Heliyon 10 (2024) e38643

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Efficacy and safety of pulmonary artery catheterization with combined transesophageal echocardiography and pressure waveform: A prospective observational study

Shosaburo Jotaki [a,*], Kenta Murotani [b], Kensuke Oshita [a], Teruyuki Hiraki [a]

[a] Department of Anesthesiology, Kurume University School of Medicine, 67 Asahi-machi, Kurume, Fukuoka, 830-0011, Japan
[b] Biostatistics Center, Kurume University, 67 Asahi-machi, Kurume, Fukuoka, 830-0011, Japan

ARTICLE INFO

Keywords:
Pulmonary artery catheter
Placement
Transesophageal echography

ABSTRACT

Objective: This study investigated whether pulmonary artery catheter placement method with combined transesophageal echocardiography and pressure waveform measurement improve the placement success rate within 5 min and reduce the incidence of arrhythmia during pulmonary artery catheter placement compared to conventional pulmonary artery catheter placement with pressure waveform measurement only.
Methods: This single center prospective observational study included 129 patients scheduled for cardiac surgery. Patients were divided into two groups. In the conventional group, the pulmonary artery catheter was placed by monitoring the pressure waveform and the length of placement; in the combination group, not only were the pressure waveform and the length monitored but also the following transesophageal echocardiography images: “mid esophageal bicaval view,” " mid esophageal modified bicaval view,” a mirror image of “mid esophageal 4 chamber view,” “mid esophageal right ventricular inflow-outflow view,” and “mid esophageal ascending aortic short axis view."
Results: A 1:1 propensity score matching was used to adjust for confounding factors. The success rates of pulmonary artery catheter placement within 5 min in the conventional and combination groups were 85.5 % vs. 97.8 % ($p = 0.032$) before matching, and 73.7 % vs. 100 % ($p = 0.001$) after matching. The incidences of arrhythmias in the conventional and combination groups were 28.9 % vs. 17.4 % ($p = 0.20$) before matching, and 28.9 % vs. 18.4 % ($p = 0.42$) after matching.
Conclusion: Pulmonary artery catheter placement with transesophageal echocardiography had a significantly higher rate of successful placement within 5 min, but no significant differences were observed in the incidences of arrhythmias.

1. Introduction

A pulmonary artery catheter (PAC) can automatically and continuously measure important circulatory parameters such as cardiac

Abbreviations: PAC, pulmonary artery catheter; TEE, transesophageal echocardiography; ME, mid esophageal; RV, right ventricular; BMI, body mass index; ASA-PS, American Society of Anesthesiologists physical status; LVEF, left ventricular ejection fraction; VT, ventricular tachycardia; VF, ventricular fibrillation; SMD, standardized mean difference.

* Corresponding author.
E-mail address: joutaki_shouzaburou@kurume-u.ac.jp (S. Jotaki).

https://doi.org/10.1016/j.heliyon.2024.e38643
Received 25 March 2024; Received in revised form 24 September 2024; Accepted 26 September 2024
Available online 27 September 2024

output, mixed venous blood oxygen saturation, and pulmonary artery pressure [1–3]. Therefore, PAC has been used for the perioperative management of critically ill patients, including those undergoing cardiac surgery [4–7]. It is particularly useful for monitoring hemodynamics in cardiac surgical patients postoperatively, as it is difficult to perform transoesophageal echocardiography (TEE) and transthoracic echocardiography. PAC is a type of monitoring equipment, so it must be placed smoothly and without complication.

PAC traditionally have been placed using pressure waveform tracing. However, conventional waveform-based PAC placement can be challenging in patients with low cardiac output, right-sided chamber dilation, ventricular dysfunction, tricuspid regurgitation, tricuspid annuloplasty, aortic root dilatation, and pulmonary hypertension, which are common findings in cardiac surgery patients [8–11]. Additionally, ventricular arrhythmias are common during PAC placement and are mostly transient, but require caution, especially in patients with heart disease [12–15].

While previous case reports have described the use of TEE for PAC repositioning in challenging cases, a formal technique or TEE views for PAC placement have not been established [16–18]. Cronin et al. recently presented a formal technique and three valid TEE views [8,9], which have received attention [19]. Theoretically, the visibility of the catheter tip allows for smoother placement and may reduce complications [8,9,19]. However, it is not known whether PAC placement using a combination method leads to smoother and safer placement than the conventional method. In this study, we investigated whether PAC placement using both TEE and pressure waveform increases the success rate of placement within 5 min and reduces the incidence of arrhythmias in patients undergoing scheduled heart surgery.

2. Materials and methods

2.1. Patients and study design

This study included patients who underwent scheduled cardiac surgery between September 7, 2022, and July 18, 2023. In our hospital, patients undergoing cardiac surgery had a pulmonary artery catheter routinely placed for perioperative management. This was a prospective, observational study. This study was approved by the Ethics Committee of our hospital, registered in the Japan Registry of Clinical Trials, and conducted in compliance with the Declaration of Helsinki. All patients signed a consent form for the PAC procedure and use of their data in this study. The exclusion criteria were: age <18 and puncture from a site other than the right internal jugular vein. Patients were divided into two groups: one receiving the conventional method and one receiving a combination method. Patients were grouped into two groups: if no TEE operator was available, PAC placement was performed using the conventional method, and if a TEE operator was available, PAC placement was performed using the combination method. The PAC operators were cardiac anesthesia fellows or attendants. The TEE operator was an anesthesiologist certified by the Japanese Board of Perioperative Transesophageal Echocardiography and the National Board of Echocardiography (Advanced PTEeXAM). The PAC used in this study was a 7.5Fr continuous cardiac output/mixed venous oxygen saturation/end-diastolic volume-pulmonary artery catheter (model 774F75; Edwards Lifesciences, Irvine, CA, USA).

