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ORIGINAL ARTICLE

Evaluation of Estimation of Physiologic Ability and Surgical Stress to predict in-hospital mortality in cardiac surgery

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Abstract

Purpose Prediction of postoperative risk in cardiac surgery is important for cardiac surgeons and anesthesiologists. We generated a prediction rule for elective digestive surgery, designated as Estimation of Physiologic Ability and Surgical Stress (E-PASS). This study was undertaken to evaluate the accuracy of E-PASS in predicting postoperative risk in cardiac surgery.

Methods We retrospectively collected data from patients who underwent elective cardiac surgery at a low-volume center ($N = 291$) and at a high-volume center ($N = 784$). Data were collected based on the variables required by E-PASS, the European system for cardiac operative risk evaluation (EuroSCORE), and the Ontario Province Risk Score (OPRS). Calibration and discrimination were assessed by the Hosmer–Lemeshow test and the area under the receiver operating characteristic curve (AUC), respectively. The ratio of observed-to-estimated in-hospital mortality rates (OE ratio) was defined as a measure of quality.

Results In-hospital mortality rates were 7.6% at the low-volume center and 1.3% at the high-volume center, accounting for an overall mortality rate of 3.0%. AUC values to detect in-hospital mortality were 0.88 for E-PASS, 0.77 for EuroSCORE, and 0.71 for OPRS. Hosmer–Lemeshow analysis showed a good calibration in all models ($P = 0.81$ for E-PASS, $P = 0.49$ for EuroSCORE, and $P = 0.94$ for OPRS). OE ratios for the low-volume center were 0.83 for E-PASS, 0.70 for EuroSCORE, and 0.83 for OPRS, whereas those for the high-volume center were 0.26 for E-PASS, 0.14 for EuroSCORE, and 0.27 for OPRS.

Conclusions E-PASS may accurately predict postoperative risk in cardiac surgery. Because the variables are different between cardiac-specific models and E-PASS, patients' risks can be double-checked by cardiac surgeons using cardiac-specific models and by anesthesiologists using E-PASS.

Keywords Cardiac surgery · Mortality · Prediction

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Introduction

Prediction of postoperative risk in surgery has become increasingly important for both surgeons and anesthesiologists. Such a prediction would be helpful in medical decision-making, informed consent, quality assurance, and healthcare management. We created a formula to predict risk for elective digestive surgery, which we designated

Estimation of Physiologic Ability and Surgical Stress (E-PASS), based on the hypothesis that overwhelming surgical stress exceeding a patient's reserve capacity leads to the disruption of homeostasis and various kinds of postoperative morbidity [1]. Therefore, when we converted these factors to numerical values, we could predict postoperative morbidity and mortality. This system is composed of the Physiological Risk Score (PRS), which represents the patient's reserve capacity; the Surgical Stress Score (SSS), which represents the severity of surgical stress; and the Comprehensive Risk Score (CRS), which is determined using these two scores. This system provides predicted postoperative mortality risk for individual patients [2]. Our multi-center prospective studies showed reproducible outcomes in predicting postoperative morbidity and in-hospital mortality [2–4]. Furthermore, several authors have reported similar results in many surgical fields, including not only digestive surgery [5–8], but also lung surgery [9, 10], vascular surgery [11, 12], and orthopedic surgery [13, 14].

In the field of cardiac surgery, various risk scoring systems have been developed, such as the Initial Parsonnet score [15], the Ontario Province Risk Score (OPRS) [16], and the European system for cardiac operative risk evaluation (EuroSCORE) [17]. These systems have each been shown to be useful in predicting postoperative mortality in cardiac surgery [18–22]. This study was undertaken to examine whether E-PASS could accurately predict the postoperative risk in elective cardiac surgery in comparison with the cardiac-specific models EuroSCORE and OPRS.

Patients and methods

Patients

Patients who underwent elective cardiac surgery performed in operating rooms between January 1, 2004 and June 30, 2010 at the National Hospital Organization (NHO) Kumamoto Medical Center ($N = 291$) or between April 1, 2005 and September 30, 2006 at Kokura Memorial Hospital ($N = 784$) were eligible for this study. The first author was a member of the Department of Anesthesiology at Kokura Memorial Hospital between April 1, 2005 and September 30, 2006, and therefore we analyzed the patients who presented during this period. There were no age limits. Elective surgery was defined as surgery that was not emergently performed within 24 h after admission [23]. The E-PASS scoring system was designed to estimate postoperative risk in elective settings and includes variables that would often be unavailable in emergency settings, such as pulmonary function test results or history of diabetes. Therefore, we evaluated only patients undergoing elective surgery in this study.

Protocol design

This was a retrospective cohort study. All data were preexisting data obtained from medical charts and did not include any personal information that would identify any of the patients. Therefore, informed consent from the patients was waived, based on the Ethical Guidelines for Epidemiological Studies, jointly issued by the Ministry of Health, Labour and Welfare and the Ministry of Education, Culture, Sports, Science and Technology of Japan. The protocol for the study was approved by the institutional review board of the National Hospital Organization (NHO) Kumamoto Medical Center on August 21, 2008 and that of Kokura Memorial Hospital on May 16, 2010. Information concerning this study was disclosed on the website of NHO Kumamoto Medical Center during the data collection phase.

