HEMODYNAMIC ASSESSMENT IN THE EMERGENCY DEPARTMENT

Tools and Information for Clinical Decision Making

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Learning objectives:
Following completion of the symposium the participant should be able to:
- *Describe hemodynamic assessment tools and hemodynamic monitoring.*
- *Discuss the use of hemodynamic trending to assess patient status in sepsis.*
- *Review the starling Curve and the use of cardiac output to guide resuscitation.*
- *Apply techniques related to hemodynamic monitoring in the ED and transport services.*

Intended Audience:
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Hemodynamic Assessment in the Emergency Department
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Hemodynamic Trending to Assess Patient Status

Although invasive hemodynamic monitoring remains the standard for management of critically ill patients, minimally invasive techniques continue to emerge and show promise as potential alternatives to the current standard. Interest in minimally invasive and noninvasive monitoring techniques is fueled in part by the limitations of current monitoring technology, said Robert N. Bilkovski, MD, associate research director in emergency medicine at Henry Ford Hospital in Detroit, Mich. Additionally, noninvasive techniques offer more potential for hemodynamic monitoring in the emergency department and the out of hospital environment. The pulmonary artery catheter (PAC) offers a good example of the mixed emotions evoked by invasive monitoring techniques. "We have a love–hate relationship with the pulmonary artery catheter," said Dr. Bilkovski "When it is used correctly, it is very helpful, but it can be difficult to use. If you wanted to place one in a patient in the emergency department, would your nurses shoot you or just kick you out of the ER?"

The PAC is used predominantly in the intensive care unit (ICU) and operating room. The device measures pulmonary artery wedge pressure, thermodilution cardiac output, and cardiac output by the Fick method. Growing controversy surrounds use of the PAC, in part because of studies that have raised questions about its utility and, more importantly, its safety. As an example, Dr. Bilkovski cited a case-control study that evaluated the use of right-heart catheterization in 5,735 critically ill adult patients who received care in ICUs at five U.S. teaching hospitals [1]. The principal endpoints of the study were survival, cost of care, intensity of care, and length of stay in the ICU and hospital. By case-matching analysis, right-heart catheterization had worse outcomes, in particular increased mortality at 30, 60, and 180 days. Additionally, use of a PAC was associated with greater hospital charges, and prolonged length of stay in the ICU.

As compared to the PAC, central venous pressure (CVP) monitoring is used more extensively, both in the ICU, the operating room, and the emergency department. However, the device has some prominent limitations related to valvular heart disease, pulmonary hypertension, ventricular compliance, and assessment of preload, said Dr. Bilkovski. CVP has been considered a reliable measure of ventricular preload in patients requiring hemodynamic monitoring. That reliability was evaluated in a group of healthy volunteers [2]. Specifically, investigators assessed the relationship between pressure estimates of ventricular preload (pulmonary artery occlusion pressure and CVP) and end-diastolic ventricular volumes and cardiac performance. Neither CVP nor pulmonary artery occlusion pressure demonstrated a significant correlation with right ventricular end-diastolic volume index (RVEDVI). However, stroke volume did correlate with RVEDVI. "My personal opinion is that there is a level of discomfort associated with putting in a central line, especially in the subclavian or internal jugular area, even in academic centers," said Dr. Bilkovski. "I think technology is starting to show that there are noninvasive ways to do this."

Esophageal Doppler monitoring (EDM) has shown some potential as a minimally invasive approach to hemodynamic monitoring. The device measures blood flow across the descending aorta. The principal limitation of the technology is that it is applicable only in mechanically ventilated patients. EDM's value as a measure of cardiac output was compared with cardiac output by thermodilution method in 46 critically ill patients [3]. Good correlation ($r = 0.95$, $p < 0.0001$) was observed between the EDM and thermodilution measurements. The investigators concluded that "transesophageal Doppler can provide a noninvasive, clinically useful estimate of cardiac output and detect hemodynamic changes in mechanically ventilated, critically ill patients." Another study evaluated EDM as an aid to hemodynamic optimization [4]. The study involved patients undergoing major elective surgery with anticipated blood loss greater than 500 mL. Patients who had EDM-directed intraoperative fluid administration had a higher stroke volume and cardiac output at the end of surgery, shorter duration of hospital stay, and earlier return of normal bowel function. "There is a fair amount of literature supporting the utility and accuracy of EDM for measuring cardiac output," said Dr. Bilkovski. "However, use of the technology is still limited to patients who are mechanically ventilated."

