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Preoperative right ventricular dysfunction requires high vasoactive and inotropic support during off-pump coronary artery bypass grafting

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Abstract

Objectives The association of preoperative RV function with hemodynamics during OPCAB or emergency conversion is not clear. The aim of this study was to investigate the association of vasoactive-inotropic score with tricuspid annular plane systolic excursion and tricuspid regurgitation in off-pump coronary artery bypass grafting, and to calculate the optimal cut-off value of tricuspid annular plane systolic excursion to predict emergency conversion to cardiopulmonary bypass.

Methods Patients over 20 years of age who had undergone off-pump coronary artery bypass grafting between April 2015 and March 2020 were enrolled in this study. We retrospectively assessed the association of intraoperative maximum "vasoactive-inotropic score", a weighted sum of various inotropes and vasoconstrictors, with tricuspid annular plane systolic excursion and tricuspid regurgitation. A receiver operating characteristic curve of conversion on tricuspid annular plane systolic excursion was also constructed.

Results 135 patients were included in final analysis. Conversion was performed in 10 cases. Multiple regression analysis showed that tricuspid annular plane systolic excursion, mild or more tricuspid regurgitation and experienced surgeon were significantly related to vasoactive-inotropic score. The receiver operating characteristic curve to predict conversion by tricuspid annular plane systolic excursion showed an optimal cut-off value of 15.0 mm and area under the curve of 0.808.

Conclusions Tricuspid annular plane systolic excursion and tricuspid regurgitation were associated with vasoactive-inotropic score in off-pump coronary artery bypass grafting. The optimal cut-off value of tricuspid annular plane systolic excursion to predict emergency conversion was 15 mm.

Keywords Tricuspid annular plane systolic excursion · Tricuspid regurgitation · Right ventricular dysfunction · Off-pump coronary artery bypass grafting · Vasoactive-inotropic score

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Introduction

Although off-pump coronary artery bypass grafting (OPCAB) is associated with lower mortality than coronary artery bypass grafting (CABG) in cardiopulmonary bypass (CPB) for high-risk patients [1–3], intraoperative hemodynamic instability results in emergency conversion from off-pump to on-pump CABG and higher morbidity and mortality than those with completed OPCAB or scheduled CPB [4–12].

Previous studies have shown that urgent surgery [5, 6, 8], triple vessel disease (TVD) [6, 8, 13], left main coronary artery (LMT) disease [7, 8, 12, 13], congestive heart failure (CHF) [6, 8, 11, 13, 14] and previous CABG [5, 8, 11] are preoperative risk factors of emergency conversion. In addition, left ventricular dysfunctions including low left

ventricular ejection fraction (LVEF) [6, 14], mitral regurgitation (MR) [12, 15], high left ventricular end diastolic pressure (LVEDP) [16] and left ventricular hypertrophy (LVH) [5] have been shown to be factors causing hemodynamic instability that can result in the need for emergency conversion.

It has been reported that right ventricular ejection fraction (RVEF) was decreased during anastomosis of the obtuse marginal (OM) artery in OPCAB [17] and that a suction-type stabilizer caused more anterior displacement and compression of the right ventricle (RV) than the left ventricle (LV) [18]. However, the association of preoperative RV function with hemodynamics during OPCAB or emergency conversion is not clear.

The vasoactive-inotropic score (VIS) as a weighted sum of various inotropes and vasoconstrictors was suggested to predict mortality and morbidity after pediatric cardiac surgery in the intensive care unit (ICU) [19, 20]. A high VIS can predict postoperative unfavorable outcomes in not only children but also adults [21]. In addition, preoperative RV dysfunction is an independent risk factor for a high VIS after adult cardiac surgery [22].

In this study, we investigated the associations of preoperative tricuspid annular plane systolic excursion (TAPSE) and tricuspid regurgitation (TR) with intraoperative maximum VIS in OPCAB, and we calculated the optimal cut-off value of TAPSE to predict emergency conversion to on-pump CABG.

