

Commentary

Hemodynamic monitoring over the past 10 years

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Abstract

Changes in hemodynamic monitoring over the past 10 years have followed two paths. First, there has been a progressive decrease in invasive monitoring, most notably a reduction in the use of the pulmonary artery catheter because of a presumed lack of efficacy in its use in the management of critically ill patients, with an increased use of less invasive monitoring requiring only central venous and arterial catheterization to derive the same data. Second, numerous clinical trials have documented improved outcome and decreased costs when early goal-directed protocolized therapies are used in appropriate patient populations, such as patients with septic shock presenting to Emergency Departments and high-risk surgical patients before surgery (pre-optimization) and immediately after surgery (post-optimization). Novel monitoring will be driven more by its role in improving outcomes than in the technical abilities of the manufacturers.

Hemodynamic monitoring is a cornerstone in the care of the hemodynamically unstable patient. It serves as a monitor both of stability and acute deterioration and of response to therapy. Although hemodynamic monitoring is also both context specific and disease specific, it is primarily driven by technology and offset by utility. Nothing underscores this concept better than the decline in the use of the pulmonary artery catheter (PAC), whose use has markedly decreased while its ability to measure increasingly more hemodynamic variables increased [1]. In its ultimate format the PAC continuously measures temperature, heart rate, mixed venous saturation of O₂ (SvO₂), cardiac output, right ventricular ejection fraction and end-diastolic volume, central venous pressure and pulmonary arterial pressure. When coupled with non-invasive pulse oximetry, it can also give total body oxygen delivery (DO₂) and consumption (VO₂). Yet despite these impressive abilities, use of the PAC has decreased primarily because few, if any, clinical trials have shown that this litany of information improves management enough to alter patient outcome [2].

Clearly, the primary changes in hemodynamic monitoring over the past 10 years can be summarized as a decrease in use of

the PAC with a greater use of measures, presumed to be less invasive, to derive the same hemodynamic data, and the institution of protocolized resuscitation approaches driven by selective hemodynamic measures. The initial logic for these trends is not clear because, until recently, patient outcomes have not been shown to be better when these data are available from the PAC, so why would outcomes improve if these same data are now available other means? Still, the major thrusts were in the realm of alternatives to the PAC, such as esophageal Doppler estimates of cardiac output [3] and arterial pressure pulse contour and signal processing estimates of stroke volume [4]. Furthermore, using only central venous and arterial access one can also measure central venous percentage saturation of hemoglobin with oxygen (SO₂), cardiac output and other more esoteric parameters such as global cardiac volumes and lung water [5]. Although other technologies studied over the past 10 years focused on regional blood flow – examples are measures of splanchnic blood flow from a PAC inserted into a hepatic vein, gastric mucosal blood flow from gastric tonometry, and liver function by indocyanine green dye clearance – the generalized use of these monitoring techniques has never caught on, primarily because they were not associated with improved patient outcomes. Importantly, no monitoring device, no matter how accurate or complete, would be expected to improve patient outcome, unless coupled to a treatment that itself improves outcome [6]. This basic truth underscores the theme that has been increasingly commonly heard, namely that technology should not drive monitoring: improved outcomes-defined treatments should.

Thus, several important clinical trials have documented that early aggressive resuscitation approached with guidance from defined hemodynamic variables using thoughtful protocols may improve outcome. Rivers *et al.* [7] showed that an aggressive resuscitation protocol guided by central venous SO₂ and pulse oximetry (arterial oxygen saturation (SpO₂)) and delivered in an Emergency Department improved

DO₂ = total body oxygen delivery; PAC = pulmonary artery catheter; pCO₂ = tissue partial pressure of carbon dioxide; pO₂ = tissue partial pressure of oxygen; SO₂ = percentage saturation of hemoglobin with oxygen; SpO₂ = arterial oxygen saturation; SvO₂ = mixed venous saturation of O₂.

outcome in patients with septic shock. This study was in contrast with the numerous earlier studies showing the futility of aggressive resuscitation once shock is established [8,9], or when PAC insertion is not associated with an aggressive resuscitation protocol [2,10]. The concept underscored by this newer trial was that appropriate resuscitation prevents subsequent tissue injury even if overt shock is present, if the resuscitation is performed early enough.

The race was then on to identify other patient subsets whose outcomes could be improved by similar aggressive resuscitation approaches. Spurred on by the initial work of Shoemaker *et al.* [11], who showed that high-risk surgical patients could have their mortality decreased by a pre-emptive resuscitation protocol aimed at achieving a high initial DO₂, referred to then as 'survivor levels of DO₂'. Although this study was criticized for not having proper control groups, it did demonstrate that preventing initial ischemia may be useful. These findings were supported by Boyd *et al.* [12], who also demonstrated a survival advantage in preemptive resuscitation. This therapeutic philosophy has been referred to a 'pre-optimization' to distinguish itself from treatment of patients already in shock. Importantly, the recent literature has shown that pre-optimization protocols improve outcome [13] and are cost-effective [14]. Because pre-optimization approaches focus on maximizing DO₂ before surgery in high-risk patients, hemodynamic measures of blood flow are all that are needed to accomplish these goals.

Carrying this theme forward, recent studies have shown that in similar high-risk surgery patients, the use of aggressive fluid resuscitation in the immediate postoperative period also improves outcome, as measured by decreased length of stay and hospital costs [3,4]. Importantly, these 'post-optimization' approaches also rely on measuring only blood pressure, cardiac output, and SpO₂, making them synchronous with the instrumentation needed for pre-optimization protocols.

Finally, functional hemodynamic monitoring techniques, such as measuring variation in pulse pressure [15] or in stroke volume [16], have been shown to be robust markers of those subjects with a high propensity for increasing cardiac output if given a fluid challenge. Clinical trials using these parameters to document efficacy will need to be done, but will probably show that these measures also aid in defining appropriate therapy when resuscitation is planned.

Thus, the future approaches to hemodynamic monitoring will, at the least, focus on measures of cardiac output, arterial pressure, and SvO₂. To the extent that these measures can be made continuously and in a non-invasive fashion they will enjoy a wider degree of application and potentially prove cost-effective. Finally, these measures will be made more effective if coupled with parallel measurements of tissue wellness with other monitoring techniques. Although measures of sublingual tissue partial pressure of carbon

dioxide (pCO₂), sublingual capillary blood flow, tissue partial pressure of oxygen (pO₂), pCO₂, pH, and even NAD⁺/NADH ratios can be made [17], their utility in the diagnosis of critical illness and monitoring of response to therapy have yet to be proven. The linkage between these non-invasive continuous measures of metabolic function, global measures of hemodynamic status and clinical outcomes needs to be made and, if shown useful, may be the direction we take in the future to guide us in the resuscitation of patients with critical illness.

Competing interests

MP is a medical advisor to Arrow International, Edwards Lifesciences and LiDCO Ltd. MP and the University of Pittsburgh co-own US patent no. 6,776,764, 'Use of aortic pressure pulse and flow in bedside hemodynamic management.'

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