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Pulmonary artery catheters: Do we still use them?

JEAN GÉLINAS MD, FRCPC

The pulmonary artery catheter (PAC) has long been considered an important component of medical therapy for critically ill patients and for patients undergoing major surgery. Since the introduction of the PAC, millions have been inserted and a review of the medical literature reveals thousands of publications dealing with PACs. Despite all this information, including recent randomized trials, the indications for the appropriate use of PACs have often been ambiguous. Many questions still persist, but with time, some answers are becoming more obvious as we gain more knowledge about PACs. This issue of *Anesthesiology Rounds* evaluates the determinants of PAC use and provides an analysis of recent randomized trials. Studies evaluating the training and educational knowledge of physicians are also assessed.

HISTORY

In the 1950s, PACs were inserted by cardiologists in cardiac catheterization laboratories using fluoroscopy. The PAC was then used only as a diagnostic tool. Later, in the 1970s, with the introduction of the balloon-tipped flow-directed catheter, the PAC was used without fluoroscopy in coronary care units, intensive care units (ICUs), and operating rooms.[1] Despite the absence of randomized trials, the use of these catheters quickly became popular and widespread. The PAC was subsequently used not only as a diagnostic tool, but also increasingly as a guide for fluid and hemodynamic therapy.

KNOWLEDGE OF HEALTHCARE PROFESSIONALS AND PROPER USE OF THE PAC

It is often assumed that the numbers and information obtained from a PAC are "real." When using a measuring instrument, it is imperative that the information provided is reliable and reproducible since important therapeutic decisions are often made based on these numbers. Some studies have questioned the reliability of the information gathered by healthcare professionals when using PACs. Among other things, the level of training for physicians in acquiring numerical data from a PAC is a crucial step in the information-gathering process. A 1990 study evaluated American and Canadian knowledge about PAC use. Physicians (496) from 13 medical institutions were evaluated, without notice, during grand rounds in the departments of anesthesiology (37.5% of respondents), internal medicine (36.5%), and surgery (23%). Respondents were more or less evenly distributed between first-year residents (PGY 1) and attending physicians. A 31-question test evaluated proper insertion technique, the complications of insertion, interpretation of waveforms, and the appropriate application of the data obtained from a PAC. Overall, 47% of respondents were unable to determine the pulmonary capillary wedge pressure (±5 mm Hg accepted as valid) from a clear tracing. Attending physicians were the "best," failing in 39.5% of cases; additionally, only 67% were able to recognize the data needed to calculate oxygen delivery.[2]

University of Montreal
Department of Anesthesiology
Faculty of Medicine

Université de Montréal
Faculty of Medicine
Department of Anesthesiology

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The following is an example of a question taken from the above study:

Which of the following attempts at PAC placement should be discontinued?

a. Blood aspirated from a PA catheter introducer into the left internal jugular reveals a pH of 7.29, PO_2 60, saturation 90%.
b. Five-beat ventricular tachycardia occurs while passing through the right ventricle.
c. While attempting catheterization, the nurse points out that the patient had an LBBB on the admission EKG.
d. The patient complains of pain at the insertion site.
e. Large V-waves are seen on the monitor.

Approximately 61% of physicians were not able to correctly answer this question and therefore, could not interpret a blood gas consistent with arterial cannulation.[2]

Another survey carried out at 3 European ICU conventions examined the way physicians responded to a relatively simple clinical problem. Physicians were asked to decide the most appropriate therapeutic option for a given clinical scenario in which no PAC hemodynamic data was available. After they had chosen their initial therapeutic strategy, hemodynamic data obtained by PAC was submitted to them. Three consecutive sets of hemodynamic information were given. Each time a new set of hemodynamic information was submitted, they were asked to re-assess their original therapy. Most of the 417 physicians taking the test were intensivists or anesthesiologists from Europe and North America. A panel of experts also took the test. Following the clinical presentation, only 38% of physicians suggested the same initial treatment as the experts (who had 100% agreement on initial therapy). More than 35% of respondents suggested at least one harmful treatment. Interestingly, the introduction of the first PAC-derived hemodynamic data significantly increased the number of correct therapies and decreased the number of wrong treatments. By the time the third set of hemodynamic data was presented, over 80% of respondents agreed with the experts and only 10% persisted in administering a potentially harmful therapy.[3] This seems to illustrate that when given adequate numerical information, clinicians are able to use PACs in a beneficial way.