Subjects

This study was approved by the Institutional Review Board of Obihiro Kosei General Hospital (No. 2020-005) and was conducted in accordance with the Declaration of Helsinki and EQUATOR guidelines. The Institutional Review Board waived the requirement for written informed consent from the patients because this was a retrospective observational study and the data were analyzed anonymously. This research was carried out without funding.

Medical records of Obihiro Kosei General Hospital between April 2015 and March 2020 were retrospectively reviewed. Patients over 20 years of age who had undergone OPCAB were enrolled in this study. Exclusion criteria were re-CABG, scheduled on-pump CABG and preoperative intra-aortic balloon pumping (IABP).

Methods

None of the patients were premedicated before general anesthesia. After a peripheral venous and arterial line had been inserted, midazolam (0.05–0.15 mg/kg) or propofol (1–2 mg/kg) was administered for induction of anesthesia.

The patients were intubated after administration of rocuronium (0.6–1.2 mg/kg) and fentanil (1–5 mcg/kg) and/or remifentanil (0.1–0.5 mcg/kg/min), and then a transesophageal echo probe, central vein catheter and pulmonary artery catheter were inserted. Patients were monitored by electrocardiography, a pulse oximeter, invasive and non-invasive arterial pressures, transesophageal echocardiography, central venous pressure, pulmonary arterial pressure, mixed venous oxygen saturation, cardiac output, bispectral index and regional cerebral oxygen saturation.

Anesthesia was maintained by sevoflurane (expiratory concentration of 1–2%) or propofol (2–5 mcg/mL by target-controlled infusion) and fentanil (total dose of 10–20 mcg/kg) and/or remifentanil (0.1–0.5 mcg/kg/min) and rocuronium (4–8 mcg/kg/min). For hypotension, ephedrine or phenylephrine was administered before central venous catheterization, and dopamine, dobutamine or norepinephrine was additionally administered after that by the decision of each anesthesiologist. For the hypotension derived from heart dislocation, most anesthesiologist performed firstly deep head down position and rapid fluid infusion, then inotropic or vasoactive agent administration, finally red blood cell transfusion in anemia cases. The anesthesiologist certified both by Japanese Society of Anesthesiologists Board and by Japanese Board of Perioperative Transesophageal Echocardiography was defined as an experienced anesthesiologist in this study.

The decision of on-pump or off-pump CABG was entrusted to the surgeon before operation. One training instructor (experienced surgeon) certified by the Japanese Board of Cardiovascular Surgery performed surgery or assisted instructively in all cases throughout surgery. All patients were operated by median sternotomy. Bilateral internal thoracic arteries (ITAs, only one side for diabetics), radial artery of the non-dominant hand, and saphenous veins were used as grafts. ITAs were harvested by the skeletonization technique using an ultrasonic scalpel (Harmonic Scalpel, Johnson & Johnson, New Brunswick, New Jersey, the United States of America).

Revascularization was performed in the order of left anterior descending artery (LAD), right coronary artery (RCA) and left circumflex artery (LCX) with the aid of carbon dioxide blower and a suction tissue stabilizer (ACROBAT-i Stabilizer, Guidant, Indianapolis, Indiana, USA) and a coronary shunt tube (Clearview, Medtronic, Minneapolis, Minnesota, USA). A heart positioner (ACROBAT-i Positioner, Guidant, Indianapolis, Indiana, USA) was also used for revascularization of the RCA and LCX. The proximal side of free grafts (radial artery and saphenous vein) was anastomosed to the ascending aorta using a proximal anastomosis device (Enclose II, Novare Surgical Systems, Cupertino, California, USA) before distal anastomosis. In cases of emergency conversion to

CPB, the operation was continued with the heart beating on CPB. Conversion was defined as unplanned use of CPB for unacceptable hemodynamic instability based on the decision of the surgeon or anesthesiologist. After surgery, all of the patients were transferred the ICU while being intubated and sedated.