2.2. PAC placement methods

In all patients, general anesthesia was administered according to the American Society of Anesthesiologists standard monitoring. After induction of general anesthesia, tracheal intubation was performed, and TEE was placed in the combination group. All patients were then placed in a head-down position at approximately 10–15°, and a central venous catheter and 8.5-Fr sheath were inserted. After the patient was returned to the flat position, heparinized saline was passed through the PAC, and the PAC was zero-calibrated. The balloon was inflated after the catheter was advanced by approximately 20 cm beyond the sheath. In the conventional group, the placement into the pulmonary artery was performed by observing the tip pressure waveform and insertion length. In the combination

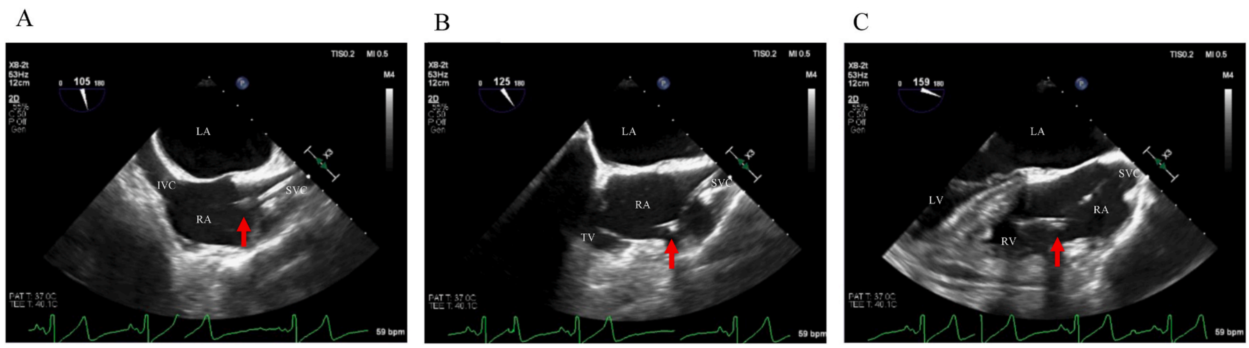

Fig. 1. TEE image used for PAC placement from the SVC to the RV. (**A**) Mid-esophageal bicaval view. A PAC with the balloon inflated (red arrow) is present in the right atrium. (**B**) Mid-esophageal modified bicaval view. A PAC with the balloon inflated (red arrow) is present in the right atrium. (**C**) The mirror image of the mid-esophageal four-chamber view. A PAC with the balloon inflated (red arrow) is present in the tricuspid valve.
TEE, transesophageal echocardiography; PAC, pulmonary artery catheter; SVC, superior vena cava; RA, right atrium; IVC, inferior vena cava; LA, left atrium; TV, tricuspid valve; RV, right ventricle; LV, left ventricle.

group, PAC placement was performed by monitoring the tip pressure, insertion length, TEE images, and the advice of the TEE operator. The TEE images were as follows: First, a bicaval view with a scanning angle of approximately 90–100° was used to confirm that the PAC was moving from the superior vena cava (SVC) toward the right atrium. Subsequently, the scanning angle was increased to approximately 120° to obtain a modified bicaval view and confirm that the PAC passed through the tricuspid valve. The scanning angle was then increased to approximately 160° while slightly advancing the probe, and a mirror image of the mid-esophageal (ME) 4-chamber view was obtained, confirming that the PAC did not get stuck in the right ventricular inflow (Fig. 1, Video 1). Subsequently, the scanning angle was returned to approximately 50–80°, and the ME right ventricular (RV) inflow-outflow view was obtained (Fig. 2, Video 1). A floating motion of the PAC tip toward the RV outflow tract was observed, and the PAC was advanced into the pulmonary artery. Finally, the ME ascending aortic short-axis view was obtained, and the PAC tip was placed at the proximal right pulmonary artery in the ascending aortic short axis (Fig. 2, Video 1).

If PAC stray was observed on TEE images, the following manipulations were made, referring to the previous article by Cronin et al. [8,9]: In the ME bicaval and the ME modified bicaval views, when the PAC was stuck in the right atrial appendage, it was rotated counterclockwise. When the PAC was directed towards the inferior vena cava or coronary sinus, it was rotated clockwise to correct the trajectory. When no floating motion toward the desired direction was observed in a mirror image of the ME 4-chamber view and the RV inflow-outflow view, or when the PAC was stuck in the RV, the PAC was rotated counterclockwise and adjusted to move toward the RV outflow tract. When it was difficult to correct the trajectory of the PAC using the above procedures, the balloon was deflated, and the PAC was temporarily withdrawn and reinserted. All patients underwent portable chest radiography immediately after PAC placement to confirm the placement position.

As normally performed, the II- and V-guided ECGs, arterial pressure waveforms, and PAC tip pressure waveforms were automatically stored in the anesthesia information managing system (ORSYS; Philips Japan, Tokyo, Japan). The panoramic view of the operating room was also recorded automatically using the operating room surveillance camera (XProtect® Smart Client 2017 R3; Milestone Systems, Brøndby, Denmark).

