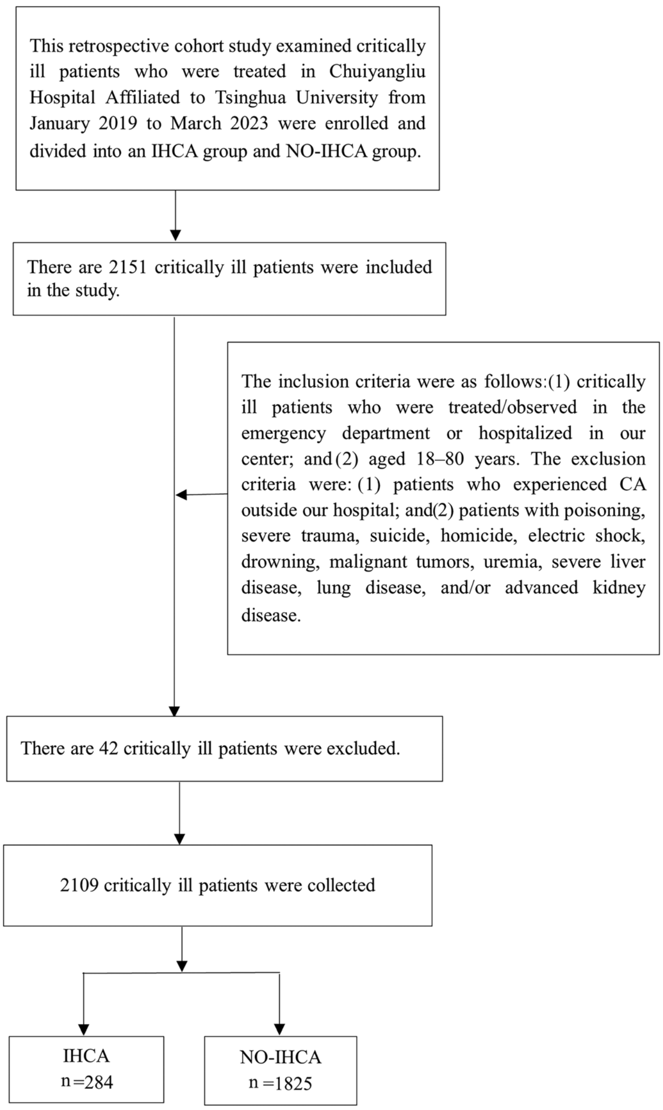

Figure 1. Research flowchart. IHCA, in-hospital cardiac arrest.

especially for those with stable vital signs and no obvious symptoms. In this study, we investigated the clinical value of MEWS combined with early-warning symptoms and ECG findings in predicting IHCA in critically ill patients.

Methods

Patients and methods

This retrospective cohort study included 2109 critically ill patients who received treatment at Chuiyangliu Hospital Affiliated to Tsinghua University (Beijing, China) from January 2019 to March 2023 were enrolled (Fig. 1). The hospital's electronic medical records system was used to retrieve essential patient information. We searched for patients with IHCA (IHCA group) using the following keywords or phrases: diagnosis at admission or discharge: cardiac arrest, successful cardiopulmonary resuscitation, ventricular fibrillation, ventricular tachycardia, respiratory arrest, sudden death, sudden cardiac death; surgery name or code: cardiopulmonary resuscitation, and chest compression. In the NO-IHCA group, we included critically ill patients who were hospitalized or received treatment in the emergency department but had not experienced IHCA. The inclusion criteria were as follows: (1) critically ill patients who were treated/observed in the emergency department or hospitalized in our center and (2) aged 18–80 years. The exclusion criteria were as follows: (1) patients who experienced CA outside our hospital and (2) patients with poisoning, severe trauma, suicide, homicide, electric shock, drowning, malignant tumors, uremia, severe liver disease, lung disease, and/or advanced kidney disease.