Data collection

Data were collected based on the variables required by E-PASS, EuroSCORE, and OPRS. Table 1 shows the variables used in each of these models. There were 10 variables required for E-PASS, 17 for EuroSCORE, and six for OPRS. The equations of the E-PASS scoring system are shown in Table 2. For the calculation of blood loss in the E-PASS system, the amount of blood returned from cell-savers or suckers to cardiopulmonary bypass machines was not included in this study. Primary and secondary endpoints were in-hospital mortality and postoperative complications, respectively. The predicted in-hospital mortality rates of these models were obtained as previously described [2, 16, 17]. All data regarding variables and endpoints were obtained in all the eligible patients.

Postoperative complications including stroke, myocardial infarction, wound infection, deep sternal infection, postoperative bleeding, gastrointestinal perforation, bacteremia, postoperative renal failure (Grade II), and pulmonary failure were defined as described previously [24]. Postoperative heart failure was defined as conditions required for a mechanical assist device, intra-aortic balloon pump (IABP), ventricular assist device, or extracorporeal membrane oxygenation implanted during or after surgery [19]. Conditions that required preoperative IABP and its continued use after operation were excluded from this complication. Refractory arrhythmia was defined as arrhythmia that required a counter shock or the insertion of pacemaker. Multiple organ failure was defined as conditions that encompassed the failure of two or more organs, i.e., postoperative heart, renal, or pulmonary failure.

Table 1 Variables required by E-PASS, EuroSCORE, and OPRS

	E-PASS	EuroSCORE	OPRS
1	Age	Age	Age
2	Severe pulmonary disease	Gender	Gender
3	Severe heart disease	Chronic pulmonary disease	Ejection fraction
4	Diabetes mellitus	Extracardiac arteriopathy	CABG or valve surgery or complex procedure
5	ASA class	Neurological dysfunction	Elective or emergency or urgent
6	Performance status	Serum creatinine	Previous cardiac surgery
7	Blood loss	Critical preoperative state	
8	Body weight	Active endocarditis	
9	Surgical duration	Unstable angina	
10	Extent of skin incision	Ejection fraction	
11		Recent myocardial infarction	
12		Pulmonary hypertension	
13		Emergency or urgent	
14		Procedure other than isolated CABG	
15		Surgery on thoracic aorta	
16		Postinfarct septal rupture	
17		Previous cardiac surgery	

E-PASS Estimation of Physiologic Ability and Surgical Stress, *EuroSCORE* European system for cardiac operative risk evaluation, *OPRS* Ontario Province Risk Score, *CABG* coronary artery bypass grafting, *ASA* American Society of Anesthiologists

Table 2 Equations for E-PASS scoring system

1. Preoperative risk score (PRS) $= -0.0686 + 0.00345X_1 + 0.323X_2 + 0.205X_3 + 0.153X_4 + 0.148X_5 + 0.0666X_6$, where X_1 is age, X_2 the presence (1) or absence (0) of severe heart disease[a], X_3 the presence (1) or absence (0) of severe pulmonary disease[b], X_4, the presence (1) or absence (0) of diabetes mellitus, X_5 the performance status index[c] (range 0–4), and X_6 the ASA physiological status classification (range 1–5)
2. Surgical Stress Score (SSS) $= -0.342 + 0.0139X_1 + 0.0392X_2 + 0.352X_3$,

   where X_1 is blood loss (in grams) divided by body weight (in kg), X_2 the surgical duration (in hours), and X_3 the extent of the skin incision (0 indicates a minor incision for laparoscopic or thoracoscopic surgery including laparoscopic- or thoracoscopic-assisted surgery; 1, laparotomy or thoracotomy alone; and 2, laparotomy and thoracotomy)
3. Comprehensive Risk Score (CRS) $= -0.328 + 0.936$ (PRS) $+ 0.976$ (SSS)
4. Predicted in-hospital mortality rates: Y (%)

CRS < 0.159	$Y = 0$
$0.159 \leq$ CRS < 2.98	$Y = -0.465 + 1.192\,(\text{CRS}) + 10.91\,(\text{CRS})^2$
CRS ≥ 2.98	$Y = 100$

[a] Severe heart disease is defined as heart failure meeting the criteria of New York Heart Association Class III or IV, or severe arrhythmia requiring mechanical support

[b] Severe pulmonary disease is defined as any condition with a percent vital capacity of less than 60% and/or a percent forced expiratory volume in 1 s of less than 50%

[c] Performance status index was based on the definition by the Eastern Cooperative Oncology Group

Statistical analysis

All statistical analyses were performed using the SPSS 17.0 (SPSS, Chicago, IL, USA) software program. Intergroup differences were assessed with the χ^2 test with Yates' correction for continuity in categorical variables. The Mann–Whitney *U*-test was used to test for differences in continuous variables. The correlation between different continuous variables or between continuous and interval variables was analyzed by Spearman rank correlation (ρ), the significance of which was determined by Spearman's rank sum test.

The power of a model to discriminate patients who died during hospitalization from those who did not was assessed by calculating the area under the receiver operating characteristic curve (AUC) [25]. The AUC value potentially ranged from 0.5 to 1.0 and the greater the AUC, the better the model. An AUC of 1.0 indicates a perfect model that has 100% sensitivity and 100% specificity. In contrast, an AUC of 0.5 indicates a model that is completely ineffective in differentiating between real cases and non-cases. Calibration power was assessed by goodness-of-fit testing using the Hosmer–Lemeshow test [26]. This test divides cases into 10 groups in order of predicted probabilities and computes a χ^2 statistic from observed and expected frequencies [26]. When $P < 0.05$, the null hypothesis was rejected, indicating that there was a significant difference between the observed and model-predicted proportions. Therefore, non-significance on the χ^2 test indicated a good fit.

