Emergency Medicine:
Open Access

Al Aseri, Emergency Medicine 2012, 2:4
http://dx.doi.org/10.4172/2165-7548.1000108

Review Article Open Access

# Vital Indices to be used in Resuscitation of Patients with Shock in the Emergency Department Setting

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## Abstract

**Background:** The outcome of shock depends on early intervention and management of patient's arrival at the hospital. Managing these patients in the emergency department (ED) can be challenging because of the complex nature and various causes of the disease. This review discusses the indices that can be used by ED staff in approaching diagnosis and the management for shock particularly circulatory shock in the ED.

**Objectives:** To review various indices which can be used by the ED physician with ease to diagnose and manage patients with shock.

**Data Sources:** Medline search from 1970 to present plus cited reference studies and abstracts from available product literature. Selection criteria included published articles and abstracts comparing the accuracy of invasive and noninvasive hemodynamic monitors and relation of their use to patients outcome.

**Discussion:** Shock is a critical condition brought on by failure of the circulatory system to maintain adequate tissue perfusion. In the busy and overcrowded arena of emergency department (ED) patient's prolong stay is unavoidable. This common phenomenon in ED perspective inevitably necessitates tangible diagnostic and therapeutic interventions to attain hemodynamic stability of patients with shock that would otherwise be performed in the ICU. This article reviews the pathophysiology of shock, common indices to monitor hemodynamic (HD) and other methods that may be helpful to diagnose and manage shock within the "golden hours" to reduce the morbidity and mortality of shock.

**Conclusion:** Early hemodynamic assessment using Goal directed resuscitation history, physical examination, vital signs, central venous pressure (CVP) and other indices should be used in combination by the ED physician to diagnose and manage shock patients successfully.

**Keywords:** Shock; Vital indices; Adequate perfusion; Resuscitation; Intensive care, Emergency department (ED)

## Introduction

Shock, in general, is failure of cardiovascular system to provide sufficient oxygenated blood to all parts of the body. The world health organization has reported that 60% of deaths in developing countries occurred due to communicable disease which involving shock at variable stage [1]. In developing countries 50% of deaths related to shock occur within the first 24 hours and often shock preceded death [2]. Nearly 750,000 peoples are affected with severe sepsis alone in the USA [3]. Sepsis is the currently 10$^{th}$ leading cause of death in USA with in hospital mortality rate of 30% equating up to 215,000 deaths annually in the USA alone. It is estimated that nearly 500,000 cases of sepsis alone are catered initially in ED annually with an average stay in ED of 5 hours (golden hours of management) [4,5].

There are several factors influencing on the mortality and morbidity related to shock include physician's failure to recognize the early signs of shock with consequent delayed response to shock management, which may lead up to 54% of mortality probably due to reduced access to health care and to the cost of care particularly in developing countries [5-8].

Therefore, the bedside physician's skillful early management of shock is very important [7] in one meta analysis significant survival benefit was observed beneficial with the use of an early quantitative resuscitation strategy [9]. Furthermore, in the management of critical shock it is proved that early goal directed therapy (EGDT) decreases significant in- hospital mortality [10].

Since, shock has a critical impact on survival due to its multi organ involvement and grave consequences particularly if un recognized, early recognition of it using shock indices in early course of presentation in ED has fundamental importance for the triaging and resuscitation in the golden hours in the ED department [11-16].

In the line of consideration of above facts we present this article discussing the important indices to be used in ED to managing shock induced critical condition encountered in most vital golden hours on presentation in ED which is recommended in its management [17-19].

## Data Sources

Medline search from 1970 to present plus cited reference studies and abstracts from available product literature.

## Study Selection

Selection criteria included published articles and abstracts comparing the accuracy of invasive and noninvasive hemodynamic monitors and relation of their use to patient's outcome.