Data collection

Patient demographics and clinical information were retrieved from the hospital's inpatient medical record system, including sex, chief complaints (which may serve as early-warning symptoms), and history of medical conditions such as hypertension, coronary heart disease, diabetes, cerebral infarction, hyperlipidemia, and renal insufficiency. ECG findings and measurements at admission (including blood pressure, heart rate, body temperature, respiratory rate, and state of consciousness) were documented. Furthermore, information regarding the occurrence of IHCA was recorded.

Definition

Determination of critically ill patients. According to expert consensus on pre-examination and triage in China, the grading criteria are formulated by objective evaluation indicators and manual rating indicators, and the critical degree of patients' conditions is divided into the following four levels: emergency and critical patient, emergency and severe patient, emergency patient, and subemergency or nonemergency patients. Grade I (such as CA, shock poisoning) and Grade II (such as stroke, chest pain, pulmonary embolism). Patients need to enter the rescue room for immediate treatment, after being transferred to the emergency intensive care unit, cardiac intensive care unit, and intensive care unit for advanced treatment.[9] In this study, patients classified as Grade I and II by pre-examination and triage were selected as critically ill patients.

Modified Early-Warning Score. Vital signs, including body temperature, blood pressure, heart rate, respiratory rate, and level of consciousness, were obtained from the charts, and converted into corresponding MEWS[6] (Table 1).

Table 1

Modified Early-Warning Score[6]

Score	3	2	1	0	1	2	3
Systolic blood pressure (mmHg)	<70	71–80	81–100	101–199		≥200	
Heart rate (beats per minute, bpm)		<40	41–50	51–100	101–100	111–129	≥130
Respiratory rate (breaths per minute)		<9		9–14	15–20	21–29	≥30
Temperature (°C)		<35		35–38.4		≥38.5	
Level of consciousness				Alert	Reacting to voice	Reacting to pain	Unresponsive

Table 2

Comparison of Characteristics for Critically Ill Patients

Factors	NO-IHCA Group (n = 1825)	IHCA Group (n = 284)	χ^2/Z	*P*
Gender, n(%)			1.719	0.190
Females	585 (32.05)	80 (28.17)		
Males	1240 (67.95)	204 (71.83)		
Age (years), M(Q1,Q3)	68.00 (60.00,74.00)	66.50 (58.00,75.00)	-0.414	0.679
Medical history				
Hypertension, n(%)	1147 (62.85)	90 (31.69)	98.388	<0.001
Diabetes, n(%)	811 (44.44)	127 (44.72)	0.008	0.930
Coronary heart disease, n(%)	807 (44.22)	128 (45.07)	0.072	0.788
Cerebral infarction, n(%)	361 (197.78)	59 (20.77)	0.152	0.696
Hyperlipidemia, n(%)	160 (8.77)	38 (13.38)	6.148	0.013
Renal insufficiency, n(%)	197 (10.79)	33 (11.62)	0.172	0.678
Early-warning symptoms, n(%)			43.056	<0.001
Others	639 (35.01)	61 (21.48)		
Chest pain	437 (23.95)	111 (39.08)		
Dyspnea	345 (18.90)	61 (21.48)		
Syncope/palpitations	166 (9.10)	26 (9.15)		
Influenza-like symptoms	130 (7.12)	8 (2.82)		
Gastrointestinal symptoms	108 (5.92)	17 (5.99)		
Electrocardiographic findings, n(%)			880.531	<0.001
Other	1384 (75.84)	53 (18.66)		
Malignant arrhythmias	68 (3.73)	183 (64.44)		
Myocardial ischemia	373 (20.44)	48 (16.90)		
MEWS M(Q1,Q3)	2.00 (1.00,4.00)	4.00 (1.00,6.00)	9.730	<0.001

IHCA, in-hospital cardiac arrest; MEWS, Modified Early Warning Score; M, median; Z, Mann-Whitney *U* test; χ^2, Chi-square test.

Early-warning symptoms. Chief complaints (early-warning symptoms) were grouped according to the *Textbook of Internal Medicine*[8]: (1) chest pain; (2) dyspnea; (3) syncope/palpitations; (4) influenza-like symptoms including fever, cough, sputum production, and sore throat; (5) gastrointestinal symptoms including nausea, vomiting, heartburn, abdominal pain, bloating, and black stool; and (6) other symptoms that could not be grouped. When multiple symptoms were self-reported, the most prominent symptom was selected for grouping.