2.3. Measurements and data collection

The placement procedure time was defined as the time from after the balloon was inflated and started to advance until the PAC tip pressure waveform became the pulmonary artery pressure waveform. The procedure time and arrhythmias were measured using monitor waveforms that were perfectly timed to the motion of the operator as captured on video in the operating room by two anesthesiologists. The procedure time was measured up to 20 min. Additionally, data on the following were obtained from electronic anesthesia records: age, sex, height, weight, body mass index (BMI), the American Society of Anesthesiologists physical status (ASA-PS), name of the disease, medical history, planned surgical procedures, and anesthesiologist who performed the PAC procedure. Further, data on left ventricular ejection fraction (LVEF), pulmonary hypertension, right-sited chamber dilation, RV dysfunction, left ventricular dysfunction, degree of tricuspid and pulmonary regurgitation, and aortic root dilation were obtained using preoperative transthoracic echocardiography performed by cardiologists, who were blinded to this study. Additionally, the mean pulmonary artery pressure immediately after PAC placement was obtained from anesthesia records.

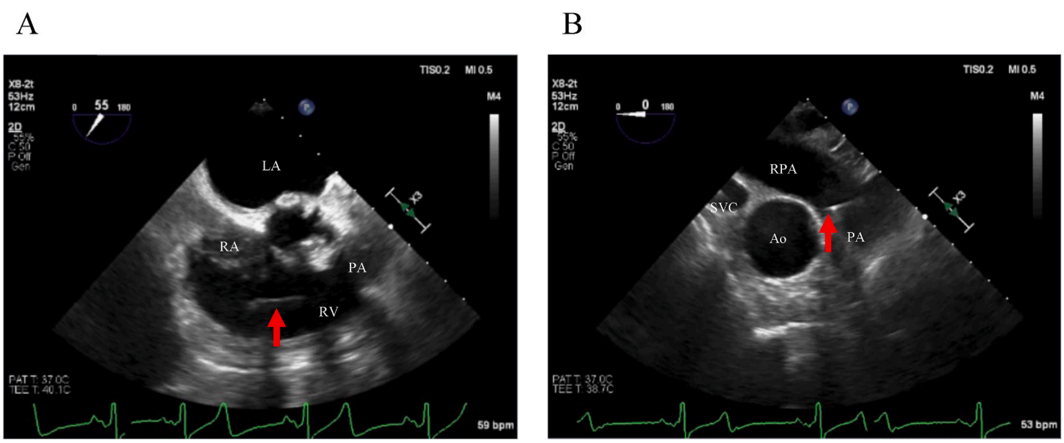

Fig. 2. TEE image used for PAC placement from the RV to the PA. (**A**) Mid-esophageal right ventricular inflow-outflow view. A PAC with the balloon inflated (red arrow) is present in the right ventricle. (**B**) Ascending aortic short-axis view. A PAC balloon (red arrow) is visualized in the proximal right pulmonary artery.
TEE, transesophageal echocardiography; PAC, pulmonary artery catheter; RV, right ventricle; PA, pulmonary artery; LA, left atrium; RA, right atrium; RPA, right pulmonary artery; SVC, superior vena cava; Ao, aorta.

2.4. Outcomes

Smooth PAC placement was defined as successful PAC placement within a 5 min threshold, which was determined based on previous articles [10,11]. The primary outcome was defined as the success rate of PAC placement within 5 min. Conversely, PAC placement was considered unsuccessful if it took longer than 5 min or if it was reinserted due to loop formation on the radiograph immediately after PAC placement. In addition, PAC failure was defined as change in the PAC operator during the procedure, use of fluoroscopy or TEE during the procedure in the conventional group, or use of fluoroscopy during the procedure in the combination group, due to difficult placement or frequent arrhythmic complications. Arrhythmia was defined as the presence of any one of non-sustained ventricular tachycardia (VT) (three or more consecutive premature ventricular contractions with a rhythm of >100 bpm and duration of <30 s), VT, ventricular fibrillation (VF), and severe atrioventricular block based on previous articles [4,12,13].

2.5. Statistical analysis

Categorical variables are expressed as number of patients (%), and continuous variables as medians (interquartile range). Fisher's

Table 1
Patient characteristics before and after propensity score matching.