## Discussion

Shock is the pathologic state characterized by significant reduction of systemic tissue perfusion, resulting in decreased tissue oxygen

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**Received** December 09, 2011; **Accepted** March 19, 2012 **Published** March 21, 2012

**Citation:** Al Aseri (2012) Vital Indices to be used in Resuscitation of Patients with Shock in the Emergency Department Setting. Emergency Medicine 2:108. doi:10.4172/2165-7548.1000108

delivery leads to hypoxia. This is an imbalance between oxygen delivery and oxygen consumption. Prolonged oxygen deprivation leads to cellular hypoxia and derangement of critical biochemical processes at the cellular level, which can progress to the systemic level [20,21]. The effects of oxygen deprivation are initially reversible, but become irreversible if untreated eventually lead to cell death, end-organ damage, multi-system organ failure, and death involving cardiac dysfunction which is end results in late stages of all types of shock. This highlights the importance of prompt recognition and reversal of shock [22,23].

Hypotension is cardinal feature of it even it is not inevitable to define the state of shock. Shock is grouped in five main pathophysiologic categories include hypovolemic, distributive, cardiac, obstructive and cytotoxic. The diagnosis and management of shock is the most frequent task encounter to emergency and critical care setting. Clinical findings are varied as per type of shock representing unique etiology, cardinal features i.e., hypotension, oligourea, cool and clammy skin, altered mentation and acidemia are common features found in all types of shock regardless etiology and suggestive features are representing specific etiology. Therefore, early diagnosis can be built on careful history followed by examination and vital indices.

## Indices of Successful Resuscitation in the ED

### Cardiovascular indices

In the early stage of shock, a surge in catecholamines and neural regulation due to anxiety and stress and other factors maintains mean arterial pressure (MAP) at the expense of decreased tissue perfusion; this explains the absence of hypotension despite the presence of the signs and symptoms of hypoperfusion. MAP is calculated as MAP = $BP_{DIA}$ + ($BP_{SYS}$ – $BP_{DIA}$)/3, where $BP_{DIA}$ and $BP_{SYS}$ are diastolic and systolic BPs, respectively.

It is fact that in the early course of hypotension prompt management even with fluid alone restores hemodynamic stability [11].

In randomized controlled trials found that early hemodynamic optimization, before the development of organ failure achieve statistically significant reductions in mortality, whereas a >20% mortality were observed in the group where interventions lately introduced [24,25].

In general MAP < 60 mm Hg always should be considered pathologic. Evidence indicates that an MAP of 65 mm Hg can be considered sufficient in most patients with septic shock. To maintain perfusion in one study it was observed that despite > 70 mmHg survival was not improved these variable results need further assessment [26].

MAP is less affected by wave reflection, characteristics of the hemodynamic monitoring system, and small-vessel vasoconstriction than that of systolic BP. It is also more accurate in patients who have low-flow states [27].

Although, the BP is an easy and universal tool for monitoring patient developing shock, studies suggest that defining cut point value determining correct tissue perfusion status is difficult in patients with shock [19,28].This reflects that BP, MAP, and heart rate alone are not considered as adequate indices for detecting tissue hypoxia and hypoperfusion [26,29,30]. As hypertensive subjects need a higher MAP to ensure the same degree of blood flow as compare to non hypertensive patients [31].

Since, Noninvasive measurements of arterial pressure become less reliable in patients who have marked hypovolemia or abnormal cardiac function Oscillometric devices can underestimate systolic blood pressure by as much as 6-19% and overestimate diastolic BP by as much as 5-27% [28].

Although, as a rule hypotension reflects failure of the sympathetic nervous system to compensate for circulatory shock, but normotension does not ensure hemodynamic stability [32]. Partly it is due to fact that changes in vital signs are late findings in shock [33]. A normal blood pressure can be sustained despite loss of up to 30% of blood volume. Despite the fact that tachycardia is independently associated with hypotension, it's sensitivity and specificity limit its usefulness in the initial evaluation of trauma victims. McGee et al. showed that only 1 in 5 patients demonstrated a postural pulse increment of ≥ 30/min or were unable to stand for vital signs because of severe dizziness after blood loss of 450-630 ml [34]. A systematic evaluation of physical findings in patients with hypovolemia found that a systolic BP <95 mm Hg is not a sensitive measure for ruling out moderate or significant blood loss [35].

