Journal of Cardiothoracic and Vascular Anesthesia 36 (2022) 4208–4212

Contents lists available at ScienceDirect

Journal of Cardiothoracic and Vascular Anesthesia

journal homepage: www.jcvaonline.com

Editorial

Where Should We Leave the Wild "Raa Raa" During Cardiopulmonary Bypass?

THE PULMONARY artery catheter (PAC), the Raa Raa, the noisy, wild lion in a British stop-motion animated children's television program[1] (Fig 1), also known as the Swan-Ganz catheter, is used frequently during cardiac surgery. The PAC might provide clinicians with important information on the preload, afterload, and contractility through the measured and derived parameters for risks stratification and guide perioperative management, particularly in patients with advanced heart failure, pulmonary hypertension, cardiogenic shock, and those who undergo heart and lung transplantation and left ventricular assist device implantation.[2]

However, right-heart catheterization using a PAC might have severe complications like other medical procedures. In this issue of the *Journal of Cardiothoracic and Vascular Anesthesia* (JCVA), 3 interesting reports were presented by Cohen et al,[3] Gonzalez et al,[4] and Rawoot et al[5] on the postoperative difficulty of removing twisted knotted and entrapped PACs after heart transplantation and mitral valve repair surgery. Cohen et al[3] described the successful removal of the distal tip of a knotted PAC beyond the superior vena cava through bedside cinching the knot tight to the introducer and removing them en bloc through a cutdown through the neck.

Gonzalez et al[4] presented 2 cases—the first for the successful removal of an entrapped PAC after repeated orthotopic heart transplantation through manipulating the nonincluded PAC in the surgical anastomosis under general anesthesia and combined fluoroscopy and transesophageal echocardiography (TEE) guidance in the operating room. Although manipulating the PAC by small, intermittent advancements, withdrawals, and twisting motions succeeded in removing the PAC intact through the introducer in this patient,[4] repeated manipulations of the PAC might have potential risks for knotting and lacerations of the PAC.[6] In the second patient, the authors[4] reported early identification of entrapped PAC after a mitral valve repair through observing blood returning from the thermistor connector and the need for resternotomy and reinstitution of cardiopulmonary bypass (CPB) to remove an entrapped PAC in the surgical suture line.

Rawoot et al[5] reported a diagnosed entrapped PAC in the right ventricle postoperatively after a combined mitral valve repair and coronary artery bypass graft (CABG). An acute angulation in the contour of the PAC resulted in the inability to withdraw the PAC beyond the tricuspid valve. In the catheterization laboratory, under fluoroscopy, a guidewire through the distal lumen of the PAC straightened the angle created and allowed a successful removal.

PAC-associated Mechanical Complications

Unfortunately, PAC-related mechanical complications, such as pulmonary artery rupture or perforation, knotting, entrapment, and entanglement in surgical anastomosis, are reported frequently in the literature. The most frequently reported PAC-related mechanical complication is pulmonary artery rupture, but it is yet a rare, life-threatening complication, with a mortality of ≤80%. Pulmonary artery catheter-associated pulmonary artery rupture can occur during the floating of the PAC and wedging of the balloon, or even with the withdrawal of the entrapped PCA in a surgical anastomosis suture line.[7] Dhamee and Pattison[8] suggested several predisposing factors for PAC-induced pulmonary artery rupture during CPB, including (1) the distal location or migration of the PAC tip; (2) surgical manipulation of the heart resulting in PAC movement; (3) a stiffened distal tip of the PAC because of the low body temperature during hypothermic CPB; and (4) an over-distended, over-pressured, or eccentrically inflated PAC, particularly for a prolonged duration.[8]

Pulmonary artery rupture might require urgent inflating and wedging of the PAC balloon into the ruptured pulmonary artery, with selective lung, or lobar isolation,[9,10] pulmonary angiography and transcatheter coil embolization, and surgical intervention with CPB.[11]

Catheter knotting also has been described as a complication of using the PAC, mainly due to excessive insertion depth.[12] In contrast to the 3 cases published in the issue of the JCVA,[3-5] surgical intervention was needed sometimes to remove the

DOI of original article: http://dx.doi.org/10.1053/j.jvca.2022.06.020, :http://dx.doi.org/10.1053/j.jvca.2022.06.023, :http://dx.doi.org/10.1053/j.jvca.2022.06.017.

