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The PICU perspective on monitoring hemodynamics and oxygen transport

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Abstract

Alterations of hemodynamics and oxygen transport balance are very common scenarios in the pediatric intensive care unit (PICU), and these alterations are as heterogeneous and diverse in nature as are the patient populations that typically exist in the PICU. Accordingly, the PICU perspective on monitoring of hemodynamics and oxygen transport balance in critically ill children must be understood in this context of heterogeneity and diversity. We provide an interpretation of the evidence supporting various monitoring strategies as presented in the The Pediatric Cardiac Intensive Care Society Evidence Based Review and Consensus Statement on Monitoring of Hemodynamics and Oxygen Transport Balance from a Pediatric Intensive Care perspective.

Keywords

oxygenation; hemodynamic monitoring; shock; pediatric intensive care unit

Believe nothing, no matter where you read it or who has said it, not even if I have said it, unless it agrees with your own reason and your own common sense.

—Buddha

Alterations of hemodynamics and oxygen transport balance are very common scenarios in the pediatric intensive care unit (PICU), and these alterations are as heterogeneous and diverse in nature as are the patient populations that typically exist in the PICU. Accordingly, the PICU perspective on monitoring of hemodynamics and oxygen transport balance in critically ill children must be understood in this context of heterogeneity and diversity. With all due respect to the proponents of evidence-based medicine, the majority of what follows is based on informed clinical opinion encompassing almost 40 combined years of experience at the bedside of critically ill children.

A relevant example of PICU-related heterogeneity, which provides the framework for the ensuing discussion, is the child with septic shock. There are 4 traditional, broad classifications of shock states: hypovolemic, cardiogenic, obstructive, and distributive shock. Septic shock is unique in that all four forms of shock may be involved simultaneously. The child with septic shock may have *hypovolemic* shock resulting from capillary leak, increased insensible fluid losses, and decreased effective blood volume

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secondary to vasodilation; *cardiogenic shock* related to myocardial-depressant effects of bacterial toxins and inflammatory cytokines; *obstructive shock* from diffuse small vessel thrombosis or abdominal compartment syndrome; and/or *distributive shock* from decreased systemic vascular resistance and cytopathic hypoxia. In some cases, patients display increased cardiac output with diminished systemic vascular resistance. The presenting symptoms in this scenario are tachycardia and bounding pulses characteristic of the distributive mode of shock or the so-called “warm” shock state. Despite this appearance, the perfusion of major organs during this shock state may remain severely compromised. Alternatively, a child with depressed cardiac output and elevated systemic vascular resistance appears cool with diminished pulses and poor capillary refill characteristic of the “cold” shock state. The degree to which an individual child with septic shock manifests these physiologic perturbations varies widely, and the perturbations can be highly dynamic during the course of disease.

Because of the rapidly changing hemodynamic state of children in shock and developmental changes that occur with age, including the wide ranges of weight and size, no single mode of hemodynamic and oxygen transport monitoring has been identified that can consistently meet the needs of the heterogeneous PICU population. Echocardiography is outstanding for addressing anatomic issues, but appears to be qualitative, at best, with regard to cardiac function in most PICU patients. For example, we have all looked after patients on large doses of inotropes who are said to have “normal” function by echocardiogram, but have continued manifestations of shock such as ongoing renal insufficiency, poor perfusion, and acidosis. Echocardiographic estimates of right ventricular pressures in PICU patients suspected of having elevated pulmonary artery (PA) pressures are often highly discordant with the clinical scenario and have correlated poorly with direct PA pressure measurements. Variations on traditional echocardiography are small, laptop-sized ultrasound monitors which are touted to provide repetitive and easy assessment of cardiac output and function. These devices seem desirable due to their ease of use, small and convenient size, and the seeming ability to be used by clinicians with little specialized echocardiographic training. Much as the “FAST” ultrasound techniques which are being used to evaluate abdominal trauma in the Emergency Department, such devices are becoming widely used in many adult and pediatric ICU’s. However, their accuracy in assessment of cardiac output when compared to thermodilution has been variable, with poor agreement between them and the “gold standard” thermodilution measurements in many studies. Whether such devices will prove useful for routine bedside monitoring in the future requires more careful and consistent evaluation.

Another means to assess cardiac performance are serial measures of biomarkers such as troponin and B-natriuretic peptide. Due to extreme alterations of cellular function and gene expression in critical illness, these biomarkers can indeed be variably increased in PICU populations without primary cardiogenic shock. The clinical applicability of these biomarker perturbations, however, remains to be determined in the general PICU population. For example, troponins can be increased in patients with status asthmaticus being treated with high levels of β -agonists, but have not correlated with cardiac dysfunction by clinical or electrocardiographic assessment. Isolated elevations of troponin can be seen in patients with muscular dystrophy and a variety of other causes such as cardiac arrest. Their utility in predicting outcome or changing management, however, is poorly defined in the pediatric population in the ICU. Among cardiac patients, serial troponins do provide some information as to cellular myocardial damage and may be beneficial to follow cardiac injury or as a marker to indicate need for more invasive investigation for myocardial ischemia such as cardiac catheterization.

Other “emerging technologies” such as femoral pulse waveform devices (PiCCO) are also touted as accurate, easy to use, and valuable over a wide range of sizes of patients. However, one wonders if the risk of continuous femoral artery catheterization is really less than that of a pulmonary artery catheter, from which more direct measurements can be obtained. PiCCO monitoring does not seem to provide consistently more reliable information than other technically less problematic trend monitors (i.e. mixed venous saturations and serial lactate measurements) in the PICU setting. The purported ability to assess “lung water” with the PiCCO device is one of the more intriguing aspects of its use but this has not become any standard of care in pediatrics.

