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Comparative Analysis of the Effectiveness of Riskometer Scales in Predicting the Risk of in-Hospital Mortality in Patients With ST-Segment Elevation Myocardial Infarction After Percutaneous Coronary Intervention

Aim Comparative evaluation of the effectiveness of riskometer scales in predicting in-hospital death (IHD) in patients with ST-segment elevation myocardial infarction (STEMI) after percutaneous coronary intervention (PCI) and the development of new models based on machine learning methods.

Material and methods A single-center cohort retrospective study was conducted using data from 4,675 electronic medical records of patients with STEMI (3,202 men and 1,473 women) with a median age of 63 years who underwent emergency PCI. Two groups of patients were isolated: group 1 included 318 (6.8%) patients who died in hospital; group 2 consisted of 4,359 (93.2%) patients with a favorable outcome. The GRACE, CADILLAC, TIMI-STe, PAMI, and RECORD scales were used to assess the risk of IHD. Prognostic models of IHD predicted by the sums of these scale scores were developed using single- and multivariate logistic regression, stochastic gradient boosting, and artificial neural networks (ANN). Risk of adverse events was stratified based on the ANN model data by calculating the median values of predicted probabilities of IHD in the compared groups.

Results Comparative analysis of the prognostic value of individual scales for the STEMI patients showed differences in the quality of the risk stratification for IHD after PCI. The GRACE scale had the highest prognostic accuracy, while the PAMI scale had the lowest accuracy. The CADILLAC and TIMI-STe scales had acceptable and comparable prognostic abilities, while the RECORD scale showed a significant proportion of false-positive results. The integrative ANN model, the predictors of which were the scores of 5 scales, was superior in the prediction accuracy to the algorithms of single- and multivariate logistic regression and stochastic gradient boosting. Based on the ANN model data, the probability of IHD was stratified into low (<0.3%), medium (0.3–9%), high (9–17%), and very high (>17%) risk groups.

Conclusion The GRACE, CADILLAC and TIMI-STe scales have advantages in the stratification accuracy of IHD risk in patients with STEMI after PCI compared to the PAMI and RECORD scales. The integrated ANN model that combines the prognostic resource of the five analyzed scales, had better quality criteria, and the stratification algorithm based on the data of this model was characterized by accurate identification of STEMI patients with high and very high risk of IHD after PCI.

Keywords Myocardial infarction; percutaneous coronary intervention; in-hospital death; prediction

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Introduction

ST-segment elevation myocardial infarction (STEMI) represents one of the most dangerous clinical forms of coronary heart disease. As reported by the Russian State Statistics Agency (Rosstat), the mortality rate associated with myocardial infarction (MI) in the Russian Federation was 39.7 per 100,000 population in 2020 [1], with a 14% hospital mortality rate (HMR) among patients with STEMI [2]. In European countries, the HMR associated with STEMI varies from 6% to 14%, indicating comparable values of these indicators and the necessity of predicting adverse events at different observation horizons [3]. In order to achieve this objective, professional communities in different countries have developed and validated prognostic scales. The most well-known of these include the Global Registry of Acute Cardiac Events risk score (GRACE), the Thrombolysis in Myocardial Infarction

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ST elevation (TIMI-STe), the Controlled Abciximab and Device Investigation to Lower Late Angioplasty Complications (CADILLAC), the Primary Angioplasty in Myocardial Infarction (PAMI), and the RECORD scales [4–8]. The structure of all these scales incorporates data pertaining to the age and Killip classification of acute heart failure (AHF). The majority of the aforementioned prognostic scales employ a set of predictor parameters, including heart rate (HR), systolic blood pressure (SBP), and the presence of type 2 diabetes mellitus (DM). In some prognostic scales, certain laboratory test and clinical examination indicators, including hemoglobin and creatinine concentrations, hematocrit, left ventricular ejection fraction (LVEF), the presence of three-vessel coronary artery disease, and the degree of coronary blood flow recovery according to TIMI criteria (0-2), are utilized as prognostic factors. Prior research has indicated that conventional prognostic scales have certain limitations in predicting the likelihood of hospital mortality in patients STEMI who have undergone percutaneous coronary intervention (PCI) [9]. PCI represents a principal strategy for myocardial revascularization and is becoming increasingly prevalent in clinical practice, underscoring the necessity to predict its immediate and long-term outcomes. At present, prediction tools are being developed through the integration of novel predictors and contemporary technologies for the processing and analysis of extensive data sets, including machine learning (ML) methodologies [10]. In contrast to conventional statistical techniques, ML algorithms are distinguished by a reduced number of assumptions and superior predictive precision.