Data including demographic, historical, and perioperative variables were obtained from medical records. A medical technologist or cardiologist assessed cardiac function systematically including preoperative TAPSE and comprehensively graded TR before surgery. TAPSE was used to evaluate RV longitudinal contractility and the value less than 17 mm meant right ventricular contractile dysfunction. Preoperative TAPSE was retrospectively re-assessed not from motion-mode (M-mode) echocardiography recommended by "guidelines and standards" [23] but from preoperative two dimensional echocardiographic apical four chamber view in this study because there was a discrepancy between the longitudinal motion of the tricuspid lateral annulus and the incidence angle of ultrasound.

VIS was calculated as (dopamine dose + dobutamine dose) (mcg/kg/min) + 10 times milrinone dose (mcg/kg/min) + 100 times (epinephrine dose + norepinephrine dose) (mcg/kg/min) + 10,000 times vasopressin dose (unit/kg/min) [19, 20] and was used to evaluate intraoperative hemodynamics. Age [6], sex [16], urgent surgery [5, 6, 8], TVD [6, 8, 13], LMT disease [7, 8, 12, 13] and CHF [6, 8, 11, 13, 14] were considered to be essential or definitive variables associated with VIS without multicollinearity among the variables and were included in multivariate regression analysis. We defined the patients who required hospitalization and treatment by a cardiologist before surgery as CHF. Urgent/emergent was defined based on Japan Cardiovascular Surgery Database. Other potential variables including TAPSE, TR, LVEF [6, 14], MR [12, 15], early diastolic trans-mitral blood flow velocity divided by early diastolic lateral mitral annulus tissue velocity (E/Ea) (There was no record of LVEDP [16].), LVH [5], Canadian Cardiovascular Society functional classification (CCS classification) [5], preoperative acute myocardial infarction (AMI) [8, 14], cerebrovascular disease (CVD) [5], diabetes mellitus (DM) [5] and anesthesiologists' or surgeons' experience [9, 11] were used in multivariate regression analysis if their P values were less than 0.1 in simple regression analysis.

The primary outcome was the association of intraoperative maximum VIS with TAPSE and TR, and the optimal cut-off value of TAPSE to predict emergency conversion was also calculated by a receiver operating characteristic (ROC) curve. The secondary outcomes were variables, perioperative course (conversion probability and durations of intubation, ICU and hospital stay) and complications (mortality, respiratory failure, renal failure, stroke, wound infection and bleeding requiring a re-operation). Preoperative

hemodialysis for chronic renal failure were excluded from acute kidney injury.

Statistical analysis

The Kolmogorov–Smirnov test and F test were used to determine whether continuous variables followed a normal distribution and the homogeneity of variance. Continuous variables were expressed as means with standard deviation (SD) or medians with interquartile range (IQR), and they were compared using Student's t test or the Mann–Whitney test. Frequencies were expressed as absolute numbers and percentages, and they were compared using the chi-square test. Multiple regression analysis was used to predict VIS based on essential or definitive variables and potential variables with a P value less than 0.1 in simple regression. Variables with variance inflation factors (VIFs) of more than 5 were considered as multicollinearity. An ROC curve was constructed to calculate sensitivity, specificity and the optimal cut-off value by maximum Youden index. Area under the curve (AUC) above 0.8 was considered accurate. A P value less than 0.05 was considered statistically significant. All statistical analyses were performed with EZR version 1.41 (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R version 3.5.2 (The R Foundation for Statistical Computing, Vienna, Austria) [24]. More precisely, it is a modified version of R commander version 2.5-1 designed to add statistical functions frequently used in biostatistics.