https://doi.org/10.1053/j.jvca.2022.07.028

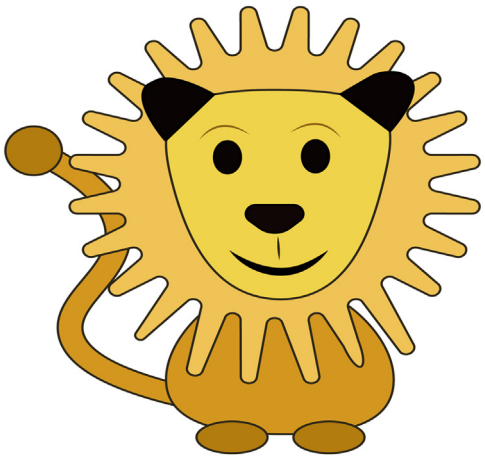

Fig 1. Illustration of the wild Raa Raa.[1]

knotted PAC. Perez d' Empaire et al[13] described successful surgical removal of the PAC knotted near the tricuspid valve and in the right ventricle, likely because of too-deep insertion of the PAC beyond the 50-cm mark. Notably, a formula proposed to calculate the ideal PAC insertion depth potentially might decrease the risk of PAC knotting.[14]

Additionally, the use of PAC has the danger of being entrapped inside the right cardiac compartment, dictating the need for action. Colombier et al[15] described an intraoperative entrapped PAC within the tricuspid valve before the start of off-pump CABG surgery, leading to changing the surgical plan to on-pump CABG to safely remove the entrapped PAC.

There are also risks of entangling the PAC into the surgical anastomosis suture line, particularly during right-side cardiac surgery (eg, tricuspid valve, pulmonary artery, and interatrial and interventricular septa surgical procedures) and heart transplantation. Trials for withdrawing the entangled PAC might result in hemodynamic compromise due to a distorted heart structure and chambers.[4] Surgical removal usually is required in these patients. Vigilance should be exercised for early identification of entrapped PAC into the surgical sutures through the early pick up of changed waveform trace, false temperature readings by the PAC's thermistor, resistance to withdrawal or further floating of the PAC, or leaking blood from the balloon's syringe for inflating the PAC's balloon or thermistor connector.[16]

Should We Stop the Routine Use of PACs for Cardiac Surgery?

Although surveying 705 North American cardiac anesthesiologists showed that 68% of the respondents used a PAC >75% of the time for cases using CPB,[17] the use of PACs has decreased over the last decades as a routine intraoperative monitoring tool. Meanwhile, the trend of regular PAC use in Europe, Asia, Australia, and Africa is unknown. The growing body of evidence demonstrated that the routine perioperative use of PAC is not associated with improved clinical outcomes, including the mortality rate.

In an observational propensity-matched study that included 11,820 patients undergoing (Society of Thoracic Surgeons indexed) CABG or valvular surgery from 2010 to 2018 at a single high-volume center, 39% of them had a PAC, and researchers found that compared with the use of central venous pressure monitoring, PAC use was not associated with improved operative mortality but with statistically significant prolonged stay in the intensive care unit and more need for packed red blood cell transfusions.[18] Shaw et al[19] demonstrated that compared with nonuse of the PAC, the PAC was associated with a similar 30-day in-hospital mortality, increased infectious morbidity, decreased length of stay, and reduced cardiopulmonary morbidity in a propensity-matched cohort study that included 6,844 patients who underwent different types of cardiac surgery.[19]

In addition to the complications associated with using the PAC, there are concerns regarding the accuracy of PAC-measured parameters. Compared with the Fick principle, cardiac output values measured with the thermodilution technique have been reported to have a percentage error of >60% precluding their accuracy.[20] Additionally, the cardiac output measured by the PAC was found to be inferior to those measured by transpulmonary thermodilution precision of 15% versus 7%, respectively.[2,21]

The costs of pulmonary artery catheterization, including the costs of equipment (eg, PAC, pressure transducers, electronic monitoring devices, and solutions), personnel (eg, physician costs for insertion and interpretation, nurses, and technicians), and PAC-related complications (eg, arrhythmias, catheter-related infection, and mechanical complications) should be taken into account.[22] The cost-effectiveness of PAC cannot be ascertained appropriately without establishing its clinical effectiveness, such as costs for managing postoperative complications, particularly after hospital discharge, loss of productivity, transportation cost, and caregivers.[23]

The cost-benefits of routine use of the PAC during cardiac surgery should be individualized based on the risks related to the local practice, patient, and surgery.