Postural hypotension (a >20-mm Hg decrease in systolic BP) provides little additional predictive value. Its sensitivity is only 9% in those younger than 65 years and 27% in those older than 65 years. In data collected from 14,325 trauma patients, aged 16-49 years, presenting to a university-based trauma center, hypotension was present in only 3.3%. Of these patients although expected, as well as, 35% ($n$ = 169) were not tachycardic. However, it was observed that hypotensive patients with tachycardia had a higher mortality rate compared with hypotensive patients who were not tachycardic ($P$ = 0.003). Patients they had both hypotension and tachycardia were associated with increased mortality and warrant careful evaluation [36].

In cardiogenic shock with ST elevation myocardial infarction (MI), the recommended systolic BP is 100 mm Hg but no strong evidence supports this recommendation [37]. Shock index (SI) (calculated as heart rate/systolic BP; normal range, 0.5-0.7) may be useful to evaluate acute critical illness in the ED including trauma cases [38,39,40,41]. In prospective study of 275 consecutive adults who presented for urgent medical care, Rady found that with apparently stable vital signs, an abnormal elevation of the SI to >0.9 patients were taken and treated as critical given admission to the hospital, and intensive therapy on admission showed SI as a good marker of impending shock [30].

Pulse pressure variation (PPV) is also considered as accurate index of fluid responsiveness in critical setting to fluid loading [39]. It is more reliable than other dynamic parameters such as systolic pressure variation or pulse stroke volume variation and it should be used in decision making for volume expansion [40,41].

In summary, emergency physicians and critical care providers should not depend only on vital signs alone as indices of optimal resuscitation.

### Central venous oxygen saturation

Interest has focused on the use of central venous oxygen saturation ($ScvO_2$) in early resuscitation of critically ill patients. It is simply the oxygen saturation of the blood sample taken from the subclavian or internal jugular vein or the right atrium. Its application depends on the concept of oxygen delivery ($DO_2$) theory, which depends on the oxygen content of arterial blood and cardiac output.

Total body oxygen consumption at rest requires only one-quarter of the $DO_2$ needed for tissue metabolism and is affected by factors that increase cellular energy requirements, such as exercise, pain, and hyperthermia. The residual oxygen remains bound to hemoglobin and passes into the venous circulation. $ScvO_2$ also provides an additional method for monitoring the adequacy of resuscitative measures in

the early stage of circulatory failure and is useful in the period after resuscitation to help titrate therapy and recognize any sudden deterioration in the patient's clinical condition [42].

Failure to achieve a $ScvO_2$ of ≥40% has a negative predictive value of almost 100% for restoration of spontaneous circulation (ROSC). $ScvO_2$ also helps to confirm return of spontaneous circulation (ROSC) rapidly. The patients do not require a pulmonary artery catheter which in itself has been questioned and can lead to adverse outcomes [43].

Reinhart et al compared the course of continuously measured mixed and central venous oxygen saturations in 32 critically ill patients with triple-lumen central vein catheters, including 29 patients requiring pulmonary artery catheterization. Their data confirmed the findings of others that in critically ill patients with circulatory failure from various causes $ScvO_2$ is generally higher than $SvO_2$ measured in the pulmonary artery. The average value (bias) for $ScvO_2$ was 7.05% ± 3.98% higher than the $SvO_2$ (precision 7.95%) [44]. It has been further observed that Pulmonary artery catheterization is *not* associated with reduced mortality in critically ill patients [45,46,47].

Data suggest that the presence of a pathologically low $ScvO_2$ very likely indicates an even lower $SvO_2$. The measurements of $ScvO_2$ can be used to guide therapy for the early phase of circulatory shock in the ED. $ScvO_2$-guided hemodynamic optimization has been shown to reduce mortality In an observational study of 98 consecutive unplanned admissions to a multidisciplinary ICU, a low $ScvO_2$ was associated with increased mortality [48].

## Central venous pressure

Central venous pressure (CVP) represents right atrial pressure, which estimates of right ventricular end-diastolic pressure and volume (preload). The normal range for CVP is 4-6 mm Hg. Many factors affect CVP measurements adversely include tricuspid valve disease, pericardial disease, abnormal right ventricular function, dysrhythmias, myocardial disease, pulmonary vascular disease, and changes in intrathoracic pressure produced by positive-pressure ventilation [49].

