Journal of Anesthesia (2025) 39:456–464
https://doi.org/10.1007/s00540-025-03486-x

ORIGINAL ARTICLE

Effect of pulmonary artery catheters in patients with cardiovascular diseases stratified based on severity: a propensity score-matched analysis

Takuya Niwa[1] · Yoshitaka Aoki[1] · Kensuke Kobayashi[1] · Kento Suzuki[1] · Takayuki Katsuragawa[1] · Soichiro Mimuro[1] · Yoshiki Nakajima[1]

Received: 16 December 2024 / Accepted: 11 March 2025 / Published online: 25 March 2025
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Abstract

Purpose This study aimed to assess the effect of pulmonary artery catheter (PAC) use on clinical outcomes in cardiovascular patients stratified by severity using the Acute Physiology and Chronic Health Evaluation (APACHE) III score.

Methods This study was conducted at Hamamatsu University Hospital and included intensive care unit (ICU) patients with cardiovascular diseases from April 2019 to March 2024. Patients were stratified into overall, severe, and critically severe cohorts based on their APACHE III scores. PAC group included those with PAC use within 24 h of ICU admission, while non-users formed the control group. The primary outcome was in-hospital mortality, whereas the secondary outcomes included ICU mortality, initiation of renal replacement therapy, mechanical circulatory support-free days at day 28, and lengths of hospital and ICU stay. One-to-one propensity score matching was performed to adjust for baseline differences.

Results Of the 1,693 patients, matched pairs were created for 210, 136, and 62 in the overall, severe, and critically severe cohorts, respectively. In-hospital mortality did not differ significantly between PAC and control groups across all cohorts (overall: 8.6% vs. 10.0%, $p=0.61$; severe: 14.0% vs. 14.0%, $p>0.99$; critically severe: 22.6% vs. 25.8%, $p=0.68$). Among secondary outcomes, PAC use was significantly associated with increased renal replacement therapy and prolonged ICU stays in the overall and critically severe cohorts.

Conclusions PAC use was not associated with improved outcomes in critically ill patients with cardiovascular diseases, even among those with a high mortality risk, suggesting the need for further studies.

Keywords Pulmonary artery catheters · Cardiovascular diseases · Mortality · Mechanical circulatory support · Renal replacement therapy

Introduction

For over 5 decades, a pulmonary artery catheter (PAC) has played a crucial role in clinical settings globally, serving as a vital monitoring device [1]. PAC is used to measure intrapulmonary and intracardiac pressures, mixed venous oxygen saturation, and various hemodynamic parameters, including cardiac output and vascular resistance [2]. These measurement parameters can be used to achieve an accurate diagnosis and guide appropriate interventions [3]. However, the routine PAC use in critically ill patients has decreased because several randomized controlled trials have shown the complications associated with PAC use, with no improvement in outcomes [4–8].

Recent studies have indicated the utility of PAC-guided management in specific scenarios, such as post-cardiotomy, acute decompensated heart failure, and sepsis-associated cardiogenic shock [2, 3, 9–12]. In high-risk surgical cases, the use of PAC and treatment based on the information obtained can reduce mortality and surgical morbidity [13–16]. Given the risk of complications such as PAC entrapment during cardiac surgery [17], a 2020 joint statement by the Japanese Society of Cardiovascular Surgery and Japanese Society of Cardiovascular Anesthesiologists recommended selective PAC use in cardiovascular surgery,

✉ Yoshitaka Aoki
ysyaoki27@gmail.com

[1] Department of Anesthesiology and Intensive Care Medicine, Hamamatsu University School of Medicine, 1-20-1 Handayama, Chuo-Ku, Hamamatsu, Shizuoka 431-3192, Japan

advocating its application in particular instances rather than universally [16]. However, there is a lack of robust, high-quality evidence to support PAC use when considering key factors such as patient risk profiles, surgical type, and specific clinical circumstances. Determining specific criteria to limit PAC usage and evaluating the proportion of patients in whom its use should be restricted remain clinical questions that require attention.