Results

A total of 160 patients were enrolled in this study and data for 135 patients were analyzed (Fig. 1). Data for patients' demographic, historical and preoperative variables are shown in Table 1. Emergency conversion to cardiopulmonary bypass was performed in 10 cases (7.4%). Intraoperative and postoperative data and details of emergency
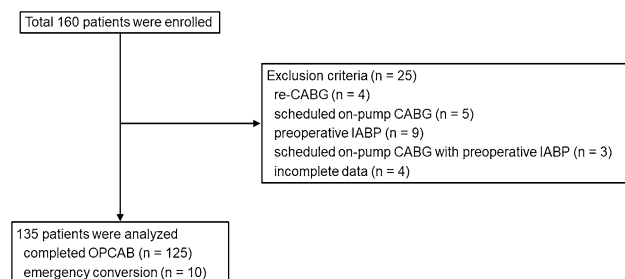
Fig. 1 Flow chart. *OPCAB* off-pump coronary artery bypass grafting, *CABG* coronary artery bypass grafting, *IABP* intra-aortic balloon pumping

Table 1 Patients' charasteristics

Variables	Completed OPCAB ($n=125$)	Converted to CPB ($n=10$)	P value
Age (year)	69.0 [60.0–76.0]	74 [67.8–79.5]	0.11
Male	98 (78.4)	9 (90.0)	0.64
Body mass index	23.7 [21.5–26.3]	23.7 [22.4–24.8]	0.86
Urgent surgery	11 (8.8)	0	0.71
ASA PS			
< 3	35 (28.0)	1 (10.0)	0.39
≥ 3	90 (72.0)	9 (90.0)	
CCS classification			
< 3	106 (84.8)	5 (50.0)	0.02*
≥ 3	19 (15.2)	5 (50.0)	
LAD disease	122 (97.6)	10 (100.0)	1.00
LCX disease	111 (88.8)	9 (90.0)	1.00
RCA disease	104 (83.2)	9 (90.0)	0.91
LMT disease	19 (15.2)	1 (10.0)	1.00
Triple vessel disease	93 (74.4)	8 (80)	0.99
Past medical history			
Congestive heart failure	22 (17.6)	6 (60.0)	< 0.01**
Unstable angina	41 (32.8)	5 (50.0)	0.50
Myocardial infarction	32 (25.6)	5 (50.0)	0.20
Hypertension	90 (72.0)	8 (80.0)	0.86
Dyslipidemia	64 (51.2)	3 (30.0)	0.34
Diabetes mellitus	73 (58.4)	7 (70.0)	0.70
Current smoker	34 (27.2)	3 (30.0)	1.00
COPD	3 (2.4)	1 (10.0)	0.69
CKD on HD	23 (18.4)	3 (30.0)	0.63
Cerebrovascular disease	23 (18.4)	2 (20.0)	1.00
ICA stenosis	20 (16.0)	1 (10.0)	0.96
PVD	15 (12.0)	2 (20.0)	0.81
Preoperative medication			
ARB	50 (40.0)	1 (10.0)	0.12
ACE inhibitor	8 (6.4)	0	0.90
Ca channel blocker	52 (41.6)	2 (20.0)	0.31
β blocker	76 (60.8)	4 (40.0)	0.34
Statin	80 (64.0)	6 (60.0)	1.00
Diuretic	30 (24.0)	5 (50.0)	0.15
Echocardiography			
LVEF (%)	59.0 [49.1–63.8]	35.5 [30.1–41.5]	< 0.01**
LVEF < 35%	10 (8.0)	5 (50.0)	< 0.001***
LVEF < 40%	18 (14.4)	6 (60.0)	< 0.01**
IVS thickness (mm)	10.0 [9.0–12.0]	10.0 [9.3–11.0]	0.59
LVPW thickness (mm)	10.0 [9.0–11.0]	10.0 [10.0–10.0]	0.88
LVH (thickness ≥ 15 mm)	8 (6.4)	1 (10.0)	1.00
E/Ea	12.9 [10.2–16.1]	16.1 [13.5–19.0]	0.08
E/Ea ≥ 10	97 (80.8)	9 (90.0)	0.32
E/Ea ≥ 14	51 (42.5)	9 (90.0)	0.29
AS ≥ mild	10 (8.1)	2 (20.0)	0.50
AR ≥ mild	35 (28.0)	5 (50.0)	0.23
MR ≥ mild	60 (48.0)	8 (80.0)	0.11
TR ≥ mild	31 (24.8)	4 (40.0)	0.50
TAPSE (mm)	19.5 [17.5–22.5]	14.3 [13.0–18.0]	< 0.001***