	Original cohort		p value	SMD	Matched cohort		p value	SMD
	Conventional group (n = 83)	Combination group (n = 46)			Conventional group (n = 38)	Combination group (n = 38)		
Age (years)	73 [65, 78]	71 [64, 75]	0.11	0.246	73 [63, 77]	71 [64, 74]	0.31	0.186
Male	55 (66.3)	30 (65.2)	1.00	0.022	26 (68.4)	27 (71.1)	1.00	0.057
Height (cm)	163 [155, 166]	161 [153, 167]	0.89	0.024	163 [155, 167]	163 [153, 170]	0.93	0.082
Weight (kg)	60 [50.4, 67.1]	59 [50.2, 70.3]	0.72	0.055	62 [50.2, 67.3]	61 [55.7, 72.3]	0.56	0.128
BMI (kg/m^2)	23 [20.8, 25.2]	23 [20.3, 25.5]	0.70	0.051	23 [21.0, 25.4]	24 [21.4, 26.0]	0.53	0.119
ASA-PS								
2	15 (18.1)	13 (28.3)	0.26	0.243	10 (26.3)	11 (28.9)	1.00	0.059
3	61 (73.5)	28 (67.4)	0.60	0.134	26 (68.4)	26 (68.4)	100	<0.001
4	7 (8.4)	2 (4.3)	0.61	0.168	2 (5.3)	1 (2.6)	1.00	0.135
LVEF (%)	64 [52, 69]	65 [55, 69]	0.74	0.128	64 [53, 70]	63 [54, 68]	0.78	0.008
PH	8 (9.6)	9 (19.6)	0.19	0.284	7 (18.4)	6 (15.8)	1.00	0.070
Right-sided chamber dilation	15 (18.1)	10 (21.7)	0.79	0.092	9 (23.7)	6 (15.8)	0.56	0.199
Post tricuspid annuloplasty	0 (0.0)	1 (2.2)	0.76	0.211	0 (0.0)	0 (0.0)	NA	<0.001
Right ventricular dysfunction	9 (10.8)	6 (13.0)	0.93	0.068	5 (13.2)	5 (13.2)	1.00	<0.001
Left ventricular dysfunction	22 (26.5)	11 (23.9)	0.91	0.060	11 (28.9)	10 (26.3)	1.00	0.059
Mean PAP (mmHg)	18 [15,21]	17 [14, 20]	0.25	0.246	16 [14, 18]	17 [14, 19]	0.59	0.056
Tricuspid regurgitation								
mild	24 (28.9)	15 (32.6)	0.81	0.080	12 (31.6)	10 (26.3)	0.80	0.116
moderate	7 (8.3)	4 (8.7)	1.00	0.009	3 (7.9)	3 (7.9)	1.00	<0.001
severe	1 (1.2)	1 (2.2)	1.00	0.075	1 (2.6)	1 (2.6)	1.00	<0.001
Pulmonary regurgitation								
mild	8 (9.6)	9 (19.6)	0.19	0.284	4 (10.5)	5 (13.2)	1.00	0.082
moderate	1 (1.2)	0 (0.0)	1.00	0.156	0 (0.0)	0 (0.0)	NA	<0.001
severe	0 (0.0)	0 (0.0)	NA	<0.001	0 (0.0)	0 (0.0)	1.00	<0.001
Aortic root dilatation	8 (9.6)	3 (6.5)	0.78	0.115	2 (5.3)	3 (7.9)	0.81	0.106
PAC operator								
fellow with <20 procedures	24 (28.9)	18 (39.1)	0.32	0.217	15 (39.5)	13 (34.2)	0.81	0.109
fellow with >20 procedures	10 (12.0)	9 (19.6)	0.37	0.207	6 (15.8)	7 (18.4)	1.00	0.070
Attendants	49 (59.0)	19 (41.3)	0.080	0.360	17 (44.7)	18 (47.4)	1.00	0.053
Surgical site								
Coronary artery	30 (36.1)	13 (28.3)	0.48	0.169	12 (31.6)	13 (34.2)	1.00	0.056
Aorta	18 (21.7)	11 (23.9)	0.94	0.053	7 (18.4)	9 (23.7)	0.78	0.129
Aortic valve	32 (38.6)	16 (34.8)	0.82	0.078	11 (28.9)	13 (34.2)	0.81	0.113
Mitral valve	29 (33.7)	17 (37.0)	0.86	0.067	15 (39.5)	12 (31.6)	0.63	0.166
Tricuspid valve	9 (10.8)	11 (23.9)	0.087	0.350	7 (18.4)	6 (15.8)	1.00	0.070
Others	3 (3.6)	0 (0.0)	0.49	0.274	0 (0.0)	0 (0.0)	NA	<0.001

Data are presented as number (%) or median [interquartile range]. Abbreviations: ASA-PS, American Society of Anesthesiologists physical status. BMI, body mass index. LVEF, left ventricular ejection fraction. PH, pulmonary hypertension. PAP, pulmonary artery pressure. PAC, pulmonary artery catheter. SMD, standardized mean difference.

exact test and the Mann–Whitney *U* test were used to test categorical and continuous variables, respectively, between the two groups. The sample size was calculated as follows: Because the success rates of placement within 5 min using the conventional method (n = 26) and the combination method (n = 6) were 69.2 % and 100 % in our hospital during the 3 months before the submission of the research protocol to the Ethics Committee, we assumed that the success rate was 70 % in the conventional group and 95 % in the combination group. The sample size needed to achieve a significant result was calculated to be 35 patients per group with an α error of 5 % and a power of 80 %; however, we set a target of at least 43–46 patients per group, assuming that the sample size may decrease by 25–30 % due to matching. We performed 1:1 propensity score matching using the nearest neighbor method, with a caliper of 0.2, without replacement. The adjustment factors by matching were the grade of tricuspid and pulmonary regurgitation, post-tricuspid valve repair, right-sided chamber dilation, pulmonary hypertension, aortic root dilation, RV dysfunction, left ventricular dysfunction, which are considered risk factors [8–11]. Additionally, LVEF, classification of PAC operator (fellows with <20 PAC procedures, fellows with >20 procedures, attendants), age, sex, height, weight, BMI, ASA-PS, planned surgery, and mean pulmonary artery pressure immediately after insertion were also adjusted. The standardized mean difference (SMD) used in propensity score matching was <0.1, indicating no difference between the groups. All statistical analyses were performed using R statistical software version 4.2.2 (The R Foundation for Statistical Computing, Vienna, Austria; www.r-project.org). Regarding the relationship between the PAC operator and PAC placement skill, it has been reported that the skill of fellows with no PAC placement experience becomes equivalent to that of experienced cardiac surgical anesthesiologists after performing more than 20 procedures [20]. Based on this report, we divided the participants into three categories: fellows with <20 cases of PAC insertion, fellows with >20 cases, and attendants. Seven fellows who performed the PAC procedures had 0–5 years of experience with cardiac surgical anesthesia. Nine attendants had 6–14 years of experience in cardiac surgical anesthesia.