The Acute Physiology and Chronic Health Evaluation (APACHE) III severity score, developed in the United States, accurately predicts mortality in intensive care units (ICUs) and has proven useful in the cardiovascular surgical population [18, 19]. In this study, we stratified ICU patients with cardiovascular diseases by mortality risk using the APACHE III severity score and hypothesized that PAC use might improve clinical outcomes in patients with higher severity levels. Specifically, we aimed to evaluate the effect of PAC on critical outcomes, including in-hospital and ICU mortality, the need for organ support, and lengths of hospital and ICU stay, across cohorts defined by varying mortality risks. By focusing on patients stratified by their predicted mortality, our objective was to provide evidence for the selective and targeted use of PAC in the management of critically ill cardiovascular patients.

Methods

Study design

This retrospective cohort study was conducted at Hamamatsu University Hospital (Shizuoka, Japan). This study was approved by the Ethics Review Board of the Hamamatsu University School of Medicine (approval number 23–138). The requirement for written informed consent was exempted. Our study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines and complied with the principles of the Declaration of Helsinki 1964, including its subsequent modifications [20].

Patient selection

We included patients admitted to the ICU of our hospital for cardiovascular diseases between fiscal year 2019 and 2023 (April 2019–March 2024). Cardiovascular diseases were defined as conditions requiring ICU admission due to cardiac disorders, under the primary care of cardiac surgeons or cardiologists. We excluded patients aged < 18 years, those readmitted to the ICU, and those with missing data. The patients were divided into the following three cohorts based on the APACHE III severity score: the overall cohort included all patients, the severe cohort included patients with APACHE III scores above the median, and the critically severe cohort included those with scores in the highest quartile.

Exposure and outcomes

Patients were classified into two groups based on PAC use within 24 h of ICU admission. The PAC group included those who underwent PAC monitoring, while the control group consisted of patients who did not undergo PAC monitoring. The primary outcome was in-hospital mortality. Secondary outcomes included ICU mortality, initiation of renal replacement therapy (RRT), mechanical circulatory support (MCS)-free days at day 28, and lengths of hospital and ICU stays. MCS encompassed intra-aortic balloon pump (IABP), Impella (a microaxial left ventricular assist device), venoarterial extracorporeal membrane oxygenation (VA-ECMO), and a ventricular assist device. For the RRT outcome, patients receiving chronic dialysis for end-stage renal disease prior to surgery were excluded to focus on those who initiated RRT during their ICU stay. However, these patients were included in the analysis of other outcomes such as mortality. The indications for RRT at our institution align with the generally accepted absolute criteria, including severe hyperkalemia, refractory metabolic acidosis, uremic complications, and life-threatening fluid overload unresponsive to medical management [21]. To minimize bias, variables from the first 24 h of ICU admission were used as covariates [22]. Outcomes were assessed based on data recorded after this initial period.

PAC insertion criteria

In our institution, PACs are frequently utilized not only for patients with cardiogenic shock but also for other critically ill patients requiring detailed hemodynamic assessment. In internal medicine, decisions regarding PAC insertion consider each patient's cardiac function, the presence and severity of pulmonary hypertension, and heart failure. For cardiac surgery cases, the need for PAC placement is evaluated based on both the patient's cardiac function and surgical factors, such as the type of procedure and the anticipated duration of cardiopulmonary arrest. These decisions are made through discussions among cardiologists or during multidisciplinary conferences involving cardiac surgeons, anesthesiologists, and clinical engineers. Patients with a PAC undergo continuous monitoring of pulmonary artery pressure, mixed venous oxygen saturation, cardiac output, and cardiac index, ensuring a comprehensive assessment of hemodynamic status. At our institution, PAC insertion is determined based on the overall clinical condition rather than a single parameter, with the priority given to patients with pulmonary hypertension or cardiogenic shock.

Data collection

The following variables were recorded within the first 24 h of ICU admission: fiscal year of ICU admission; age; sex; body mass index (BMI); emergency ICU admission; cardiopulmonary arrest before ICU admission; end-stage renal disease; cardiovascular surgery; coronary artery disease; aortic disease; heart valve disease; use of mechanical ventilation; use of MCS; use of dopamine, dobutamine, norepinephrine; presence of acute kidney injury; APACHE III; APACHE II; and Simplified Acute Physiology Score II (SAPS II) scores; and lactate levels. Outcome variables included in-hospital mortality; ICU mortality; use and timing of MCS; use and timing of RRT; and lengths of hospital and ICU stays, recorded until day 28 or until the patient's first hospital discharge, whichever came first.