The ratio of observed-to-estimated in-hospital mortality rates (OE ratio) was used as a measure of quality. The 95% confidence intervals (CIs) of the OE ratio were determined by Katz's method for risk ratio [27]. When the OE ratio of a hospital is smaller than 1, the observed mortality rate of the hospital is lower than the expected rate, indicating that the quality of surgical performance is better than expected.

Results

Demographic data and clinical outcome

Demographic data of the subjects are shown in Table 3. Unstable angina pectoris was the most common disease at the NHO Kumamoto Medical Center, whereas angina pectoris on effort was the most common disease at Kokura Memorial Hospital. Co-morbidities of the subjects are listed in Table 4. Incidences of co-morbidities were similar at the two hospitals. Table 5 shows the main surgical procedures performed in this series. Off-pump coronary artery bypass grafting (CABG) was the most common procedure at both hospitals. On-pump CABG was infrequently performed at Kokura Memorial Hospital (8 of 310 cases undergoing CABG). Table 6 summarizes the demographic data of patients according to the main procedures undertaken at each hospital. In general, NHO Kumamoto Medical Center tended to demonstrate larger values for both surgical duration and cardio-pulmonary bypass time, but smaller values for blood loss compared with those for Kokura Memorial Hospital. Details of postoperative complications are noted in Table 7. The incidences of most postoperative complications at Kokura Memorial Hospital were significantly lower than those at NHO Kumamoto Medical Center. The postoperative complication rates were 27.1% (79/291) for NHO Kumamoto Medical Center and 8.4% (66/784) for Kokura Memorial Hospital, accounting for an overall morbidity rate of 13.5% (145/1,075). Table 8 shows treatment outcome according to surgical procedure in all patients. Replacement of thoracic aortic aneurysm (TAA) showed the highest incidences of both postoperative complications and in-hospital mortality. For all procedures, both postoperative morbidity and mortality rates were higher for NHO Kumamoto Medical Center than those for Kokura Memorial Hospital. In total, in-hospital mortality rates were 7.6% (22/291) for NHO Kumamoto Medical Center and 1.3% (10/784) for Kokura Memorial Hospital, yielding an overall mortality rate of 3.0% (32/1,075). At NHO Kumamoto Medical Center, nine patients died of bacteremia, four patients died of postoperative heart failure, three patients died of multiple organ failure, two patients died of postoperative renal failure, two patients died of pulmonary failure, one patient died of stroke, and one patient died of peritonitis with perforated bowel. At Kokura Memorial Hospital, three patients died of postoperative renal failure, three patients died of postoperative heart failure, two patients died of multiple organ failure, one patient died of bacteremia, and one patient died of postoperative pulmonary failure.

Table 3 Demographic data of the subjects

Age	Median (range) years = 69 (20–90)	
Gender	Male:female = 699:376	
Primary disease	NHO Kumamoto Medical Center *N*	Kokura Memorial Hospital *N*
Unstable angina pectoris	58	70
Angina pectoris on effort	54	234
Aortic valve stenosis or regurgitation	51	170
Mitral valve stenosis or regurgitation	45	141
Thoracic aortic aneurysm	35	71
Myocardial infarction	34	51
Left atrial myxoma	5	8
Atrial septal defect	5	12
Others	4	20
Total	291	784

NHO National Hospital Organization

Table 4 Co-morbidities in the study subjects

	NHO Kumamoto Medical Center	Kokura Memorial Hospital
Hypertension	158/291 (54.3%)	350/784 (44.6%)
Diabetes mellitus	70/291 (24.1%)	216/784 (27.6%)
Old cerebral infarction	40/291 (13.7%)	120/784 (15.3%)
Chronic heart failure	38/291 (13.1%)	74/784 (9.4%)
Old myocardial infarction	31/291 (10.7%)	66/784 (8.4%)
Atrial fibrillation	23/291 (7.9%)	94/784 (12.0%)
Chronic obstructive pulmonary disease	18/291 (6.2%)	87/784 (11.1%)
Hyperlipidemia	17/291 (5.8%)	150/784 (19.1%)
Chronic renal failure	16/291 (5.5%)	89/784 (11.4%)
Angina pectoris	7/291 (2.4%)	56/784 (7.1%)
ASO	6/291 (2.1%)	31/784 (4.0%)
Sick sinus syndrome	5/291 (1.7%)	24/784 (3.1%)
Cardiac shock requiring IABP	5/291 (1.7%)	14/784 (1.8%)
Others	11/291 (3.8%)	7/784 (0.9%)

These co-morbidities were observed in 259 patients (89.0%) at NHO Kumamoto Medical Center and in 676 (86.2%) patients at Kokura Memorial Hospital

NHO National Hospital Organization, *ASO* arteriosclerosis obliterans, *IABP* intra-aortic balloon pump

Table 5 Main surgical procedures in the study subjects

Main surgical procedure	NHO Kumamoto Medical Center *N*	Kokura Memorial Hospital *N*
Off-pump CABG	92	302
On-pump CABG	44	8
Mitral valve plasty or replacement	40	120
Aortic valve plasty or replacement	34	103
Double valve surgery	13	24
Replacement of thoracic aortic aneurysm	29	60
Ascending aorta replacement	13/29	0/60
Total arch replacement	10/29	52/60
Replacement of the descending aorta	2/29	2/60
Replacement of the thoraco-abdominal aorta	4/29	6/60
Replacement of TAA with additional procedures[a]	6	21
CABG with valve surgery	16	90
Patch closure for ASD or VSD	6	14
Resection of myxoma	5	8
Others	6	34
Total	291	784