3. Results

A total of 131 patients were eligible for the study, but one patient did not provide consent. Of the remaining 130 patients, 84 were classified in the conventional group and 46 in the combination group. Data for one patient in the conventional group were not stored; therefore, 83 patients in the conventional group and 46 patients in the combination group were included in the analysis. For PAC operators in the original cohort, more than half of the conventional group comprised attendants. Conversely, more than half of the combination group comprised fellows. However, no significant differences were observed in the patient characteristics before and after matching (Table 1). The success rate of placement within 5 min before matching was significantly higher in the combination group than in the conventional group (85.5 % vs. 97.8 %, p = 0.032). The reasons for failure of placement in the conventional group included placement time >5 min (n = 10), using TEE during the procedure due to placement difficulties (n = 1), and reinsertion due to loop formation on the radiograph immediately after placement (n = 1). The reason for failure of placement in the combination group was placement time >5 min (n = 1) in a patient with post-tricuspid annuloplasty. The success rate of placement within 5 min after matching was significantly higher in the combination group than in the conventional group (73.7 % vs. 100 %, p = 0.001) (Table 2). The incidence of arrhythmias in the conventional and combination groups before and after matching was not significantly different (before matching; 28.9 % vs. 17.4 %, after matching; 28.9 % vs. 18.4 %, p = 0.20, p = 0.42). The types of arrhythmia in the conventional group were non-sustained VT (n = 24) and severe atrioventricular block (n = 1). The type of arrhythmia in the combination group was non-sustained VT (n = 8). No incidences of two or more arrhythmias were reported in the combination group (Table 2). The placement times in the conventional and combination groups before and after matching were similar (Table 2, Fig. 3). However, in the conventional group, three patients required more than 20 min for PAC placement: two underwent PAC placement under fluoroscopy, and one had surgery started without PAC placement to prioritize surgery. The distribution of PAC placement times before and after matching showed that the cumulative success rate within 60 s tended to be higher in the conventional group; however, the cumulative success rate within 90 s or more tended to be higher in the combination group (Fig. 4). The success rate of placement within 1 min in the conventional and combination groups before and after matching was not significantly different (before matching; 54.2 % vs. 41.3 %, after matching; 47.4 % vs. 42.1 %, p = 0.20, p = 0.82). The success rate of placement within 3 min in the conventional and combination groups before matching was not significantly different (80.7 % vs. 91.3 %, p = 0.13). However, the success rate of placement within 3 min after matching was significantly higher in the combination group than in the conventional group (71.1 % vs. 92.1 %, p = 0.038).

Table 2
Outcomes before and after propensity score matching.

	Original cohort			Matched cohort		
	Conventional group (n = 83)	Combination group (n = 46)	p value	Conventional group (n = 38)	Combination group (n = 38)	p value
PAC placement within 5 min	71 (85.5)	45 (97.8)	0.032	28 (73.7)	38 (100.0)	0.001
Arrhythmia	24 (28.9)	8 (17.4)	0.20	11 (28.9)	7 (18.4)	0.42
Two or more arrhythmias	8 (9.6)	0 (0.0)	0.050	2 (5.3)	0 (0.0)	0.49
Placement time (s)	59 [33, 121]	70 [54, 119]	0.22	73 [43, 238]	66 [56, 115]	0.65

Data are presented as number (%) or median [interquartile range]. Abbreviations: PAC, pulmonary artery catheter.

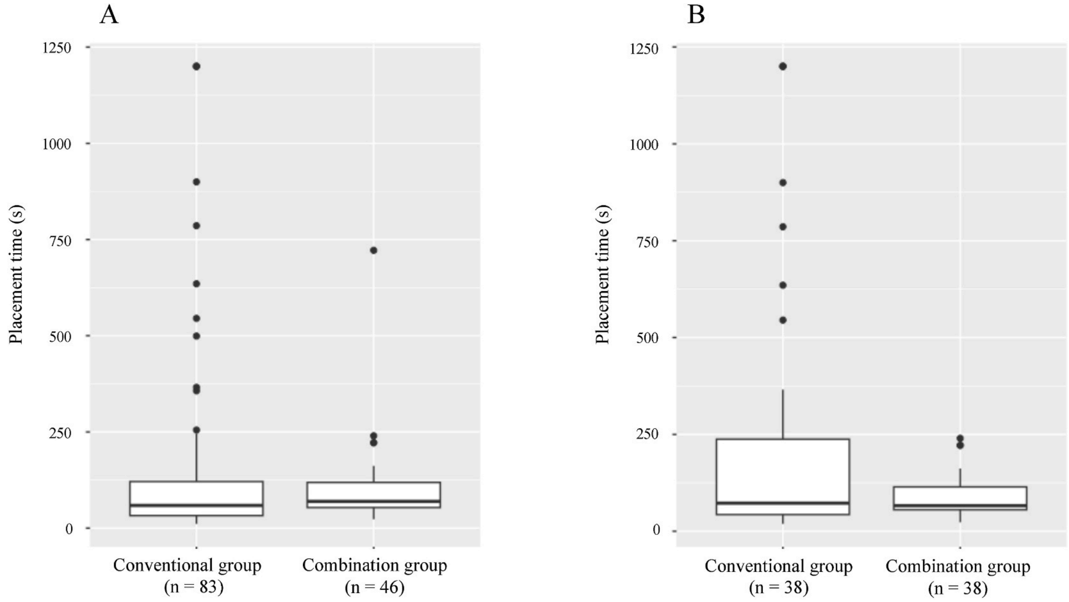

Fig. 3. Boxplots of PAC placement time for the conventional and combination groups. (**A**) Before propensity score matching. (**B**) After propensity score matching.
PAC, pulmonary artery catheter.