Table 3

Baseline Characteristics of the Training Cohort and the Testing Cohort

Factors	Test Set (n = 633)	Training Cohort (n = 1476)	χ^2/Z	*P*
Gender, n (%)			0.925	0.336
Females	209 (33.02)	456 (30.89)		
Males	424 (66.98)	1020 (69.11)		
Age (years), M (Q1, Q3)	68.00 (59.00,74.00)	68 (60.00,74.00)	0.200	0.841
Medical history				
Hypertension, n (%)	387 (61.14)	850 (57.59)	2.301	0.129
Diabetes, n (%)	297 (46.92)	641 (43.43)	2.187	0.139
Coronary heart disease, n (%)	281 (44.39)	654 (44.31)	0.001	0.972
Cerebral infarction, n (%)	139 (21.959)	281 (19.038)	2.370	0.124
Hyperlipidemia, n (%)	57 (9.005)	141 (9.553)	0.156	0.692
Renal insufficiency, n (%)	72 (11.374)	158 (10.705)	0.205	0.651
Early-warning symptoms, n (%)			3.111	0.683
Others	224 (35.387)	476 (32.249)		
Chest pain	153 (24.171)	395 (26.762)		
Dyspnea	116 (18.325)	290 (19.648)		
Syncope/palpitations	58 (9.163)	134 (9.079)		
Influenza-like symptoms	42 (6.635)	96 (6.504)		
Gastrointestinal symptoms	40 (6.319)	85 (5.759)		
Electrocardiographic findings, n (%)			4.734	0.094
Other	410 (64.771)	1027 (69.580)		
Malignant arrhythmias	84 (13.270)	167 (11.314)		
Myocardial ischemia	139 (21.959)	282 (19.106)		
MEWS M (Q1, Q3)	2.00(1.00,4.00)	2.00(1.00,4.00)	-1.085	0.278

MEWS, Modified Early Warning Score; M, median; Z, Mann-Whitney *U* test; χ^2: Chi-square test.

Table 4

Univariate and Multivariate Analysis of Factors Influencing IHCA in Critically Ill Patients

	Univariate		Multivariate	
Factors	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***
MEWS	1.08 (1.01–1.15)	0.016	1.03 (1.01–1.06)	0.021
Gender, male	1.45 (1.03–2.06)	0.036	1.58 (0.97–2.57)	0.064
Age (years)	0.99 (0.98–1.00)	0.221	1.01 (0.99–1.03)	0.502
Early-warning symptoms,				
Others	1 (reference)			
Chest pain	3.25 (2.13–4.96)	<0.001	1.40 (0.81–2.44)	0.232
Dyspnea	2.02 (1.25–3.26)	0.004	2.04 (1.10–3.80)	0.024
Syncope/palpitations	2.61 (1.48–4.60)	<0.001	2.68 (1.28–5.61)	0.009
Influenza-like symptoms	0.69 (0.26–1.81)	0.455	0.77 (0.22–2.61)	0.670
Gastrointestinal symptoms	1.49 (0.69–3.23)	0.310	1.99 (0.75–5.28)	0.167
Electrocardiographic findings				
Other	1 (Reference)			
Malignant arrhythmias	81.73 (50.39–32.57)	<0.001	85.31 (50.72–143.50)	<0.001
Myocardial ischemia	3.89 (2.38–6.36)	<0.001	4.24 (2.54–7.06)	<0.001

CI, confidence interval; IHCA, in-hospital cardiac arrest; MEWS, Modified Early-Warning Score; OR, odds ratio.

