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Performance of the GRACE and the ACTION risk model in the prediction of in-hospital mortality: external validation, model revision and updating in the Thai Percutaneous Coronary Intervention Registry

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► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/openhrt-2024-003027).

To cite: Kiatchoosakun S, Chamnarnphol N, Wongwipaporn C, *et al*. Performance of the GRACE and the ACTION risk model in the prediction of in-hospital mortality: external validation, model revision and updating in the Thai Percutaneous Coronary Intervention Registry. *Open Heart* 2025;**12**:e003027. doi:10.1136/openhrt-2024-003027

Received 22 October 2024
Accepted 24 March 2025

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ABSTRACT

Background External validation is crucial before implementing a risk score model in clinical practice. This study examined the performance of Global Registry of Acute Coronary Events (GRACE) and Acute Coronary Treatment and Intervention Outcomes Network (ACTION) Registry–Get With The Guidelines (GWTG) (ACTION Registry–GWTG) Risk Score (AR-G RS) using the Thai Percutaneous Coronary Intervention Registry (TPCIR).

Methods Included in this study were 11 455 patients with acute coronary syndrome (ACS) undergoing percutaneous coronary intervention (PCI) between November 2015 and May 2018. GRACE and AR-G RS models were externally validated, revised and updated using discrimination (C-statistic score) and calibration (Hosmer-Lemeshow (HL) indexes). Clinical predictors were selected stepwise from the multivariate analysis to evaluate the performance of each risk score in the revised and updated model.

Results In-hospital mortality was 4.4%. GRACE and AR-G RS demonstrated good discrimination for in-hospital mortality (C-statistics 0.8957 and 0.8823, respectively) with optimal calibration (HL, p=0.036 and 0.006, respectively) and penalty rates of 0.005 and 0.006, respectively. The updated model significantly improved the discrimination performance compared with the original GRACE and AR-G RS models, with a C-statistic of 0.9118 and a penalty of 0.006.

Conclusion GRACE and AR-G RS maintained a good performance in TPCIR. Based on routine PCI practice, we demonstrated that the updated model could improve the accuracy of GRACE and AR-G RS in predicting in-hospital mortality among patients with ACS who underwent PCI.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Global Registry of Acute Coronary Events (GRACE) and Acute Coronary Treatment and Intervention Outcomes Network (ACTION) Registry–Get With The Guidelines (GWTG) (ACTION Registry–GWTG) (AR-G) Risk Scores have been used for risk stratification of patients with acute coronary syndrome (ACS) for many years. The performance of both scores has not been well tested in contemporary, real-world practice in Asian countries.

WHAT THIS STUDY ADDS

⇒ We have demonstrated the good performance of both GRACE and AR-G Risk Scores in predicting in-hospital mortality using the nationwide registry of 11 455 consecutive patients with ACS. The revised and updated model helps further improve the discrimination performance compared with the original risk scores.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ GRACE and AR-G Risk Scores are still useful tools for predicting in-hospital mortality in patients with ACS. The revised and updated model could also be a good alternative for risk stratification in patients with ACS.

INTRODUCTION

Risk stratification is essential for triaging and managing patients with acute coronary syndrome (ACS). Knowing the risk status of patients with ACS facilitates the development of different treatment strategies, including coronary revascularisation, antithrombotics and medical treatment regimens.[1 2] Several risk predictor models have been developed over the past decade to estimate the risk of all-cause mortality. The Global Registry of Acute Coronary Events (GRACE) risk model has been validated and accepted as a screening tool for patients with ACS in current cardiology practice.[3–6] The accuracy of the GRACE