Additionally, it is assumed that PAC-related complications increase the aforementioned overall costs and also decrease patient satisfaction.

Where Should We Leave the Wild “Raa Raa” PAC During Cardiopulmonary Bypass?

Several strategies have been proposed to avoid PAC-related mechanical adverse events.

First, caution is required to avoid advancing the PAC beyond the estimated means (standard deviation) of depths from the skin to the right ventricle, pulmonary artery, and pulmonary artery wedge pressure without obtaining the expected waveform, which are equal to 24.6 cm (3), 36 cm (4), and 42.8 cm (5.7), respectively.[24]

Second, using a proper imaging modality, TEE can confirm the appropriate position and exclude improper placement of the PAC, particularly in the cardiac operating room settings (Table 1, Video 1, A-G).[25-27] Baer et al[28] concluded that the proper final destination of the PAC in the wedge position could

Table 1
Transesophageal Echocardiography-Guided Confirmation of the Proper Positions of the Pulmonary Artery Catheter

Position of the PAC	TEE View	Findings
Proper insertion of the PAC's introducer	Midesophageal bicaval view Midesophageal modified bicaval view	The guidewire can be identified as a small, strongly echogenic dot in the SVC and RA (Video 1, A). Injecting 5-10 cc of normal saline solution through the introducer can detect a spontaneous echo contrast in the right atrium.
Floating the PAC's balloon beyond the 20cm mark	Midesophageal RV inflow outflow Midesophageal 4-chamber view	A large, strong echo with side lobes and an acoustic shadow, approximately 1 cm wide, with pulsatile, swinging motion can be seen in the RA and then observed while entering the RV through the tricuspid valve (Video 1, B-D).
Suggested coiling of the PAC	Midesophageal RV inflow outflow Midesophageal bicaval view Midesophageal modified bicaval view	When the PA catheter did not enter the RV The balloon can be found in the inferior vena cava or the right atrium without shuttle movement. These findings indicate that the PAC should be withdrawn once.
Floating the PAC's balloon to the PA	Midesophageal RV inflow outflow view Modified aortic valve long-axis Ascending aortic SAX	It shows pulsatile to-and-from movement (shuttle movement) (Video 1, E and F) and then disappears into the distal right PA in the lung parenchyma (Video 1, G). A bright echogenic mobile spot might be detected in the right PA in all 3 views. Visualization of the left PA is challenging due to the interposed air-filled left bronchus, so nonvisualization of the PAC in the RPA and main PA was assumed to have reached the LPA.
Obtaining the wedge pressure tracing	Midesophageal AA SAX	The catheter portion is simultaneously immobilized with the loss of shuttle movement "anchoring sign."

NOTE. Produced from Raut et al,[25] Tempe et al,[26] and Orihashi et al.[27]
Abbreviations: AA, ascending aorta; LPA, left pulmonary artery; PA, pulmonary artery; PAC, pulmonary artery catheter; RA, right atrium; RV, right ventricle; RPA, right pulmonary artery; SAX, short axis; SVC, superior vena cava; TEE, transesophageal echocardiography.

be secured safely at the 1 o'clock position in the TEE upper esophageal short-axis aorta and long-axis main and right pulmonary arteries views.