Table 1 (continued)

Data were expressed as absolute numbers (percentage), means (± standard deviation) or medians [interquartile range]

OPCAB off-pump coronary artery bypass grafting, *CPB* cardiopulmonary bypass, *ASA PS* American Society of Anesthesiologists physical status, *CCS classification* Canadian Cardiovascular Society functional classification, *LAD* left anterior descending artery, *RCA* right coronary artery, *LCX* left circumflex artery, *LMT* left main coronary artery, *COPD* chronic obstructive pulmonary disease, *CKD* chronic kidney disease, *HD* hemodialysis, *ICA* internal carotid artery, *PVD* peripheral vascular disease, *ARB* angiotensin receptor blocker, *ACE* angiotensin converting enzyme, *Ca* calcium, *LVEF* left ventricular ejection fraction, *IVS* interventricular septum, *LVPW* left ventricular posterior wall, *LVH* left ventricular hypertrophy, *E* early diastolic trans-mitral blood flow velocity, *Ea* early diastolic lateral mitral annulus tissue velocity, *AS* aortic stenosis, *AR* aortic regurgitation, *MR* mitral regurgitation, *TR* tricuspid regurgitation, *TAPSE* tricuspid annular plane systolic excursion

$*P < 0.05; **P < 0.01; ***P < 0.001$

conversion are shown in Table 2. One patient was converted at harvest of ITA graft because of ventricular fibrillation (VF). 7 converted patients had TAPSE less than 17 mm (one case at harvest of ITA graft, 2 cases at LAD anastomosis, 4 cases at RCA anastomosis). One patient in whom conversion was performed died from intractable VF of unknown cause on the first postoperative day. E/Ea was not evaluated in 6 cases because of an emergent operation with simple echocardiography assessment. There were no missing data for variables to be used in multivariate analysis and ROC curve analysis.

TAPSE, TR and experienced surgeon with *P* values less than 0.1 in univariate analysis were included in the multivariate analysis (Table 3). Age and TAPSE were included in multiple regression analysis not as categorical but as continuous variables because there were linear relations between VIS and those variables. A normal quantile–quantile plot (normal Q–Q plot) showed that the residual of VIS had a normal distribution (Fig. 2). There was no multicollinearity among variables since all VIFs were less than 2. As a result of multiple regression analysis, a significant regression equation was found (adjusted coefficient of determination (adjusted R^2) of 0.161, $P < 0.001$). In addition, TAPSE (standardized partial regression coefficient (β) of -0.173, $P = 0.044$), TR (β 0.291, $P < 0.001$) and experienced surgeon ($\beta - 0.187$, $P = 0.022$) were significant predictors of VIS (Table 4).

As shown in Fig. 3, the ROC curve of emergency conversion on TAPSE showed an optimal cut-off value of 15.0 mm (sensitivity of 0.600 and specificity of 0.936) and AUC of 0.808 (95% confidence Interval (CI) 0.645–0.971).

Discussion

In this study, we found that TAPSE and TR were associated with intraoperative maximum VIS and that the optimal cut-off value of TAPSE to predict emergency conversion was 15 mm. The results suggested that TAPSE and TR are independent predictors of hemodynamic instability

during OPCAB and that TAPSE has better discrimination power for emergency conversion to on-pump CABG. The findings of this study can help the decision-making in terms of "whether this patient is suitable for off-pump bypass or not?".