Monitoring-guided hemodynamic optimization, particularly early introduction of hemodynamic optimization, has shown potential to improve outcomes in septic patients. In some of the earliest work in the field, Shoemaker et al. found that supranormal oxygen delivery improves outcomes in critically ill patients. In one study, survivors among critically ill surgical patients had greater oxygen delivery (DO_2) values than did non-survivors [5]. Another study yielded similar results: High-risk surgical patients who had augmented DO_2 had a lower mortality compared to a control group [6]. Bishop et al. reported that severely injured trauma patients who achieved supranormal DO_2 within 24 hours had reduced mortality and a lower rate of organ failure [7]. Another report showed that severely injured patients who achieved optimal hemodynamic values had improved survival, regardless of the resuscitation technique used [8]. "The one limitation of these results is that they have all come from the same institution," said Dr. Bilkovski. "No other institution has been able to replicate these results."

Investigators at Dr. Bilkovski's institution evaluated the impact of early goal-directed therapy in the treatment of severe sepsis and septic shock [9]. The approach has been used extensively in the ICU, but this study sought to determine the feasibility and efficacy of early goal-directed therapy before admission to the ICU. The study involved 263 patients, 130 of whom wee randomized to early hemodynamic optimization. In-hospital mortality was significantly reduced by the goal-directed therapy (30.5% vs. 46.5%, $p = 0.009$). The improved survival was associated with a significantly higher mean central venous oxygen saturation ($ScvO_2$), lower lactate concentration, lower base deficit, and a higher pH value between 7 and 72 hours ($p \leq 0.02$ for all comparisons). Patients assigned to early goal-directed therapy also had significantly lower APACHE II scores ($p < 0.001$), suggesting less severe organ dysfunction.

Stroke volume variation (SVV) represents another development in minimally and noninvasive hemodynamic monitoring. To date, the technique has been used almost exclusively in Europe, where the monitoring equipment is manufactured, according to Dr. Bilkovski. One recent study evaluated SVV to guide fluid therapy in mechanically ventilated patients [10]. The technique was compared with pulse pressure variation (PPV), stroke volume index (SVI), and several other standard preload indices. SVV and PPV were the most accurate methods for predicting fluid responsiveness, and SVV was more accurate than PPV. Both SVV and PPV correlated significantly with changes in SVI ($p < 0.001$). Like EDM, SVV's applicability is limited to mechanically ventilated patients. Additionally, other studies have yielded inconsistent findings. One investigation found that SVV predicts fluid responsiveness [11], whereas another study found no correlation between SVV and SVI [12].

The era of truly noninvasive monitoring of cardiac output has arrived with the ultrasound cardiac output monitor (USCOM), said Dr. Bilkovski. Recently released in the United States, USCOM assesses cardiac output by means of continuous-wave Doppler ultrasound, which measures blood flow across the aortic valve. "In contrast to the descending aorta, the aortic valve does not vary from beat to beat, so we should be able to obtain a more reliable and more robust cardiac output measurement from beat to beat," said Dr. Bilkovski. USCOM has considerable potential as a noninvasive means of monitoring goal-directed therapy to achieve hemodynamic optimization, he added. With respect to hemodynamic trending, USCOM can be used to monitor stroke volume response to fluid challenge. Cardiac output can be monitored in real time, and the technology can be used to guide resuscitation efforts. In summary, Dr. Bilkovski said fluid challenge will optimize stroke volume, which in turn should optimize cardiac output. Invasive hemodynamic monitoring currently is the mainstay for treatment of critically ill patients, but minimally invasive techniques are becoming more prevalent in clinical settings. Noninvasive cardiac output monitoring shows promise, and its value in clinical practice will be defined by ongoing clinical investigation.

Hemodynamic Monitoring in the Emergency Department

A combination of noninvasive hemodynamic monitoring and assessment of tissue oxygenation ultimately may offer the ideal approach to improving outcomes in critically ill patients. A monitoring strategy that relies on physical examination is no longer sufficient, said H. Bryant Nguyen, MD, assistant professor of emergency medicine at Loma Linda University, in Loma Linda, Calif. Invasive monitoring currently has the best supporting science but is impractical for many settings. Findings on physical examination, including postural hypotension, status of skin and mucous membranes, mental status, and capillary refill time, lack the sensitivity, specificity, or both to provide for reliable assessment of patients [13]. Additionally, blood pressure monitoring reflects afterload, but the ausculatory method may underestimate actual blood pressure [14].

As an indication of patient status, blood pressure does not reflect the adequacy of flow to tissues. In point of fact, systemic hypoperfusion usually precedes hypotension, especially in septic patients [15]. Neither blood pressure nor heart rate reliably predicts cardiac output until "extreme hypotension occurs [16]." "In a hemorrhagic shock model, it is possible to lose up to 20% of blood volume with no loss in blood pressure," said Dr. Nguyen. "It's possible to compensate pretty well up to 20% blood loss, which is pretty significant." In contrast to simple blood pressure measurements, the shock index (heart rate/ systolic blood pressure) has shown potential for evaluation of critically ill patients in the emergency department. As an example, a shock index of 0.9 (0.5 to 0.7 considered normal) was associated with emergency department triage to priority status, increased likelihood of hospital admission, and continued therapy in the ICU [17].