Statistical analyses

We used propensity score analysis to adjust for baseline characteristics between the PAC and control groups, calculating propensity scores using a generalized linear regression model based on predetermined covariates listed in Table 1, including patient characteristics at ICU admission and treatments within the first 24 h. Propensity scores were matched one-to-one using nearest-neighbor matching without replacement, with a caliper width of 20% of the standard deviation of the scores on the logit scale [23, 24]. We assessed the balance of baseline variables using the absolute

Table 1 Baseline patient characteristics before and after propensity score matching in the overall cohort

Variable	Before propensity score matching			After propensity score matching		
	PAC ($n=745$)	Control ($n=948$)	Absolute standardized differences (%)	PAC ($n=210$)	Control ($n=210$)	Absolute standardized differences (%)
Characteristic at ICU admission						
Fiscal year, n (%)						
2019	200 (26.9)	243 (25.6)	2.8	33 (15.7)	31 (14.8)	2.6
2020	179 (24.0)	182 (19.2)	11.7	21 (10.0)	26 (12.4)	7.5
2021	166 (22.3)	188 (19.8)	6.0	31 (14.8)	44 (21.0)	16.2
2022	124 (16.6)	126 (13.3)	9.4	59 (28.1)	51 (24.3)	8.7
2023	76 (10.2)	209 (22.1)	32.6	66 (31.4)	58 (27.6)	8.3
Age (years), mean (SD)	70.3 (11.5)	71.7 (11.9)	11.4	70.6 (11.3)	69.5 (13.0)	8.9
Male, *n* (%)	519 (69.7)	689 (72.7)	6.7	145 (69.1)	148 (70.5)	3.1
BMI (kg/m^2), mean (SD)	22.9 (4.0)	23.2 (4.5)	7.5	23.2 (4.4)	23.1 (4.6)	3.3
Emergency ICU admission, *n* (%)	178 (23.9)	423 (44.6)	44.7	89 (42.4)	85 (40.5)	3.9
Cardiopulmonary arrest before ICU admission, *n* (%)	37 (5.0)	74 (7.8)	11.6	27 (12.9)	23 (11.0)	5.9
End-stage renal disease, *n* (%)	70 (9.4)	85 (9.0)	1.5	15 (7.1)	14 (6.7)	1.9
Cardiovascular surgery, *n* (%)	634 (85.1)	558 (58.9)	61.1	147 (70.0)	152 (72.4)	5.2
Coronary artery disease, *n* (%)	253 (34.0)	203 (21.4)	28.3	50 (23.8)	52 (24.8)	2.2
Aortic disease, *n* (%)	188 (25.2)	230 (24.3)	2.3	67 (31.9)	68 (32.4)	1.0
Heart valve disease, *n* (%)	462 (62.0)	369 (38.9)	47.4	126 (60.0)	127 (60.5)	1.0
Treatments and prognostic indicators within 24 h of ICU admission						
Mechanical ventilation, *n* (%)	696 (93.4)	265 (28.0)	180.5	165 (78.6)	169 (80.5)	4.7
Mechanical circulatory support, *n* (%)	74 (9.9)	18 (1.9)	34.5	22 (10.5)	15 (7.1)	11.8
Dopamine, *n* (%)	321 (49.8)	42 (6.0)	95.2	61 (29.1)	69 (32.9)	8.2
Dobutamine, *n* (%)	168 (22.6)	55 (5.8)	49.4	40 (19.1)	34 (16.2)	7.5
Norepinephrine, *n* (%)	293 (39.3)	184 (19.4)	44.8	87 (41.4)	87 (41.4)	<0.1
Acute kidney injury, *n* (%)	11 (1.5)	21 (2.2)	5.5	7 (3.3)	8 (3.8)	2.6
APACHE III score, mean (SD)	67.1 (22.3)	60.3 (27.4)	27.4	72.5 (29.2)	69.0 (30.9)	11.5
APACHE II score, mean (SD)	17.5 (6.1)	16.2 (7.3)	19.4	19.2 (7.7)	18.3 (7.8)	12.7
SAPS II score, mean (SD)	37.0 (13.3)	31.9 (16.5)	33.7	40.4 (16.5)	39.0 (18.2)	3.6
Lactate (mmol/L), mean (SD)	4.0 (2.8)	2.4 (2.9)	55.5	4.2 (3.7)	3.9 (4.2)	2.8

PAC Pulmonary artery catheter, *ICU* Intensive care unit, *SD* Standard deviation, *BMI* Body mass index, *APACHE* Acute physiology and chronic health evaluation, *SAPS* Simplified acute physiology score

standardized difference and determined that balance was not achieved if the value exceeded 10% [25].