NHO National Hospital Organization, *CABG* coronary artery bypass grafting, *TAA* thoracic aortic aneurysm, *ASD* atrial septal defect, *VSD* ventricular septal defect

[a] Additional procedures indicates CABG or valve surgery

Relationship between predicted mortality rates and postoperative events

Figure 1 shows the relationship between the predicted mortality rates and proportion of in-hospital mortalities in each model. The patients were divided into four groups according to the order of the predicted mortality rates in each model. The proportion of patient deaths significantly differed from the risk bands in all models (E-PASS: $P < 0.0001$, EuroSCORE: $P < 0.0001$, OPRS: $P = 0.00044$ analyzed by χ^2 test). In risk band 4 of E-PASS, the predicted mortality rates for non-surviving patients (median 0.190, range 0.098–0.47, $N = 26$) were significantly higher than those for the surviving patients (0.12, 0.076–0.34, $N = 243$, $P < 0.0001$ analyzed by Mann–Whitney *U*-test). In contrast, there were no significant differences between the predicted mortality rates for non-surviving and surviving patients in risk band 4 of either the EuroSCORE (median 0.21, range 0.12–0.67, $N = 20$ vs. 0.19, 0.12–0.89, $N = 249$, $P = 0.85$) or OPRS (median 0.12, range 0.057–0.13, $N = 17$ vs. 0.081, 0.081–0.13, $N = 252$, $P = 0.69$). The predicted mortality rate of E-PASS was significantly correlated with that of EuroSCORE ($\rho = 0.443$, $N = 1{,}075$, $P < 0.0001$) and that of OPRS ($\rho = 0.314$, $N = 1{,}075$, $P < 0.0001$).

Similarly, the proportion of patients who developed postoperative complications differed significantly between

Table 6 Demographic data of the subjects according to main surgical procedure

Surgical procedures	NHO Kumamoto Medical Center				Kokura Memorial Hospital			
	N	Surgical duration (min)	Blood loss (g)	CPB time (min)	*N*	Surgical duration (min)	Blood loss (g)	CPB time (min)
Off-pump CABG	92	365 (140–670)[a]	362 (30–2000)	–	302	255 (110–550)	350 (45–1510)	–
On-pump CABG	44	327 (235–650)	258 (68–875)[e]	118 (59–220)	8	332 (240–430)	430 (280–650)	122 (74–164)
Mitral valve surgery	40	327 (200–685)[a]	200 (34–836)[e]	182 (82–325)[a]	120	197 (115–640)	300 (80–1230)	80 (42–309)
Aortic valve surgery	34	247 (149–470)[a]	159 (31–628)[c]	125 (75–308)[a]	103	195 (125–430)	250 (80–1070)	78 (50–182)
Double valve surgery	13	330 (260–533)	212 (74–460)[e]	205 (159–399)[a]	24	297 (165–600)	340 (180–1700)	120 (83–239)
Replacement of TAA with or without additional procedures[f]	35	465 (260–880)[b]	517 (190–2893)	230 (90–358)[a]	81	345 (195–1325)	580 (100–2300)	150 (63–366)
CABG with valve surgery	16	375 (300–755)[d]	279 (180–2580)[e]	195 (151–325)[a]	90	330 (113–680)	465 (70–1890)	124 (54–223)

NHO National Hospital Organization, *CPB* cardio-pulmonary bypass, *CABG* coronary artery bypass grafting, *TAA* thoracic aortic aneurysm

[a] $P < 0.0001$, [b] $P < 0.0005$, [c] $P < 0.005$, [d] $P < 0.01$, [e] $P < 0.05$, as compared to counterparts at Kokura Memorial Hospital

[f] Additional procedures indicate CABG or valve surgery. Data for each variable in individual procedures were compared between hospitals using the Mann–Whitney *U*-test

the risk bands in any model, as shown in Fig. 2 (E-PASS: $P < 0.0001$, EuroSCORE: $P < 0.0001$, OPRS: $P < 0.0001$). In risk band 4 of E-PASS, the predicted mortality rates for patients with postoperative complications (median 0.150, range 0.080–0.47, $N = 76$) were significantly higher than those for patients without complications (0.11, 0.076–0.340, $N = 193$, $P < 0.0001$). Similar results in risk band 4 were obtained with regard to EuroSCORE (median 0.24, range 0.12–0.89, $N = 72$ vs. 0.17, 0.12–0.75, $N = 197$, $P = 0.0004$) but not OPRS (0.099, 0.057–0.13, $N = 58$ vs. 0.081, 0.081–0.13, $N = 211$, $P = 0.23$).