Comparisons of invasive monitoring and clinical examination for determining preload have consistently favored the invasive approach. One representative study showed that therapy suggested by clinical examination was changed 48% of the time after catheterization [18]. Another study found a 50% error rate for clinical examination, and therapy was changed 58% of the time after catheterization [19]. An evaluation of clinical assessment of central venous pressure in ICU patients found high rates of inaccuracy among medical students, residents, and staff physicians [20]. Invasive monitoring has a demonstrated ability to guide hemodynamic optimization. For example, preoperative placement of a pulmonary artery catheter was used to monitor and optimize cardiac index, oxygen delivery, and oxygen consumption in high-risk surgical patients [6]. Patients who received the catheter had a lower mortality, fewer complications, shorter duration of hospitalization and ICU stay, and less need for mechanical ventilation. Moreover, invasive monitoring was associated with lower costs. In another study, invasive monitoring of early goal-directed therapy showed that optimization of central venous pressure, mean arterial pressure, and central venous oxygen saturation improved outcomes in critically ill patients [9].

Esophageal Doppler monitoring (EDM) has demonstrated potential as a minimally invasive alternative to invasive monitoring. EDM was compared with clinical evaluation for assessment of hemodynamic status in critically ill patients presenting to the emergency department [21]. Assessment focused on preload, contractility, and afterload, and the variables were recorded as high, normal, or low by the attending physician prior to EDM. Therapeutic decisions were recorded before and after EDM. Physician agreement with EDM ranged between 39% and 48% for the three variables, and treatment changed in about a third of cases following EDM. "This study showed that EDM is a less invasive alternative, is feasible and convenient for use in the emergency department, is more accurate than a clinician's assessment, and leads to a significant change in therapy," said Dr. Nguyen. More recently, EDM was investigated as a means of guiding hemodynamic optimization in patients undergoing cardiac surgery [22]. Patients were randomized to conventional hemodynamic monitoring or to an EDM-guided algorithm designed to maintain a target stroke volume. Patients randomized to the algorithm had fewer complications, and the EDM-guided resuscitation was associated with a significant reduction ($p = 0.02$) in the length of hospital stay.

Because EDM is applicable only to intubated patients, a reliable minimally or noninvasive hemodynamic monitoring technique is still needed. An ultrasound cardiac output monitor (USCOM) has demonstrated potential as a possible noninvasive alternative to standard hemodynamic monitoring techniques. The device determines cardiac output by means of continuous-wave Doppler ultrasound monitoring of the aortic valve. USCOM was compared with standard thermodilution technique using a pulmonary artery catheter (PAC) in 24 patients who were mechanically ventilated following cardiac surgery [23]. Investigators obtained 40 paired measurements from 22 patients, and the ultrasound signal was unacceptable in two patients. The USCOM demonstrated good correlation with PAC, leading the authors to conclude that the USCOM monitor "has a place in intensive care monitoring. It is accurate, rapid, safe, well tolerated, noninvasive, and cost-effective." However, they noted that the device's suitability for patients with high and low cardiac output requires further validation.

Dr. Nguyen and colleagues at his institution also have evaluated the USCOM monitoring device and presented results at the annual meeting of the American College of Emergency Physicians [24]. Paired USCOM measurements of cardiac index and stroke volume index were obtained by two blinded operators, including physicians, students, nurses, and paramedics. The investigators obtained 52 paired measurements in 44 patients presenting to the emergency department. The ultrasound signal was inadequate in five other patients. The USCOM monitoring device demonstrated good correlation between operators for both cardiac index ($r2 = 0.87$, $p = 0.001$) and stroke volume index ($r2 = 0.84$, $p = 0.001$). Dr. Nguyen and his associated concluded that the USCOM "is a feasible, noninvasive hemodynamic monitoring device in the ED with acceptable inter-rater agreement when utilized by ED personnel involved in patient care. Its ease of use suggests further study is needed to examine the utility of this device in the hemodynamic assessment and resuscitation of critically ill patients presenting to the ED."

Tissue oxygenation monitoring represents yet another potentially useful strategy for hemodynamic optimization, said Dr. Nguyen. Indices that have been evaluated include base deficit, lactate, gastric pH, and sublingual carbon dioxide partial pressure (pCO_2). Base deficit is the amount of base required to titrate 1 L of blood to normal pH. The index is an indicator of volume deficit and has been found potentially useful as a guide to volume replacement in the resuscitation of trauma patients [25]. The reliability of base deficit as a tissue oxygenation index is affected by bicarbonate, temperature, ethanol consumption, and heparin, said Dr. Nguyen. Associations of base deficit with mortality and of other factors affecting mortality were examined in 3,791 trauma patients who had an arterial blood gas sample obtained in the first 24 hours [26]. More than 80% of the patients (3,038) exhibited a base deficit. By logistic regression analysis, base deficit demonstrated an association with mortality, as did older age, injury mechanism, and head injury. Base deficit also added significantly to the predictive value of the Revised Trauma Score and the Trauma Injury Severity Score. "If a patient had a base deficit of about 10 or higher, the mortality risk was up to 60%," said Dr. Nguyen. "As base deficit of 20 was associated with a mortality risk of 80%. So, using base deficit in triage or trauma resuscitation can help make a disposition."