Categorical variables are presented as numbers and percentages and continuous variables as means and standard deviations. Group comparisons were made using the Chi-squared test for categorical variables and the student's t test for continuous variables. After propensity score matching, risk differences with 95% confidence intervals (CIs) were calculated for dichotomous outcomes, and group comparisons were conducted using the Chi-squared test. For continuous outcomes, group means were compared using Student's t test, and 95% CIs for the mean differences were reported.

As a sensitivity analysis, Kaplan–Meier survival analysis was performed for a 28-day period, with log-rank tests used for comparisons in the overall, severe, and critically severe cohorts after propensity score matching. In addition, we performed three subgroup analyses of the primary outcome of in-hospital mortality: patients with cardiovascular surgery, those requiring emergency admission to the ICU, and those undergoing mechanical ventilation. For these analyses, patients were stratified into overall, severe, and critically severe cohorts based on the median and third quartiles of APACHE III scores, similar to the main analysis. Propensity scores were used to adjust for baseline differences within each subgroup.

p value < 0.05 were considered statistically significant. All statistical analyses were performed using Stata/MP 18 (STATA Corp, College Station, TX, USA).

Results

Figure 1 summarizes the patient selection process. During the study period, 1,820 patients with cardiovascular diseases were admitted to the ICU. After applying the exclusion criteria, 1,693 patients were included in the overall cohort. Of these, 860 with APACHE III scores above the median (59 points) formed the severe cohort; and 426 patients with APACHE III scores in the third quartile (73 points) or higher constituted the critically severe cohort. In each cohort, the patients were divided into two groups based on the presence or absence of PAC. After 1:1 propensity score matching, the matched cohorts included 210, 136, and 62 pairs in the overall, severe, and critically severe cohort, respectively.

Table 1 shows baseline patient characteristics before and after propensity score matching in the overall cohort. Patients admitted to the ICU in 2020; those who were younger; underwent cardiovascular surgery; had coronary artery disease; had heart valve disease; were on mechanical ventilation or mechanical circulatory support; received dopamine, dobutamine, or norepinephrine; had higher APACHE III, APACHE II, or SAPS II scores; or had higher lactate levels were more likely to receive PAC monitoring, while patients admitted in 2023; those with emergency ICU admission; or those who experienced cardiopulmonary arrest before ICU admission were less likely to receive PAC, compared to their counterparts. After propensity score matching, the patient characteristics of the two groups were almost balanced. The backgrounds of patients in the severe and critically severe cohorts are presented in Online Resource 1 and Online Resource 2, respectively. Similar to the overall cohort, patient characteristics were almost balanced between the two other groups after propensity score matching.

Table 2 presents the outcomes after propensity score matching. The primary outcome of in-hospital mortality showed no significant differences between the groups across all cohorts. In the overall cohort, in-hospital mortality was 8.6% in the PAC group and 10.0% in the control group, with a risk difference of −1.4% (95% CI −7.0 to 4.1; $p = 0.61$). In the severe cohort, in-hospital mortality was 14.0% in both groups, with a risk difference of 0.0% (95% CI −8.2 to 8.2; $p > 0.99$). In the critically severe cohort, in-hospital mortality was 22.6% in the PAC group and 25.8% in the control group, with a risk difference of -3.2% (95% CI −18.3 to 11.8; $p = 0.68$). PAC use was significantly associated with increased rates of renal replacement therapy and prolonged ICU stays in the overall and critically severe cohort, whereas no significant differences were observed between the two groups for other secondary outcomes.

Figure 2 shows the Kaplan–Meier curves for the overall, severe and critically severe cohort, with no significant difference in survival between the PAC and control groups (log-rank $p = 0.43$, 0.81, and 0.48). Table 3 summarizes the three subgroup analyses, all of which showed no significant differences in mortality between the PAC and control groups.

Discussion

In this study, we evaluated whether PAC improves outcomes in patients with severe cardiovascular disease stratified by the APACHE III severity score through propensity score matching. The primary outcome, in-hospital mortality, did not differ significantly between the PAC and control groups across all cohorts. Secondary outcomes showed increased RRT utilization with PAC use and prolonged ICU stays in the overall and critically severe cohorts. Sensitivity and subgroup analyses confirmed the robustness of these findings, demonstrating no significant differences in mortality between the groups. These results suggest that PAC use may not substantially improve clinical outcomes in critically ill cardiovascular patients.