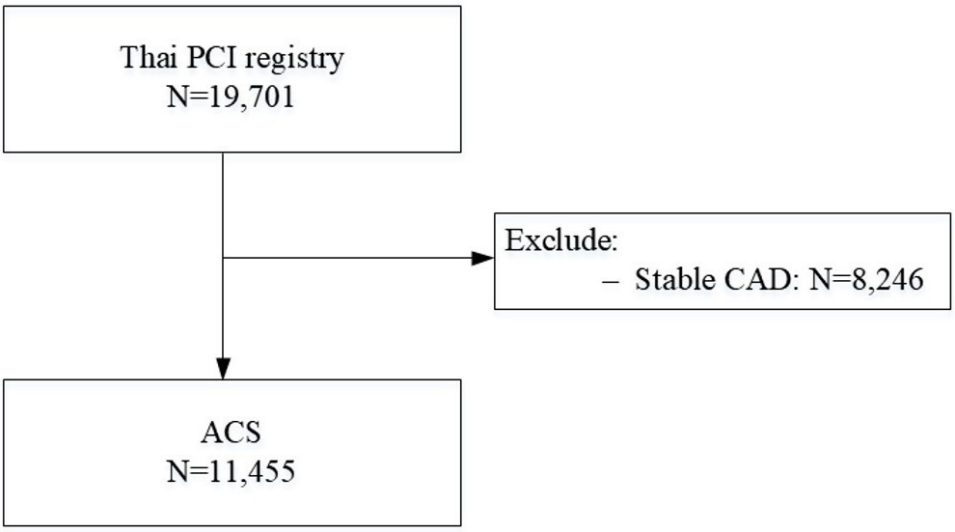

Figure 1 Flow data for analysis. ACS, acute coronary syndrome; PCI, percutaneous coronary intervention; CAD, coronary artery disease.

Risk Score (GRACE RS) model has been confirmed by external validation using different study cohorts.[6–10] A more recent risk score (RS) for in-hospital death, using data derived from the Acute Coronary Treatment and Intervention Outcomes Network (ACTION) Registry–Get With The Guidelines (GWTG) (ACTION Registry–GWTG) Risk Score (AR-G RS), offers a more contemporary risk prediction tool for patients with ACS.[11] However, these RS have limitations, are derived from selected populations and contain many selection criteria. The Cardiovascular Intervention Association of Thailand initiated a Thai Percutaneous Coronary Intervention Registry (TPCIR) that included patients undergoing percutaneous coronary intervention (PCI) in Thailand. The main objective of this prospective registry was to collect a national database of Thai patients who underwent PCI, including patient demographic, clinical, angiographic and procedural characteristics. Furthermore, registration provides an opportunity to evaluate the accuracy of GRACE and AR-G RS in predicting in-hospital mortality in the Thai population. Therefore, the objectives of this study were: (1) to externally validate the performance of GRACE and AR-G RS in TPCIR and (2) to revise and update the GRACE and AR-G RS using the new or additional risk factors guided by the Thai PCI database.

MATERIALS AND METHODS

The TPCIR is a clinical database that includes all patients undergoing PCI between November 2015 and May 2018 at 39 voluntary cardiac centres in Thailand.

All consecutive patients 18 years or older who underwent PCI were included in the registry, and written informed consent was obtained prior to enrolment and PCI procedures. TPCIR includes information on age, sex, clinical presentation, coronary risk factors, kidney disease, cerebrovascular disease, peripheral vascular disease, presence or absence of heart failure, coronary artery anatomy, procedural details, equipment and PCI, mainly in-hospital complications and death.

Investigators and research nurses from all the sites participated in several network meetings, including hands-on training workshops for electronic case record form (eCRF) data collection and input eCRFs. Each site investigator continuously monitored data accuracy, quality assurance and quality control. All inconsistent data were corrected by agreement between the PCI registry consortium and the study sites. The rationale and design of the TPCIR were described in Sansanayudh *et al*.[12]

Data maintenance and monitoring were performed by the Data Management Unit (DMU), and at least 10% of the cases at each site were selected for data completion and audit.

Definition

Standard definitions were documented and trained prior to data capture in TPCIR. Death was defined as all-cause mortality during hospitalisation. ST-elevation ACS (STE-ACS) and non-ST-elevation ACS (NSTE-ACS) (non-ST-elevation myocardial infarction and unstable angina) were classified according to the European Society of Cardiology Guideline.[1 13] Procedure success was defined as <50% residual stenosis with normal coronary flow. Myocardial infarction was defined according to the fourth universal definition of myocardial infarction,[14] and renal failure was defined as creatinine >1.5 mg/dL or Glomerular Filtration Rate (GFR) <60 mL/min/m^2 at admission. Cardiogenic shock on admission was defined as (a) systolic blood pressure (SBP) <90 mm Hg for 30 min, (b) adequate fluid therapy and (c) signs of poor tissue perfusion. In-hospital adverse events included stroke (new neurological deficit occurring after the procedure) or access site complications such as haematoma or pseudoaneurysm. Major bleeding was defined as any bleeding

Table 1 Estimation of coefficients based on Thai ACS compared with coefficients from GRACE and ACTION models