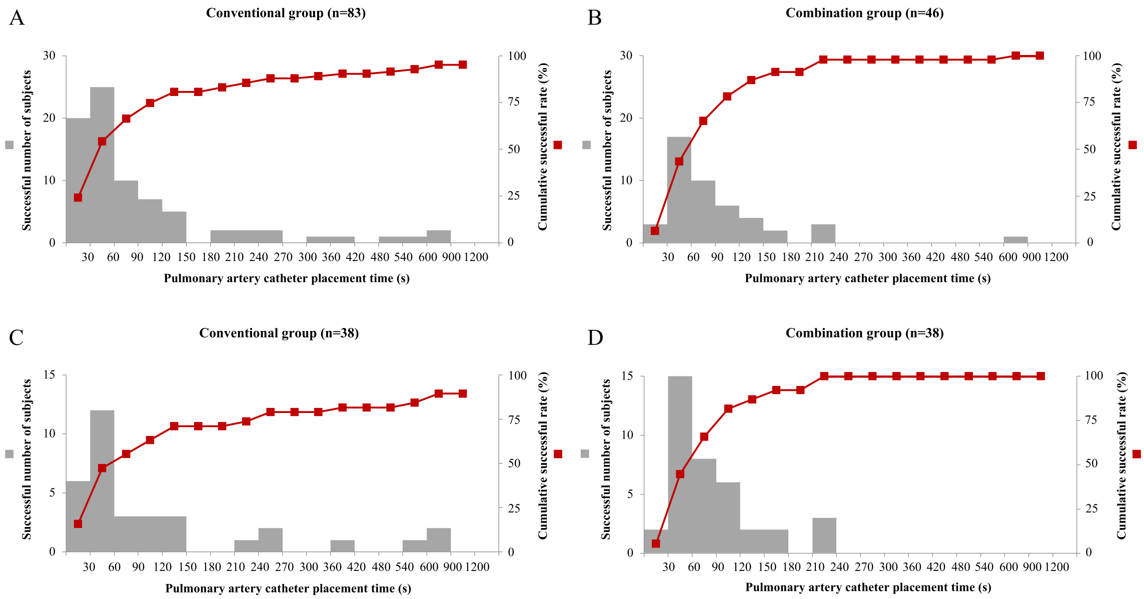

Fig. 4. Distribution of PAC placement times. (**A**) Conventional group before propensity score matching. (**B**) Combination group before propensity score matching. **(C)** Conventional group after propensity score matching. (**D**) Combination group after propensity score matching.
PAC, pulmonary artery catheter.

4. Discussion

In this study, we investigated whether PAC placement using both TEE and pressure waveform increases the success rate of placement within 5 min and reduces the incidence of arrhythmias in patients undergoing scheduled heart surgery. We found that the TEE-combination placement technique increased the success rate of PAC placement within 5 min, but there was no significant difference in the incidence of arrhythmias.

This study is significant because it was previously unknown whether smooth and safe placement of PAC can be achieved using the combination placement method in patients undergoing cardiac surgery. Previous prospective studies only included patients with chronic thromboembolic pulmonary hypertension, which is a very rare disease, and the primary endpoint was the correct location of the PAC placement in the pulmonary artery [8,9]. Although some previous case reports have shown the usefulness of PAC placement with TEE, but not with a consistent TEE view or technique [16–18]. In this study we defined smooth PAC placement as placement within 5 min based on previous studies [10,11]. From a clinician's point of view, if there are no problems, placement usually takes approximately 1 min. Therefore, it was reasonable to assume, as in previous articles, that PAC placement that takes more than 5 min would not be considered smooth.

One of the reasons for the higher success rates of placement within 5 min in this study was that we always tried to visualize the catheter tip using five TEE views. Cronin et al. presented the following three valid views: an ME modified bicaval view, ME RV inflow-outflow view, and ME ascending aortic short-axis view [8,9]. However, full observation of the migration into the inferior vena cava and RV inflow is difficult. Therefore, we added the "ME bicaval view" and a mirror image of the "ME 4 chamber view" in this study. Notably, these additional images are very easy to obtain, requiring only a change in the scanning angle, or a slight advancement of the probe from the three previously proposed views and very little additional time. The mirror image of the "ME 4 chamber view" is unique and is not included in the 28 basic TEE images [21]. However, adding this image is believed to increase the possibility of continuously visualizing the tip of the PAC and reducing straying in the RV. Another reason for the higher success rates, which has been suggested in a previous article, is that the floating motion of the PAC in the right ventricle in the direction of the RV outflow tract may have reduced the stuck to the RV and facilitated placement in the pulmonary artery [22].

No significant differences were noted in the incidence of arrhythmias between the two groups. One reason for this may be that the sample size was too small for this effect and another reason may be that even with TEE imaging, it was inevitable that the tip of the PAC would come into contact with the RV outflow tract and pulmonary valve as it passed through the pulmonary valve, causing an arrhythmia. However, the incidence of non-sustained VT tended to be lower in the combination group, with no multiple cases reported. This may be because we did not advance the PAC with the catheter tip stuck in the right ventricle in the combination group.