To the best of our knowledge, the present study is the first to evaluate the effectiveness of PAC in patients with cardiovascular diseases categorized based on the severity. We hypothesized that PAC reduces mortality in high-risk

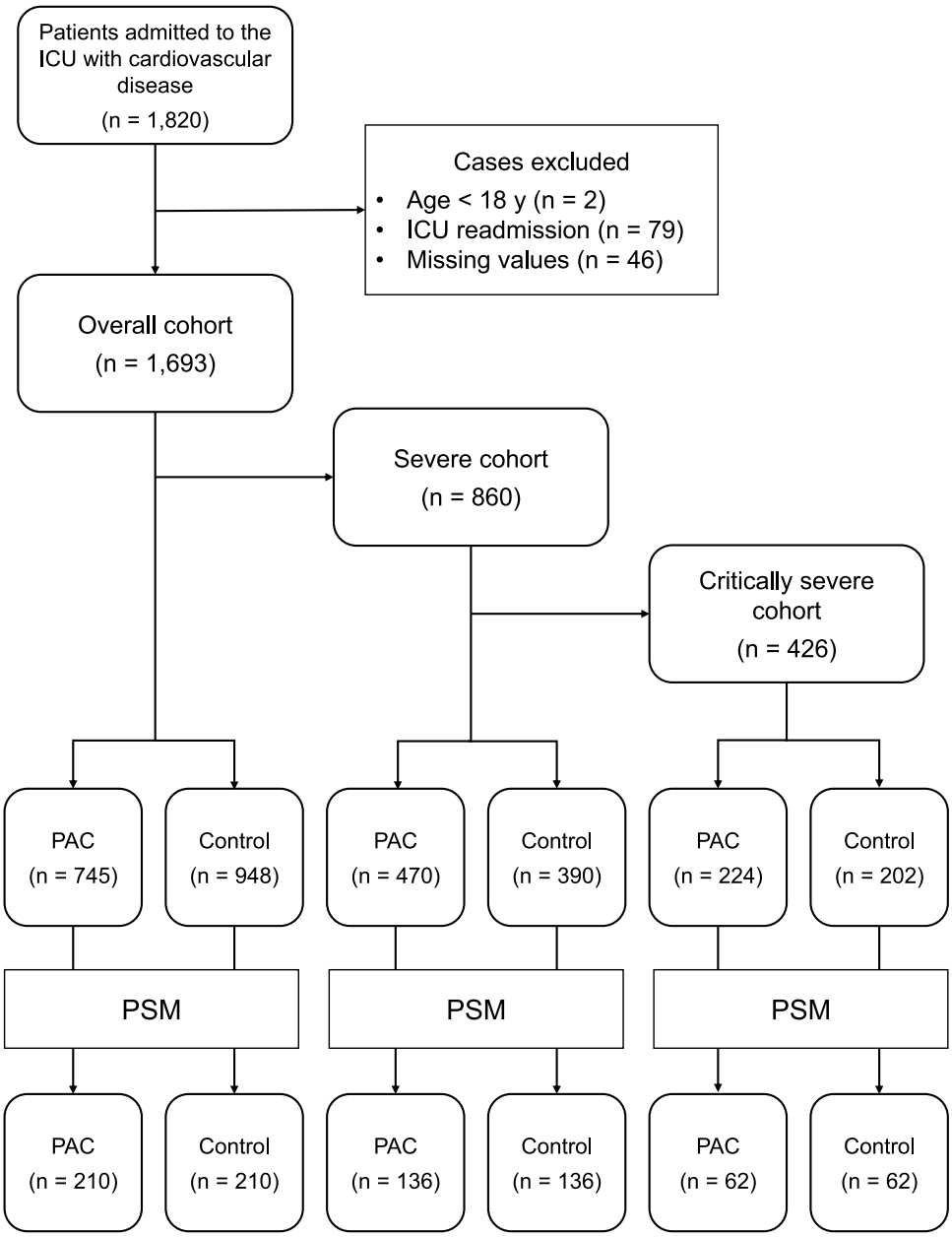

Fig. 1 Patient selection flowchart. *ICU* Intensive care unit *PAC* Pulmonary artery catheter, *PSM* Propensity score matching

patients; however, our findings showed no significant reduction in mortality, even in the most severe cohort. This result contradicts previous reports suggesting the effectiveness of PAC in specific scenarios, such as cardiogenic shock and high-risk cardiac surgery, presenting an unexpected result [2, 3, 9, 10, 12–15]. A Korean cohort study found perioperative PAC use reduced 1-year mortality in cardiac surgery, particularly in off-pump grafting and low-volume centers [26]. While the Japanese Society of Cardiovascular Anesthesiologists advocates for case selection in PAC use, there is a need to further identify and clarify specific clinical situations where PAC is most beneficial, supported by robust evidence.