ECG findings. The ECG findings are evaluated by the attending physician and cardiologist based on *internal medicine* and are divided into groups:

(1) Malignant arrhythmias: premature ventricular contractions, ventricular fibrillation, ventricular tachycardia, ventricular flutter, CA, and third-degree atrioventricular (AV) block.
(2) Myocardial ischemia: ST-segment elevation myocardial infarction (STEMI) and non-ST-segment elevation myocardial infarction (NSTEMI). STEMI including anterior, inferior, posterior, and (high) lateral wall myocardial infarction. NSTEMI, which is a typical angina symptom or typical ischemic ECG change (new-onset or transient ST-segment depression ≥0.1 mV or T-wave inversion ≥0.2 mV) and indicates changes in the markers of myocardial injury.
(3) Others: sinus arrhythmia, atrial fibrillation, type 1 second-degree AV block, and type 2 second-degree AV block.

Sample size calculation

Five variables in MEWS, 5 dummy variables for early-warning symptoms, and 2 dummy variables for ECG findings. Considering that 2 additional variables may be explored in the middle, the new scoring model is constructed with at least 14 variables. According to Riley et al.,[10] the pre-experiment predicted area under the curve (AUC) is at least 0.75, the prevalence is 0.08, and 1770 samples are required samples. Considering that there may be problems such as unqualified data in the middle, it is proposed to expand the total number of samples by 10%, and a total of 1947 people are needed.

Statistical analysis

Statistical analysis was conducted using IBM SPSS 25.0 software (IBM Corp., Armonk, NY, USA). Normally distributed quantitative data are expressed as mean ± standard deviation ($\bar{\chi} \pm S$), and intergroup comparisons were based on the *t* test. Nonnormally distributed measurement data are presented using median (P25, P75) and compared using the Mann-Whitney *U* test. Qualitative data are presented using the number of cases and percentages and compared using the chi-square test or Fisher's exact test as appropriate. The patients were randomly divided into 2 sets at the ratio of 7:3, for training set and test set, respectively. Statistically significant indicators in the univariate analysis were further analyzed in multivariate logistic regression analysis. Receiver operating characteristic curves were plotted to analyze the diagnostic value of each element. The area AUC was used to evaluate the predictive ability of the model. The generated prediction models were evaluated using 10-

Table 5

The Results of the Analysis of the Training Set and Test Set

Data	Precision	Recall	f1-Score	AUC	PPV	NPV
Training set	0.751	0.864	0.804	0.885	0.963	0.466
Test set	0.838	0.864	0.806	0.860	0.960	0.444

ACU, area under the curve; NPV, negative predictive value; PPV, positive predictive value.

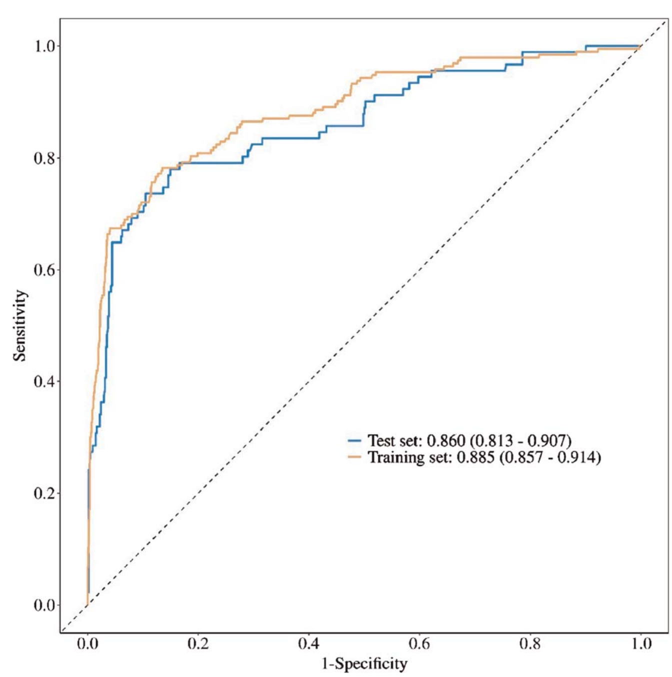

Figure 2. The AUC of the training set and test set. AUC, area under the curve.