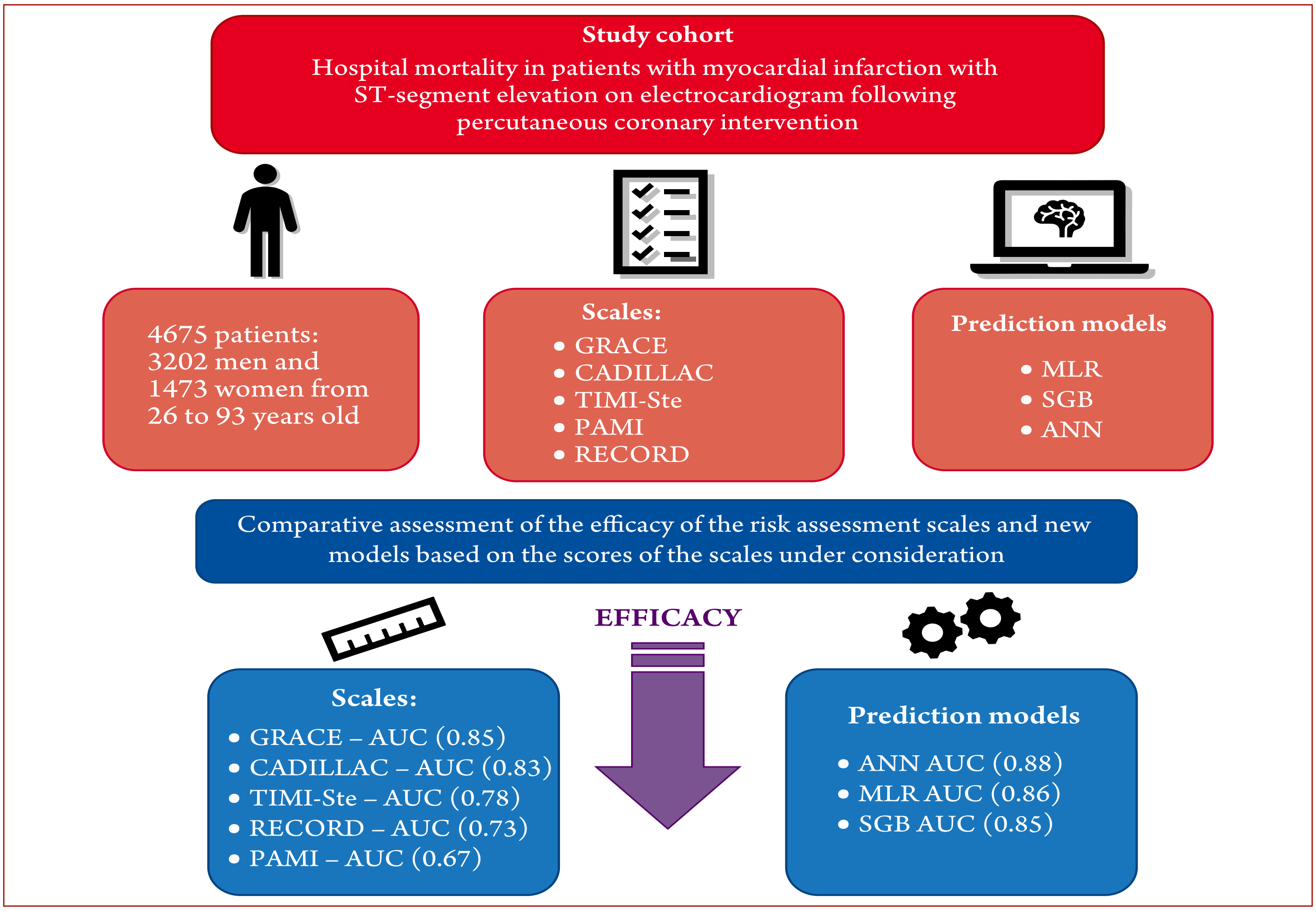
Objective

The objective of the study was to conduct a comparative evaluation of the effectiveness of risk assessment scales in predicting HMR in STEMI patients after PCI and in developing new models based on ML methods.

Material and Methods

A single-center cohort retrospective study was conducted to analyze the data from 4,675 electronic medical records of 3,202 male and 1,473 female patients with STEMI aged 63 [55; 70] years (ranging from 26 to 93 years) who were admitted to the Regional Vascular Center of the Primorsky Krai Clinical

Central illustration. Comparative Analysis of the Effectiveness of Riskometer Scales in Predicting the Risk of in-Hospital Mortality in Patients With ST-Segment Elevation Myocardial Infarction After Percutaneous Coronary Intervention



ANN, artificial neural network; SGB, stochastic gradient boosting; MLR, multivariate logistic regression.

