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Pulmonary Artery Catheter and Fluid Management in Acute Lung Injury and the Acute Respiratory Distress Syndrome

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Pulmonary artery catheterization was first performed by Lewis Dexter and colleagues [1,2] in 1945, and was then used in cardiac catheterization laboratories to diagnose congenital heart disease, mitral valve disease, and left ventricular failure. In 1970, Swan and colleagues [3] reported that the procedure could be performed at the bedside using a specially designed balloon-tipped catheter, and shortly thereafter the pulmonary artery catheter (PAC) was introduced for clinical use. The PAC provides a wealth of information about circulatory and respiratory systems and intravascular fluid volume over time. Specifically, the PAC allows measurement of central venous and pulmonary arterial pressure, pulmonary artery occlusion pressure (PAOP, or "wedge" pressure), mixed venous blood gases, and indicator-dilution cardiac output. Based on these quantitative data, systemic and pulmonary vascular resistance can be derived. Thus, the PAC quickly became widely used in critically ill patients, in spite of the lack of evidence for its benefit or safety.

The PAC is frequently used in patients with acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) [4], both to confirm the diagnosis and to optimize hemodynamic management. In this article, we review the evidence on the use of the PAC in patients with ALI/ARDS, paying particular attention to the recently published fluid and catheter treatment trial by the ARDS Clinical Trials Network [5,6].

The pulmonary artery catheter and fluid management in the acute respiratory distress syndrome

In healthy animals, high pulmonary capillary pressure causes ultrastructural damage to the capillary walls, with a resulting "high permeability" (capillary leak) type of edema. A high concentration of leukotriene B4 and inflammatory cells is also found in the bronchoalveolar lavage of these animals, suggesting the onset of an inflammatory process [7]. Studies in animals with ALI indicate that the degree of edema is reduced if left atrial pressure is lowered [8] and that continuous infusion of furosemide improves oxygenation and decreases positive end-expiratory pressure (PEEP) requirements [9]. Theoretically, measurement of the PAOP and cardiac output may make it possible for physicians to maintain pulmonary vascular pressures at a lower level, thus reducing the quantity of pulmonary edema that may develop in the presence of an increase

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in lung vascular permeability [10,11]. Also, maintaining a lower pulmonary capillary pressure may prevent or minimize damage (''stress failure'') to the capillary wall [7]. Furthermore, the measurement of pulmonary arterial pressure and cardiac output may guide the administration of vasoactive agents to optimize cardiac output, maintain or improve renal function, and increase systemic blood pressure and blood flow to vital organs [10].

Based on the above rationale, the PAC has been commonly used in patients with ALI/ARDS. Although the data obtained from the PAC provide considerable physiologic information about the systemic and pulmonary derangements that occur in patients with ALI [10], it is important to clarify if such information improves therapy or clinical outcomes. In a retrospective study of 113 patients with ARDS in whom pulmonary artery pressure and PAOP were monitored, Simmons and colleagues [12] found that survivors lost weight and had a significantly lower cumulative positive fluid balance compared with nonsurvivors. Mitchell and coworkers [13] randomized 52 patients with pulmonary edema (already being managed with a PAC) to either an extravascular lung water (EVLW) management (based on bedside indicator-dilution measurements) or a ''routine'' wedge pressure management group. The EVLW management strategy achieved both a lower overall net fluid balance and a lower extravascular lung water, and was associated with improved mortality and shorter ICU length of stay, although some of these patients had cardiogenic pulmonary edema. These studies suggested that achieving a lower fluid balance in ARDS patients may be associated with improved clinical outcomes.

In a retrospective study of 40 ARDS patients, those patients who experienced a reduction of wedge pressure of at least 25% during acute management (first 48 hours) were found to have better survival than those patients who did not experience such a reduction in wedge pressure (75% versus 29% survival, $P < .02$) [14]. In addition, Fergusson and coworkers [15] showed that persistently elevated PAOP ($>$ 18 mm Hg) was a strong predictor of mortality in a post hoc analysis of 120 patients with ARDS. A study by Martin and colleagues [16] showed that combination therapy with furosemide and albumin over a 5-day period in 37 ALI patients with hypoproteinemia was accompanied by weight loss and led to improvements in oxygenation and hemodynamics. About a third of these patients had a PAC inserted and no differences were noted in PAOP [17]. A recent study by the same group suggests that the benefits are only seen in patients who receive both albumin and furosemide, but not furosemide alone [18]. Finally, in an observational study of 135 patients with ALI, Marinelli and colleagues [19] showed that the information provided by the PAC led to a change in therapy in 78% of these patients.

However, the clinical value of the PAC has been controversial. First of all, even though the PAC is frequently used in critically ill patients, there is no evidence that it improves outcomes [20]. The absence of benefit may be related to data misinterpretation [21–24], incorrect action based on unambiguous data [25], or simply to the lack of effective treatments to use in combination with PAC information. Furthermore, observational studies suggested an increase in mortality in the elderly [26] and patients with acute myocardial infarction [27,28] managed with a PAC. In 1996, Connors and colleagues [29] published a multi-institutional, case-matched study of critically ill patients that adjusted for treatment selection with propensity scores, and reported that the use of PAC was associated with increased mortality. Because of the nonrandomized design of these studies and because baseline characteristics of the patients may not have been the same, their results were not conclusive. However, concern that the PAC may be harmful led to calls for a moratorium on the use of the PAC or the conduction of randomized controlled trials to settle the issue [30,31].

Only in recent years has the medical community generated prospective randomized controlled data to establish the clinical risk/benefit ratio of use of the PAC in critically ill and ALI/ARDS patients [32–34], culminating with the recently published fluid and catheter treatment trial (FACTT), which addressed both the issue of the PAC [5] and fluid management [6]. A summary of these recent papers is presented in Table 1. This summary excludes the recent trials conducted in high-risk surgical patients [35] and congestive heart failure [36] because the focus of this article is patients with ALI/ARDS.

The previous randomized controlled trials failed to show any benefit from the use of the PAC in terms of mortality or organ failure, but also there was no major harm. These studies were not entirely conclusive though, since they had some limitations such as a small sample size [32], the inclusion of severely ill patients with a high mortality [34], lack of a control arm with a central venous catheter (CVC), lack of training of the