A survey of English-speaking anesthesiologists conducted in Eastern Canada found that timing for optimal wedge measurement was known by 89% of respondents. However, when asked to evaluate a tracing of the wedge procedure, only 60% of respondents could actually find the correct wedge to within ±10 mm Hg.[4] This illustrates the need, not only to act upon numerical information, but also to be able to obtain "true" numerical information.

With such important deficiencies in the basic knowledge about PAC use, the question is whether PAC is "bad" technology or if it is simply a technology that is "badly used." Certification and proof of competence are demanded for many less invasive medical procedures. Regardless of why the PAC (or any other medical technology) might be beneficial or harmful, it is *how* it is used in everyday medical practice that determines patient outcome. The author has observed that in many ICUs, the wedge and numerous hemodynamic values change at the beginning and end of the nursing shift. Re-calibration, a new leveling, a new observer, and a few other factors can explain this phenomenon. Some have referred to this as the "change of shift wedge." In certain institutions, it has even been accepted as "normal." Unfortunately, the wedge differences are sometimes very significant and can dramatically alter medical therapy. These observer biases add an often forgotten, but important dimension to the interpretation of hemodynamic information obtained from the PAC.

VARIABILITY IN THE USE OF PACS

It is interesting to examine the significant differences in PAC utilization from country to country. A study of catheter use in different ICUs in Europe found a large difference in the prevalence of PACs *in situ* on a pre-selected day; 29.4% of patients in Finnish ICUs had a PAC, while only 4.1% of Danish ICU patients had a PAC.[5] Similarly, a comparison of patients in France and the United States revealed that patients with equal APACHE scores were more likely to have a PAC inserted in the United States.[6] Another study demonstrated that in units staffed by intensivists, the use of PACs was 66% less than in units staffed by doctors not trained in critical care.[7] The same study also revealed that surgical units were twice as likely to install PACs than medical ICUs or combined medico-surgical ICUs.

Thus, the use of PACs appears to be based on something other then hard medical criteria. Experience, level of training, country of origin, and type of medical practice all seem to have an important impact on PAC utilization.

WHICH PAC NUMBERS ARE IMPORTANT?

The amount of information (numbers) obtained from a single set of hemodynamic measurements can

TABLE 1: Six basic hemodynamic measurements

- Heart rate
- Arterial blood pressure
- Central venous pressure
- Pulmonary artery pressure
- Wedge pressure
- Cardiac output

be overwhelming. From a few basic numbers, the computer calculates many more. The 6 basic hemodynamic variables are shown in Table 1. The weight and height of the patient are also important in order to standardize (index) certain values for comparison; for example, the cardiac output should be indexed. From these 6 basic values, a large quantity of other numbers can be obtained. Arterial and mixed venous oxygen saturations, and hemoglobin are 3 other variables needed for oxygen delivery and oxygen consumption calculations.

The 6 basic hemodynamic parameters and the cardiac index are more than sufficient to evaluate hemodynamics in clinical practice. The "extra information" obtained through computer calculations are simply values derived from the 6 basic parameters and often seem to make hemodynamic assessment more complicated, while adding little or no new useful information. An in-depth review of these parameters is beyond the scope of this article.

TRIALS EVALUATING PACS

The evolution of PAC use in coronary care units illustrates how the employment of this new technology changed with time. In the 1980s, observational studies of patients with congestive heart failure secondary to acute myocardial infarction (MI) monitored with PACs failed to show a benefit from PAC use. In patients with cardiogenic shock, mortality rates were almost identical with or without a PAC. Patients with less-advanced disease seemed to do better when they were managed without a PAC.[8,9] Patients treated with PACs were said to be sicker and this was thought to be the reason for their poorer prognosis.

As knowledge of coronary artery disease evolved, it became clear that coronary reperfusion strategies using anticoagulation, thrombolysis, balloon angioplasty, or coronary artery bypass grafting (CABG) preserved myocardial function and therefore, improved outcome. A PAC does little to alter the underlying disease process in coronary disease; it can only supply information about the hemodynamic state of the patient. Often, in a monosystemic disease like heart failure, the information gained by the PAC is only a numeric representation of what may be deduced by simple clinical bedside skills, an ECG, and an X-ray of the chest. The use of cardiac echography has also diminished the need for PACs in coronary care units. For example, a patient having an MI who is short of breath, has crackles on physical exam, and is hypotensive, is most likely in heart failure. PAC insertion would often only delay revascularization therapy exposing the patient to unwarranted risk.