No significant differences were noted in the time required for placement between the two groups. The time required for placement in the conventional group was short when placement was achieved on the first attempt because TEE visualization was not required. However, difficulty in placement was noted in some patients; therefore, the time required for placement varied widely, and the final median time required for placement was not significantly different from that in the combination group.

Several previous case reports have suggested the usefulness of TEE in challenging cases. However, prediction of the difficulty in PAC placement is not always easy. Moreover, in difficult cases, the blood may warm and soften the catheter over time, making it difficult to place even with the use of TEE. TEE is now a valuable monitor in the anesthesia field, and its use is increasingly recommended for monitoring non-cardiac organs and catheter placement [23,24]. Given that the use of TEE in cardiac surgery patients is mandatory, and complications from TEE manipulation are rare, this combination method may be considered from the first attempt if a TEE operator is present.

Recently, PAC placement using the combined fluoroscopic technique was reported to be faster and safer than that using conventional methods for patients expected to have difficulty with PAC placement [25,26]. A radiological technician easily manages fluoroscopic guidance, and this visual placement is available in the presence of one anesthesiologist. Additionally, the entire length of the inserted catheter is visible during the procedure, enabling prompt recognition of complications, such as loop formation and stray catheterization. However, fluoroscopic equipment is not always available in operating rooms, and its use for all patients is impractical because of the time required for preparation, the large size and heavy weight of the equipment, and the problem of radiation exposure. TEE does not involve radiation exposure and has been always used in cardiac surgery patients except when contraindicated. Therefore, the results of this study may contribute to the patients scheduled for cardiac surgery undergoing PAC placement. However, if the PAC coils up in the SVC, as has been reported in a previous report, it is difficult to correct with TEE. In such cases, fluoroscopy use should be considered [27].

This study has some limitations. First, the rules that determined assignment to either the conventional or combination group was based on the availability of a TEE operator. We have tried to correct this by performing propensity score matching; however, there may be implicit bias. Second, the PAC operators were adjusted by dividing them into three groups according to procedure experiences, but not by individual experiences. However, placement skills have been reported to be equivalent among operators with experience in >20 cases of PAC insertion, and the adjustment by operator category in this study might be considered acceptable [20]. Third, this study was a single-center prospective observational study. Therefore, a large prospective randomized controlled trial is required to verify the validity of these results.

5. Conclusions

This study showed that PAC placement with a combination of TEE and pressure waveform measurement had a significantly higher rate of successful placement within 5 min. No significant differences were observed in the incidence of arrhythmias or the time required for PAC placement between the two groups; however, a trend towards a lower incidence of arrhythmias and a narrower variation in the time required was observed in the combined group. Therefore, this combination technique may be ideal for PAC placement in patients undergoing cardiac surgery, especially for those in whom placement is difficult.

Ethical statement

The study was approved by the Ethics Committee of Kurume University Hospital (approval number 22103), registered in the Japan Registry of Clinical Trials (registration number: jRCT1070220099) and conducted in compliance with the Declaration of Helsinki. All the enrolled patients signed an informed consent form.

Funding

This research did not receive any specific funding.

Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

CRediT authorship contribution statement

Shosaburo Jotaki: Writing – original draft, Project administration, Investigation, Formal analysis, Data curation. **Kenta Murotani:** Project administration, Formal analysis, Conceptualization. **Kensuke Oshita:** Investigation, Conceptualization. **Teruyuki Hiraki:** Writing – review & editing, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors thank Editage (www.editage.jp) for their English language editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e38643.