There have been some studies on RV function during OPCAB. Kwak et al. reported that a significantly reduced RVEF accompanied by an increase in RV afterload and decrease in cardiac output (CO) was observed during anastomosis of the OM artery [17]. Couture et al. reported that heart dislocation (90° anterior displacement) and compression of the RV to a greater extent than that of the LV are responsible for hemodynamic alterations when using suction-type stabilizers [18]. In animal experiments, a pig heart retracted with a suction tissue stabilizer caused primarily RV diastolic dysfunction without concurring valvular incompetence [25]. Emergency conversion was determined more often at RCA anastomosis than at LCX anastomosis in this study. Preoperative RV dysfunction, low TAPSE or TR, might become worse due to heart dislocation with a suction-type stabilizer not only for LCX anastomosis but also for RCA anastomosis and result in hemodynamic instability or emergency conversion.

RV dysfunction after CABG has also been reported. TAPSE and strain of the RV significantly decreased 6 days and 3 months after OPCAB compared to those before surgery [26]. Diastolic RV function at the end of surgery and peak systolic velocities of the lateral tricuspid annulus 3 months after surgery were similarly impaired in both compared OPCAB and on-pump CABG [27, 28]. RV dysfunction due to OPCAB might already occur during surgery and lead to hemodynamic instability or emergency conversion.

Patel et al. reported that the main reasons for conversion were hypotension ischemia (76%), hemorrhage (8%) and VF (8%) [4]. Emergency conversion due to hemorrhage can occur regardless of RV function and reduce the AUC of the ROC curve on TAPSE. Nevertheless, TAPSE could accurately predict emergency conversion in this study. That implied that RV systolic dysfunction is highly associated with severe hypotension and even VF during OPCAB.

Table 2 Intraoperative and postoperative data

Variables	Completed OPCAB (n = 125)	Converted to CPB (n = 10)	P value
Intraoperative data			
Anesthesia time (min)	343 [315–380]	433 [391–452]	< 0.001***
Operation time (min)	266 [240–300]	351 [315–378]	< 0.001***
Experienced anesthesiologist	42 (33.6)	2 (20.0)	0.50
Experienced surgeon	114 (91.2)	9 (90.0)	1.00
Number of anastomosis	3.0 [3.0–4.0]	3.5 [3.0–4.0]	0.84
Blood loss (ml)	698 [506–1090]	935 [593–1801]	0.21
Maximum VIS	9 [6.0–13.0]	10 [6.3–12.8]	0.64
Reason of conversion			
Systemic hypotension		6 (60.0)	
Pulmonary hypertension		1 (10.0)	
Bleeding		1 (10.0)	
Ventricular fibrillation		2 (20.0)	
Timing of conversion			
Harvest of ITA graft		1 (10.0)	
Anastomosis to LAD		3 (30.0)	
Anastomosis to RCA		5 (50.0)	
Anastomosis to LCX		1 (10.0)	
Postoperative data			
Death within POD 30	0	1 (10.0)	0.10
Graft occlusion	19 (15.6)	1 (10.0)	1.00
Respiratory failure	0	0	
Acute kidney injury	7 (6.9)	1 (14.3)	1.00
Stroke	4 (3.2)	0	1.00
Wound infection	0	0	
Bleeding	1 (0.8)	0	1.00
Ventilator ≥ 12 h	7 (5.6)	3 (30.0)	0.03*
VIS is not 0 ≥ 12 h	31 (24.8)	4 (40.0)	0.50
ICU stay ≥ 24 h	16 (12.8)	5 (50.0)	< 0.01**
Hospital stay ≥ 30 days	14 (11.2)	4 (40.0)	0.04*

Data were expressed as absolute numbers (percentage), means (± standard deviation) or medians [interquartile range]

OPCAB off-pump coronary artery bypass grafting, *CPB* cardiopulmonary bypass, *VIS* vasoactive-inotropic score, *ITA* internal thoracic artery, *LAD* left anterior descending artery, *RCA* right coronary artery, *LCX* left circumflex artery, *POD* postoperative day, *ICU* intensive care unit

*P < 0.05; **P < 0.01; ***P < 0.001

Urgent surgery, TVD, LMT disease and CHF were not associated with VIS in contrast to results of previous studies [5–8, 11–13]. There were many urgent cases in which IABP or scheduled on-pump CABG was performed preoperatively and these cases were excluded from this study. Severity of coronary artery stenosis of 75% to 100% was not considered in TVD and LMT disease. Similarly, the severity of CHF was not considered. That might have affected the results obtained by using these variables in multivariate analysis.