Lactic acidosis, which reflects anaerobic metabolism, has been shown to correlate with overall oxygen debt and survival in critically ill patients [27]. Studies dating back more than 30 years have show that lactate levels correlate with outcome and reflect the severity a patient's condition [28,29]. Lactate and central venous oxygen saturation ($ScvO_2$) were evaluated as indicators of response to resuscitation in critically ill patients presenting to the emergency department [30]. The results showed that initial resuscitation led to improvement in standard hemodynamic parameters but did not improve $ScvO_2$ or lactate levels in 31 of 36 patients involved in the study. Additional resuscitative therapy led to a significant decrease in lactate and a significant increase in $ScvO_2$ without significant changes in blood pressure, heart rate, or shock index. The investigators concluded that a majority of critically ill patients require additional resuscitative therapy to restore adequate systemic oxygenation after initial resuscitation and hemodynamic stabilization in the emergency department. They also concluded that $ScvO_2$ and lactate levels can be used to guide the additional therapy. Other studies have shown that lactate clearance predicts outcome in septic patients. For example, one study showed that a low lactate clearance rate predicted an increased mortality risk in critically ill septic patients with normal lactate levels [31]. Dr. Nguyen and colleagues reported that early lactate clearance may reflect resolution of global tissue hypoxia and correlates with a reduced mortality risk. Greater lactate clearance within 6 hours of emergency department intervention was associated with better outcomes compared to patients who had lower clearance rates [32]. "We found that if we can reduce lactate in septic shock by 10% within 6 hours, survival is about 60%," said Dr. Nguyen. "Those who do not decrease lactate by more than 10% have a 20% survival, a 40% absolute difference."

The role of pH as a prognostic factor in critically ill patients has been evaluated somewhat less extensively, but available data suggest the parameter might be useful in patient monitoring. Gastric mucosal pH was evaluated in 80 adult ICU patients, 54 of whom had normal pH and 26 of whom had low pH values [33]. Patients with low gastric intramucosal pH had a significantly higher mortality ($p < 0.04$) and higher rates of sepsis and multisystem organ failure ($p < 0.01$). Moreover, patients with persistently low gastric pH during the first 12 hours after admission had a mortality of 86.7% compared to 26.8% for patients with normal pH ($p < 0.001$).

Microcirculatory flow in the sublingual space has been evaluated as a potential prognostic factor in several recent studies. Weil et al. found that sublingual pCO_2 increases as mean arterial pressure and cardiac index decrease and as lactate level increases, predicting increased risk for circulatory shock and mortality [34]. Sakr et al. also found that persistent alterations in sublingual microcirculation are associated with organ failure and mortality in septic patients. Conversely, increased microvascular perfusion was associated with better outcomes [35]. Marik and Bankov reported that sublingual microcirculation was a better predictor of outcome than were lactate and venous oxygen saturation and was more responsive to therapeutic interventions [36]. "The available evidence suggests that a combination of noninvasive approach and assessment of tissue oxygenation might be the way to go in terms of hemodynamic monitoring in critically ill patients," said Dr. Nguyen.

The Use of the Starling Curve and Cardiac Output to Guide Resuscitation

Shock represents a loss of homeostasis and more specifically an imbalance between oxygen delivery and oxygen consumption. A third component of shock is oxygen demand in tissues, which drives oxygen consumption. "An imbalance between oxygen delivery and consumption had several adverse consequences, including tissue hypoxia, acidosis, and organ dysfunction," said Nathan I. Shapiro, MD, an instructor in emergency medicine at Harvard Medical School and Beth Israel Deaconess Medical Center in Boston. Blood leaves the heart with a certain level of oxygen saturation, typically 95–100%, and thus begins the delivery side of the balancing act. Upon reaching the microcirculation, about 20–30% of the oxygen is removed, and oxygen saturation is 70–80% in blood that is returning to the heart through the venous system. "When there is increased oxygen demand and more oxygen is pulled out of the blood, low oxygenation will result," said Dr. Shapiro. "In a patient in shock, oxygen demand exceeds the uptake. As a result, we need to increase oxygen delivery." An evaluation of early goal-directed therapy for septic patients showed that "if we pay attention to balancing oxygen supply and demand, and if we intervene early and aggressively, we can improve outcomes [9]." The protocol employed in the study included three key target parameters. Central venous pressure (CVP) was to be maintained at 8–12 mm Hg, and a 500 cc fluid bolus was administered if CVP declined to less than 8 mm Hg. The target for mean arterial pressure was 60–90 mm Hg, and vasoactive agents were given if the pressure fell below 60 mm Hg. Finally, the minimum value for systemic venous oxygenation was 70%, and red cell transfusion or dobutamine was administered if venous oxygenation declined to less than 70%. "In reality, this protocol is an effort to normalize basic components of oxygen delivery and oxygen uptake," said Dr. Shapiro.