Hospital No. 1 (Vladivostok, Russian Federation) between 2015 and 2021. The study was conducted in accordance with the ethical principles set forth in the Declaration of Helsinki and received approval from the local ethics committee of Far Eastern Federal University.

Inclusion criteria: a confirmed diagnosis of STEMI and PCI performed on the first day of hospital treatment.

Exclusion criteria: non-ST-segment elevation MI, unstable angina pectoris, and no indications for PCI.

All patients underwent emergency invasive coronary angiography (CAG), which was followed by transluminal balloon angioplasty with stenting of the infarct-related artery. This was conducted using a General Electric Innova 3100 angiographic system. Two distinct groups of patients were identified. Group 1 comprised 318 patients (6.8%) who died during their hospital stay. Group 2 included 4357 patients (93.2%) with a favorable outcome. The underlying cause of mortality was cardiogenic shock in 117 patients, recurrent ventricular tachyarrhythmias in 55 patients, mechanical complications in 43 patients, severe heart failure in 37 patients, multiple organ dysfunction syndrome associated with severe combined pathology and infectious complications in 34 patients, and recurrent MI in 32 patients.

The study design was comprised of three distinct stages. In the initial stage of the study, a statistical analysis was conducted to evaluate the values of 16 predictors utilized in the analyzed scales across the comparison groups. In the second stage, the scales were evaluated for their ability to stratify the risk of hospital mortality in the study sample. In the third stage of the study, prognostic models for HMR were developed. In algorithms based on univariate logistic regression, a total score for each scale was employed as the sole predictor variable. The multivariate logistic regression, stochastic gradient boosting (SGB), and artificial neural network (ANN) models included five predictors, derived from the analyzed scales (see Table 5).

The statistical analysis methods employed included Lilliefors, chi-squared test, Fisher's test, Mann-Whitney test, and univariate logistic regression. The variables are presented as median and interquartile range (Me [Q1; Q3]) due to the fact that the data did not exhibit a normal distribution. The observed differences were determined to be statistically significant at the $p < 0.05$ level. The ML methods included multivariate logistic regression, SGB, and ANN. The architecture of the fully connected ANN comprised two hidden layers with a rectified linear unit (ReLU) activation function, which included 10 and 8 neurons, respectively.

Results

A total of 16 predictors included in the structure of the GRACE, CADILLAC, TIMI-STe, PAMI, and RECORD scales were utilized for the purpose of analyzing the risk of hospital mortality (Table 1).

The CAG results identified patients with three-vessel disease and abnormal coronary perfusion after PCI (TIMI 0–2). Due to the null dispersion in the categorical features of the GRACE scale (ST-segment elevation, diagnostically significant increase in the level of cardiac-specific enzymes, cardiac arrest at the time of admission) across all patients, these features were excluded from consideration as predictors of hospital mortality. The risk stratification of hospital mortality was conducted in accordance with the scoring systems of each scale (Table 2). The all-cause HMR in STEMI patients following PCI was used as study endpoint, which was expressed as a categorical binary variable (i.e., «absence» or «occurrence»).

A risk stratification of adverse events was conducted using the ANN model, whereby the median values of prognostic probabilities of in-hospital mortality in the comparison groups were calculated. The median values were correlated with the thresholds of low and very high risk The threshold delineating moderate and high risk was defined as the arithmetic mean between the medians of the prognostic probability of in-hospital mortality in the groups of surviving and deceased patients (Table 3). The quality of prognostic models was evaluated using six metrics: area under the ROC curve (AUC), sensitivity (Sen), specificity (Sp), positive predictive value (PPV), negative predictive value (NPV), harmonic mean of precision and recall (F1).

An intergroup analysis of the values of predictors of in-hospital mortality included in the structure of individual scales revealed that the majority of them exhibited statistically significant differences (Table 4).