Third, low-threshold suspicion of PAC entrapment should be considered in case of altered or lost previously obtained PAC waveform, observing visible blood inside the PAC balloon-inflating syringe, or returning blood through the thermistor's connection.[16] Moreover, the freely mobilized PAC for a few centimeters through the introducer without associated hemodynamic compromise always should be confirmed before closing the cardiac chambers and sternum to exclude entrapped or entangled PAC and avoid the need for redo surgery or interventions to remove the catheter.[16]

There is no substantial body of evidence supporting the optimal placement of the PAC during CBP. There are several suggested options (Fig 2, A-E); each has possible advantages and disadvantages. First, leaving the PAC in place in the pulmonary artery and excluding wedged or inflated balloon (Fig 2, A) might offer the availability of measured and calculated data needed to guide weaning off CPB after the conclusion of the surgical procedure, particularly in case of difficult weaning. However, this option might increase the risks for all possible mechanical complications, including pulmonary artery injury by the stiffened PAC's tip during the hypothermic CPB.[8] Second, some anesthesiologists prefer withdrawing the catheter 5 cm into the main pulmonary artery (Fig 2, B),[29,30] which does not preclude the possibility of entangling the PAC into surgical sutures in the pulmonary trunk or tricuspid valve.[7,16] Third, withdrawing the PAC to the right ventricle (Fig 2, C) or right atrium (Fig 2, D) still risks being entrapped in the surgical suture line, especially in the case of right-heart surgery.[4,6] Finally, although withdrawal of the PAC into the superior vena cava (Fig 2, E) during CPB seems a safe option, there is a need to readvance the PAC after separation from the CPB, which can be associated with the possible complications of PAC floatation attempts.[12] Additionally, this option results in missing the valuable measurements needed in complicated cases while discontinuing the CPB.

The data available regarding the proper location of the PAC during CPB to avoid PAC-related mechanical complications are derived from individual care reports, case series, or personal experiences. The authors think that the reported cases in this issue of the *JCVA*[3-5] showed the need for the *JCVA* to, firstly, lead a survey of the current worldwide practice to manage the PAC during CPB. Secondly, these cases showed the need for the development of multinational societies' consensus on the recommended location of the PAC during CPB through collaboration between the 2 societies, considering the JCVA as the official journal, including the European Association of Cardiothoracic and Vascular Anaesthesiology and Intensive Care and the Chinese Society of Cardiothoracic and Vascular Anesthesiology, until there is a large multicenter observational study to evaluate the adverse event incidence with regard to the different recommended PAC locations during CPB.