Figure 3 shows the AUC of each model for the detection of in-hospital mortality. The AUCs (95% CI) were 0.81 (0.71–0.91) for E-PASS, 0.75 (0.66–0.84) for EuroSCORE, and 0.72 (0.61–0.82) for OPRS at the NHO Kumamoto Medical Center (Fig. 3a). The AUCs (95% CI) were 0.90 (0.83–0.97) for E-PASS, 0.75 (0.65–0.86) for EuroSCORE, and 0.71 (0.60–0.83) for OPRS at Kokura Memorial Hospital (Fig. 3b). In all patients (Fig. 3c), the AUCs (95% CI) were 0.88 (0.82–0.94) for E-PASS, 0.77 (0.70–0.83) for EuroSCORE, and 0.71 (0.63–0.79) for OPRS. The AUC for E-PASS in all patients was significantly higher than that for OPRS, since the lower limit of the 95% CI for E-PASS (0.82) exceeded the upper limit for the OPRS (0.79). The Hosmer–Lemeshow tests demonstrated a good calibration power in all models; $\chi^2 = 4.4$, $P = 0.81$ for E-PASS, $\chi^2 = 7.5$, $P = 0.49$ for EuroSCORE, and $\chi^2 = 2.9$, $P = 0.94$ for OPRS.

Table 9 displays the OE ratios in each model. In any model, the OE ratio for Kokura Memorial Hospital showed a smaller value than that for NHO Kumamoto Medical Center.

Discussion

We evaluated the efficacy of the E-PASS scoring system in cardiac surgery in comparison with those of EuroSCORE and OPRS, using data from low- and high-volume hospitals in Japan. To our knowledge, this is the first report to analyze the usefulness of E-PASS in cardiac surgery. Although the equation for predicting the mortality rate with E-PASS was created using data for digestive surgery, the present study demonstrated that this equation showed a surprisingly good calibration and discrimination performance in cardiac surgery. These data suggest that the hypothesis for E-PASS may remain true in cardiac surgery as well; that is, overwhelming surgical stress exceeding a patient's reserve capacity results in the disruption of homeostasis and various postoperative complications. It is possible that the estimation of postoperative risk can be discussed using the same metrics in both digestive and cardiac surgery. Further studies will gauge the validity of this equation in the future.

Table 7 Incidence of postoperative complications

	NHO Kumamoto Medical Center ($N = 291$)	Kokura Memorial Hospital ($N = 784$)	P value
Wound infection	25 (8.6%)	19 (2.4%)	<0.0001
Postoperative heart failure	13 (4.5%)	10 (1.3%)	0.0013
Postoperative renal failure	12 (4.1%)	12 (1.5%)	0.011
Refractory arrhythmia	9 (3.1%)	7 (0.9%)	0.0081
Stroke	8 (2.7%)	4 (0.5%)	0.0019
Postoperative pulmonary failure	8 (2.7%)	3 (0.4%)	0.00061
Bacteremia	5 (1.7%)	4 (0.5%)	0.053
Deep sternal infection	5 (1.7%)	11 (1.4%)	0.70
Postoperative bleeding	4 (1.4%)	12 (1.5%)	0.85
Multiple organ failure	3 (1.0%)	2 (0.3%)	0.097
Gastrointestinal perforation	1 (0.3%)	–	0.10
Total	93	84	<0.0001

These postoperative complications were observed in 79 patients (27.1%) at NHO Kumamoto Medical Center and in 66 patients (8.4%) at Kokura Memorial Hospital. Data for each variable in individual complications were compared between hospitals using the χ^2 test with Yates' correction for continuity

NHO National Hospital Organization

Table 8 Treatment outcome according to surgical procedures

Surgical procedures	N	Postoperative complications (+)	In-hospital mortality (+)
CABG (on-pump or off-pump)			
NHO Kumamoto Medical Center	136	25 (18.4%)[a]	4 (2.9%)[c]
Kokura Memorial Hospital	310	18 (5.8%)	0 (0%)
Total	446	43 (9.6%)	4 (0.9%)
Valve surgery (mitral, aortic, or double)			
NHO Kumamoto Medical Center	87	21 (24.1%)[a]	6 (6.9%)[e]
Kokura Memorial Hospital	247	17 (6.9%)	4 (1.6%)
Total	334	38 (11.4%)	10 (3.0%)
Replacement of TAA with or without additional procedures[f]			
NHO Kumamoto Medical Center	35	18 (51.4%)[b]	7 (20.0%)[c]
Kokura Memorial Hospital	81	13 (16.0%)	3 (3.7%)
Total	116	31 (26.7%)	10 (8.6%)
CABG with valve surgery			
NHO Kumamoto Medical Center	16	9 (56.3%)[b]	4 (25.0%)[c]
Kokura Memorial Hospital	90	13 (14.4%)	3 (3.3%)
Total	106	22 (20.8%)	7 (6.6%)
Others			
NHO Kumamoto Medical Center	17	7 (41.1%)[c]	1 (5.9%)
Kokura Memorial Hospital	56	5 (8.9%)	0 (0%)
Total	73	12 (16.4%)	1 (1.4%)
Total	1,075	146 (13.6%)	32 (3.0%)

Incidences of postoperative complications and in-hospital mortality rates in all patients were analyzed according to the main surgical procedures

NHO National Hospital Organization, *CABG* coronary artery bypass grafting, *TAA* thoracic aortic aneurysm

[a] $P < 0.0001$, [b] $P < 0.0005$, [c] $P < 0.005$, [d] $P < 0.01$, [e] $P < 0.05$, as compared to counterparts at Kokura Memorial Hospital

[f] Additional procedures indicate CABG or valve surgery. Data for each variable in individual procedures were compared between hospitals using the χ^2 test with Yates' correction for continuity