For example, in Group 1, the majority of patients were older, had lower body weight and SBP, and higher HR. In comparison with patients with a favorable outcome, the deceased patients exhibited lower levels of hemoglobin, hematocrit, and LVEF, as well as higher creatinine levels and a higher Killip class of AHF. It is noteworthy that a history of type 2 DM was significantly more prevalent across Group 1 patients, while the prevalence of hypertension was comparable. A noteworthy attribute of this group was the delayed initiation of reperfusion therapy, which was observed in 71.7% of patients and was associated with an almost twofold increase in the probability of in-hospital mortality (odds ratio [OR] 1.9; $p < 0.0001$). The presence of three-vessel disease and an insufficient degree of coronary perfusion recovery (TIMI 0–2) were observed twice as often in patients who died as compared to those with a favorable outcome of PCI, which significantly increased the risk of in-hospital mortality (OR 2.5 and 2.6, respectively). Moreover, the localization of STEMI in the anterior LV wall was also associated with an elevated risk of in-hospital mortality following PCI (OR 1.5; $p < 0.0001$). The stratification of in-hospital mortality risk using conventional scales in the cohort of interest revealed that the prognostic values of the scales differed (see Table 2). The OR calculation demonstrated a

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Table 1. Predictors used in the analyzed risk assessment scales

Scale	Predictors
GRACE	Age, HR, SBP, Killip class of AHF, creatinine, cardiac arrest at admission, ST-segment elevation, diagnostically significant elevation of cardiac specific enzymes
TIMI-STe	Age, Killip class of AHF, HR, SBP, weight, type 2 DM, hypertension, history of angina pectoris, time to revascularization >4 h, anterior MI
CADILLAC	Age, Killip class of AHF, GFR, LVEF, blood flow TIMI (0–2), hematocrit, three-vessel disease
RECORD	Age, Killip class of AHF, SBP, type 2 DM, ST-segment elevation, hemoglobin
PAMI	Age, Killip class of AHF, HR, type 2 DM, anterior MI

HR, heart rate; SBP, systolic blood pressure; AHF, acute heart failure;
DM, diabetes mellitus; MI, myocardial infarction; TIMI, Thrombolysis In Myocardial Infarction score.

notable increase in the probability of in-hospital mortality among patients at high risk of an unfavorable outcome, from 4.2 times according to the PAMI scale to 11 times when assessed using the GRACE scale. In contrast, low-risk score values were predominant among those with favorable outcomes, and exhibited an inverse relationship with HMR, as evidenced by OR values: 0.08 (CADILLAC) – 0.41 (TIMI-STe). The moderate-risk subgroup exhibited an inverse correlation with HMR, though to a lesser degree than the low-risk cohort (OR 0.29–0.51). The TIMI-STe scale was the sole exception, showing no intergroup disparities within this category of risk (OR 1.05; p = 0.706). Nevertheless, this scale demonstrated the highest positive predictive value (PPV) among high-risk patients, indicating a high probability of correctly identifying in-hospital mortality. The RECORD scale demonstrated the lowest value for this indicator, which can be attributed to a notable prevalence of false-positive cases of in-hospital mortality among patients with a favorable outcome of PCI.

In the third stage of the study, five univariate logistic regression models were developed using the total scores of the individual scales as the sole predictor variable (Table 5). The data were divided into two subsets for the purposes of training,

Table 2. Stratification of the risk of in-hospital mortality in STEMI patients who have undergone PCI using the analyzed scales

Predictor	Group 1 (n = 318)	Group 2 (n = 4357)	OR (95 % CI)	PPV	p
GRACE					
Total score, Me [Q1; Q3]	194 [163; 223]	135 [117; 157]	—	—	< 0.0001
Low risk (< 126)	17 (5.32 %)	1573 (36.11 %)	0.1 (0.06–0.16)	0.01	< 0.0001
Moderate risk (126–154)	46 (14.45 %)	1602 (36.76 %)	0.29 (0.21–0.4)	0.03	< 0.0001
High risk (> 154)	255 (80.23 %)	1182 (27.13 %)	10.9 (8.19–14.44)	0.18	< 0.0001
TIMI-STe					
Total score, Me [Q1; Q3]	6 [4.75; 7]	5 [4; 6]	—	—	< 0.0001
Low risk (0–4)	80 (25 %)	1959 (44.95 %)	0.41 (0.32–0.53)	0.04	< 0.0001
Moderate risk (5–6)	161 (50.7 %)	2158 (49.54 %)	1.05 (0.83–1.31)	0.07	0.706
High risk (7–14)	77 (24.3 %)	240 (5.51 %)	5.48 (4.11–7.3)	0.24	< 0.0001
CADILLAC					
Total score, Me [Q1; Q3]	9 [7; 11]	4 [2; 7]	—	—	< 0.0001
Low risk (0–2)	15 (4.79 %)	1628 (37.37 %)	0.08 (0.05–0.14)	0.01	< 0.0001
Moderate risk (3–5)	52 (16.17 %)	1378 (31.62 %)	0.42 (0.31–0.57)	0.04	< 0.0001
High risk (6–18)	251 (79.04 %)	1351 (31.01 %)	8.72 (6.32–11)	0.16	< 0.0001
PAMI					
Total score, Me [Q1; Q3]	7 [5; 10]	4 [2; 7]	—	—	< 0.0001
Low risk (0–2)	26 (8.18 %)	1113 (25.55 %)	0.26 (0.17–0.39)	0.02	< 0.0001
Moderate risk (3–6)	104 (32.7 %)	2132 (48.94 %)	0.51 (0.4–0.65)	0.05	< 0.0001
High risk (7–15)	188 (59.12 %)	1112 (25.51 %)	4.22 (3.34–5.33)	0.14	< 0.0001
RECORD					
Total score, Me [Q1; Q3]	3 [3; 4]	2 [1; 3]	—	—	< 0.0001
Low risk (0–1)	17 (5.33 %)	1438 (33 %)	0.11 (0.07–0.19)	0.01	< 0.0001
High risk (2–6)	301 (94.67 %)	2919 (67 %)	8.34 (5.33–14.28)	0.09	< 0.0001

