Invasive Hemodynamic Monitoring

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KEYWORDS

- Cardiac output • Central venous pressure • Pulmonary artery catheter
- Pulmonary artery occlusion pressure • Pulmonary pressure

KEY POINTS

- Proper use of invasive monitoring must begin with careful attention to the details of making the measurements and making the measurements safely.
- A useful start in managing hypotension is to consider whether the problem is a cardiac output problem or a systemic vascular resistance problem.
- If the cardiac output is the primary problem, the next question is whether this is due to a cardiac function problem or return problem (venous return).
- Measurements of cardiac output and central venous pressure are central to separating these possibilities.
- Trends in cardiac output and central venous pressure are more useful than static measures.
- Pressure tracings can provide diagnostic information beyond the simple hemodynamic measures, including indications of pulmonary function.

INTRODUCTION

The use of invasive hemodynamic monitoring has decreased significantly over the past 2 decades. An important likely factor is failure to find an effect on outcome in an evidence-based medicine driven approach to patient management.[1] However, lack of evidence of benefit does not mean that there is no benefit. Studies on the use of pulmonary artery catheters (PACs) have been limited by lack of algorithms that can show their usefulness, lack of precision in making the measurements, and lack of physiologic rationale of what actually can be fixed based on the information obtained.[2–5] Invasive monitoring also requires a greater skill set on the part of the practitioner, yet studies have shown a striking lack of knowledge of the measurements obtained with the PAC.[6,7] Another issue is the risks associated with insertion of the

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catheter. However, a major component of such risks is the insertion of a central venous line, which needs to be inserted anyway in most critically ill patients to allow infusion of vasoactive drugs. Furthermore, less invasive devices are not necessarily noninvasive and carry risks of their own, including cannulation of brachial or femoral arteries, which are more invasive than the simple insertion of radial artery catheters. In general, the less invasive the device the less accurate, precise, and reliable it is. Less invasive devices cost more than the simple PAC and the information they give also is more limited. Although the complexity of clinical problems makes it difficult to rigorously establish a role for PACs in randomized trials, the author's sense is that there will likely remain a place for their use in complex patients who are difficult to manage. However, use of PACs requires knowledge of how to use them properly. This article begins with a short review of the basic physiology that determines cardiac output and blood pressure, thus to understand how the measurements obtained can be used for both diagnosis and direct management. Data from a PAC only can be useful if properly measured, so the basics of making such measurements are reviewed. Use of the PAC in making a diagnosis and for management is addressed; these are not the same, and the emphasis is on the use of a responsive approach to management. Finally, the author explores uses of the PAC that are not indications by themselves for placing the catheter, but can provide useful information when a PAC is in place.

Purpose of the Circulation

The primary purpose of the circulation is to deliver the appropriate amount of oxygen and nutrients to the tissues to meet their needs and to remove wastes. The delivery of oxygen (Do_2) is determined by the product of cardiac output (Q), hemoglobin concentration ([Hgb]), and the saturation of hemoglobin, which in turn is determined by the partial pressure of oxygen (Po_2) and a constant (*K*) that gives the O_2-carrying capacity of hemoglobin:

$$Do_2 = Q \times [Hgb] \times O_2 \text{ saturation} \times K$$

Values for *K* used in the literature vary from 1.34 to 1.39. Isolated pure hemoglobin carries 1.39 mL O_2 per gram, but blood also has methemoglobin and carboxyhemoglobin so that lower empiric values for *K* are used for determining the oxygen content in blood. This simple equation indicates that only 3 variables can increase or decrease Do_2. The range of manipulation of hemoglobin is usually not large, and that of saturation even less. For example, an increase in arterial O_2 saturation from 85% to 100% only increases Do_2 by 18% and increases [Hgb] from 90 to 100 g/L by 11%. It should thus be evident that cardiac output is the primary variable that can be manipulated for making major changes in Do_2.

Regulation of Cardiac Output

Cardiac output is determined by the interaction of cardiac function and a function that defines the return of blood to the heart (venous return function) (**Fig. 1**).[8,9] A key implication of this statement is that the heart only can pump out what comes back to it. In turn, this is primarily determined by the properties of venous drainage back to the heart because almost 70% of blood volume is in small systemic veins and venules.[10] By stretching the small veins and venules, this volume creates an elastic recoil pressure that drives flow back to the heart through the small resistance that separates the venous reservoir from the right heart.[8,9] In this analysis arterial blood pressure does not have a significant impact on the return of blood to the heart, for it is the volume