The present study demonstrated a higher AUC value in E-PASS than in EuroSCORE or OPRS for cardiac surgery. The AUC values for EuroSCORE (0.77) and OPRS (0.71) in the present study were similar to those previously reported; 0.75–0.83 for EuroSCORE and 0.68–0.70 for OPRS [17–19, 21, 22]. The AUC value for E-PASS (0.88) in the present study was comparable to that (0.86) obtained in our multicenter cohort study of digestive surgery [28]. Tang et al. demonstrated an extremely high AUC value for E-PASS, 0.92 with 95% CI of 0.87–0.97 for elective open abdominal aortic aneurysm surgery [12]. These higher AUC values for E-PASS may be attributable to the inclusion of intraoperative variables, such as surgical duration and blood loss. These variables are not included in either Euro SCORE or OPRS. It is difficult to predict the amount of blood loss before surgery, which is a significant factor influencing the degree of surgical stress. Therefore, E-PASS cannot provide a predicted mortality rate before surgery and this is a limitation of E-PASS as a prediction model. However, information regarding postoperative risk

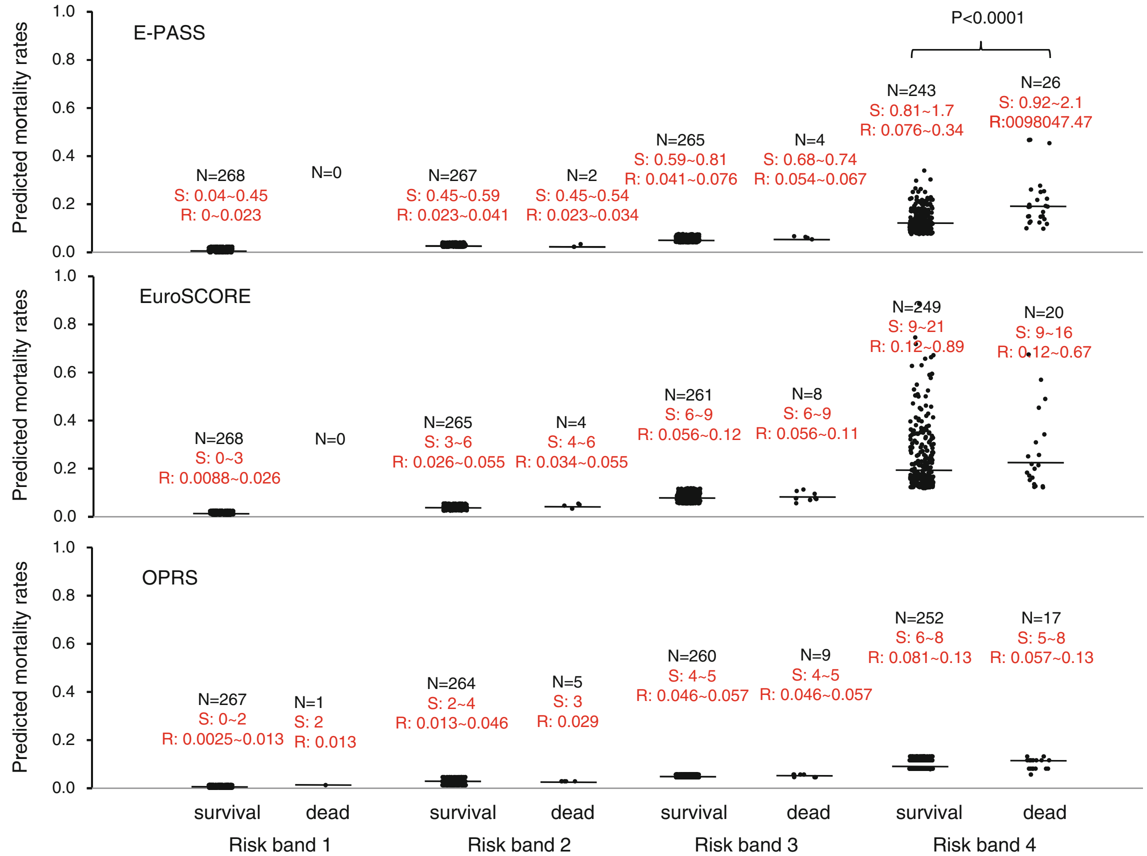

Fig. 1 Relationship between predicted mortality rates and in-hospital mortality in each model. Patients were divided into 4 risk bands in order of predicted mortality rates in each model. In each risk band, the predicted mortality rates were plotted in relation to the presence (*dead*) or absence (*survival*) of in-hospital mortality. *Bars* indicate the median values of the predicted mortality rates in each column. *S* and *R* indicate the range of scores and the predicted mortality rates in each model, respectively. *E-PASS* Estimation of Physiologic Ability and Surgical Stress, *EuroSCORE* European system for cardiac operative risk evaluation, *OPRS* Ontario Province Risk Score

immediately after the completion of surgery is also useful for both cardiac surgeons and anesthesiologists. This information can be used for medical decision-making and informed consent following surgery.

In addition, the present study points to a possible use of E-PASS for surgical audit. Similar results for OE ratios were obtained for the low- and high-volume hospitals, as determined by all of the models studied. The OE ratios for the low-volume hospital were 3.1–5.0 times higher than those for the high-volume center. A similar result was obtained in the field of digestive surgery, showing that a significantly lower mortality rate was observed in patients who underwent surgery at hospitals with a high volume of procedures compared with those treated at hospitals with a low or medium volume of procedures [3]. It is therefore conceivable that such a volume-outcome relationship may exist in Japanese cardiac surgery as well. A larger multi-center prospective study is necessary to gauge the efficacy of the E-PASS as an outcome assessment tool in cardiac surgery.

