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Teboul, Jean-Louis; Cecconi, Maurizio; Scheeren, Thomas W L

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EDITORIAL

Is there still a place for the Swan–Ganz catheter? No

Jean-Louis Teboul[1,4*], Maurizio Cecconi[2] and Thomas W. L. Scheeren[3]

There is no doubt that the pulmonary artery catheter (PAC) provided intensivists with a lot of hemodynamic information more than 20 years ago, at a time when there was nothing else to help them to assess the hemodynamic status, to make the diagnosis of mechanisms of shock states, and to select the appropriate treatment and to monitor its effects.

There is also no doubt that the use of the PAC in intensive care units (ICU) has dramatically declined worldwide over the past 25 years [1]. This is partly because the PAC is perceived by ICU physicians as an invasive and cumbersome procedure, which needs much knowledge and expertise in terms of measurements and interpretation of data to be adequately used. In addition, it is likely that intensivists have been discouraged to use the PAC after the publication of randomized controlled trials (RCT) showing no clinical benefit [2, 3]. The decline of the PAC can also be partly explained by its competition with less invasive hemodynamic monitoring and ultrasonographic methods that have developed in recent years [4]. Finally, emergence of novel techniques able to monitor real-time CO and dynamic indices of fluid responsiveness [5] have also contributed to the reduced interest of intensivists in the PAC.

In this article, we present the reasons for not using the PAC in the ICU in 2018. These reasons can be summarized in simple words: there is no clinical situation where the hemodynamic information provided by the PAC is superior to that obtained less invasively and moreover, in most situations where assessment of cardiac function or volume status is required, the PAC performs far worse than other more modern technologies (Table 1).

In the 1980s, one of the main reasons to insert a PAC was to estimate cardiac output (CO) through the thermodilution method. This was a revolutionary innovation at that time, but today many non-invasive, minimally invasive, or less invasive hemodynamic monitors are perfectly valuable for that purpose. The inconvenience of the PAC is that it cannot provide continuous real-time CO monitoring, even when a modified catheter equipped with thermal filament is used.

Another reason to insert a PAC in the past century was to assess the left and right heart function through the analysis of the relationships between the CO and the pulmonary artery occlusion pressure (PAOP) and the right atrial pressure (RAP), respectively. However, such an analysis most often required repeated measurements of CO and filling pressures after therapeutic challenges to be reliably interpreted. The complexity of the CO-cardiac filling pressure relationships and the potential errors of measurements of PAOP and RAP often made the assessment of cardiac function unreliable. Today, there is no need for any RCT to confirm that echocardiography performs far better than PAC for the purpose of assessing the cardiac function. The technological advances in echocardiography (Doppler-derived indices, speckle tracking, real-time 3-D imaging, etc.) have made the use of PAC for the cardiac evaluation purpose a technique of the Middle Ages.

An additional piece of information that made the PAC attractive in the past was the measurement of pulmonary artery pressure (PAP), which was used to assess the severity of specific diseases affecting the pulmonary vasculature (e.g., pulmonary embolism, acute pulmonary hypertension) and their response to therapies. Echocardiography can provide an estimation of the PAP (using

*Correspondence: jean-louis.teboul@aphp.fr
[4] Service de Réanimation Médicale, Hôpital de Bicêtre, Hôpitaux Universitaires Paris-Sud, 78, rue du Général Leclerc, 94 270 Le Kremlin-Bicêtre, France
Full author information is available at the end of the article

For contrasting viewpoints, please go to https://doi.org/10.1007/s00134-018-5140-x and https://doi.org/10.1007/s00134-018-5158-0.

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Table 1 Arguments for no longer using a pulmonary artery catheter

Clinical problems	PAC solutions	PAC shortcomings	Alternative methods
Assessment of cardiac output	Cardiac output measurement (thermodilution)	Invasiveness, no real-time cardiac output monitoring even with its continuous mode	Less or minimally invasive methods providing real-time cardiac output monitoring
Assessment of left heart function	Analysis of PAOP and cardiac output relationships	Invasiveness, other more accurate methods available	Echocardiography (LVEF, Sm)
Assessment of right heart function	Analysis of RAP and cardiac output relationships RAP/PAOP ratio	Invasiveness, other more accurate methods available	Echocardiography (RVEDA/LVEDA, TAPSE, Sa)
Assessment of pulmonary artery pressure	Direct measurement	Invasiveness, other accurate methods available	Echocardiography
Assessment of volume status and fluid responsiveness	Analysis of RAP, PAOP, and their changes with fluid administration	Invasiveness, more accurate other methods available	Less or non-invasive methods providing preload responsiveness indices (PPV, SVV, PLR)
Assessment of pulmonary edema and its mechanism	PAOP	Invasiveness, more accurate other methods available	Transpulmonary thermodilution (EVLW and PVPI)
Assessment of adequacy of perfusion	SvO_2, VO_2	Invasiveness	Capillary refill time, skin mottling, $ScvO_2$, Pcv-aCO_2, blood lactate