	PCI registry		GRACE cohort	ACTION Registry
	Revised GRACE/ ACTION	Updated GRACE/ ACTION	9 Predictors	9 Predictors
Predictors	Coefficient (95% CI)	Coefficient (95% CI)	Coefficient (95% CI)	Coefficient (95% CI)
Age, per 1 year increase	0.043 (0.034 to 0.052)	0.042 (0.032 to 0.051)	0.053 (0.044 to 0.062)	0.040 (0.036 to 0.041)
Creatinine, per 1 mg/dL increase	0.124 (0.076 to 0.173)	0.121 (0.069 to 0.173)	0.182 (0.140 to 0.300)	
Heart failure				0.564 (0.495 to 0.631)
Heart rate, per 1 beat per minute increase	0.014 (0.010 to 0.018)	0.010 (0.006 to 0.016)	0.009 (0.005 to 0.013)	0.0009 (0.0086 to 0.0104)
SBP, per 1 mm Hg decrease	−0.012 (−0.015 to −0.008)	−0.010 (−0.014 to −0.006)	−0.017 (−0.019 to −0.012)	−0.0018 (−0.0019 to −0.0017)
STEMI versus NSTEMI	0.315 (0.075 to 0.554)	0.397 (0.138 to 0.656)		0.597 (0.536 to 0.663)
Cardiogenic shock at start PCI	0.756 (0.496 to 1.017)	0.477 (0.191 to 0.763)		1.468 (1.386 to 1.550)
Initial cardiac enzyme-level elevation positive	−1.028 (−1.602 to −0.455)	−0.965 (−1.578 to −0.351)	0.470 (0.278 to 0.693)	
Killip class, per increase in class	0.837 (0.737 to 0.937)	0.475 (0.361 to 0.588)	0.693 (0.593 to 0.829)	
Creatinine clearance, per 1 mL/min/1.73 m^2				−0.020 (−0.019, −0.021)
ST-segment deviation*†			0.875 (0.642 to 1.099)	
Elevated cardiac enzyme†			0.470 (0.278 to 0.693)	
Cardiac arrest at hospital arrival†			1.459 (1.030 to 1.905)	1.613 (1.528 to 1.699)
Troponin ratio†				0.008 (0.008 to 0.010)
Access site				
Brachial and other versus radial		1.367 (−0.728 to 3.461)		
Femoral versus radial		0.367 (0.091 to 0.643)		
Combination versus radial		0.892 (0.278 to 1.507)		
ET tube intubation		1.407 (1.142 to 1.671)		
Procedure intra-aortic balloon pump (IABP)		0.812 (0.535 to 1.089)		
Arrhythmia and medical treatment				
Arrhythmia and medical treatment versus none		0.451 (0.148 to 0.754)		
Arrhythmia and no medical treatment versus none		0.404 (−0.054 to 0.863)		
New requirement for dialysis		0.931 (0.408 to 1.455)		
PCI failure		0.886 (0.499 to 1.274)		
Procedure complications		0.431 (0.106 to 0.757)		
Intercept	−7.171	−7.205	−7.7035	−4.143

Original GRACE model: $ln\left[\frac{p}{1-p}\right] = -7.704 + (0.053 \times AGE) + (0.182 \times Creatinine) + (0.693 \times Killip\ class) + (0.009 \times Heart\ rate) + (-0.017 \times SBP)$

Original ACTION model: $ln\left[\frac{p}{1-p}\right] = -4.143 + (0.040 \times AGE) + (0.0009 \times Heart\ rate) + (-0.0018 \times SBP) + (0.597 \times STEMI) + (0.564 \times Heart\ failure) + (1.468 \times Cardiogenic\ shock) + (-0.020 \times Creatinine\ clearance)$

*ST-segment deviation was not included for external validation stage because only NSTEMI was collected for this variable in PCI registry.
†No data.
ACS, acute coronary syndrome; ACTION, Acute Coronary Treatment and Intervention Outcomes Network; ET, endotracheal; GRACE, Global Registry of Acute Coronary Events; NSTEMI, non-ST-elevation myocardial infarction; PCI, percutaneous coronary intervention; SBP, systolic blood pressure; STEMI, ST-elevation myocardial infarction.

associated with the need for blood transfusion and a drop in haemoglobin >30 g/L.