STEMI, ST-segment elevation myocardial infarction; PCI, percutaneous coronary intervention;
OR, odds ratio; CI, confidence interval; PPV, positive predictive value.

Table 3. Stratification of risk of hospital mortality in STEMI patients who have undergone PCI using the ANN model

Risk level, %	Probability ranges for hospital mortality	PPV
Low	< 0.3	0.01
Moderate	0.3–9	0.04
High	9–17	0.13
Very high	> 17	0.32

STEMI, ST-segment elevation myocardial infarction; PCI, percutaneous coronary intervention; ANN, artificial neural network; PPV, positive predictive value.

cross-validation, and final testing. 30% for final testing and 70% for training and cross-validation, which was performed using the stratified Monte Carlo method on 50 samples. The data analysis and model development were conducted using the Python programming language.

A comparative analysis of the quality indicators of prognostic algorithms of univariate logistic regression revealed a considerable degree of variability in the AUC metric, with values ranging from 0.673 in the PAMI-based model to 0.849 in the GRACE model. This observation indicates that the latter model demonstrates superior prognostic properties. This model demonstrated the highest values for the remaining quality indicators: Sp, PPV, and F1. The CADILLAC model demonstrated the second highest prognostic accuracy, whereas the lowest values of the quality metrics for the PAMI model indicated its limited prognostic potential for estimating the probability of in-hospital mortality in the cohort of interest. The univariate logistic regression models with the predictors used in the RECORD and TIMI-STe scales demonstrated acceptable prognostic accuracy. However, they exhibited inferior performance in some quality metrics in comparison to the CADILLAC model. In order to enhance the accuracy of HMR prediction, integrated models were developed based upon ML methods, namely multivariate logistic regression, SGB, and ANN. In these models, a combination of scores derived from five analyzed scales was employed as predictors (Figure 1).

A comparative analysis of the significance of differences in the AUC metric obtained on test samples of eight models confirmed the prognostic advantages of the GRACE scale in relation to other univariate logistic regression algorithms ($p < 0.0001$) and comparable values of this indicator and models based on multivariate logistic regression and SGB ($p = 0.17$ and $p = 0.10$, respectively; Table 6).

The ANN model exhibited superior prognostic accuracy in comparison to univariate and multivariate models, as well as to the SGB. This was demonstrated by the highest values of the main quality metrics, including AUC (0.88), Sp (0.832), PPV (0.158), and F1 (0.267), as well as the results of statistical hypothesis testing ($p < 0.0001$). The data from this model were used to stratify a probability of in-hospital mortality, with the following categories of risk: low (< 0.3%), moderate (0.3–

Table 4. Predictors of the risk assessment scales in STEMI patients who underwent PCI in the comparison groups