Table 6

The Performance of Prediction Models (under 10-Fold Cross-Validation Model)

Factors	AUC	Accuracy	Precision	SE	*P*	Sensitivity	Specificity	HL-*P*
MEWS	0.671	0.742	0.688	0.019	<0.001	0.553	0.739	<0.001
Age (years)	0.492	0.621	0.654	0.020	0.679	0.127	0.938	<0.001
Gender, male	0.519	0.659	0.631	0.018	0.291	0.718	0.321	<0.001
Early-warning symptoms	0.527	0.712	0.774	0.017	0.139	0.785	0.350	0.001
Electrocardiographic findings	0.723	0.7986	0.811	0.014	<0.001	0.813	0.758	0.027
Combination	0.902	0.884	0.842	0.011	<0.001	0.907	0.739	0.054

ACU, area under the curve; HL-*P* value, Hosmer-Lemeshow; MEWS, Modified Early-Warning Score; SE, standard error.

fold cross verification, and the AUC, accuracy, sensitivity, and specificity were reported. Hosmer-Lemeshow goodness of fit test was used to compare the calibration degree of the model and Delong test was used to compare the AUC. Missing values for covariates were accounted for using multiple imputations by chained equations. A *P* value of <0.05 was considered statistically significant.

Results

Population characteristics

A total of 2109 critically ill patients met the inclusion criteria, including 1444 male patients and 665 female patients. Among 2109 critically ill patients included in the present analysis, 284 critically ill patients experienced IHCA group and 1825 critically ill patients experienced NO-IHCA group (Fig. 1). The basic characteristics of the 2 groups are illustrated in Table 2. The IHCA group and NO-IHCA group showed no statistically significant differences in sex, age, diabetes, coronary heart disease, cerebral infarction, and renal insufficiency ($P > 0.05$). However, the groups differed significantly concerning hypertension, hyperlipidemia, early-warning symptoms, ECG findings, and MEWS ($P < 0.05$) (Table 2).

A total of 2109 critically ill patients were included in the model development, randomly divided into 2 cohorts at the ratio of 7:3. The training set included 1476 critically ill patients and the test set included 633 critically ill patients. The training set was used to develop the model and the test set was used to test the model. The basic characteristics of the training set and test set are listed in Table 3. There was no statistically significant difference between the training set and the test set ($P > 0.05$).

Results of univariate analysis and multivariate logistic regression analysis

Patients' clinical information was included in univariate logistic regression to analyze risk factors univariate and multivariate logistic regression analysis with IHCA (0 = no, 1 = yes) as the dependent variable and MEWS, age, gender, early-warning symptoms, and ECG findings as the independent variables. The result revealed that MEWS, early-warning symptoms, and ECG findings were all risk factors for IHCA in critically ill patients ($P < 0.05$) (Table 4).

Table 7

AUC Comparison Test of Receiver Operating Characteristic Curves

Factor	AUC	SE	AUC Difference	Z	*P*
MEWS	0.671	0.019	0.231	5.511	<0.001
Combination	0.902	0.011			

ACU, area under the curve; SE, standard error.

The results of the analysis of the training cohort and testing cohort

The AUC of the training set and the test set were 0.885 and 0.860. The precision, recall, and f1-score of the training set were 0.751, 0.864, and 0.804. The precision, recall, and f1-score of the test set were 0.838, 0.864, and 0.806. The positive predictive value (PPV) and negative predictive value (NPV) of the training set were 0.963 and 0.466. The PPV and NPV of the test set were 0.960 and 0.444 (Table 5 and Fig. 2).

The performance of prediction models (under 10-fold cross-validation model)

The AUC values for MEWS, age, gender, early-warning symptoms, and ECG findings Combination were 0.671, 0.492, 0.519, 0.527, and 0.723, respectively. The AUC value for the combination of age, gender, MEWS, early-warning symptoms, and ECG findings was 0.902 ($P < 0.001$), which was higher than MEWS (Table 6, Table 7, and Fig. 3).