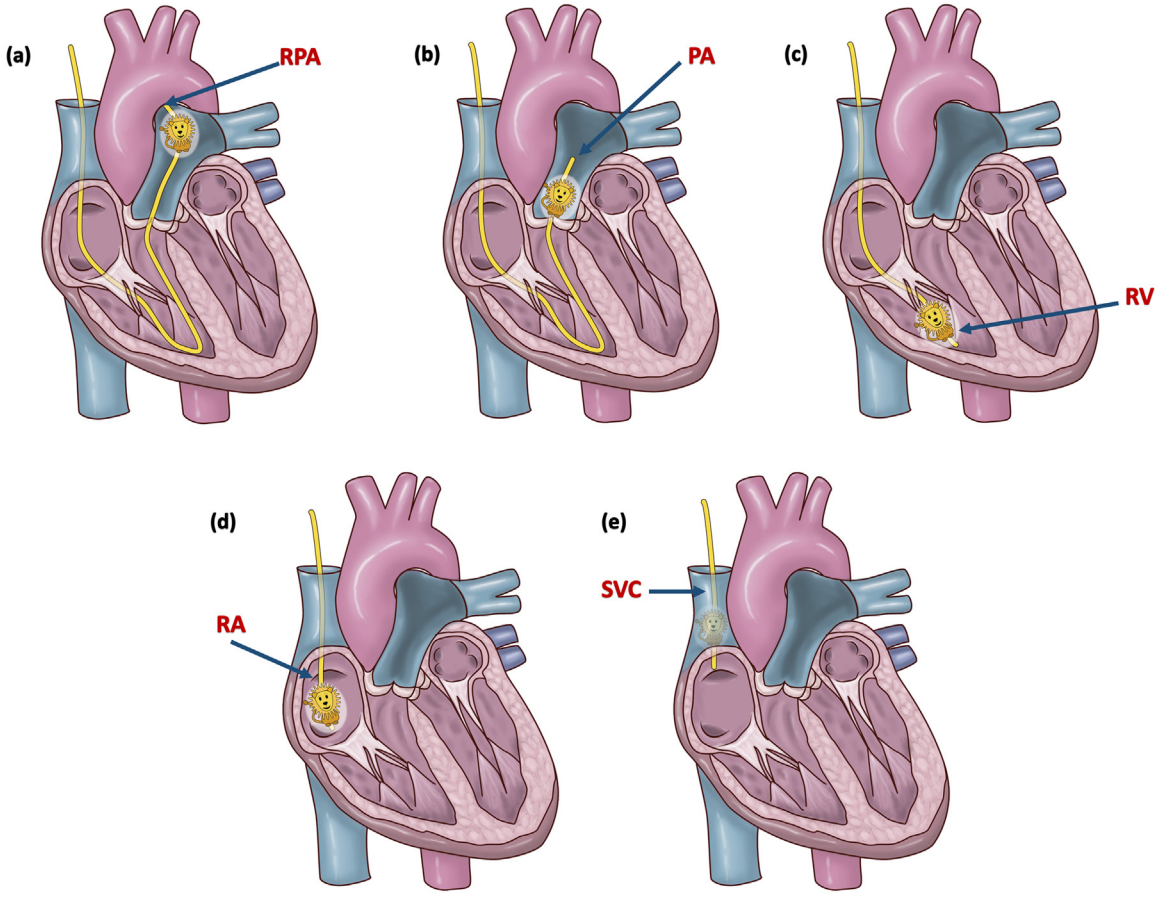

Fig 2. The recommended different locations of the simulated pulmonary artery catheter with the wild "Raa Raa," the noisy, wild lion in a British stop-motion animated children's television program[1] inside, (A) the right pulmonary artery, (B) withdrawn 5 cm in the main pulmonary artery, (C) RV, (D) right atrium, and (E) SCV during the cardiopulmonary bypass. Abbreviations: PA, pulmonary artery; RA, right atrium; RPA, right pulmonary artery; RV, right ventricle; SCV, superior vena cava.

Conflict of Interest

MRT received free airway devices from Ambu and Airtraq used in 3 published studies. The author has no direct or financial interest in any industry, including Ambu and Airtraq.

Acknowledgments

The authors thank Dr. Theofani Antoniou, Dr. Theofili Koussi, and Dr. Areti Falara, Onassis Cardiac Surgery Centre, for providing the transesophageal echocardiography loops included.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1053/j.jvca.2022.07.028.

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References

1 Raa Raa the noisy lion. Available at: https://en.wikipedia.org/wiki/Raa_Raa_the_Noisy_Lion. Accessed July 17, 2022.
2 Rozental O, Thalappillil R, White RS, et al. To swan or not to swan: Indications, alternatives, and future directions. J Cardiothorac Vasc Anesth 2021;35:600–15.
3 Cohen SM, Gold AK, Augoustides JGT. Removal of a knotted Swan Ganz catheter in the superior vena cava post heart transplant—revisiting a rare complication of pulmonary artery catheter placement. J Cardiothorac Vasc Anesth. 2022;36: 4226–27.
4 Gonzalez LS, Coghlan C, Alsatli RA, et al. The entrapped pulmonary artery catheter. J Cardiothorac Vasc Anesth. 2022;36:4203–12.
5 Rawoot I, Madathil T, Panidapu N, et al. Entrapped pulmonary artery catheter: What can be done. J Cardiothorac Vasc Anesth. 2022;36:4203–12.
6 Garg L, Arkles JS, Schaller RD. Percutaneous removal of a pulmonary artery catheter inadvertently sutured to the heart during valve surgery. JACC Case Rep 2020;2:2323–6.
7 Huang GS, Wang HJ, Chen CH, et al. Pulmonary artery rupture after attempted removal of a pulmonary artery catheter. Anesth Analg 2002;95:299–301.