Risk adjustments regarding patient populations and surgical procedures are necessary to compare surgical quality between hospitals. However, it is conceivable that the inclusion of intraoperative variables, such as blood loss, would confound the results of treatment outcome. For example, an inexperienced surgeon will usually have a larger amount of blood loss and therefore the predicted mortality rates for his or her patients will be higher in the E-PASS system. The observed mortality rate would be higher but the OE ratio may be compensated for by a higher predicted mortality rate. However, such confounding factors seem to be unlikely in digestive surgery. We recently developed a modified E-PASS, designated as mE-PASS, for use in digestive surgery. This modification includes a median value of SSS according to the accumulated data on the surgical procedure, instead of including the variables for SSS, blood loss, surgical duration, and extent of skin incision [28]. This modification enables us to predict the postoperative mortality rate before surgery, as in the case with EuroSCORE and OPRS. The AUC for mE-

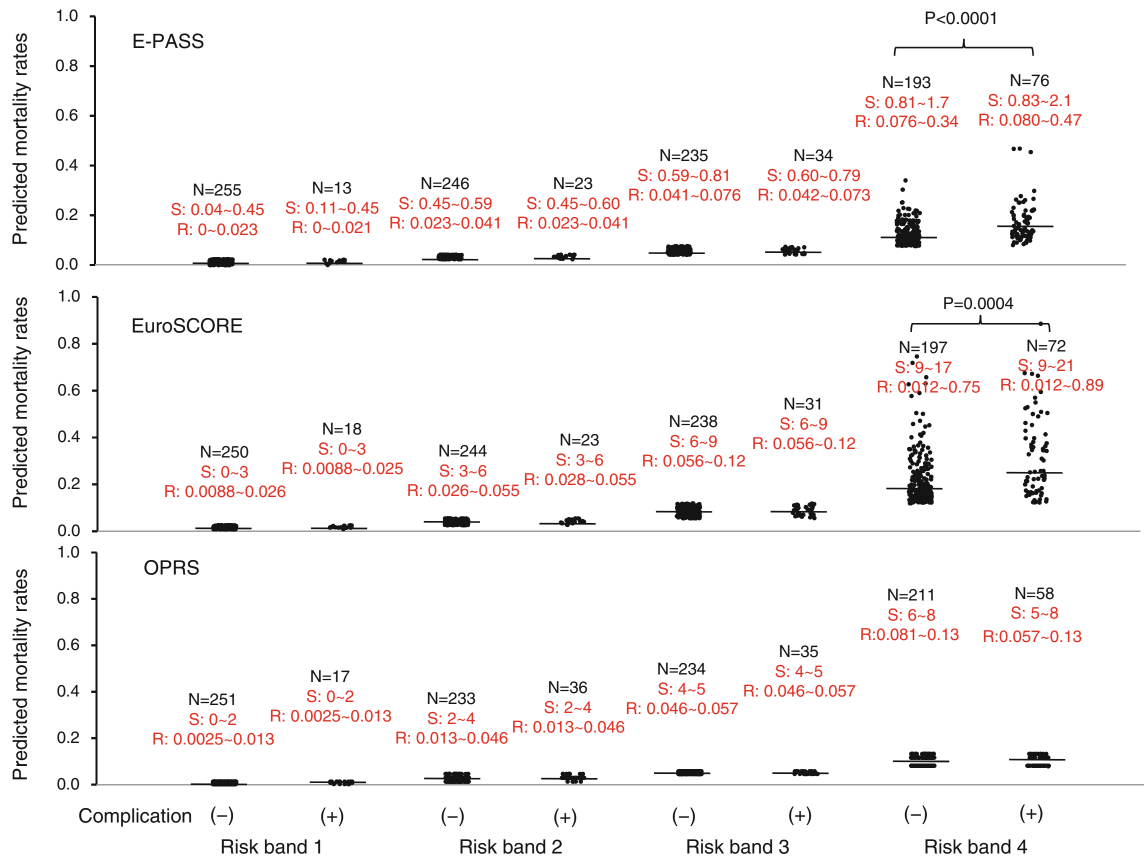

Fig. 2 Relationship between predicted mortality rates and postoperative complications in each model. Patients were divided into 4 risk bands in order of predicted mortality rates in each model. In each risk band, the predicted mortality rates were plotted in the presence (*complication* +) or absence (*complication* –) of postoperative complications. The *bars* indicate the median values of predicted mortality rates in each column. *S* and *R* indicate the range of scores and the predicted mortality rates in each model, respectively. *E-PASS* Estimation of Physiologic Ability and Surgical Stress, *EuroSCORE* European system for cardiac operative risk evaluation, *OPRS* Ontario Province Risk Score

PASS (0.86) to detect in-hospital mortality is quite similar to that of the conventional E-PASS (0.86) and seems to be better than that of other models, including the Portsmouth modification of the Physiologic and Operative Severity Score for the enUmeration of Mortality and Morbidity (P-POSSUM) (0.81) and the American Society of Anesthesiologists (ASA)-status based model (0.73) [28]. If we obtain a large amount of data regarding E-PASS in cardiac surgery, a similar modification could be created, as in the case of digestive surgery.

There have been many models developed for the prediction of postoperative risk in cardiac surgery, and clinicians may wonder why a new model is necessary. We propose that our new model, E-PASS, provides confirmation of the results of cardiac-specific models by double-checking results using different variables, such as performance status, ASA class, and history of diabetes. The patient's postoperative risk can be double-checked by cardiac surgeons using EuroSCORE or OPRS and by anesthesiologists using E-PASS. Since surgical audits in which hospitals are compared sometimes lead to misunderstandings, surgical quality should be carefully weighed in different arenas.