Isolated measurements of CVP are not reliable in predicting fluid responsiveness [50,51]. CVP has a poor correlation with cardiac index, stroke volume, left ventricular end-diastolic volume, and even right ventricular end-diastolic volume [52]. Based on this and the poor correlations described above, it is impossible to define ideal values of CVP.

## End-Tidal carbon dioxide

Studies evaluating the perfusion of the splanchnic circulation have used sublingual capnometry. Sublingual capnometry is performed using a sensor placed under the tongue that measures the partial pressure of carbon dioxide in the sublingual tissue ($P_{sl}CO_2$). Although studies are limited, available data indicate that $P_{sl}CO_2$ can be used as a predictor of patient outcome. Normal values for $P_{sl}CO_2$ are reported to range from 43 to 47 mm Hg [53] $P_{sl}CO_2$ is the difference between $P_{sl}CO_2$ and $P_aCO_2$, termed the "$P_{sl}CO_2$ gap." A $P_{sl}CO_2$ gap of >25 mm Hg is reported to identify patients at a high risk of death [54,55].

The decrease in cardiac output and pulmonary blood flow during cardiac arrest result in decreased elimination of carbon dioxide by the lungs and low $PetCO_2$. Successful resuscitation results in an increase in the cardiac output that will in turn, lead to an increase in $PetCO_2$ [56].

A prospective observational study measured initial $PetCO_2$ and $PetCO_2$ after 1 min of CPR in 76 patients. The $PetCO_2$ levels were compared between the group of patients with asphyxial cardiac arrest and the group with cardiac arrest following MI or pulmonary embolism. Only patients with initial pulse less electrical activity (PEA) were included in the study. A significant difference was found between $PetCO_2$ of patients with asphyxial compared to MI/PE cardiac arrest (initial $PetCO_2$ 49.9 ± 31.4 vs. 17.2 ± 8.3 mm Hg, respectively, $P < 0.05$; $PetCO_2$ after 1 min of CPR 38.7 ± 20.3 mm Hg vs. 18.9 ± 9.2 mm Hg, respectively, $P < 0.05$). The authors concluded that $PetCO_2$ in PEA possibly indicates the mechanism of cardiac arrest. In combination with other signs, the level of $PetCO_2$ might influence the approach to and treatment of patients with PEA in the out-of-hospital setting. In addition capnographic monitoring is a useful guide to the adequacy of closed cardiac compressions during CPR [57].

A recent prospective semi-blind study involved 47 men and 26 women referred to the ED for respiratory distress. Arterial blood gas pressures and side stream $PetCO_2$ ($SSetCO_2$) measurements were performed and recorded for all patients; a significant correlation was found between $SSetCO_2$ and arterial $PCO_2$ ($r = 0.792$). A good correlation was found between $SSetCO_2$ and arterial $PCO_2$ in the ED setting. Young age may increase the arterial $PCO_2$/$SSetCO_2$ gradient, whereas a raised temperature may decrease this gradient. Further studies are needed to confirm these findings in the normal healthy population [58].

Several studies have demonstrated increased mortality in patients who have either low concentrations of transcutaneous oxygen or high concentrations of carbon dioxide. Marked differences were observed in the survivor and non survivor temporal patterns of $PtcO_2$ , $PtcCO_2$ , and $PtcO_2$ /$PtcCO_2$ values, during initial resuscitation in the ED in 48 consecutive severely injured patients by prospective assessment of $PtcO_2$ and $PtcCO_2$) [59].

To summarize, $PetCO_2$ can be used as reasonable index for optimal resuscitation and in diagnosing and managing some of the critical cases likewise, cardiac arrest, pulmonary embolism, hyperthermia, hypothermia, esophageal intubation, and in cases of decrease or increase in cardiac output).

## Sublingual capnography

Sublingual capnography is a technically simple, noninvasive, inexpensive method that is not affected by changes in gastric pH and appears to provide potentially useful prognostic information on adequacy of resuscitation. Weil and coworkers investigated the feasibility and predictive value of sublingual $PCO_2$ measurements as a noninvasive and early indicator of systemic perfusion failure. In a study of patients presenting to the ED in a variety of shock states, they found that sublingual capnography was useful in differentiating between patients with circulatory shock and elevated lactate levels and patients without shock and normal lactate levels [53].

