The pulmonary artery catheter in 2008 – A (finally) maturing modality?

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ABSTRACT

The first description of the flow-directed pulmonary artery catheter (PAC) was published in the 1970s by Jeremy Swan and William Ganz. Ever since its clinical debut, many controversies surrounded the use of the PAC. Regardless of these controversies, the most fundamental issues surrounding this hemodynamic monitoring device remain unresolved, including the exact indications, contraindications, identification of patients who potentially benefit from this technology, and the way we interpret and use PAC-derived parameters. Despite recent intensification of attacks against the use of the PAC by its opponents, it seems overly harsh to discount a technology that might be beneficial in appropriately selected clinical situations, especially when considering the fact that our true knowledge of this technology is somewhat limited. In fact, the PAC may still play an important role considering the resurgence of the concepts of euvolemic resuscitation and hemodynamic sufficiency.

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Key Words: Euvolemic resuscitation, hemodynamic monitoring, hemodynamic sufficiency, pulmonary artery catheter, surgical critical care

INTRODUCTION

The first description of the flow-directed pulmonary artery catheter (PAC) was published in the 1970s by Jeremy Swan and William Ganz.¹ Ever since its clinical debut, significant controversies surrounded the use of the PAC.²⁻⁷ Regardless of these controversies, the most fundamental issues surrounding this hemodynamic monitoring technique remain unresolved, including the exact indications, contraindications, patient populations who may potentially benefit from this technology, and the way we use and interpret PAC-derived parameters.

THE THREE “LAYERS” OF HEMODYNAMIC MONITORING

When treating patients who require hemodynamic monitoring, one can utilize any one of the three “layers” of monitoring currently available in the modern Intensive Care Unit (ICU) [Table 1]. The first layer relies on easily obtainable clinical information to determine patient resuscitation status.⁸ Here, vital signs, urine output, and laboratory values (base deficit, lactate – the so-called metabolic debris) allow the clinician to determine if volume-based resuscitative efforts are reaching previously established endpoints and may give some indication of under- or over-resuscitation. The second layer involves the use of more elaborate monitoring techniques, including central venous pressure (CVP) and central venous O₂ determinations, bladder pressure measurements, and basic intensivist bedside sonography (vena cava diameter determinations). The third layer of monitoring consists of the PAC, advanced transthoracic and transesophageal echocardiography, as well as esophageal Doppler monitoring (EDM) and

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related techniques. In addition, there is a collection of developing and not yet fully established monitoring technologies, which include arterial waveform analysis/interpretation devices, tissue O_2 determination devices, and new devices that use complex algorithms to derive hemodynamic values from existing clinical/monitoring data.\(^6\)\(^7\)\(^8\)\(^9\)\(^10\) As these hemodynamic monitoring methods evolve, undergo more complete clinical evaluation/validation, and their accuracy improves, it is likely that the various layers of hemodynamic monitoring will be reshaped.

### PULMONARY ARTERY CATHETER: CONTROVERSIES

The use of PAC appears to be on the downward trend according to the recent article by Wiener and Welch in the Journal of the American Medical Association (JAMA).\(^7\) Authors of that article noted a gradual decline in the use of the PAC from a high of 5,660/1,000 medical admissions to just under 2,000 medical admissions today.\(^5\)\(^6\) Why such a trend? Is this surprising? What is the future of this 40-year-old technology?

According to Rubenfeld et al., the PAC may be undergoing a slow demise.\(^5\) In fact, the authors of a very strong and arguably very biased editorial regarding the original article by Wiener and Welch\(^7\) compare the PAC to a relic of the past, a rare curiosity.\(^5\) Are they right? Or are they short sighted? While we do not disagree with the evidence pointing to no benefit of the PAC in certain clinical settings, one must recognize that there are always two sides to a fair and balanced argument.\(^2\)\(^3\) This recent JAMA letter is not an isolated attack on the PAC. In fact, issues of PAC safety [Table 2], brought to the forefront by Connors in 1996, prompted a controversial call for the United States Food and Drug Administration to halt the use of the PAC pending further study.\(^12\)

To add fuel to the fire, many proponents and most critics of the PAC feel unusually strong about their position—a phenomenon all too commonly seen in medicine. To limit this bias, and for the sake of a fair and balanced argument, let’s eliminate statements such as “our experience” or “our institution” from this discussion, unless such experiential statements are based on at least some clinical evidence. Moreover, let’s suppose that an evidence-based, balanced approach to using the PAC exists. While we do not disagree that, in terms of absolute numbers, the use of the PAC is declining, we would like to propose a different interpretation of factors that contributed to the conclusions of the original study by Wiener and Welch.\(^7\)

Is it possible that the observed decline in the use of PACs is due to a more focused, evidence-based, and more judicious use of this hemodynamic monitoring technique? Perhaps, it is simply a reflection of the hypothesis that we are beginning to better understand when to use and when not to use the PAC. After all, it was not until recently that studies demonstrating the usefulness of the PAC in highly selected patient groups were published.\(^2\)\(^3\) Moreover, it may truly be that the PAC has to be used very selectively to improve outcomes, just like any other diagnostic modality. In other words, perhaps we should acknowledge that the PAC has been overused in the past and its utilization was so indiscriminate that patient outcomes were not only unaffected but perhaps worsened. But should this equate to proclaiming the demise of the PAC? Let’s take a step back...