Statistical analysis

Continuous variables were presented as mean±SD, and categorical variables were described as frequencies and percentages. Differences between the patient groups for categorical variables were examined using the χ^2, Fisher's exact or the z-test. Differences in continuous variables between groups were assessed using the Student's t-test. Univariate analysis examined the relationship between each variable and the mortality rate (online supplemental table 1). Variables that achieved a p value <0.01 were selected for further testing in a multivariate model. ORs and 95% CIs illustrate the association between potential risk factors and mortality.

The GRACE and AR-G RS models were externally validated in Thai PCI data as follows: First, the scores were calculated for individual patients based on the original models described in online supplemental table 2. Nine predictors were initially included in both GRACE and AR-G RS; however, only three (ST-segment deviation, elevated cardiac enzyme and cardiac arrest at hospital arrival/PCI procedure) and two (cardiac arrest at hospital arrival/PCI procedure and troponin ratio) predictors were not available in our data. Therefore, the corresponding scores were calculated based on six

Table 2 Estimation of calibration and C-statistic performances of GRACE and ACTION models

Model	Predictors	C-statistics (95% CI)	Shrinkage Value	Penalty	Hosmer-Lemeshow GoF (df)	P value	O/E Median (IQR)
M0: original model							
GRACE	$\ln\left[\frac{p}{1-p}\right] = Age + HR + SBP + Killip\ class + Cr + Enzyme\ level$	0.8957 (0.8818 to 0.9096)	0.995	0.005	16.44 (8)	0.036	0.998 (0.795, 1.004)
ACTION	$\ln\left[\frac{p}{1-p}\right] = Age + HR + SBP + STEMI + HF + Shock + CrCl$	0.8823 (0.8676 to 0.8970)	0.994	0.006	21.40 (8)	0.006	0.999 (0.667, 1.006)
M1: model revision/updated							
GRACE and ACTION	$\ln\left[\frac{p}{1-p}\right] = Age + HR + SBP + STEMI + Killip\ class + Shock + Cr + Enzyme\ level$	0.9118 (0.8999 to 0.9237)	0.994	0.006	34.80 (8)	<0.001	0.996 (0.588, 1.004)
M2: model updated							
GRACE and ACTION	$\ln\left[\frac{p}{1-p}\right] = Age + HR + SBP + STEMI + Killip\ class + Shock + Cr + Enzyme\ level + Access\ site + IABP + ET\ tube + Arrhythmia + Newdialysis + Failure + Complication$	0.9353 (0.9243 to 0.9463)	0.998	0.002	18.17 (8)	0.020	1.000 (0.564, 1.004)

C-statistic of the derivative GRACE model was 0.83. C-statistic of the derivative ACTION model was 0.88.
Shock—cardiogenic shock. Access site—initial access site. ET tube—ET tube intubation. New dialysis—new requirement for dialysis. Failure—procedure final result (failure or success). Complication—procedure complication. IABP-- intra-aortic balloon pump.
ACTION, Acute Coronary Treatment and Intervention Outcomes Network; ET, endotracheal; GoF, goodness of fit; GRACE, Global Registry of Acute Coronary Events; HF, heart failure; HR, admission heart rate; O/E, observed to expected ratio; SBP, admission systolic blood pressure; STEMI, ST-elevation myocardial infarction.

of the seven predictors. Second, logistic regression was constructed by separately regressing in-hospital deaths on the GRACE and AR-G RS. Performance was assessed, including the calibration and discrimination of the original GRACE/AR-G RS. The C-statistic and its 95% CI were estimated for discrimination performance.[15] A calibration, agreements between predicted probability and observed outcome, was assessed by estimating the observed to expected (O/E) ratio, testing by Hosmer-Lemeshow goodness of fit, calibration plot and shrinkage value.[7 16–18] Finally, the GRACE and AR-G RS models were revised and updated to improve their performances. For model revision, the coefficients of all predictors that appeared in either the GRACE or AR-G RS model were re-estimated based on Thai PCI data. Next, model updating was performed by simultaneously considering significant predictors suggested from our data added to the model already containing the significant predictors from GRACE or AR-G RS models. Only significant predictors were retained in the final updated model.

The study complied with the Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis statement.[19] All analyses were performed using STATA V.17.1 (StataCorp, College Station, Texas, USA).