As seen above, when examining the use of a PAC in congestive heart failure, the therapy chosen in response to the hemodynamic information is crucial in improving patient outcome. In the critical care literature, Shoemaker et al was the first to report that using the PAC to guide therapy to achieve supranormal levels of cardiac index, oxygen delivery, and oxygen consumption resulted in decreased mortality in critically ill patients.[10] Inotropes, vasodilators, and diuretics were all used and guided by PAC-derived hemodynamic information in the treatment group.[10] However, subsequent studies evaluating supraphysiologic inotropic-driven therapy failed to show beneficial results, or demonstrated increased mortality.[11,12] The trend now, ironically perhaps, is to use beta-blockers in high-risk patients. This again seems to illustrate that the PAC is a monitoring system whose information needs to be used appropriately to be of benefit. In the end, the ultimate determinant of outcome is the therapeutic intervention used, regardless of PAC use.

The process of studying the indications for PAC use through randomized trials has been difficult. A prospective, randomized, controlled trial was attempted in Ontario, but 47% of patients randomized to the control group were crossed over to the PAC group because their physicians felt it was unethical to keep patients in the control group.[13] A prospective cohort study by Connors et al in over 5500 patients suggested that PACs may actually cause harm.[14] This was not a randomized study, but it relied on sophisticated statistical analysis to adjust for differences in severity of illness in patients. An accompanying editorial suggested PAC use be halted unless a large, randomized trial was undertaken.[15]

In recent years, a number of randomized trials have been published examining PACs in different clinical situations. The use of a PAC in aortic surgery has been evaluated by several authors.

- One study compared the use of central venous pressure (CVP) and PAC monitoring in patients undergoing infrarenal aortic surgery. Exclusion criteria included an ejection fraction <40% and renal failure. The presence of coronary artery disease was evaluated by clinical and scintigraphic means and patients with significant disease were excluded. Of the 190 patients screened, 102 were ultimately randomized; no difference in clinical outcome could be found.[16]

- Another study by Valentine et al evaluated the usefulness of preoperative "optimization" and perioperative treatment with a PAC compared with no PAC and simple preoperative hydration. Patients with uncompensated cardiac disease, recent MI, and recent CABG were excluded. Patients with creatinine levels above 3.0 mg/dL were also excluded. All patients were screened with thallium scintigraphy. Patients randomized to receive a PAC were admitted to the ICU preoperatively and administered: IV fluids, and/or nitroglycerin, and/or nitroprusside, and/or dopamine according to a complex algorithm that had to meet predetermined hemodynamic values. The control group had 1-2 ml/kg/hr of IV fluids administered preoperatively. One hundred and twenty patients were randomized. The authors found "hemodynamic abnormalities" needing "pharmacological correction" in 50% of the patients with PAC; 50% received nitrates or inotropic agents. Although there was no overall difference in outcome, patients randomized to the PAC group had more intraoperative complications and were given significantly more fluid perioperatively.[17] It seems that what was really evaluated in this study was the complex algorithm and not the measuring instrument.
- A meta-analysis, which included this last trial and 3 other small, randomized trials evaluating PACs in elective aortic surgery, failed to show improvement in outcome or a decrease in complications with the use of a PAC. Fluid administration was higher in the PAC group, but this did not translate into improved outcome measures.[18] The PAC treatment groups in all of these studies were treated to "supraphysiologic" hemodynamic values. Again, in these studies, it could be argued that the PAC was only a monitoring tool and that the "supraphysiologic" interventions were the real differences being evaluated. Therefore, it can be said that the use of a PAC to maximize hemodynamics to supraphysiologic values is probably ineffective and should not be done.
- A recent study has shown that in high-risk aortic surgery, outcome seems to be improved with the use of beta-blockers;[19] this is obviously the opposite of what is attempted with supraphysiologic resuscitation.
- A single-centre study randomized critically ill ICU patients to a PAC group (n=95) or a control group (n=106). Indications for randomization were circulatory shock and/or oliguria unresponsive to a 500 ml bolus, need for a vasoactive infusion, or respiratory failure needing mechanical ventilation. No elective high-risk surgery patients were included. Formal treatment protocols were deliberately not used in order to allow the ICU physician to make decisions with or without a PAC. Supranormal physiologic manipulations were not done in any patients in this study. Most patients were randomized because they were in septic shock; nevertheless, patients with cardiogenic and hypovolemic shock were included. No difference in patient mortality was noticed, but more renal failure and thrombocytopenia were found in the PAC group. On average, patients in the PAC group received significantly more fluids.[20]
- A recent multicentre trial[21] recruited and randomized 1994 patients into a PAC group with goal-directed therapy or a standard-care group without the use of a PAC. Eligible patients were ≥60 years-of-age with American Society of Anesthesiology (ASA) class III or IV and scheduled for elective or urgent major abdominal, thoracic, vascular, or hip fracture surgery. Goals in the PAC group were oxygen delivery of 550-600 ml per minute per square meter of body surface area, cardiac index of 3.5-4.5 liters per minute per square meter, a mean arterial pressure of 70 mm Hg, a pulmonary capillary wedge pressure of 18 mm Hg, a heart rate of <120 beats per minute and a hematocrit of >27%. Measures to achieve these goals were fluid loading, inotropic support, vasodilator therapy, vasopressors for hypotension, and blood transfusion to meet the hematocrit requirements. No difference in mortality was found between the two groups. The PAC group had a higher incidence of embolisms (8 events vs 0 events). The PAC group also received more inotropic agents, vasodilators, antihypertensive medication, packed red cells, and colloids. This was obviously a very large study representing many of the patients encountered in everyday practice. The goal-directed therapy is not a direct reflection of everyday