Our study demonstrated that PAC use was associated with increased RRT utilization in the overall and critically severe cohorts. These results align with a nationwide study using data from the Japanese Intensive Care Patient Database (JIPAD) [27], suggesting that PAC's proactive hemodynamic management may have lowered the threshold for initiating RRT, indicating an active approach to renal support in critically ill patients. However, while the JIPAD study reported that ICU mortality was significantly lower and the use of IABP and VA-ECMO was higher in the PAC use group than in the non-PAC use group [27], our study found no significant differences in ICU mortality or MCS-free days at 28 days between the PAC and control groups. Considering

Table 2 Outcomes after propensity score matching

	PAC	Control	Difference (95% CI)	p value
Overall cohort	*n* = 210	*n* = 210		
In-hospital mortality, *n* (%)	18 (8.6)	21 (10.0)	−1.4 (−7.0–4.1)	0.61
ICU mortality, *n* (%)	10 (4.8)	9 (4.3)	0.5 (−3.5–4.5)	0.81
Initiation of RRT, *n* (%)	17 / 195 (8.7)	5 / 196 (2.6)	6.2 (1.6–10.7)	0.008
MCS-free days at day 28, mean (SD)	26.1 (5.9)	26.3 (5.8)	−0.2 (−1.3–0.9)	0.73
Length of hospital stay, days, mean (SD)	28.9 (28.7)	27.2 (37.9)	1.7 (−4.8–8.1)	0.61
Length of ICU stay, days, mean (SD)	4.7 (7.5)	3.1 (3.1)	1.7 (0.6–2.8)	0.003
Severe cohort	*n* = 136	*n* = 136		
In-hospital mortality, *n* (%)	19 (14.0)	19 (14.0)	0.0 (−8.2–8.2)	> 0.99
ICU mortality, *n* (%)	11 (8.1)	9 (6.6)	1.5 (−4.7–7.7)	0.64
Initiation of RRT, *n* (%)	16 / 117 (13.7)	8 / 116 (6.9)	6.8 (−1.0–14.5)	0.09
MCS-free days at day 28, mean (SD)	25.1 (7.5)	25.7 (6.7)	−0.6 (−2.2–1.1)	0.52
Length of hospital stay, days, mean (SD)	31.5 (32.1)	29.2 (43.7)	2.3 (−6.9–11.4)	0.62
Length of ICU stay, days, mean (SD)	5.6 (8.9)	4.6 (13.6)	1.0 (−1.7–3.8)	0.46
Critically severe cohort	*n* = 62	*n* = 62		
In-hospital mortality, *n* (%)	14 (22.6)	16 (25.8)	−3.2 (−18.3–11.8)	0.68
ICU mortality, *n* (%)	7 (11.3)	8 (12.9)	−1.6 (−13.1–9.9)	0.78
Initiation of RRT, *n* (%)	10 / 49 (20.4)	3 / 49 (6.1)	14.3 (1.2–27.4)	0.04
MCS-free days at day 28, mean (SD)	23.6 (9.1)	23.2 (9.4)	0.5 (−2.8–3.8)	0.78
Length of hospital stay, days, mean (SD)	35.0 (37.0)	31.3 (59.6)	3.7 (−13.9–21.3)	0.68
Length of ICU stay, days, mean (SD)	6.0 (6.8)	3.9 (3.4)	2.2 (0.3–4.1)	0.03

PAC Pulmonary artery catheter, *CI* Confidence interval, *MCS* Mechanical circulatory support, *ICU* Intensive care unit, *RRT* Renal replacement therapy, *SD* Standard deviation

The severe cohort consisted of patients with APACHE III scores above the median, whereas the critically severe cohort included patients with APACHE III scores in the highest quartile

that hospital and ICU mortality differ in the Japanese ICU setting due to resource optimization [28], hospital mortality may be a more reliable and less biased outcome measure than ICU mortality. A notable limitation of the JIPAD study is its lack of data on the timing of MCS interventions, such as IABP and VA-ECMO, as well as the absence of information on Impella, a device increasingly utilized in recent years. In contrast, our single-center study provided precise data on the timing of MCS interventions, including Impella use, and adopted MCS-free days at 28 days as an outcome, enabling a more nuanced evaluation of PAC-related outcomes and offering clearer insights into its role in contemporary cardiovascular critical care.