The biggest criticism of the PAC technology revolves around the fact that medical practitioners fail to agree on the meaning of PAC-derived hemodynamic parameters and thus on how to translate these parameters into specific PAC-directed clinical interventions and when to institute these interventions. Therefore, an effort to standardize the interpretation of PAC-derived data may be the first step toward better understanding of what the data actually means.\(^9\) In other words, we are studying a modality we cannot quite agree on how to use… But what if such agreement could be reached?

In a recent study, the use of digital output volumetric PACs was associated with decreased inter-rater variability of data-driven treatment selections and improved inter-rater agreement with clinical practice guidelines when compared with traditional waveform output PAC.\(^9\) More studies of how to use the PAC, as opposed to the multimillion-dollar elaborate trials of outcomes in the presence or absence of this hemodynamic monitoring modality, would actually provide some benefit to both the patients and the clinicians. Once we learn how and...
when to use the PAC and perhaps evolve other means of displaying and interpreting PAC-derived data, we just might begin to understand how to use this hemodynamic monitoring modality.

There are numerous aspects of the PAC use that remain to be fully elucidated: (a) the optimization of oxygen delivery based on stroke volume per unit of body mass,[10,13] (b) the development of new "vital signs" based on beat-to-beat variability within various PAC-derived parameters,[13,14] and (c) validation of the proposed benefits of the PAC in the most severely injured trauma patients,[2] among many others. Perhaps, the most clinically relevant aspect of PAC use is the refinement of ICU resuscitations [Table 3]. The remainder of this discussion will focus on this use of the PAC.

For example, both animal and human studies provide some evidence that maintenance of the left ventricular stroke volume at or above 0.7–1.0 mL/kg may be physiologically advantageous to the patient.[10,13,15-17] In general, animal studies have demonstrated that surviving animals tend to have higher stroke volumes than nonsurviving animals.[18,19] The PAC may be uniquely positioned as the preferred method of hemodynamic monitoring in critically ill patients who require prolonged periods of hemodynamic monitoring (more than 24 h).[20] Unlike echocardiography or EDM, the PAC provides reliable real-time stroke volume information without the need for frequent bedside retesting (i.e., echocardiography) or probe readjustments (i.e., EDM).[20-22]

PACs used today are not the same catheters that were introduced over 30 years ago. They evolved significantly and are now capable of continuous measurements not only of cardiac output but also of mixed venous oxygen saturation. The modern PAC has the potential to dramatically influence our understanding of dynamic clinical situations, especially when compared to even quite recent past, when PAC-derived measurements were obtained and interpreted only several times per day. Again, the ability of the PAC to obtain continuous, multiparameter data constitutes an inherent advantage over various snapshot techniques.[23]

Another important consideration is the use of the PAC as a confirmatory tool and a brake to volume infusions, especially during massive resuscitations. The use of the PAC in this capacity may provide a mechanism to avoid many of the complications associated with the emergence of iatrogenic-induced resuscitation-related tissue edema.[9,10] The use of optimized volume resuscitations along with appropriate PAC-directed use of vasopressors and/or inotropes could potentially result in reduced incidence of the abdominal compartment syndrome and pulmonary edema, both of which are often seen during massive volume resuscitations.[10,23,24] The FACTT trial results seem to support this contention, and while the authors concluded that their study did not detect a difference in mortality, the conservative fluid strategy improved lung function and shortened the duration of mechanical ventilation and intensive care stay, without increasing nonpulmonary organ failures. These findings

| Category / Event Type                                           | Incidence   |
|----------------------------------------------------------------|-------------|
| Catheter placement                                             | 2.7%‑3.4%   |
| Unsuccessful placement                                         |             |
| Hematoma                                                       | 2.8%        |
| Arterial puncture                                              | 1.5%        |
| Pneumothorax - approximately                                   | 1%          |
| Mechanical                                                     |             |
| Catheter looping                                               | 0.2%        |
| Pulmonary artery perforation/ hemorrhage                       | 0.2%        |
| Thrombosis                                                     |             |
| Venous thrombosis                                              | 2.6%        |
| Arhythmia                                                      |             |
| Any aberrant rhythm                                            | 12%-46%     |
| Ventricular tachycardia                                         | 1.5%-23%    |
| Right bundle branch block                                      | 2.6%        |
| Infection                                                      |             |
| Bacterial colonization                                         | 35%         |
| Positive blood culture                                         | 0.6%‑5.4%   |
| PAC-associated bacteremia/sepsis                               | 1.3%-2.2%   |
| Infarction                                                     |             |
| Pulmonary artery infarction                                    | 1.7%        |
| Valvular injury                                                |             |
| Postmortem pulmonic valve injury                               | 15%         |
| Sources: Elliott et al. Chest 1979; 76:647-652 and Boyd et al. Chest 1983; 84:245-249. PAC: Pulmonary artery catheters |