practice, but does include many of the interventions employed when "fine tuning" patients using PACs. It is difficult to imagine a bigger and better study being undertaken that would deal with the perioperative period in a more comprehensive fashion. This study strongly suggests that aggressive PAC-guided management of hemodynamics is not indicated for everyday medical practice.

RECOMMENDATIONS FOR PAC USE

The great majority of the above studies demonstrate that the non-selective use of PACs does not improve outcome. Some of the reasons why this monitoring system might not change outcomes were examined. Regardless of the reasons, obviously it is the end result that counts. It is the author's opinion that routine perioperative use of a PAC cannot be justified in the majority of patients.

Although there is very little clinical research to support the following view, PAC use does seem acceptable on a case-by-case basis when the primary purpose is to help in the diagnosis of various clinical conditions. An interesting study compared hypotensive patients whose therapy was changed based on PAC data to those whose therapy was not changed, also based on PAC insertion. The group of patients with therapeutic alteration had a 59% mortality, while the group with no change in therapy had 100% mortality.[22] The PAC, in these cases, was used strictly as a diagnostic tool (as it was used originally, before it became popular to "guide" often ill-proven therapies).

In the author's view, if a PAC is to be of benefit, 4 basic requirements need to be met in order to use the monitoring system appropriately (Table 2). The first involves the proper handling of the catheter. Insertion needs to be done with expertise and prompt removal remains a priority. Reduction of the numerous possible complications (be they mechanical or infectious) also needs to be addressed during manipulations. Adequate "hands-on" bedside teaching of these techniques is essential. Secondly, data collection requires adequate zeroing, calibration, and meticulous leveling. Waveform analysis can be confusing in certain clinical conditions. A relatively small difference in estimated wedge pressure can dramatically alter therapy. While the PAC is *in situ,* regular data collection should be done. If the data are not collected, and/or not evaluated, the PAC should be removed. Again, bedside teaching and discussion of the proper way to analyze waveforms and of the possible pitfalls during data collection seem necessary in the training process. Thirdly, proper interpretation of the collected information is essential. Finally, implementation of the proper therapy must follow. The best information and understanding of the PAC are of little use if the wrong therapeutic decisions are made.

TABLE 2: Requirements for the use of a PAC

1. Proper catheter manipulation including reduction of possible complications (mechanical or infectious)
2. Adequate zeroing, calibration, and leveling for data collection
3. Proper interpretation of the collected information
4. Proper implementation of therapy

Improvements in outcome with PAC use are possible only if all the above steps are followed correctly.

CONCLUSION

As with all new medical technologies, the use of the PAC has evolved over time. Extensive medical literature has consistently demonstrated that the PAC does not improve outcome and may actually cause harm. As discussed above, the reasons for this are complex and we must re-evaluate the ways that PACs are used. Routine perioperative use of PACs does not seem justified. For a PAC to be beneficial, proper insertion and manipulation, appropriate collection and interpretation of the derived data, and correct therapeutic interventions are all necessary since the prognosis may be adversely affected if an invasive device is inserted, but not used or used improperly. PACs may be more useful as diagnostic tools than as therapeutic guides, especially if the therapies they are guiding are not effective in improving outcome. It is possible that a subset of patients may benefit from perioperative PAC use, but this patient population needs to be defined and studied. Defining this patient population is as important as determining which PAC-guided therapeutic aims or interventions should be studied. A PAC is simply a monitoring system. As with any invasive device, it has associated complications. Therefore, the benefits of using PACs must outweigh the possible complications.

Jean Gélinas, MD, *is both an anesthesiologist and an intensivist working at the Maisonneuve-Rosemont Hospital, Montréal.*

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