References

[1] L.Q. Rong, et al., Two- or 3-dimensional echocardiography–derived cardiac output cannot replace the pulmonary artery catheter in cardiac surgery, J. Cardiothorac. Vasc. Anesth. 34 (2020) 2691–2697, https://doi.org/10.1053/j.jvca.2020.06.068.
[2] I.T. Bootsma, et al., The contemporary pulmonary artery catheter. Part 2: measurements, limitations, and clinical applications, J. Clin. Monit. Comput. 36 (2022) 17–31, https://doi.org/10.1007/s10877-021-00673-5.
[3] C.R. Kelly, L.E. Rabbani, Videos in clinical medicine. Pulmonary-artery catheterization, N. Engl. J. Med. 369 (2013) e35, https://doi.org/10.1056/NEJMvcm1212416.
[4] M.F. Roizen, D.L. Berger, R.A. Gabel, Practice guidelines for pulmonary artery catheterization: an updated report by the American Society of Anesthesiologists task force on pulmonary artery catheterization, Anesthesiology 99 (2003) 988–1014, https://doi.org/10.1097/00000542-200310000-00036.
[5] O. Judge, et al., Current use of the pulmonary artery catheter in cardiac surgery: a survey study, J. Cardiothorac. Vasc. Anesth. 29 (2015) 69–75, https://doi.org/10.1053/j.jvca.2014.07.016.
[6] M.I. Akhtar, et al., Multicenter international survey on cardiopulmonary bypass perfusion practices in adult cardiac surgery, J. Cardiothorac. Vasc. Anesth. 35 (2021) 1115–1124, https://doi.org/10.1053/j.jvca.2020.08.043.
[7] J. Arias-Ortiz, J.L. Vincent, The pulmonary artery catheter, Curr. Opin. Crit. Care 29 (2023) 231–235, https://doi.org/10.1097/MCC.0000000000001040.
[8] B. Cronin, R. Robbins, T. Maus, Pulmonary artery catheter placement using transesophageal echocardiography, J. Cardiothorac. Vasc. Anesth. 31 (2017) 178–183, https://doi.org/10.1053/j.jvca.2016.07.012.
[9] B. Cronin, et al., Pulmonary artery catheter placement aided by transesophageal echocardiography versus pressure waveform transduction, J. Cardiothorac. Vasc. Anesth. 32 (2018) 2578–2582, https://doi.org/10.1053/j.jvca.2018.05.018.
[10] S. Hakata, et al., An analysis of the factors influencing pulmonary artery catheter placement in anesthetized patients, Ann. Card Anaesth. 18 (2015) 474–478, https://doi.org/10.4103/0971-9784.166442.
[11] Y. Miyata, et al., An analysis of factors influencing pulmonary artery catheter passage through the tricuspid and pulmonary valves, J.A. Clin. Rep 6 (2020) 38, https://doi.org/10.1186/s40981-020-00344-5.
[12] M.S. Gwak, et al., Incidence of severe ventricular arrhythmias during pulmonary artery catheterization in liver allograft recipients, Liver Transplant. 13 (2007) 1451–1454, https://doi.org/10.1002/lt.21300.
[13] T. Pipanmekaporn, N. Bunchungmongkol, Y. Punjasawadwong, Impact of patients' positions on the incidence of arrhythmias during pulmonary artery catheterization, J. Cardiothorac. Vasc. Anesth. 26 (2012) 391–394, https://doi.org/10.1053/j.jvca.2011.10.013.
[14] H. Satoh, et al., An analysis of the factors producing multiple ventricular arrhythmias during pulmonary artery catheterization, Ann. Card Anaesth. 20 (2017) 141–144, https://doi.org/10.4103/aca.ACA_18_17.
[15] C.L. Sprung, et al., Prophylactic use of lidocaine to prevent advanced ventricular arrhythmias during pulmonary artery catheterization. Prospective double-blind study, Am. J. Med. 75 (1983) 906–910, https://doi.org/10.1016/0002-9343(83)90862-8.
[16] W.S. Turnage, H. Fontanet, Transesophageal echocardiography-guided pulmonary artery catheter placement, Anesth. Analg. 77 (1993) 858–859, https://doi.org/10.1213/00000539-199310000-00036.
[17] D.K. Tempe, et al., Case 5–2004: transesophageal echocardiography-guided insertion of a pulmonary artery catheter, J. Cardiothorac. Vasc. Anesth. 18 (2004) 657–662.
[18] R. Matyal, et al., Inadvertent placement of a flow-directed pulmonary artery catheter in the coronary sinus, detected by transesophageal echocardiography, Anesth. Analg. 102 (2006) 363–365, https://doi.org/10.1213/01.ane.0000195340.65783.81.

[19] J. Baer, M.M. Wyatt, K.R. Kreisler, Utilizing transesophageal echocardiography for placement of pulmonary artery catheters, Echocardiography 35 (2018) 467–473, https://doi.org/10.1111/echo.13812.

[20] H. Hamaba, et al., An analysis of prior experience influencing quality of pulmonary artery catheter placement in residents, Ann. Card Anaesth. 23 (2020) 161–164, https://doi.org/10.4103/aca.ACA_220_18.

[21] R.T. Hahn, et al., Guidelines for performing a comprehensive transesophageal echocardiographic examination: recommendations from the American Society of Echocardiography and the society of cardiovascular anesthesiologists, J. Am. Soc. Echocardiogr. 26 (2013) 921–964, https://doi.org/10.1016/j.echo.2013.07.009.

[22] K. Orihashi, et al., Usefulness of transesophageal echocardiography for guiding pulmonary artery catheter placement in the operating room, Heart Ves. 9 (1994) 315–321, https://doi.org/10.1007/BF01745097.

[23] L. Vetrugno, F. Barnariol, E. Bignami, G.D. Centonze, A. De Flaviis, F. Piccioni, E. Auci, T. Bove, Transesophageal ultrasonography during orthotopic liver transplantation: show me more, Echocardiography 35 (2018) 1204–1215, https://doi.org/10.1111/echo.14037.

[24] L. Vetrugno, F. Barbariol, U. Baccarani, F. Forfori, G. Volpicelli, G. Della Rocca, Transesophageal echocardiography in orthotopic liver transplantation: a comprehensive intraoperative monitoring tool, Crit. Ultrasound J. 9 (2017) 15, https://doi.org/10.1186/s13089-017-0067-y.

[25] L. Weinberg, et al., Video fluoroscopy for positioning of pulmonary artery catheters in patients undergoing cardiac surgery, J. Cardiothorac. Vasc. Anesth. 29 (2015) 1511–1516, https://doi.org/10.1053/j.jvca.2015.07.033.

[26] D. Marchesini, et al., Video fluoroscopy for pulmonary artery catheter insertion in high-risk situation of knotting or misplacement, Eur. Rev. Med. Pharmacol. Sci. 24 (2020) 11768–11772.

[27] J.D. Lorenz, et al., Difficult placement of a pulmonary artery catheter: stenosis of the internal jugular vein from previous cannulation or a pathologic cause? J. Cardiothorac. Vasc. Anesth. 37 (2023) 2378–2381, https://doi.org/10.1053/j.jvca.2023.07.013.