| Category / Event Type                                           | Incidence   |
|----------------------------------------------------------------|-------------|
| PACs were overused in the past - the decrease in PAC utilization may well be a reflection of more selective and judicious use of these devices. |
| Clinicians continue to disagree with regard to interpretation of PAC findings and implementation of clinical interventions based on PAC findings/interpretations - we need to "agree to agree" More evidence is emerging with regard to patient subgroups and clinical situations that are more likely to benefit from the use of the PAC |
| Simplified and streamlined display of PAC-derived data may contribute to improved agreement among interpreting physicians with regard to the meaning and utility of this hemodynamic information as well as the implementation of appropriate clinical interventions. Pulmonary artery catheters may be best used in optimization of goal-directed resuscitations. The use of the PAC to optimize oxygen delivery while ensuring adequate resuscitation end points may help prevent the appearance of iatrogenic complications associated with excessive fluid resuscitation and resulting tissue edema while maintaining adequate tissue perfusion and oxygenation (Figures 1-3). Pulmonary artery catheter use to maintain optimal stroke volume per unit of body weight ratios (i.e., 0.7–1.0 mL/kg) may be associated with more "physiologic" resuscitations - outcome studies of such approach are clearly warranted. Other directions of study with regard to PAC use in resuscitations include the development of new "vital signs" based on minute-to-minute variability in various PAC-derived hemodynamic parameters and prospective validation of PAC use in patients who have been previously shown to benefit from aggressive hemodynamic monitoring in retrospective and small prospective studies. |

PAC: Pulmonary artery catheters
support the use of a conservative fluid management strategy in acute lung injury/acute respiratory distress syndrome patients.\(^4\) Use of the PAC may facilitate this just enough but not too much approach to fluid resuscitation. The clinical end point of truly goal-directed resuscitation would be the state of hemodynamic sufficiency [Figure 1].

To effectively calibrate ICU resuscitations, it has been postulated that the CVP may be useful as the accelerator pedal – an indicator that more fluid is needed and the PAC may be useful as the brake pedal – an indicator of the need for less volume and more forward flow during such resuscitations. In that capacity, the PAC is used to indicate that the patient has achieved optimal volume resuscitation and may require an addition of either a vasopressor or an inotrope for further enhancement of forward flow and/or attainment of adequate blood pressure parameters and thus optimized tissue perfusion [Figure 2].\(^{10,24}\)

**CONCLUSIONS**

It is unlikely that placement of a PAC or an oximetric central venous catheter alone, without integration into an organized program of early recognition, aggressive algorithmic resuscitation, and frequent reassessment would improve patient mortality. The value/utility of resuscitation techniques based on the CVP and PAC may in fact rest in telling us when to stop large-volume fluid resuscitation and when to start inotropic and/or vasopressor support. In an analogy between surgical ICU resuscitations and driving a car, CVP can be used as the accelerator pedal, while the PAC can be used as the brake pedal. Avoidance of iatrogenically induced tissue edema is a noble concept, and it may just be feasible using the concept of hemodynamic sufficiency.

In final comments, it seems overly harsh to discount a technology that might be beneficial in certain selected clinical scenarios, especially when considering that our true knowledge of this technology is still limited. With too many unknowns and potential ways to improve our understanding of the PAC, we are not ready to say, “the eyes cannot see what the mind does not know.”

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There are no conflicts of interest.
The concept of organ perfusion pressure and its relationship to the balance of the mean arterial pressure (MAP), the central venous pressure, and the efficient output of the cardiac pump. Imbalances between the arterial inflow and central venous pressures affect the end organ flow efficiency (curved red and blue arrows) and contribute to venous congestion and organ dysfunction. Eventually, the state of iatrogenic edema leads to inefficient end organ functioning.

Note that, in addition to inotrope regulation of cardiac pump, both the arterial and central venous pressures affect the end organ flow efficiency (curved red and blue arrows) and contribute to venous congestion and organ dysfunction. Eventually, the state of iatrogenic edema leads to inefficient end organ functioning. Other less invasive methods of hemodynamic monitoring await full clinical validation.

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