Prevention of tissue hypoxia requires a three-prong strategy: maintenance of an adequate preload and an adequate perfusion pressure and matching oxygen delivery with consumption, which involves maintaining cardiac output. CVP is used as a surrogate for preload, but cardiac output is the true object of interest, said Dr. Shapiro. Cardiac output is the product of heart rate and stroke volume. Stroke volume consists of end diastolic volume (EDV) and ejection fraction. EDV can be measured by CVP. "We ought to be asking why we are using CVP as a surrogate for end-diastolic volume, stroke volume, and cardiac output when there are now ways to measure cardiac output noninvasively," said Dr. Shapiro. Fluid responsiveness offers a means to assess preload and, ultimately, cardiac output. If the addition of a fluid bolus increases cardiac output, the patient exhibits fluid responsiveness. Continual administration of fluid until cardiac output no longer responds has the effect of maximizing oxygen delivery. CVP is problematic because it measures pressure and not volume and depends on both fluid and compliance of the heart. As the compliance of the heart varies, so will pressure measurement but not volume measurement, said Dr. Shapiro. CVP also poses a problem because the normal or ideal CVP is unknown. Patients and their hearts vary, and hearts also differ in various physiologic states. Finally, CVP's influence on cardiac output, which comprises preload and contractility, is unclear.

"Some patients have increased contractility, so, for a given preload, they will have a higher stroke volume or cardiac output," said Dr. Shapiro. "Others will have low contractility, and at the same preload, they will have a different stroke volume and cardiac output. If we take just one static measurement, we're not going to know where we are in terms of stroke volume or cardiac output. We'll just know where we are in preload. This variability really presents a challenge."

Michard and Teboul reviewed published, peer-reviewed studies investigating predictive factors for fluid responsiveness in ICU patients [37]. They identified 12 studies that evaluated both static and dynamic parameters of cardiac preload. Dynamic parameters (such as inspiratory decrease in right atrial pressure) predicted fluid responsiveness with high positive and negative predictive values. In contrast, static parameters (such as right atrial pressure and pulmonary artery occlusion pressure) did not discriminate between responders and nonresponders. Evaluation of CVP yielded inconsistent results, as some studies showed CVP discriminated between responders and nonresponders but other studies did not. CVP has demonstrated a similar lack of prognostic value in other studies. Kumar et al. found no correlation between CVP and stroke volume index (SVI) or between change in CVP and change in SVI in healthy volunteers [2]. Brock et al. also found no correlation between CVP and SVI or cardiac index in hypovolemic post-cardiac surgery patients [38].

The ultrasonic cardiac output monitor (USCOM) was compared with the Swan-Ganz catheter for measurement of cardiac output in 36 patients undergoing coronary revascularization [39]. The comparison showed that cardiac output and stroke volume assessed by USCOM correlated well with the invasive measures and with central venous saturation percentage. The authors concluded that the USCOM devices makes it possible "to determine noninvasively beat-to-beat cardiac output in postcardiac surgery patients without the possible complications associated with invasive right-heart catheterization." As mentioned above, esophageal Doppler monitoring (EDM) was associated with fewer complications and a briefer hospital stay compared to conventional hemodynamic management [22]. "In the next few years, I think we will see a lot of ways to go about monitoring hemodynamic status in critically ill patients," said Dr. Shapiro. "Noninvasive measurement of cardiac output is going to happen. It is clear that technology will solve the problems. The question is whether we will be ready to implement this in our practices. It is important to start thinking about the concept of noninvasive monitoring so that we can start to incorporate it into practice, because it is the wave of the future."

Noninvasive Pre-Hospital and Inter-Facility Monitoring

An increasing volume of inter-facility transport and changing clinical characteristics of transported patients will fuel development and implementation of noninvasive approaches to perform hemodynamic monitoring. In the United States, malpractice has affected transport volume and the acuity of transferred patients, said Robert Sherwin, MD, assistant professor of emergency medicine at Wayne State University in Detroit. In particular, malpractice has led to increased concentration and regionalization of medical specialists. For example, in Philadelphia and the four-county surrounding area, the number of hospitals offering neurosurgical care has decreased from 12 to two, although the total number of neurosurgeons in the area has not changed. The number of hospitals with hand surgeons has declined from seven to two. Emergency departments with on-call orthopedic surgeons have dwindled from 18 to five, and only four EDs have on-call plastic/oral surgeons, down from 12.