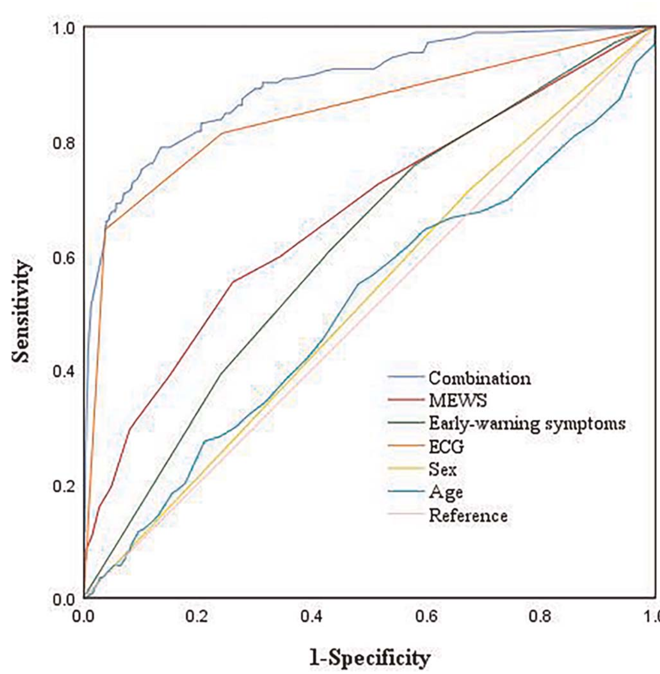

Figure 3. Receiver operating characteristic curves of MEWS combined with early-warning symptoms and ECG findings in predicting IHCA in critically ill patients. ECG, electrocardiogram; IHCA, in-hospital cardiac arrest; MEWS, Modified Early-Warning Score.

Discussion

IHCA is an acute clinical event with high mortality and unpredictability, and predicting IHCA is of great importance for reducing mortality and improving prognosis. The combination of MEWS with early-warning symptoms and ECG findings may enable quick and accurate assessment of the disease condition, thereby lowering the incidence of IHCA in critically ill patients.

In the present study, the MEWS differed significantly between the IHCA group and NO-IHCA group, confirming the role of MEWS in predicting IHCA in critically ill patients. However, MEWS can only be used to assess vital signs. In deteriorating patients with normal vital signs, MEWS cannot be used to make a timely and accurate judgment. In our study, the MEWS, early-warning symptoms (proportions of chest pain, dyspnea, syncope/palpitations), and ECG findings (proportion of malignant arrhythmias and myocardial ischemia) in the IHCA group were worse than those in the NO-IHCA group. In addition, multivariate logistic regression analysis showed that hypertension, MEWS, early-warning symptoms, and ECG findings were risk factors for IHCA in critically ill patients. MEWS alone had an AUC of 0.671, a sensitivity of 0.553, and a specificity of 0.739 in predicting IHCA in critically ill patients, showing low performance. This is because MEWS assesses disease conditions based only on vital signs and has low accuracy when the disease condition changes without specific manifestations. We also found that the AUC of MEWS combined with early-warning symptoms and ECG findings was 0.902 (P <0.001), with a sensitivity of 0.907 and specificity of 0.739, which was greater than those of MEWS, early-warning symptoms, and ECG findings alone. This indicated that the combination could reliably predict IHCA in critically ill patients, thereby compensating for the limitations of MEWS.

CA is typically preceded by a cluster of identifiable clinical symptoms, which are closely related to survival. Proper identification and management of these symptoms will lower the incidence of IHCA. Chest pain, dyspnea, and syncope/palpitations are the most common early-warning symptoms.[11] Eloi et al.[8]observed that early-warning symptoms were independent predictors of CA. Similarly, in our study, we found that chest pain was a main early-warning symptom and a major contributor to IHCA. A previous study demonstrated that chest pain is often associated with cardiovascular diseases.[7] Dyspnea serves as another important signal of IHCA. However, dyspnea can arise from both cardiogenic and noncardiogenic etiologies, and the underlying mechanisms leading to dyspnea can be diverse, encompassing conditions such as shock or intoxication.[11] Therefore, additional clinical information should be collected for the differential diagnosis of patients presenting with dyspnea. Syncope and palpitations are frequent clinical occurrences that can stem from a multitude of causes, including Brugada syndrome,[12] neurological disorders,[13] or hypertrophic obstructive cardiomyopathy.[14] Therefore, it is crucial to use caution in treating patients experiencing syncope, ensuring a thorough differentiation of the underlying causes. We also found that influenza-like symptoms may be useful in predicting IHCA among critically ill patients. Many patients may ignore "cold" symptoms and fail to treat them in a timely fashion, leading to disease deterioration and even CA. Our previous study demonstrated that influenza-like symptoms contribute to the development of CA.[15] Therefore, patients with these symptoms should be properly managed in a timely manner.