RESULTS

Patients and procedural characteristics

In total, 19 701 patients were enrolled in the TPCIR group. Of these, 8246 were excluded due to stable coronary artery diseases, leaving 11 455 patients with STE-ACS and NSTE-ACS for use in the analyses of external validation (figure 1). Online supplemental table 3 summarises the clinical, angiographic and procedural characteristics of patients with TPCIR compared with those in the GRACE and AR-G RS models. There was very few missing data and the number and percent of missing data were shown in Online supplement table 4. The mean age of patients in the TPCIR was 64.0 years, and 44.6% were diabetic. Prior coronary artery bypass graft (CABG) and cerebrovascular disease were found in 1.0% and 5.4%, respectively. NSTE-ACS was more common than STE-ACS (52.2% vs 47.8%). The most common initial vascular access sites were the femoral artery (50.1%) and radial arteries (48.1%). The procedural failure rate was 4.1%, and the PCI complication rate was 5.7%. Cardiogenic shock at the beginning of PCI was recorded in 1452 patients (12.7%), and the overall in-hospital mortality rate was 4.4%.

Compared with the derivations of GRACE RS, the study population in TPCIR was more likely to be younger (median age 64.0 years vs 66.3 years); had lower SBP (median 133 mm Hg vs 140 mm Hg), similar heart rate (HR) (median 76 beats per minute) and serum creatinine (median 1 mg/dL); and had more severe heart failure (Killip class ≥3; 15.2% vs 4.1%), diabetes (44.6% vs 23.3%) and hypertension (38.3% vs 26.0%). A smaller proportion of the patients in the TPCIR had peripheral arterial disease (1.4% vs 10.3%), prior CABG (1.0% vs 12.6%), ST depression (22.4% vs 54.1%), T-wave inversion (15.8% vs 28.4%), severe angina (37.9% vs 68.1%) and cerebrovascular accident/stroke (0.6% vs 8.3%). The use of aspirin, angiotensin-converting enzyme inhibitors and statins was more common in TPCIR patients than those in the GRACE registry. The median serum creatinine level was 1.0 mg/dL in both the TPCIR and GRACE RS.

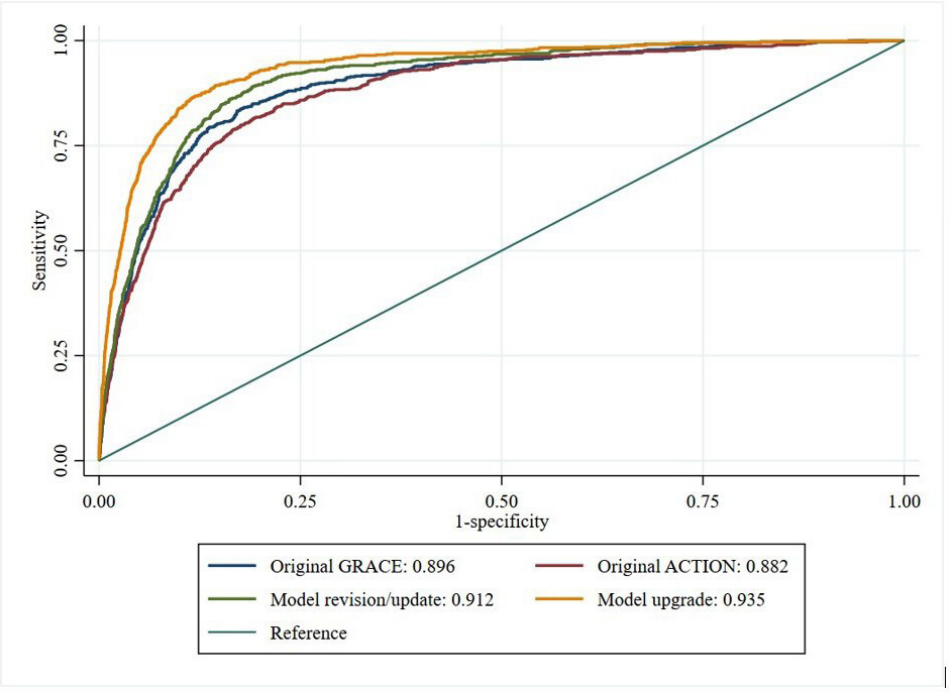

Figure 2 Receiver operating characteristic (ROC) curves of original, revised and updated models of Global Registry of Acute Coronary Events (GRACE) and Acute Coronary Treatment and Intervention Outcomes Network (ACTION) Registry–Get With The Guidelines (GWTG) (ACTION Registry–GWTG) Risk Score (AR-G RS) in the Thai Percutaneous Coronary Intervention (PCI) Registry.