Technological improvements will continue to swell the population of patients who are technology dependent, such as those requiring cardiac balloon pumps, ventricular assist devices, and extracorporeal membrane oxygenation. Moreover, procedures once considered high risk and performed only at tertiary care centers increasingly are being done at satellite centers and community hospitals that formerly could not support the interventions. Complications of those procedures have contributed to the increased volume of interfacility transfers and the increased acuity of transferred patients, said Dr. Sherwin. The growing need for noninvasive monitoring in interfacility transport and prehospital settings has not been matched by the volume of research in the area. "There is a paucity of research and literature on noninvasive monitoring of prehospital patients or interfacility transfers," said Dr. Sherwin. "We need more research, especially more outcome-based research."

The need for noninvasive monitoring techniques was illustrated in a recent evaluation of hemodynamic management of patients undergoing interfacility transport for suspected acute aortic dissection [40]. The study showed that pretransport hemodynamic therapy was frequently omitted and when administered was often inadequate. Another study evaluated potential adverse effects associated with interfacility transfer [41]. The study involved 3,298 patients who were hospitalized for chest pain or related complaints after transfer from the emergency department at a different facility. The analysis found no evidence that interfacility transfer increases the risk of mortality, duration of hospital stay, or hospital readmission. Noninvasive monitoring techniques currently being investigated include radial artery tonometry (RAT), bispectral index (BIS), transcutaneous oxygen tension (TOT), and impedance cardiography (ICG). Available data for each of the techniques is too limited to draw any conclusions at this point.

RAT continuously monitors blood pressure by means of a transducer attached to the skin just above the radial artery. A preliminary clinical evaluation compared RAT with invasive monitoring in 22 high-risk surgical patients [42]. The noninvasive technique exhibited poor correlation with invasive monitoring for systolic, diastolic, and mean pressure. The investigators concluded that RAT offers a reliable trend indicator of pressure changes during anesthesia induction and might be considered an alternative to invasive pressure measurement. However, the accuracy of absolute RAT values was moderate and unpredictable. Additionally, about 20% of the RAT readings were unacceptable and could not be used in the data analysis, said Dr. Sherwin. A more recent study evaluated the feasibility of RAT for continuous out-of-hospital blood pressure monitoring [43]. The study involved 29 patients transported by airplane, helicopter, or ground vehicle, and RAT was compared with conventional oscillometric cuff methods. A total of 139 paired assessments of mean arterial pressure were available for comparison. RAT demonstrated good correlation with oscillometric measurement across the range of mean arterial pressures (42 to 163 mm Hg). RATs performance did not appear to be adversely affected by the out-of-hospital setting. However, no outcome data were collected from the study.

BIS is a sedation monitor that is used extensively and has a large body of anesthesia literature to validate it, said Dr. Sherwin. A feasibility study showed that BIS can be used to monitor patients being transported by helicopter [44]. "There are data to show that when you use something like this in critically ill patients who are being sedated you have fewer issues with hypertension, less tachycardia, and less agitation," said Dr. Sherwin. "During transfer of patients who need a continuous airway, you want to keep them down and have an objective score to shoot for. Bispectral index monitoring is a reasonable alternative to consider. A lot of study need to be done in the future to validate the use, but I think the opportunity exists." TOT was prospectively evaluated in 151 severely injured patients, who were followed from arrival at the emergency department through transport to the operating room and then to the ICU [45]. Comparison of measurements in survivors and nonsurvivors revealed significantly greater cumulative deficits of cardiac index, arterial hypoxemia, and tissue perfusion in nonsurvivors.

"Transcutaneous oxygen tension is a surrogate for tissue perfusion," said Dr. Sherwin. "It is based on the concept that tissue tends to lose perfusion first in the skin and gut, and this is where it is picked up first." To date no significant literature on ICG in the prehospital setting has developed. Multiple studies have correlated its use with thermodilution. In general, the studies have shown poor correlation for ejection fraction but better correlation with thermodilution for cardiac index, said Dr. Sherwin.

Temple University in Philadelphia has an ongoing study to evaluate the ultrasonic cardiac output monitor (USCOM) for hemodynamic monitoring of adult patients who require interfacility transport and who are receiving or require intravenous vasoactive agents. Outcomes include the hemodynamic effects of ventilation profile and medication adjustments, length of hospital stay, and length of ICU stay. The study also includes a survey of practitioners to determine their confidence in optimizing hemodynamic profiles. Thus far, the study has produced some notable cases, said Dr. Sherwin. In a patient with sepsis, noninvasive cardiac output monitoring had a favorable effect on patient safety and use of existing vasoactive agents and helped prevent cardiac collapse. In a patient with pulmonary edema, noninvasive monitoring allowed aggressive management of afterload reduction and helped the patient avoid mechanical ventilation. Finally, a patient with chronic obstructive pulmonary disease and multisystem organ failure benefited from monitoring to determine the optimal positive end-expiratory pressure and guide administration of intravenous boluses.