ECG is instrumental in predicting IHCA in critically ill patients. Timely ECG upon admission can discern potential shifts in a patient's condition. Thorén et al.[16]found that patients who underwent ECG monitoring experienced a marked reduction in the incidence of IHCA when compared with those who were not monitored. In the present study, malignant arrhythmias were the predominant ECG finding associated with IHCA, and patients presenting with malignant arrhythmias on ECG were at a higher risk of developing IHCA compared with those who had other ECG abnormalities. Vallabhajosyula et al.[17] found that patients with CA who developed STEMI had worse survival outcomes. In the Chinese Acute Myocardial Infarction Registry Study, IHCA was found in 3.4% of patients with malignant arrhythmias.[2] Patients with malignant arrhythmias often exhibit lesions in one or more coronary arteries, which can precipitate hemodynamic instability and even pump failure in severe cases.

In our current study, chest pain emerged as the most prevalent early-warning symptom of CA. STEMI was identified as the most frequent cardiac etiology underlying CA and the primary trigger for life-threatening arrhythmias. Early and aggressive management of patients experiencing chest pain accompanied by STEMI can markedly diminish the incidence and mortality rates of IHCA. We also found that NSTEMI was another contributor to IHCA. Tanveer et al.[18] found that many patients experiencing CA had NSTEMI on ECG. For patients with NSTEMI and an elevation in the aVR lead on ECG, a greater likelihood of IHCA was observed in those with more advanced cardiovascular conditions.[19] Because patients with NSTEMI generally have better survival, early identification of these patients can improve their overall survival outcomes.

Comorbidities such as hypertension and hyperlipidemia can also lead to adverse outcomes.[20,21] Hypertension serves as a predictive factor of IHCA in critically ill patients because chronic hypertension can prompt cardiac remodeling, structural changes, and arrhythmias in severe cases.[20] Accordingly, patients with cardiovascular diseases have a greater risk of CA and should be monitored closely. Autopsy results have shown that the leading causes of sudden cardiac death in 5516 cases in China were hypertension, coronary heart disease, and diabetes.[22] According to the *Report on Cardiac Arrest and Cardiopulmonary Resuscitation in China (2022): A Summary*, hypertension, hyperlipidemia, and smoking were independent risk factors for CA,[2] which is consistent with our findings.

Limitations

This study had some limitations. First, this study was a single-center retrospective study with a small sample size; therefore, large-scale prospective studies are required to validate our results. Second, in the future, the study period can be extended and multicenter cooperation can be extended to include more patients' data for analysis, explore more relevant factors affecting the occurrence of IHCA, and select more accurate and effective indicators to optimize the model to reduce the occurrence of IHCA.

Conclusion

In summary, MEWS combined with early-warning symptoms and ECG findings can be a valuable predictor of IHCA in critically ill patients, thereby contributing to reducing the IHCA incidence in this high-risk population.

Conflict of interest statement

The authors declare no conflict of interest.

Author contributions

Wei G designed this study. Zhang W performed the work and drafted the manuscript. Wei G contributed to interpreting the data and refined the drafted manuscript. All authors have read and approved the final manuscript.

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Ethical approval of studies and informed consent

The study followed the principles of the Declaration of Helsinki as revised in 2013. The data has been anonymized to protect patient privacy. This study was approved and written informed consent was waived by the Ethics Committee of Beijing Chuiyangliu Hospital (no. CYLER [2023-021KY], November 11, 2023) owing to the anonymized retrospective nature of the analysis.

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