Compared with the AR-G RS, the TPCIR population was more likely to be younger (mean age 64.0 years vs 64.6 years) and more likely to have cardiogenic shock at admission (12.7% vs 4.0%), STE-ACS (47.8% vs 39.0%), be a smoker (57.8% vs 34.4%) and have diabetes (44.6% vs 33.5%). However, TPCIR patients were less likely to have hypertension (61.0% vs 74.3%), peripheral arterial disease (1.4% vs 9.8%), dyslipidaemia (57.0% vs 61.5%), chronic lung disease (3.5% vs 14.8%), prior CABG (1.0% vs 13.8%) and prior cerebrovascular disease (5.4% vs 12.2%). In addition, they also had lower creatinine clearance (mean 62.7 mL/min vs 68.9 mL/min) and haemoglobin levels (mean 127 g/L vs 138 g/L).

In the univariate analysis, in-hospital mortality was related to age, presence of heart failure, Killip classification, cardiogenic shock at presentation, HR, serum creatinine level, STE-ACS, female sex, diabetes mellitus, peripheral artery disease, requirement of in-hospital dialysis, cerebrovascular disease, site of vascular access, use of intra-aortic balloon pump (IABP), required endotracheal (ET) tube intubation, procedural failure and presence of procedural complications (online supplemental table 1).

Performance of the GRACE/AR-G RS model in the TPCIR

The estimation of coefficients based on the TPCIR, compared with coefficients from the GRACE and ACTION models, is shown in table 1. The results indicate the same direction of relationship between the predictor variables in the TPCIR cohort and those in the GRACE/AR-G RS. The GRACE/AR-G RS model was updated using the variables in TPCIR, and the variables that had an impact on the clinical outcome were as follows: vascular access site (femoral vs radial), ET tube intubation, use of IABP, arrhythmia, new requirement for dialysis, PCI failure and procedural complications.

GRACE and AR-G RS were calculated and fitted to in-hospital mortality, indicating good performance in discriminating and calibrating for both GRACE and AR-G RS models, with corresponding C-statistics of 0.8957 (95% CI 0.8818 to 0.9096) and 0.8823 (95% CI 0.8676 to 0.8970), O/E ratios of 0.998 (95% CI 0.795 to 1.004) and 0.999 (95% CI 0.667 to 1.006) and penalty rates of 0.005 and 0.006, respectively (table 2, figure 2). The two models were revised by retuning the coefficients of eight significant predictors (age, HR, SBP, ST-elevation myocardial infarction, Killip class, cardiogenic shock, serum creatinine and cardiac biomarker level) that were included in either the GRACE or AR-G RS model, yielding an excellent C-statistic of 0.918 (95% CI 0.8999 to 0.9237), but a slightly poorer calibration with an O/E ratio of 0.996 (95% CI 0.588 to 1.004) and penalty of 0.006 (table 2, figure 3). Finally, this revised model was updated by simultaneously including seven significant predictors (initial access site, ET tube, IABP, arrhythmia, new dialysis, procedural failure and complications) significantly associated with death in TPCIR. This updated model could significantly improve discrimination performance when compared with the original GRACE and AR-G RS models, with a C-statistic of 0.9353 (95% CI 0.9243 to 0.9463), O/E ratio of 1.000 (95% CI 0.564 to 1.004) and penalty of 0.002 (table 2).