The clinical implication of the present study suggest that PAC use may have limited effectiveness, even in critically ill cardiovascular patients with high mortality risk. These results challenge the assumption that PAC improves outcomes in the most critically ill and align with the global trend of reducing routine PAC use. PAC remains a valuable tool for managing critically ill and surgical patients with complex hemodynamic abnormalities; however, given its high invasiveness and cost, its use should be tailored to individual needs and reserved for cases where less invasive, lower-cost alternatives are insufficient to optimize outcomes while minimizing complications [29, 30]. Further research is needed to refine patient selection and optimize its use in critical care.

The present study had some limitations. First, its single-center design in Japan may limit the generalizability of the findings. In addition, the reduced sample size owing to patient stratification and propensity score matching lowered the statistical power, making it difficult to detect significant differences. Future studies with larger, multicenter cohorts are needed to validate these results. Second, the lack of standardized criteria for interventions such as PAC, MCS, and RRT left decisions to individual clinicians' discretion. The absence of predefined parameters for these interventions may have introduced variability in patient management, potentially leading to selection bias. However, the limited number of medical staff in this single-center study likely ensured a degree of consistency in clinical practice. Finally, the decision to stratify patients by APACHE III scores rather than specific cardiac diseases could be debated. However, the consistent increase in in-hospital mortality across the overall, severe, and critically severe cohorts after propensity score matching supports the appropriateness of APACHE III for stratifying mortality risk.