In conclusion, Dr. Sherwin reiterated the need for more outcome-based research into noninvasive hemodynamic monitoring for critically ill patients. Though largely untested in the medical transport arena, noninvasive monitoring of parameters such as cardiac output and systemic vascular resistance has considerable potential for guiding therapy adjustments during transport.

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Continuing Education Post-Test

Continuing Education questions for

Hemodynamic Assessment in the Emergency Department, Tools and Information for Clinical Decision Making

Please choose the best answer for each question below, and shade the corresponding oval on the answer sheet at the end of the test.

Lecture 1: Hemodynamic Training in the Management of Sepsis

1) In addition to preload, the force of cardiac contraction is dependent upon ____________ and ____________?

a) Dromotropy and inotropy
b) Dromotropy and afterload
c) Afterload and inotropy

2) Which of the following statements regarding central venous oximetry ($ScvO_2$) is INCORRECT?

a) A normal $ScvO_2$ is a 70-75 %
b) Hypothermia can result in elevation of the $ScvO_2$
c) Lactic acidosis occurs when there is an imbalance between oxygen delivery (DO_2 and oxygen consumption (VO_2)
d) Falling of the $ScvO_2$ occurs in the delivery independent portion of metabolism
e) Hypoxia can result in lowering of the $ScvO_2$

3) True or false, in the 1996 JAMA article by Connors et al. use of the pulmonary artery catheter was associated poorer survival rates at 30, 60 and 180 days compared to matched pairs managed without a pulmonary artery catheter?

a) True
b) False

4) Which of the following measurements according to the findings reported by Kumar et al. (CCM, 2004) has the greatest correlation with right ventricular end diastolic volume indices (RVEDVI)?

a) Pulmonary artery occlusion pressure (PAOP)
b) Central venous pressure (CVP)
c) Stroke volume index (SVI)

5) Cardiac output measured by the ultrasound cardiac output monitor (USCOM) utilizes _______ Doppler ultrasound intimated across the __________.

a) Pulse Wave, aortic valve
b) Continuous Wave, aortic valve
c) Continuous Wave, descending aorta
d) Pulse Wave, aortic arch
e) none of the above

Lecture 2: Hemodynamic Monitoring in the Emergency Department

6) Which of the following physical findings, according to McGee et al. (JAMA, 1999) has the greatest sensitivity and specificity (respectively) for identification of hypovolemia?

a) Postural hypotension, skin/mucous membranes
b) Mental status, capillary refill
c) Skin/mucous membranes, capillary refill
d) Skin/mucous membranes, postural hypotension
e) Capillary refill,, mental status

7) Use of the central venous pressure monitor is useful in guiding intravenous fluid requirements. Which of the following conditions may result in an overestimation of CVP?

a) Tricuspid valve stenosis
b) Right ventricular failure
c) Constrictive pericarditis
d) All of the above
e) None of the above

**8) Which of the following pairs most accurately represents the response of stroke volume following an intravenous fluid
challenge?**

a) Δ 0% → hypovolemia
b) $\Delta < 10\%$ → euvolemia
c) $\Delta > 10\%$ → hypovolemia
d) a, b and c
e) b and c

9) True or false, the rate of lactate clearance is not associated with survival amongst septic patients?

a) True
b) False

10) Which of the following methodologies is best utilized to monitor microcirculatory flow?

a) Lactate
b) Base deficit
c) Esophageal Doppler Monitor
d) Sublingual PCO_2
e) Central venous oximetry ($ScvO_2$)

Lecture 3: Use of the Startling Curve and Cardiac Output to Guide Resuscitation

11) Which of the following parameters is not necessary for calculation of oxygen delivery (DO_2)?

a) Hemoglobin
b) Arterial oxygen saturation (SaO_2)
c) Stroke volume
d) Oxygen extraction ratio (O_2ER)
e) Heart rate

12) According to the early goal directed therapy (EGDT) protocol, which of the following is not a recognized end-point?

a) Central venous pressure (CVP) = 8–12 mm Hg
b) Mean arterial pressure (MAP) = 65–90 mm Hg
c) Cardiac output (CO) > 5 L/min
d) Central venous oximetry ($ScvO_2$) <70%
e) Hematocrit >30%

13) According to Starling forces, given a fixed preload and afterload, increases in contractility will result in __________ stroke volume?