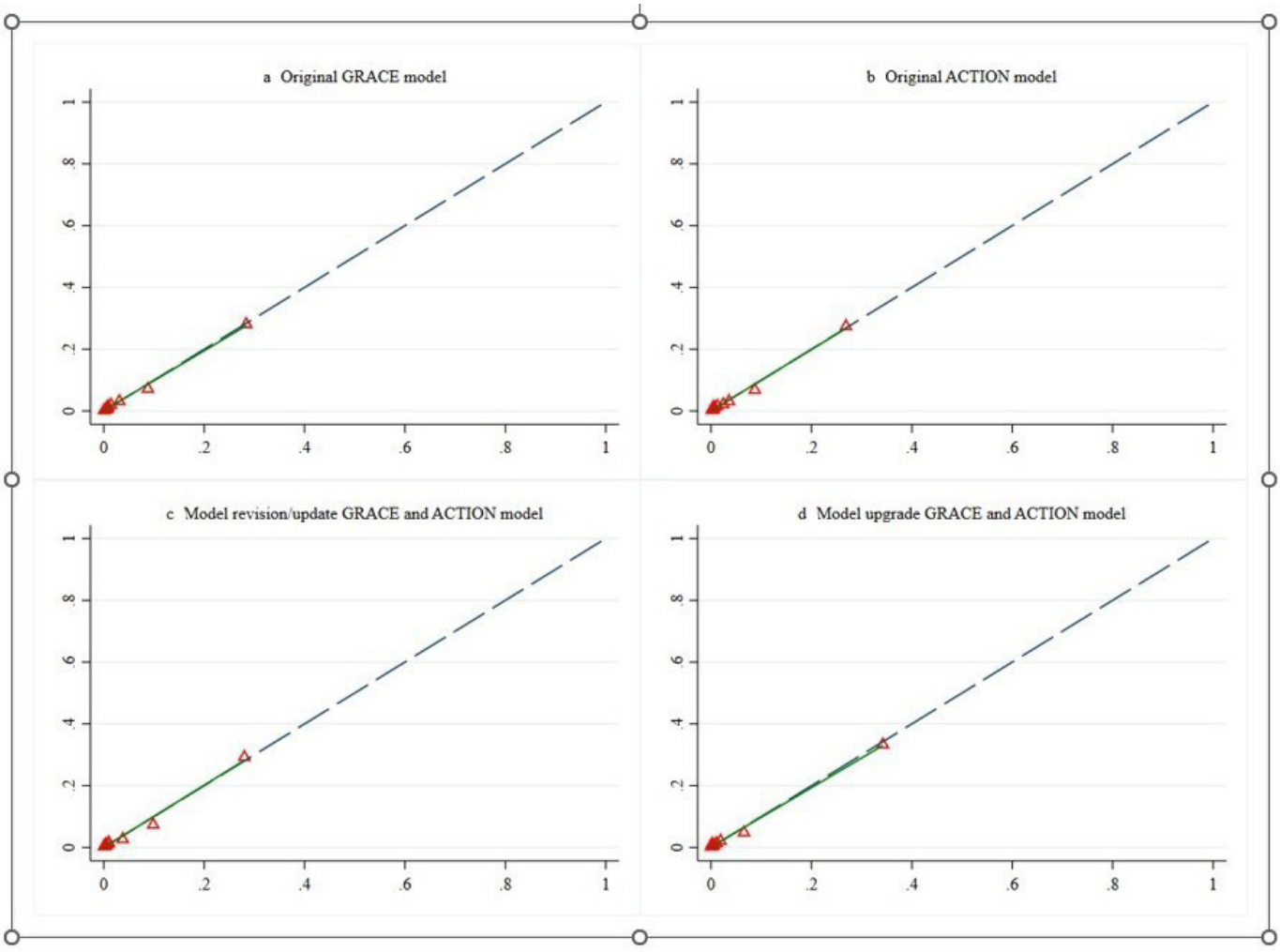

Figure 3 Calibration plots of original, revised and updated model of Global Registry of Acute Coronary Events (GRACE) and Acute Coronary Treatment and Intervention Outcomes Network (ACTION) Registry–Get With The Guidelines (GWTG) (ACTION Registry–GWTG) Risk Score (AR-G RS) in the Thai Percutaneous Coronary Intervention (PCI) Registry. A) Original GRACE model, B) Original ACTION model, C) Model revision/update GRACE and ACTION model, and D) Model upgrade GRACE and ACTION model.

DISCUSSION

We have demonstrated that the GRACE and AR-G RS had good discrimination for predicting in-hospital death in the TPCIR, and the revised and updated model helps improve the discrimination performance compared with the original RS.

The main objective of a prognostic model or RS is to improve the prediction of clinical decisions and outcomes. Generally, the performance of RS models tends to be less accurate in the new population than in the original or developing population. External validation is a crucial process to evaluate the accuracy of the RS model in a new population that may not contain the same clinical characteristics and risk factors.[20] The evolution of interventional cardiology in recent decades, such as using primary PCI as the default treatment in patients with STE-ACS, new P2Y12 inhibitors and routine use of radial access, has reduced in-hospital mortality dramatically.[1 21 22] In this validation cohort, the prevalence of cardiogenic shock, heart failure and diabetes was higher than in the original GRACE and AR-G RS cohorts, reflecting the heterogeneity of clinical severity. However, the in-hospital mortality rate in TPCIR was 4.4%, comparable to previous studies.[3 23]

The purpose of GRACE and AR-G RS is to evaluate the initial or on-admission risk of patients with ACS to guide treatment protocols that are mainly invasive or non-invasive. GRACE was developed in non-PCI and PCI centres, which may have different patient care strategies. GRACE RS is not the 'real PCI-related' RS, and clinical concern has been raised when applied among patients with ACS who underwent PCI, which has become a standard practice in current interventional cardiology.