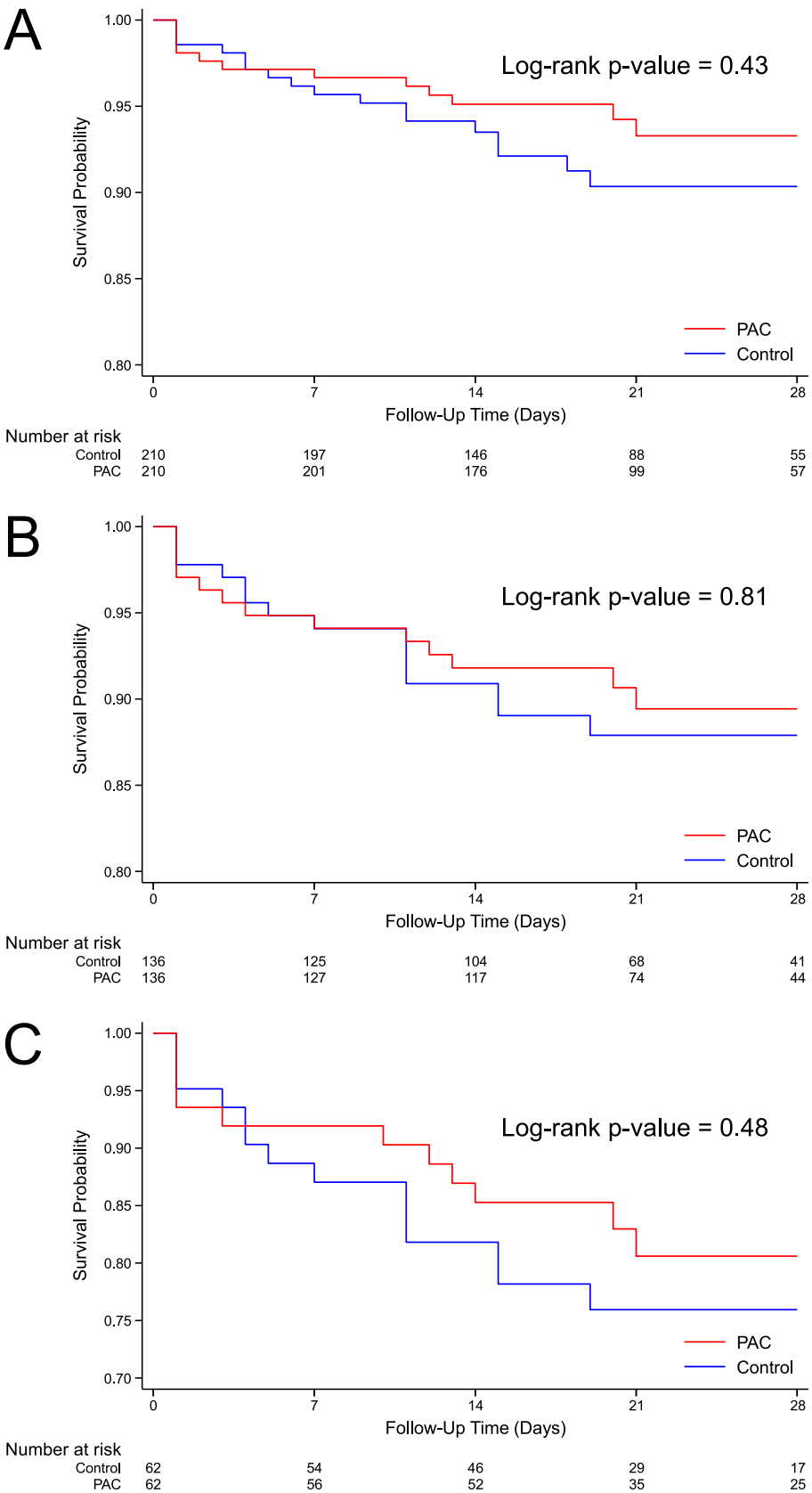

Fig. 2 Kaplan–Meier survival curves for 28-day follow-up after propensity score matching. Cumulative survival probabilities for (A) overall, (B) severe, and (C) critically severe cohorts, comparing the PAC and control groups. Statistical analysis using the log-rank test reveals no significant differences between the groups in any cohort. *PAC* Pulmonary artery catheter

Table 3 In-hospital mortality across three subgroups after propensity score matching

	PAC	Control	Risk difference (95% CI)	p value
Cardiovascular surgery				
Overall cohort	4 / 144 (2.8%)	5 / 144 (3.5%)	0.7% (−4.7–3.3)	0.73
Severe cohort	4 / 84 (4.8%)	2 / 84 (2.4%)	2.4% (−3.2–8.0)	0.41
Critically severe cohort	3 / 44 (6.8%)	3 / 44 (6.8%)	0.0% (−10.5–10.5)	> 0.99
Emergency ICU admission				
Overall cohort	16 / 95 (16.8%)	18 / 95 (19.0%)	−2.1% (−13.0–8.8)	0.71
Severe cohort	13 / 56 (23.2%)	18 / 56 (32.1%)	−8.9% (−25.4–7.6)	0.29
Critically severe cohort	7 / 18 (38.9%)	7 / 18 (38.9%)	0.0% (−31.8–31.8)	> 0.99
Mechanical ventilation				
Overall cohort	18 / 170 (10.6%)	19 / 170 (11.2%)	−0.6% (−7.2–6.0)	0.86
Severe cohort	17 / 88 (19.3%)	16 / 88 (18.2%)	1.1% (−10.4–12.7)	0.84
Critically severe cohort	14 / 38 (36.8%)	15 / 38 (39.5%)	−2.6% (−24.5–19.2)	0.81

PAC Pulmonary artery catheter, *CI* Confidence interval, *ICU* Intensive care unit

The severe cohort consists of patients with an APACHEIII score above the median, while the critically severe cohort includes patients with an APACHEIII score in the highest quartile

Conclusions

The propensity score analysis showed no association between PAC use and improvements in clinical outcomes, such as mortality, MCS, RRT, and length of stay, even when the patients were stratified based on severity. To justify PAC use, further studies are required to effectively identify critically ill patients who would benefit from PAC and determine the appropriate extent of its application.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00540-025-03486-x.

Author contributions TN and YA contributed substantially to the study design. KK, KS, and TK contributed substantially to data acquisition. All statistical analyses were performed by YA. TN and YA contributed to manuscript writing, and KK, KS, TK, SM, and YN contributed to manuscript revision. All the authors have read and approved the final version of this manuscript.

Data Availability The datasets generated and/or analyzed during the present study are available from the corresponding author upon reasonable request and with approval from the Institutional Review Board of Hamamatsu University School of Medicine, in accordance with institutional policies.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

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