Emerging technology in acute resuscitation monitoring

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ABSTRACT

Fluid optimization in the resuscitation of shock became the mainstay of treatment following the advent of Early Goal-Directed Therapy (EGDT) by Rivers *et al.* in 2001 [1]. Patients presenting in shock require prompt optimization of volume status and cardiac output to ensure adequate perfusion. Poor optimization may be associated with prolonged hospital and intensive care unit stays. The prior gold standard, pulmonary artery catheterization, is rarely available in the emergency department setting and its invasive nature has led to recent re-evaluation of its clinical utility. However, there are new monitoring technologies that are being studied in the intensive care unit setting that may soon be available in emergency departments to aid in nursing and physician decision making to improve acute resuscitation.

Keywords: Critical Care; Monitoring;
Minimally-Invasive; Resuscitation

1. HISTORY

In 1870, Adolf Fick proposed a method to determine cardiac output utilizing the relationship between rate of oxygen uptake and consumption in an organ by calculating the difference in oxygen content of arterial blood and mixed venous blood [2]. However, Fick's model was rarely used at the time due to the difficulty and danger of obtaining mixed venous blood samples; it was only tested on animals initially. It would not be until more than half of a century following his publication, that Werner Forssmann, in 1922, would demonstrate the first recorded cardiac catheterization in humans [3]. In an effort to elucidate the benefits of direct cardiac administration of medications as well as study the metabolic mechanisms of the human body, Forssmann would self-catheterize with a ureteral catheter without complication. Though already being performed in animals, human cardiac catheterization opened a world of possibilities in the realm of hemodynamic monitoring, particularly application of the direct Fick principle.

A century after Fick's description of cardiac output, an article in the New England Journal of Medicine described catheterization of the heart with a balloon-tipped catheter [4]. Advancements since the time of hemodynamic monitoring via cardiac catheterization have led to several hemodynamic minimally invasive techniques that have become available providing continuous CO measurement, with or without the utilization of invasive calibration.

2. CURRENT NEEDS

Hemodynamic monitoring to confirm diagnosis or as a guide for therapeutic intervention in critically ill patients in the emergency department currently requires invasive methods such as pulmonary artery catheterization (PAC), central venous catheterization, and arterial lines. The former has lost its role as the first choice of hemodynamic monitoring and optimization in the intensive care unit (ICU) and is rarely used in the emergency department due to complications and the availability of less invasive devices to measure cardiac output (CO) [5]. Adverse events associated with placement of the PAC range from local pain, infection, or hemorrhage at the insertion site, to death [6-11]. These complications can be expected to occur more frequently in non-ideal settings, particularly during emergent placement [11]. It is with this understanding that application of the minimally-invasive methods of hemodynamic monitoring should be reviewed in the emergency setting.

3. NEW TOOLS

A number of systems are now available that are less invasive than pulmonary artery catheterization. They also provide beat to beat stroke volume measurement and other parameters based on pulse contour and stroke volume analysis when heart rhythms and respiratory status are stable. The systems more directly estimate volume status with different assumptions than pressure measurements such as central venous pressure that intend to estimate left ventricular end diastolic pressure in lieu of left ventricular end diastolic volume.

Stroke volume variation may more accurately identify

Scientific
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patients who are preload responsive, in other words, those patients who will have additional increase in cardiac output with the administration of further volume. This is a key parameter that clinicians struggle with particularly during early resuscitation as they attempt to optimize volume status without the causing pulmonary edema. Many of the other tools used to estimate this parameter, such as central venous pressure, serial vena cava index ultrasound, esophageal Doppler, and pulmonary artery catheterization, have logistic, invasive, and other limitations on their use in the emergent setting. Therefore, further examination of these newly available technologies is warranted.

Arterial pulse-wave analysis PiCCO (PiCCO Plus; Pulsion Medical Systems, Munich, Germany) and LiDCO (LiDCO Plus; LiDCO, Cambridge, UK) systems are validated by numerous studies and have shown overall good correlation compared with the pulmonary artery thermodilution technique [12-14]. They can be manually calibrated by transpulmonary thermodilution (PiCCO), lithium dilution (LiDCO), or previous measurement of the aortic diameter, to compensate for inter-individual differences in arterial compliance [15,16].