Our study was based on daily routine practice, which provides evidence of the effectiveness of PCI in patients with ACS. Using a nationwide population of 19 701 consecutive patients presenting at 39 hospitals in Thailand, we validated two significant RS in Thai patients with ACS who underwent PCI. The GRACE RS performed well and had excellent discriminative

power for predicting in-hospital mortality. This result strengthens the reproducibility and generalisability of the GRACE RS in different populations, as reported by previous external validation studies, although it was developed over 20 years ago.[2 4 11 24] In contrast, the AR-G RS developed from a large cohort in the USA is more contemporary than the GRACE RS, and about half of the patients underwent PCI (mainly primary PCI). The composition of both RS is similar, and the discriminative power is expected to be the same. Raposeiras-Roubin *et al* showed that AR-G RS was not better than GRACE RS for predicting patient outcomes.[2] In contrast, Parco *et al* reported that the AR-G risk model was superior in predicting in-hospital mortality compared with GRACE RS among 1567 patients with ACS who underwent invasive treatment in Germany.[25]

Our updated model was performed by simultaneously including more than seven significant additional predictors (initial access site, ET tube, IABP, arrhythmia, new dialysis, procedural failure and complications), which significantly improved the discrimination performance when compared with the original GRACE and AR-G RS models without compromising the penalty. This result confirmed the predictive value of these risk factors, which can be found in routine daily interventional cardiology practice. As reported in previous studies, the updated model in the TPCIR highlights the impact of vascular access sites and post-PCI complications on clinical outcomes.[25–29]

The strength of this study is the prospective design used to obtain data from consecutive patients with unselected ACS in daily routine practice. The variables included in the study were available from standard cardiac catheterisation laboratory practice. The large number of patients collected from nationwide study centres increased the accuracy of the updated model compared with other validation studies. The updated GRACE and AR-G RS calibration also indicates that the model has a suitable generalisation property and ensures that it performs well on a new dataset. In addition, the accuracy of both models was not compromised, although significant advances in interventional cardiology have been established, and PCI has become a pivotal procedure for all patients with ACS. The advantage of this study was that all patients underwent PCI, ensuring consistency in the intervention. Additionally, the TPCIR includes new and essential variables that provide clinically meaningful data compared with previous studies.

This study has several limitations. TPCIR is a voluntary registry; all contributing hospitals have PCI capabilities, and the outcomes of these hospitals may not represent all hospital management for these patients. Variables for risk adjustment were limited to those available in the TPCIR. Incorporating more data, such as left ventricular ejection fraction and door-to-device time, would likely improve the predictive performance.

CONCLUSIONS

The GRACE and AR-G RS still perform well in TPCIR. Based on routine PCI practice, we demonstrate that the updated model can improve the accuracy of GRACE and AR-G RS to predict in-hospital mortality among patients with ACS who underwent PCI.

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Acknowledgements The authors thank (a) the Thai PCI Registry, which received a grant from Thailand's Health System Research Institute (HSRI), and (b) Mr Bryan Roderick Hamman for assistance with the English language presentation of the manuscript.

Contributors Conception and design of the study: SK, NC, AT, NS. Funding acquisition: NS. Data collection: SK, NC, CW, BP, WR, SS, AT, NS. Data analysis: SK, NC, CW, BP, WR, SS, AT, NS. Oversight of the conduct of the registry: SK, NC, WR, AT, NS. Manuscript writing: SK, NC, CW, BP, WR, SS, AT, NS. Guarantor: NS.

Funding The Thai PCI Registry received a research grant from the Health System Research Institute (HSRI) of Thailand.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by the Central Research Ethics Committee (CREC) of Thailand (COA-CREC 006/2018) and/or local EC/IRB when required by each institute before patient enrolment. The informed consent from the patients or their legal representatives was obtained before enrolment in the study.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. All data and statistical methods are available upon request. Please send inquiries to the corresponding author or the Cardiovascular Intervention Association of Thailand.

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