Predictor	Group 1 (n = 318)	Group 2 (n = 4,357)	OR (95 % CI)	p
Age, years (Me [Q1; Q3])	71 [63; 78]	62 [55; 69]	—	< 0.0001
Weight, kg (Me [Q1; Q3])	78 [70; 85]	80 [71; 90]	—	< 0.0001
AHF Killip class (Me [Q1; Q3])	3 [2; 4]	1 [1; 2]	—	< 0.0001
HR, bpm (Me [Q1–Q3])	86 [72; 100]	72 [65; 80]	—	< 0.0001
SBP, mm Hg (Me [Q1; Q3])	110 [90; 130]	130 [120; 150]	—	< 0.0001
Hb, g/L (Me [Q1–Q3])	132 [118; 144]	141 [129; 151]	—	< 0.0001
Ht, % (Me [Q1; Q3])	35.8 [32; 39.23]	38.3 [34.9; 41.7]	—	< 0.0001
Cr, μmol/L (Me [Q1–Q3])	130 [96; 196]	97 [81; 115]	—	< 0.0001
GFR, mL/min (Me [Q1–Q3])	45.6 [30.8; 70.4]	77.6 [58.8; 99]	—	< 0.0001
LVEF, % (Me [Q1–Q3])	47 [38; 55]	56 [50; 61]	—	< 0.0001
Three-vessel disease	108 (33.96 %)	738 (16.94 %)	2.5 (1.97–3.22)	< 0.0001
TIMI 0–2	10 (3.14 %)	64 (1.47 %)	2.6 (1.3–5.05)	0.01
Time to revascularization > 4 h	228 (71.7 %)	2534 (58.17 %)	1.9 (1.4–2.4)	< 0.0001
Anterior MI	178 (55.97 %)	2017 (46.30 %)	1.5 (1.17–1.85)	0.0001
Hypertension	168 (52.83 %)	2099 (48.19 %)	1.2 (0.96–1.51)	0.1232
DM type 2	100 (31.45 %)	830 (19.05 %)	1.9 (1.5–2.5)	< 0.0001

STEMI, ST-segment elevation myocardial infarction; PCI, percutaneous coronary intervention; OR, odds ratio; CI, confidence interval; AHF, acute heart failure; HR, heart rate; SBP, systolic blood pressure; Hb, hemoglobin; Ht, hematocrit; Cr, creatinine; GFR, glomerular filtration rate; LVEF, left ventricular ejection fraction; TIMI, Thrombolysis In Myocardial Infarction score; MI, myocardial infarction; DM, diabetes mellitus.

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Table 5. Evaluation of the accuracy of prognostic models for HMR in patients with STEMI who have undergone PCI

Model	Validation sample						Test sample					
	AUC	Sen	Sp	PPV	NPV	F1	AUC	Sen	Sp	PPV	NPV	F1
ULR PAMI, total score	0.673	0.6	0.67	0.091	0.962	0.161	0.666	0.588	0.668	0.107	0.96	0.181
ULR RECORD, total score	0.73	0.682	0.694	0.122	0.97	0.21	0.728	0.674	0.693	0.137	0.967	0.228
ULR TIMI-STe, total score	0.783	0.765	0.692	0.079	0.99	0.146	0.783	0.781	0.688	0.125	0.983	0.215
ULR CADILLAC, total score	0.828	0.818	0.705	0.101	0.989	0.179	0.824	0.76	0.725	0.105	0.987	0.186
ULR GRACE, total score	0.849	0.75	0.766	0.14	0.985	0.239	0.839	0.771	0.769	0.143	0.986	0.239
MLR GCRPT	0.858	0.8	0.778	0.093	0.992	0.167	0.84	0.737	0.78	0.092	0.991	0.164
SGB GCRPT	0.846	0.778	0.769	0.086	0.992	0.157	0.842	0.789	0.784	0.095	0.992	0.17
ANN GCRPT	0.88	0.818	0.832	0.158	0.992	0.267	0.856	0.78	0.806	0.134	0.99	0.228

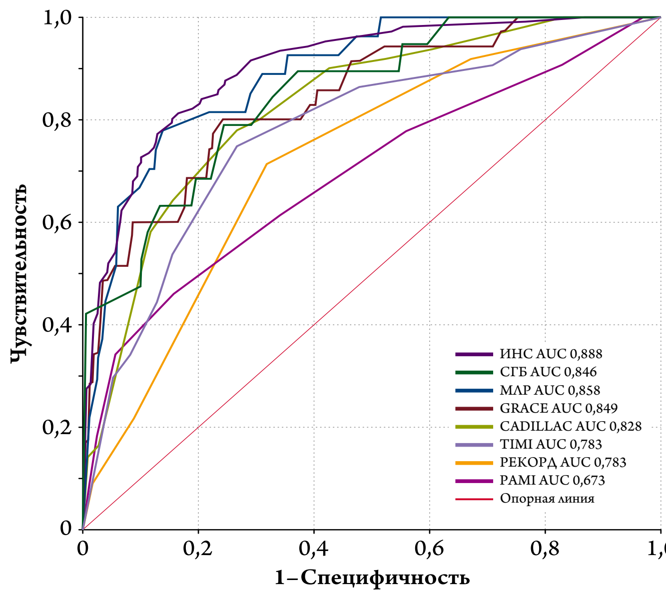
HMR, hospital mortality rate; STEMI, ST-segment elevation myocardial infarction; PCI, percutaneous coronary intervention; AUC, area under the ROC curve; Sen, sensitivity; Sp, specificity; PPV, positive predictive value; NPV, negative predictive value; F1, harmonic mean of precision and recall; ULR, univariate logistic regression; MLR, multivariate logistic regression; SGB, stochastic gradient boosting; ANN, artificial neural network; GCRPT, combined model based on the GRACE; CADILLAC; RECORD; PAMI; TIMI-STe scales.