In contrast to other models, E-PASS cannot be applied to emergency procedures. E-PASS includes variables that are often unavailable in emergency situations, such as spirometry test results and history of diabetes. Because elective procedures are performed more frequently than emergency surgery, the application of this model in elective settings will provide meaningful information. In the present study, elective procedures accounted for 77 and 93% of all surgeries during the study periods at the low- and high-volume hospitals, respectively. Moreover, the postoperative mortality rates for emergency surgery are usually much higher than those for elective surgery. Therefore, we consider that emergency surgery should be evaluated separately from elective surgery, instead of including variables related to the urgency of surgery. We are currently constructing a new model for emergency surgery that can be applicable to both digestive and cardiac surgery. This model requires only four variables and demonstrates high calibration and

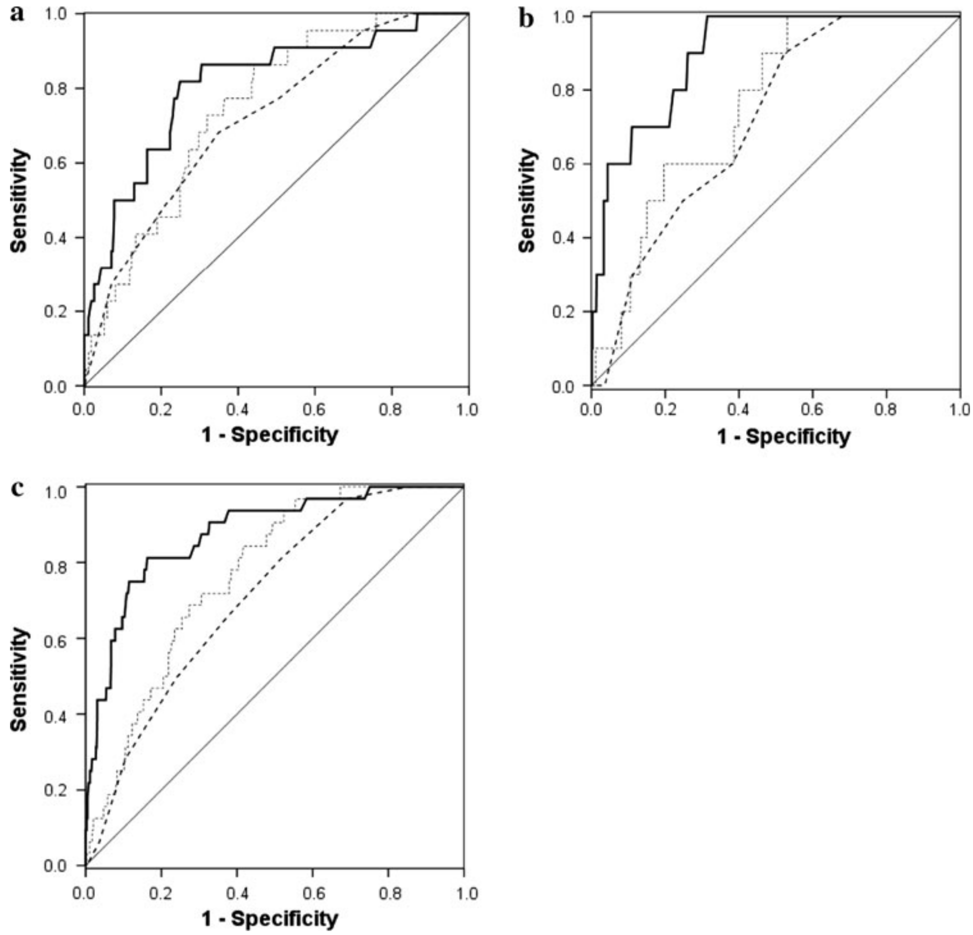

Fig. 3 Receiver operating characteristic curve analysis to detect in-hospital mortality. The discriminatory power of each model to detect in-hospital mortality was evaluated using the area under the receiver operating characteristic curve for the National Hospital Organization Kumamoto Medical Center (**a**), the Kokura Memorial Hospital (**b**), and for all patients (**c**). *Solid lines* Estimation of Physiologic Ability and Surgical Stress (*E-PASS*). *Dotted lines* European system for cardiac operative risk evaluation (*EuroSCORE*). *Dashed lines* Ontario Province Risk Score (*OPRS*)

Table 9 Ratio of observed- to expected-mortality rates (OE ratio) in each model

	N	E-PASS	EuroSCORE	OPRS
NHO Kumamoto Medical Center	291	0.83 (0.49–1.4)	0.70 (0.41–1.2)	0.83 (0.49–1.4)
Kokura Memorial Hospital	784	0.26 (0.13–0.52)	0.14 (0.072–0.26)	0.27 (0.14–0.55)
Total	1,075	0.50 (0.33–0.76)	0.31 (0.21–0.45)	0.64 (0.41–0.99)

Data are presented as OE ratios (95% confidence intervals)

E-PASS Estimation of Physiologic Ability and Surgical Stress, *OPRS* Ontario Province Risk Score

discrimination power. Studies on the usefulness of this new model will be published soon.

In conclusion, the present study suggests that E-PASS, which was constructed for digestive surgery, may predict postoperative mortality for cardiac surgery as accurately as cardiac-specific models. Further studies are needed to validate these promising results.

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