There are several limitations in this study. First, maximum VIS within 24 h after ICU admission in cardiac surgery is a good predictor of worse outcomes; however, there is little evidence that intraoperative maximum VIS represents hemodynamics or postoperative complications in OPCAB. Yamazaki et al. reported that a high VIS at the end of adult cardiac surgery on CPB was associated with high rates of morbidity and mortality [29]. Second, although midazolam, propofol, sevoflurane, fentanyl, remifentanil, ephedrine, phenylephrine, and fluid and blood transfusion volumes could affect VIS, they were not included in multiple regression analysis. Third, pulmonary artery catheter was inserted in all subjects. Insertion of the catheter could worsen TR and hemodynamics. In addition, the mechanism of TR was not considered. Fourth, transthoracic echocardiography was performed at various times from just before the surgery to one month before.
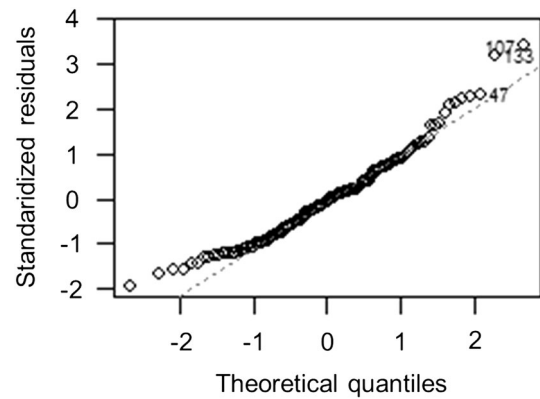
Table 3 Simple regression analysis to predict vasoactive-inotropic score

Variables	B	SE	T value	P value
CCS classification ≥ 3	0.85	1.38	0.61	0.54
Myocardial infarction	1.68	1.18	1.42	0.16
Diabetes mellitus	− 0.43	1.08	− 0.40	0.69
Cerebrovascular disease	0.35	1.36	0.26	0.80
LVEF < 35%	2.50	1.67	1.49	0.14
LVEF < 40%	1.56	1.38	1.13	0.26
LVH (thickness ≥ 15 mm)	1.12	2.12	0.53	0.60
E/Ea ≥ 10	1.15	1.42	0.81	0.42
E/Ea ≥ 14	1.73	1.09	1.60	0.11
MR ≥ mild	0.76	1.06	0.72	0.47
TR ≥ mild	4.90	1.13	4.33	< 0.001***
TAPSE (mm)	− 0.34	0.15	− 2.25	0.03*
Experienced anesthesiologist	1.67	1.12	1.49	0.14
Experienced surgeon	− 4.93	1.81	− 2.72	< 0.01**

B partial regression coefficient, *SE* standard error, *CCS classification* Canadian Cardiovascular Society functional classification, *LVEF* left ventricular ejection fraction, *LVH* left ventricular hypertrophy, *E* early diastolic trans-mitral blood flow velocity, *Ea* early diastolic lateral mitral annulus tissue velocity, *MR* mitral regurgitation; *TR* tricuspid regurgitation, *TAPSE* tricuspid annular plane systolic excursion

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

Fig. 2 Normal quantile–quantile plot. Normal quantile–quantile plot (Normal Q–Q plot) showed that the residual of VIS had a normal distribution

Furthermore, RV function indicators other than TAPSE and TR could not be assessed. Fifth, the patient's physique and cardiac size were not taken into account in TAPSE. Sixth, we decided the variables for multiple regression analysis based on previous reports about emergency conversion or hemodynamics of OPCAB [5–16]. It is possible that unknown confounding factors caused bias. In this study, there was a positive weak correlation between TAPSE and LVEF (Spearman's rank coefficient 0.294, $P < 0.001$). This is a limitation in all retrospective studies. Finally, it is difficult to generalize the ROC curve based on only 10 converted patients.