## Passive leg raising

Straight-leg raising which is 45° elevation for 4 min while maintaining the trunk supine results in an increase in right and left ventricular preload [54,55].This maneuver may help in predicting individual fluid responsiveness during spontaneous and positive-pressure breathing while avoiding the hazards of unnecessary fluid loading [60-62].

Passive leg raising (PLR) is a reversible maneuver that mimics rapid fluid loading (RFL) by shifting venous blood from the legs toward the intrathoracic compartment and by increasing right and left ventricular preloads, thereby increasing stroke volume (SV) and cardiac output. Thus, when SV increases with PLR it should increase with RFL

as well. It has been known for a long time that PLR can mimic the hemodynamic effects of RFL. The way by which PLR can alter preload is probably an increase in the mean systemic pressure, the driving force for venous return. Recently, Karim L Oakhal and collegues assessed the influence of PLR-induced changes in preload on the performance of PLR-induced change in pulse pressure ($\Delta_{PLR}PP$) and cardiac output ($\Delta_{PLR}CO$) for fluid responsiveness prediction the result also found to be useful PLR as a valuable assessment tool in intubated and sedated patient in intensive care setting [63].

## Lactate and Base Deficit (BD)

As a product of anaerobic glycolysis, lactate is an indirect measure of oxygen debt. As tissue oxygen delivery falls below the threshold required for efficient oxidative phosphorylation, cells metabolize glucose into pyruvate and then lactate rather than entering the Krebs cycle during aerobic metabolism, with the help of pyruvate dehydrogenase. Increasing evidence indicates that inhomogeneity in the regional circulation and microcirculation plays a crucial role in the pathogenesis of organ dysfunction. In experimental and clinical conditions, serum lactate levels are strongly associated with tissue hypoxia [64]. Lactate level are commonly used to stratify risk and to asses adequacy of CPR in the intensive care unit and ED [65-67,25 ]. It is also possible to measure accurate blood lactate using handheld analyzer from venous blood [68,69]. It has been observed that it is an important prognostic and diagnostic indicator in dealing shock Scalea et al. found that 80% of 40 blunt trauma victims with head injuries had elevated blood lactate levels, despite normal vital signs and urine output [70].

In another study Jeng et al noted that the average base deficit and blood lactate level were abnormal despite normal vitals signs in patients with burns resuscitated to normal vital signs and urine output. These finding of increased lactate level and failure to improve it's level being important prognostically suggestive of vital role of lactate monitoring during management. Base deficit (BD) in perfusion-related metabolic acidosis reflects the amount of base (mmol) required to titrate 1 L whole blood to a normal pH, assuming normal physiologic values of $PaO_2$, $PaCO_2$, and temperature [71,72,73,74].

It is well documented that lactate levels >4 mmol/L are strongly associated with worse patient outcomes. Perhaps more important than single values is the time to normalization of lactate levels, termed "lactate clearance time." Multiple studies have documented the usefulness of lactate clearance time as a predictor of patient mortality [75,76]. A good correlation exists between arterial and venous samples of lactate. The trend of lactate concentrations is a better indicator than a single value and it is a better prognostic indicator than oxygen-derived variables [77,78].

Numerous studies have shown that high lactate concentration in the presence of the systemic inflammatory response syndrome (SIRS) criteria is diagnostic, therapeutic, and prognostic marker of global tissue hypoxia in circulatory shock[79,80,81]. A high lactate level significantly increases ICU admission rates and mortality rates in normotensive patients [24,81-86]. Broder and Weil observed that serum lactate levels >4 mmol/L were associated with a survival of only 11% in critically ill patients [87]. Another study showed that lactate better predicted outcome for patients in septic shock than hemodynamic indices [88]. Weil and Afifi showed that lactate correlated with cumulative oxygen debt and was a predictor for survival [79]. Dunham et al demonstrated that serum lactate and BD are more sensitive than blood pressure or cardiac output in predicting severity and mortality in hemorrhagic shock [89]. The longer the lactate is elevated, the more a patient is likely to develop multi organ dysfunctional syndrome (MODS) and die [80,90-93]. "lactime" has been described as the time during which lactate remains >2 mmol/L and observed that this duration of lactic acidosis was predictive of organ failure and survival. A single measurement has been debated as an indicator of mortality in patient with global hypoperfusion.