9%), high (9–17%), and very high (> 17%) (see Table 3). The consistent increase in the PPV metric values associated with the escalation in risk category (0.01, 0.04, 0.13, and 0.32, respectively) confirmed the correctness of the stratification.

Discussion

In recent years, there has been a notable increase in the utilization of predictive analytics methodologies in the field of clinical medicine. This is evidenced by the growing number of scientific studies that are focused on the enhancement of prediction tools [11]. In the present study, two of the five examined scales (GRACE and RECORD) were constructed using data from the corresponding registries of patients with acute coronary syndrome, while the remaining three (PAMI, CADILLAC, and TIMI-STe) were based on data from registries of patients with a refined diagnosis of STEMI. The CADILLAC scale is the only one that includes indicators of coronary lesions and coronary blood flow recovery, which is associated with more accurate stratification of the risk of in-hospital mortality following endovascular revascularization. Concurrently, an assessment of the values of the 16 factors incorporated into the structure of these scales revealed that the majority of them exhibited a statistically significant correlation with the study's endpoint (see Table 4). The results obtained confirm the data on the universal prognostic ability of the previously identified risk metric indicators for determining the probability of in-hospital mortality in various variants of acute ischemic myocardial injury [12].

Figure 1. ROC curves of univariate and multivariate models of hospital mortality rate



ANN, artificial neural network; SGB, stochastic gradient boosting; MLR, multivariate logistic regression.

The evaluation of the prognostic value of individual scales in the cohort of interest demonstrated a variable quality of risk stratification for in-hospital mortality following PCI (see Table 2). The GRACE scale demonstrated the highest prognostic accuracy, which is associated with an optimal set of clinical features that characterize the current circulatory status. In contrast, the PAMI scale exhibited the lowest level of prognostic accuracy. The CADILLAC scale demonstrated the second highest prognostic capacity, which can be attributed to the incorporation of factors such as three-vessel disease, LVEF, glomerular filtration rate (GFR), and TIMI (0–2) into its structure. These factors are closely associated with the study's endpoint [3]. The RECORD scale, developed based on data from the Russian registry of patients with ACS, exhibited comparable probability of identifying patients at high risk of dying in hospital (OR 8.34 and 8.72, respectively) to that of the CADILLAC scale. However, it demonstrated a considerable number of false-positive results, as indicated by the low values of the PPV metric. It is plausible that the distortion of prognostic results when utilizing this scale is attributable, at least in part, to the fact that less than one-third of the patients included in this registry underwent PCI. The TIMI-STe scale, developed on the basis of the results of the InTIME II (Intravenous nPA for Treatment of Infarcting Myocardium Early II) study, conducted on cohorts of patients with STEMI, demonstrated an acceptable quality of stratification of in-hospital mortality high-risk groups, as evidenced by the highest value of true positive results. In studies conducted by other researchers comparing the quality of HMR prognosis in STEMI patients following PCI, the GRACE, CADILLAC, and TIMI-STe scales were also demonstrated to possess advantages over other stratification tools [13].

An active search is currently being conducted to identify new predictors of adverse events associated with STEMI [14, 15]. In various publications, the newly identified predictors of in-hospital mortality in this category of patients were most often represented by comorbidity indicators, blood leukocyte count, the blood cell ratio, criterion limits of LVEF, atrial fibrillation, symptom-to-door and symptom-to-balloon times, signs of PCI failure (slow flow and no reflow phenomena), and others [9, 16]. In recent years, the anatomic SYNTAX SCORE calculator has been enhanced through the incorporation of six clinical and functional indicators into its structure. These include age, sex, LVEF, GFR, the presence of chronic obstructive pulmonary disease, and the involvement of peripheral arterial beds. Nevertheless, the SYNTAX SCORE 2 scale, developed on this basis, has been demonstrated to exhibit insufficient reproducibility and prognostic accuracy in a number of studies. This is due, among other factors, to the restricted range of clinical characteristics that are required to identify patients with STEMI with an elevated risk of in-hospital mortality [17].