8 Dhamee MS, Pattison CZ. Pulmonary artery rupture during cardiopulmonary bypass. J Cardiothorac Anesth 1987;1:51–6.
9 Damm C, Degen H, Stoepel C, et al. Management of a catheter-induced rupture of a pulmonary artery[article in German] Dtsch Med Wochenschr 2010;135:1914–7.
10 Booth KL, Mercer-Smith G, McConkey C, et al. Catheter-induced pulmonary artery rupture: Haemodynamic compromise necessitates surgical repair. Interact Cardiovasc Thorac Surg 2012;15:531–3.
11 Abreu AR, Campos MA, Krieger BP. Pulmonary artery rupture induced by a pulmonary artery catheter: A case report and review of the literature. J Intensive Care Med 2004;19:291–6.
12 Evans DC, Doraiswamy VA, Prosciak MP, et al. Complications associated with pulmonary artery catheters: A comprehensive clinical review. Scand J Surg 2009;98:199–208.
13 Perez d'Empaire P, Derzi S, Latter D, et al. Pulmonary artery catheter knotted in the tricuspid valve apparatus requiring surgery with cardiopulmonary bypass: A case report. A A Pract 2019;13:181–4.
14 Walz R, Roth S, Hollmann MW, et al. Formula for safe insertion depth of a pulmonary artery catheter. Br J Anaesth 2021;127;e25-e-27.
15 Colombier S, Rancati V, Marcucci C, et al. Tricuspid valve Swan-Ganz catheter entrapment before cardiac surgery. Anaesth Rep 2020;8:e12085.
16 Chan WH, Hsu CH, Lu CC, et al. Early recognition of an entrapped pulmonary artery catheter by blood leaking into the syringe and thermistor connector during cardiac surgery. Acta Anaesthesiol Taiwan 2012;50:38–40.
17 Judge O, Ji F, Fleming N, et al. Current use of the pulmonary artery catheter in cardiac surgery: A survey study. J Cardiothorac Vasc Anesth 2015;29:69–75.
18 Brown JA, Aranda-Michel E, Kilic A, et al. The impact of pulmonary artery catheter use in cardiac surgery [e-pub ahead of print]. J Thorac Cardiovasc Surg. https://kdcanada.org/10.1016/j.jtcvs.2021.01.086. Accessed August 20, 2022.
19 Shaw AD, Mythen MG, Shook D, et al. Pulmonary artery catheter use in adult patients undergoing cardiac surgery: A retrospective, cohort study. Perioper Med (Lond) 2018;7:24.
20 Dhingra VK, Fenwick JC, Walley KR, et al. Lack of agreement between thermodilution and Fick cardiac output in critically ill patients. Chest 2002;122:990–7.
21 Monnet X, Persichini R, Ktari M, et al. Precision of the transpulmonary thermodilution measurements. Crit Care 2011;15(4):R204. https://doi.org/10.1186/cc10421.
22 American Society of Anesthesiologists Task Force on Pulmonary Artery Catheterization. Practice guidelines for pulmonary artery catheterization: An updated report by the American Society of Anesthesiologists Task Force on Pulmonary Artery Catheterization. Anesthesiology 2003;99:988–1014.
23 Stevens M, Davis T, Munson SH, et al. Short and mid-term economic impact of pulmonary artery catheter use in adult cardiac surgery: A hospital and integrated health system perspective. Clinicoecon Outcomes Res 2021;13:109–19.
24 Tempe DK, Gandhi A, Datt V, et al. Length of insertion for pulmonary artery catheters to locate different cardiac chambers in patients undergoing cardiac surgery. Br J Anaesth 2006;97:147–9.
25 Orihashi K, Nakashima Y, Sueda T, et al. Usefulness of transesophageal echocardiography for guiding pulmonary artery catheter placement in the operating room. Heart Vessels 1994;9:315–21.
26 Raut MS, Hanjoora VM, Chisti MA. Transesophageal echocardiography guidance for expedited pulmonary artery catheter insertion and accurate estimation of cardiac output. Ann Card Anaesth 2018;21:339–40.
27 Tempe DK, Batra UB, Datt V, et al. Where does the pulmonary artery catheter float: Transesophageal echocardiography evaluation. Ann Card Anaesth 2015;18:491–4.
28 Baer J, Wyatt MM, Kreisler KR. Utilizing transesophageal echocardiography for placement of pulmonary artery catheters. Echocardiography 2018;35:467–73.
29 Mittnacht AJC, Reich DL, Sander M, et al. Monitoring of the heart and vascular system. In: Kaplan JA, editor. Kaplan's cardiac anesthesia: For cardiac and noncardiac surgery, 7th ed., Philadelphia, PA: Elsevier; 2017.
30 Stone JG, Khambatta HJ, McDaniel DD. Catheter-induced pulmonary arterial trauma: Can it always be averted? J Thorac Cardiovasc Surg 1983;86:146–50.