a) Increased
b) Decreased
c) No change

14) According to Starling forces, stroke volume changes >10% in response to a 200 ML intravenous fluid bolus would indicate the state of?

a) Hypervolemia
b) Hypovolemia
c) Euvolemia

15) According to the data presented by Kumar et al. (CCM, 2004) choose the most appropriate correlation coefficient between central venous pressure (CVP) and stroke volume index (SVI).

a) 0.10 – 0.15
b) 0.20 – 0.25
c) 0.30 – 0.35
d) 0.40 – 0.45
e) 0.50 – 0.55

Lecture 4: Noninvasive Prehospital and Interfacility Monitoring

16) True or false, the volume of interfacility transports is growing each year?

a) True
b) False

17) Which of the following is NOT affecting the frequency of interfacility transports?

a) Increased regionality (i.e. trauma centers)
b) The presence of evidence based outcome research on interfacility transports
c) Consolidation of sub-specialties (i.e. neurosurgeons, orthopedic surgeons, etc.) within a metropolitan area
d) Worsening medical malpractice climate
e) Regionalized quaternary care (i.e. ECMO, balloon pumps, etc.)

18) Which of the following noninvasive devices has been applied in the prehospital/interfacility transports setting?

a) Bispectral index monitoring (BIS)
b) Radial artery tonometry
c) Impedance cardiography (ICG)
d) Ultrasound cardiac output monitor (USCOM)
e) Ventricular assist devices

19) True or false, there is a wealth of research supporting the use of noninvasive monitoring devices in the interfacility transports arena?

a) True
b) False

Notes

CME Post-Test

Directions
For 2 hours of category 1 credit, shade the oval beside your answers on the form below. Complete the CME Post-Test and CME Evaluation Form. The CME Post-Test and CME Evaluation Form must be filled out completely for you to receive credit. This credit is valid through March 1, 2007. No credit will be given after this date.

For CME credit, please detach this Examination Answer Sheet/Registration Information/CME Evaluation Form, fill it out, sign it, and mail it in the envelope provided to the following address:

Temple University School of Medicine
The Albert J. Finestone, M.D.
Office for Continuing Medical Education
3400 North Broad Street
Philadelphia, PA 19140-9977

Please make a copy of this page before mailing, and retain it for your records.

Examination Answer Sheet

Please shade the oval next to your answer for each of the questions of the Post-Test component of this CME program.

1. ◯ **A** ◯ **B** ◯ **C**
2. ◯ **A** ◯ **B** ◯ **C** ◯ **D** ◯ **E**
3. ◯ **True** ◯ **False**
4. ◯ **A** ◯ **B** ◯ **C**
5. ◯ **A** ◯ **B** ◯ **C** ◯ **D** ◯ **E**
6. ◯ **A** ◯ **B** ◯ **C** ◯ **D** ◯ **E**
7. ◯ **A** ◯ **B** ◯ **C** ◯ **D** ◯ **E**
8. ◯ **A** ◯ **B** ◯ **C** ◯ **D** ◯ **E**
9. ◯ **True** ◯ **False**
10. ◯ **A** ◯ **B** ◯ **C** ◯ **D** ◯ **E**
11. ◯ **A** ◯ **B** ◯ **C** ◯ **D** ◯ **E**
12. ◯ **A** ◯ **B** ◯ **C** ◯ **D** ◯ **E**
13. ◯ **A** ◯ **B** ◯ **C**
14. ◯ **A** ◯ **B** ◯ **C**
15. ◯ **A** ◯ B ◯ **C** ◯ **D** ◯ **E**
16. ◯ **True** ◯ **False**
17. ◯ **A** ◯ **B** ◯ **C** ◯ **D** ◯ **E**
18. ◯ **A** ◯ **B** ◯ **C** ◯ **D** ◯ **E**
19. ◯ **True** ◯ **False**

Registration Information

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CME Evaluation Form

Please provide an answer to the following questions that have been designed for your Self-Assessment AFTER completing this CME program. These questions will give you a measure of the success the program has achieved for your personal professional expertise AND assist us in evaluation of our program.
(Please circle the single best answer.)

E = Excellent
G = Good
A = Average
F = Fair
P = Poor

1.	To what extent were the objectives of this educational activity met?	**E G A F P**
2.	To what extent were you satisfied with the overall quality of this educational activity?	**E G A F P**
3.	To what extent did the monograph present scientifically rigorous and balanced information?	**E G A F P**
4.	To what extent did this educational activity change your knowledge/attitudes?	**E G A F P**
5.	Rate the value of the activity based on learning/unit time.	**E G A F P**
6.	To what extent were the authors free of commercial bias?	**E G A F P**
7.	Rate the likelihood you will make a change in practice behavior based on your participation in the activity.	**E G A F P**

8. Commitment to change: What change(s), if any, do you plan to make in your practice as a result of reading this monograph?

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