It is best to follow lactate levels over time rather than relying on a single value for several reasons first, blood lactate concentrations reflect the interaction between the production and elimination of lactate. For example, a patient with sepsis along with hepatic dysfunction may have a higher lactate concentration compared with a patient without liver disease but with a similar degree of stress. Second, an increased lactate concentration may indicate mechanisms other than cellular hypoxia, such as up-regulation in epinephrine-stimulated Na/K–ATPase activity in skeletal muscle and inhibition of pyruvate metabolism or an increase in its production [25,96-100]. In a randomized, controlled study, Boyd et al. showed improved survival in high-risk surgical patients treated with hyperdynamic means to decrease lactate before, during, and after surgery compared to conventional therapy [97].

In a recent prospective observational study included 111 patients, Nguyen et al found that only lactate clearance was significantly associated with decreased mortality rates in the multivariate comparison ($P = 0.04$). An approximately 11% decrease in likelihood of mortality was found for each 10% increase in lactate. Patients with higher lactate clearance after 6 h of ED intervention have improved outcomes compared with those with lower lactate clearance. Multivariate logistic regression modeling was then performed using the statistically significant univariate variables. Whether it comes from anaerobic metabolism, inhibition of pyruvate dehydrogenase, or increased pyruvate production, lactate still correlates with survival. This is also true in the presence of liver failure [25,100,101].

To summarize, in any type of shock the longer the lactate level is elevated, the more likely is a patient to develop MODS and die regardless of the presence or absence of liver failure, Lactate clearance is significantly associated with a decreased mortality rate, It is best to follow lactate levels over time rather than relying on a single value and high lactate concentration in the presence of SIRS criteria is a diagnostic, therapeutic, and prognostic marker of global tissue hypoxia in circulatory shock.

The BD can indirectly reflect the blood lactate level. BD is the amount of base (in millimoles) required to titrate 1L whole blood to a pH of 7.4 (with 100% oxygen saturation and a $PaCO_2$ of 40). Therefore, the presence of a BD indicates an acidosis, resulting from fixed acids rather than hypercapnea. Unfortunately, it may reflect acidosis not related to elevated levels of lactate.

In a retrospective study of 3791 trauma patients, Rutherford et al found base deficit stratified mortality [100]. Davis et al retrospectively evaluated almost BD values from 3000 trauma patients and determined that admission values identified those likely to need transfusions [101]. One study, looking at 52 trauma patients, discovered no relationship between serum lactate level and BD or anion gap (AG) of note, serum lactate did not get above 5 mmol/L [102]. This is important based on other studies that revealed improved correlation of lactate level with AG as lactate levels rose. Iberti et al showed that 100% of surgical ICU patients with higher lactate levels (>10 mmol/L) had AG values >16 [103]. However, when lactate was between 5 and 9.9 mmol/L, 50% of patients had an AG <16. When lactate levels were <5 mmol/L, 79% of patients had AG values <16. These results may explain why the

first study did not show a lactate level and BD correlation. Davis et al reported excellent correlation of BD and blood lactate in a swine hemorrhagic model. It should be noted that lactate levels rose to 10 mmol/L with an associated BD of 4.6 mmol/L. When other processes are present, which might contribute to acidosis i.e. hyperchloremia and renal failure in which BD may not be due solely to elevated blood lactate levels. When possible, a blood lactate level should probably be obtained in addition to the BD.

## Summary

The ED is becoming an integral part of the chain of survival because the progression or resolution of organ dysfunction in critical illness is significant during the ED stay. The unavoidable duration of stay in ED frequently necessitates diagnostic and therapeutic interventions to attain hemodynamic stability that would otherwise be performed in the ICU. Early hemodynamic assessment using Goal directed resuscitation history, physical examination, vital signs, CVP, and other indices should be used in combination. In order to achieve definite parameters using these vital indices are yet to achieve, opening the vista of reaching that far using further multi centre trials.

### Acknowledgment

This project funded by College of Medicine Research Centre, Deanship of Research, King Saud University.

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