The demonstration almost a decade ago that adults presenting with septic shock have a survival advantage when initial resuscitation is targeted toward normalization of superior vena cava saturations has generated considerable interest (and controversy) in the critical care literature [1, 2]. Since the initial euphoria, the study by Rivers et al. is now viewed with well founded equipoise by many, and in fact the concept of “early goal directed therapy” is being formally re-tested in an ongoing multi-center, randomized clinical trial (ClinicalTrials.gov Identifier: NCT00510835). An analogous study in pediatric patients with septic shock demonstrated a similar survival advantage, but the generalizability of these data to the PICU population in the United States is questionable given the very high baseline mortality in the pediatric study [3]. The question that remains unanswered, in our opinion, is whether these studies have demonstrated that normalization of superior vena cava saturations is a key singular goal onto itself, or if recognition and aggressive resuscitation at presentation (i.e. being a “good doctor”) are the important factors that impact outcome.

The accuracy of superior vena cava saturations, relative to true mixed venous saturations (i.e. PA saturations), is open to debate and subject to interpretation. Multiple studies have compared parallel samples of superior vena cava saturations and true mixed venous saturations measured from the PA. Interestingly, studies that have generated nearly identical “r values” by linear correlation analyses have come to diametrically opposed conclusions regarding the reliability of superior vena cava saturations [4, 5]. Presently, we believe that tracking superior vena cava saturations should be viewed as a sometimes useful adjunct to trend, rather than a singular endpoint, in the management of heterogeneous patients in the PICU with hemodynamic derangements.

Serial measurements of lactate and non-invasive estimates of mixed venous saturations (i.e. NIRS) fall into the same category as superior vena cava saturations: sometimes useful adjuncts for trending, rather than singular endpoints in managing PICU patients with heterogeneous forms of cardiovascular compromise. The primary advantage of NIRS and related technology (i.e. visible light spectroscopy) is the non-invasive nature of the technology. The “goodness of fit” between NIRS-derived measurements and central venous saturations is open to the same debate and subjectivity as that described above for superior vena cava saturations and PA-derived true mixed venous saturations. Interestingly, a very recent study demonstrated that goal directed therapy guided by serial lactate measurements was equivalent, in terms of survival/mortality outcome, to goal-directed therapy guided by superior vena cava saturations in adults with septic shock [6].

One clear observation with the monitoring devices and measures discussed herein is that the “true” accuracy of the data obtained is most often compared to thermodilution from a pulmonary artery catheter—which remains the “gold standard” as most reflective of the patient’s hemodynamic status. This observation, coupled with the technical and economic challenges that “emerging technologies” often face as they aim to become imbedded in routine care of the patient with shock, lead us to conclude that the “emerging technologies” require further refinement (i.e. they need to “emerge” further) before being used routinely in

the PICU setting. It is a conundrum, however, that the very technique which forms the basis for all other modalities to be measured against, however, is the one that is now most often ignored. Use of the PA catheter in pediatric ICU's is almost obsolete. This has occurred largely from the debates over the "usefulness" of the PA catheter, which has raged among adult intensivists for decades and has influenced the use of the PA catheter in pediatrics as well. Just as in many other areas of medicine, however, what has been discarded in the past may deserve reexamination. It is of interest that after many years of acceptance as the "optimal" means of CPR, breathing is now being reconsidered as to whether it is helpful or harmful [8]. This harkens back to the earliest days of CPR when breathing was considered unnecessary and which is coming back into vogue today. Similarly, MAST trousers for Fontan patients to increase venous return was practiced fairly routinely when the authors were fellows, dropped out of fashion, and now is returning as a supportive tool. While there is no doubt that a non-invasive or simple tool to assess hemodynamics and cardiac performance would be a major boon to pediatric ICU care, none of the aforementioned techniques have proven to be better (or as good) as the PA catheter.

This leads us to consider a "back to the future" approach as the optimal means for assessing hemodynamic and cardiac performance in the ICU. Since the PA catheter is the "gold standard" then perhaps the PA catheter should be the modality of choice when one really needs to know the hemodynamic status of the critically ill child. We are cognizant of the controversy that surrounds the PA catheter. Not surprisingly to us, the indiscriminate use of the PA catheter will lead to studies demonstrating "no benefit" and even potential harm [7]. However, we strongly contend that selective use of a PA catheter should remain in the armamentarium of the critical care physician, and are leveraging the privilege of writing this opinion piece as a call to action to the pediatric critical care community. When one truly needs to know the hemodynamics of the critically ill child, there is no substitute that consistently matches the performance of the PA catheter—provided that the clinical team at the bedside knows how to set it up, perform the calculations, and interpret the data accurately. Arguments surrounding inaccurate interpretation of PA catheter-derived data are now becoming a self-fulfilling prophecy. By not placing PA catheters under the banner of "evidence-based medicine" we are rapidly losing the opportunity to teach our trainees how to perform a procedure and correctly interpret data that should otherwise be fundamental for any critical care physician.

One last comment concerns the physical exam. One potential drawback of all monitoring modalities, including the PA catheter, is the risk of paying attention to the monitor, the number, or the trend, without paying attention to the physical state of the patient. There is no substitute for sequential physical examination to evaluate the effectiveness (or lack thereof) of our interventions and therapeutic decisions. While in some patients, those with purpura fulminans as an example, clinical exams are impaired, such patients are rare. All of the aforementioned modalities for monitoring hemodynamics and oxygen transport need to be integrated with the physical exam, rather than serving as isolated parameters to pursue regardless of what our eyes, ears, and hands are telling us. When this integration fails to yield an improvement in hemodynamics and/or oxygen transport, then strong consideration should be given to the selected placement of a PA catheter, if feasible.

Challenging dogma is often an excellent means to move medical care forward, but sometimes looking backward to what has worked well in the past can serve the same purpose.

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