In our study, the objective of improving the quality of in-hospital mortality risk stratification was based on the development of prognostic models based on modern ML methodologies. The predictors of these models were the total scores from the analyzed scales. This allows for the unification of the system of measuring probabilistic assessments of adverse events and the development of integrated prognostic models. The findings of the present study indicated that the univariate models based on the total GRACE and CADILLAC scales exhibited superior prognostic accuracy, thereby substantiating the prognostic value of the factors incorporated into their structure. The maximum values of the quality metrics of the integrated ANN-based model indicate that the integration of the prognostic resources of the analyzed scales markedly enhances the accuracy of in-hospital mortality risk stratification. The reliability of the ANN model was confirmed by estimating the probability of unfavorable outcomes in a cohort of patients with a very high risk of in-hospital mortality. According to the PPV metric, this probability was 0.32 (see Table 3).

The limitations of the study can be attributed to its retrospective design, the omission of the SYNTAX SCORE 2 scale from the analysis due to an insufficient set of clinical features for risk stratification of adverse events, and the necessity to validate the models developed based on cohorts of STEMI patients from other medical facilities.

Table 6. Comparison of the AUC metric in prognostic models

#	Model	AUC	95 % CI	p
1	ULR PAMI, total score	0.666	(0.660–0.672)	p_{1-2}<0.0001; p_{1-3}<0.0001; p_{1-4}<0.0001; p_{1-5}<0.0001; p_{1-6}<0.0001; p_{1-7}<0.0001; p_{1-8}<0.0001
2	ULR RECORD, total score	0.728	(0.724–0.733)	p_{2-1}<0.0001; p_{2-3}<0.0001; p_{2-4}<0.0001; p_{2-5}<0.0001; p_{2-6}<0.0001; p_{2-7}<0.0001; p_{2-8}<0.0001
3	ULR TIMI-STe, total score	0.783	(0.779–0.788)	p_{3-1}<0.0001; p_{3-2}<0.0001; p_{3-4}<0.0001; p_{3-5}<0.0001; p_{3-6}<0.0001; p_{3-7}<0.0001; p_{3-8}<0.0001
4	ULR CADILLAC, total score	0.824	(0.821–0.831)	p_{4-1}<0.0001. p_{4-2}<0.0001; p_{4-3}<0.0001. p_{4-5}<0.0001; p_{4-6}<0.0001. p_{4-7}<0.0001; p_{4-8}<0.0001
5	ULR GRACE, total score	0.839	(0.833–0.845)	p_{5-1}<0.0001; p_{5-2}<0.0001; p_{5-3}<0.0001; p_{5-4}<0.0005; p_{5-6}=0.17. p_{5-7}<0.10; p_{5-8}<0.0001
6	MLR GCRPT	0.840	(0.832–0.847)	p_{6-1}<0.0001; p_{6-2}<0.0001; p_{6-3}<0.0001; p_{6-4}<0.0001; p_{6-5}=0.17. p_{6-7}=0.13; p_{6-8}<0.0001
7	SGB GCRPT	0.842	(0.836–0.848)	p_{7-1}<0.0001; p_{7-2}<0.0001; p_{7-3}<0.0001; p_{7-4}<0.0001; p_{7-5}=0.10. p_{7-6}=0.13; p_{7-8}<0.0001
8	ANN GCRPT	0.856	(0.849–0.864)	p_{8-1}<0.0001; p_{8-2}<0.0001; p_{8-3}<0.0001; p_{8-4}<0.0001; p_{8-5}<0.0001; p_{8-6}<0.0001; p_{8-7}<0.0001

AUC, area under the ROC curve; CI, confidence interval; ULR, univariate logistic regression; MLR, multivariate logistic regression; SGB, stochastic gradient boosting; ANN, artificial neural network; GCRPT, combined model based on the GRACE; CADILLAC; RECORD; PAMI; TIMI-STe scales; p_{1-8}, significance of differences in the comparison groups.

Conclusion

The findings of the present study indicated that, in comparison to the RECORD and PAMI scales, the GRACE, CADILLAC, and TIMI-STE prognostic tools demonstrated superior performance in stratifying the risk of in-hospital mortality in patients with ST-segment elevation myocardial infarction following percutaneous coronary intervention. The univariate logistic regression models based on the GRACE and CADILLAC scales exhibited superior prognostic value in comparison to those based on other scales. An integrative artificial neural network model incorporating a combination of scores from five scales demonstrated superior quality criteria

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in comparison to multivariate logistic regression models and stochastic gradient boosting. The stratification algorithm, based on the data from this model, demonstrated an accurate identification of patients with ST-segment elevation myocardial infarction at high and very high risk of in-hospital mortality following percutaneous coronary intervention.

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