Conclusion

Preoperative TAPSE and TR were significantly associated with intraoperative maximum VIS in OPCAB and the optimal cut-off value of TAPSE to predict emergency conversion was 15 mm. Further large-scale prospective studies are needed.

Table 4 Multiple regression analysis to predict vasoactive-inotropic score

Variables	B [95% CI]	SE B	β	T value	P value
Intercept	14.016 [4.331, 23.700]	4.893	< 0.001	2.864	< 0.01**
Age (year)	0.038 [− 0.056, 0.131]	0.047	0.066	0.796	0.428
Male	− 0.183 [− 2.580, 2.214]	1.211	− 0.012	− 0.151	0.880
Urgent surgery	2.104 [− 1.496, 5.705]	1.819	0.094	1.157	0.250
LMT disease	0.534 [− 2.280, 3.347]	1.422	0.031	0.375	0.708
Triple vessel disease	1.845 [− 0.399, 4.089]	1.134	0.131	1.627	0.106
Congestive heart failure	− 0.487 [− 3.022, 2.049]	1.281	− 0.032	− 0.380	0.705
TR ≥ mild	4.054 [1.690, 6.417]	1.194	0.291	3.394	< 0.001***
TAPSE (mm)	− 0.302 [− 0.597, − 0.008]	0.149	− 0.173	− 2.030	0.044*
experienced surgeon	− 4.012 [− 7.435, − 0.588]	1.730	− 0.187	− 2.319	0.022*

B partial regression coefficient, *CI* confidence interval, *SE* standard error, *β* standardized partial regression coefficient, *LMT* left main coronary artery, *TR* tricuspid regurgitation, *TAPSE* tricuspid annular plane systolic excursion

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$
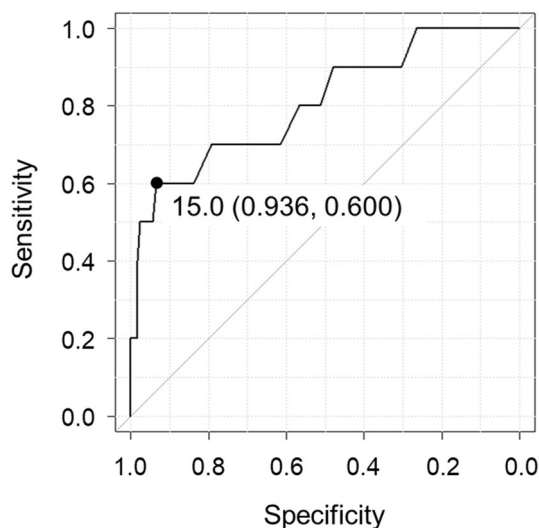
Fig. 3 Receiver operating characteristic (ROC) curve of emergency conversion on tricuspid annular plane systolic excursion (TAPSE). The ROC curve showed that the optimal cut-off value of TAPSE was 15.0 mm (sensitivity of 0.600 and specificity of 0.936) with AUC of 0.808 (95% CI 0.645–0.971)

Compliance with ethical standards

Conflict of interest statement Tatsuya Kunigo declares that he has no conflict of interest. Yusuke Yoshikawa declares that he has no conflict of interest. Shuji Yamamoto declares that he has no conflict of interest. Michiaki Yamakage declares that he has no conflict of interest.

Ethical approval This study was approved by the Institutional Review Board of Obihiro Kosei General Hospital, Hokkaido, Japan (No. 2020–005).

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