PAC pulmonary artery catheter, *PAOP* pulmonary arterial occlusion pressure, *LVEF* left ventricular ejection fraction, *Sm* tissue Doppler imaging of mean systolic velocity of the lateral mitral annulus, *RAP* right atrial pressure, *RVEDA* right ventricular end-diastolic area, *LVEDA* left ventricular end-diastolic area, *TAPSE* tricuspid annular plane systolic excursion, *Sa* tissue Doppler of mean systolic velocity of the lateral tricuspid annulus, *PPV* pulse pressure variation, *SVV* stroke volume variation, *PLR* passive leg raising, *EVLW* extravascular lung water, *PVPI* pulmonary vascular permeability index, SvO_2 mixed venous blood oxygen saturation, VO_2 oxygen consumption, $ScvO_2$ central venous blood oxygen saturation, *Pcv-aCO*$_2$ difference in carbon dioxide pressure between the central venous blood and the arterial blood

the Bernoulli's equation) and more importantly directly assess its impact on the right ventricular function [6].

Given that not all patients with shock are fluid responsive and that inappropriate fluid administration may cause harm, prediction of fluid responsiveness is an important issue [5]. Unfortunately, cardiac filling pressures such as RAP and PAOP measured using a PAC are inappropriate for that purpose [7]. First, there are numerous conceptual and methodological reasons for filling pressures not to be accurate markers of preload [8]. Second, assessing preload is not the same as assessing preload responsiveness so that a given value of any measure of preload cannot predict the hemodynamic response to fluid infusion [4]. Many less invasive hemodynamic devices that provide dynamic preload responsiveness indices (such as pulse pressure variation) and tests (such as passive leg raising) perform far better than cardiac filling pressures in predicting the response to fluid administration [5]. This also argues against the use of PAC to initiate and guide fluid resuscitation in shock states.

The PAC was used in the past for assessing the presence and the nature of pulmonary edema (hydrostatic vs. increased permeability) through measurements of PAOP and its changes. We know today that this is an approximate method, first because PAOP does not reflect the lung capillary hydrostatic pressure well [9] and second because physiologically there is no straightforward relationship between PAOP and the amount of pulmonary edema as reported in ICU patients [10]. A less invasive technique such as transpulmonary thermodilution can provide quantitative estimation of the extravascular lung water and of the degree of lung capillary leakage [4].

In the early 1990s, the PAC was also used to assess global tissue oxygenation through measurements of oxygen delivery (DO_2) and oxygen consumption (VO_2). This was the time of deliberate attempts to achieve "supra-normal" values of DO_2 in order to increase further VO_2 and reduce the global oxygen deficit of critically ill patients or high-risk surgical patients [11]. This attitude was defeated in RCTs in the mid-1990s [12], such that today it is clearly recommended not to systematically attempt to achieve "supra-normal" values of DO_2 in ICU patients [13]. This obviously makes the need to insert the PAC far less indisputable than two decades ago.

In conclusion, we strongly believe that the PAC belongs to the museum of intensive care medicine. Although we acknowledge that 25 years ago, it was a wonderful tool to assess hemodynamics at the bedside, there is no indication to use it today since, besides its invasiveness, it cannot provide information as reliable as given by more recently available bedside hemodynamic monitoring techniques.

Author details
[1] Medical Intensive Care Unit, Bicetre Hospital, Paris-South University Hospitals, Inserm UMR_S999, Paris-South University, Le Kremlin-Bicetre, France. [2] IRCCS Instituto Clinico Humanitas, Humanitas University, Milan, Italy. [3] Department of Anesthesiology, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands. [4] Service de Réanimation Médicale, Hôpital de Bicêtre, Hôpitaux Universitaires Paris-Sud, 78, rue du Général Leclerc, 94 270 Le Kremlin-Bicêtre, France.

Compliance with ethical standards

Conflicts of interest
JLT is a member of the medical advisory board of Pulsion Medical Systems and received honoraria from Edwards Lifesciences and Masimo Inc. for consulting. MC consulted and lectured for Edwards Lifesciences, LiDCO, and Cheetah Medical. TS received honoraria from Edwards Lifesciences and Masimo Inc. for consulting and received honoraria from Pulsion Medical Systems for lecturing.

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