3.1. PiCCO

The PiCCO system requires central venous access and the cannulation of a large arterial vessel for transpulmonary thermodilution calibration. Typical parameters followed are cardiac output, end diastolic volume, systemic vascular resistance, and stroke volume variation. In addition to using stroke volume variation to predict volume responsiveness, a new parameter, pulmonary vascular permeability index is available. This is suggested to differentiate inflammatory induced capillary leak from congestive cardiac edema although further testing is needed [17,18].

3.2. LiDCO

The LiDCO system allows minimally invasive calibrated, continuous, real-time monitoring of cardiac output through a bolus indicator dilution method and pulse contour analysis. The transpulmonary bolus indicator dilution ca-libration is similar to transpulmonary thermodilution, however, only a peripheral (brachial) intravenous and peripheral (radial) arterial line are required [19-21]. The LiDCO system requires a peripheral venous catheter as well as an arterial line. A nonreactive Lithium chloride (0.15 mmol) bolus is injected into the peripheral venous line and detection of the indicator in the arterial blood by the lithium-sensitive electrode produces a lithium concentration-time curve [20]. A robust number of parameters that includes cardiac output, end diastolic volume, systemic vascular resistance, and stroke volume variation can be evaluated on a beat-to-beat basis.

3.3. FloTrac/Vigileo

The recently introduced, 3rd generation FloTrac/Vigileo (Edwards Lifesciences, Irvine, CA), calculates continuous CO from arterial pressure waveform characteristics utilizing an expanded patient algorithm database including height, weight, age and sex, and real-time arterial pressure waveform analysis, rather than requiring external calibration. It automatically calculates key flow parameters every 20 seconds as well as recognizes and adjusts for hyperdynamic, and vasodilated patient conditions allowing for volume or cardiovascular intervention (preload, afterload, and contractility). The direct proportionality between arterial pulsatility and the stroke volume in conjunction with heart rate is used to calculate CO. Sex, age, and the body surface area are used to correct for interindividual differences in arterial compliance based on the model described by Langewouters *et al.* [22]. In addition to CO (index), the FloTrac/Vigileo calculates stroke volume variation (SVV). Systemic vascular resistance and the systemic vascular resistance index are calculated if central venous pressure is available. Continuous central venous oxygen saturation can be obtained and displayed as well with implementation of specialized central venous catheterization. Please see **Table 1**.

4. CONCLUSION

With the emergence of noninvasive and less invasive hemodynamic monitoring and their documented suc-

Table 1. Arterial flow continuous cardiac output monitoring systems.

Device	Continuous CO monitoring	BP monitoring	Requires central venous access	Calibration necessary	Limitations
LiDCO	Yes	Yes	Yes	Yes[**]	Arterial flow signal quality. Rapid changes in vascular motor tone
PiCCO	Yes	Yes	Yes	Yes	Arterial flow signal quality. Rapid changes in vascular motor tone
FloTrac/Vigileo	Yes	Yes	Yes[*]	No	Impaired accuracy due to changes in vascular motor tone without calibration

[*]For continuous ScvO$_2$ monitoring. [**]Rapid; cal available but not required.

cess in the critically ill patient, it is appropriate to question the lack of studies of these devices in the emergency department, and the potential benefits to critically ill patients it affords therein. Continuous cardiac output monitoring that informs optimal preload and afterload can guide the timing of fluid, vasopressor, and inotrope therapies. Such goal directed or quantitative resuscitation efforts can be associated with improved outcomes, decreased length of stay, and reduced complications [23]. The advanced available technology and the increasingly complex patients presenting to emergency departments requiring acute resuscitation increases the likelihood that today's nurses will begin to see these new systems deployed to the emergency department environment to pro- vide critical monitoring.

5. ACKNOWLEDGEMENTS

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