HEMODYNAMIC MONITORING IN SHOCK

Iulian Stratan

HOW AND WHERE SHOULD I MEASURE ARTERIAL PRESSURE IN A SHOCKED PATIENT AND WHAT DOES IT MEAN?

Shock results from poor tissue perfusion and tissue hypoxia from inadequate circulatory compensations needed to sustain acutely increased body metabolism. In critically ill patients, tissue hypoxia is due to disordered regional distribution of blood flow both between and within organs. Briefly, oxygen bound to hemoglobin is transported in the red blood cell by a convective process (cardiac output - CO) to the tissue, where it dissociates from hemoglobin to reach the mitochondria. In the normal state, oxygen delivery DO_2 =1,34 x Hb x CO x SaO_2 + 0.003 X PaO_2 where 1.34 is the amount of oxygen carried by 1g of hemoglobin, Hb is the hemoglobin concentration, SaO_2 is the arterial oxygen saturation and 0.003 is the solubility of oxygen in plasma) is more than sufficient to meet oxygen consumption (VO_2) demands of all tissue and organs. Under a given level of oxygen transport, VO_2 begins to decline and becomes supply dependent. Then, this result, after turning to anaerobic glycolysis to generate adenosine triphosphate, in lactic acidosis (1).

Oxygen deprivation states in critically ill patients are often referred as shock states. Basically, shock can be related to loss in oxygen carrier (hemorrhage or anemia), impaired CO (CO=heart rate x stroke volume) due to hypovolemia (hemorrhage) or cardiac dysfunction (cardiogenic shock) or oxygen neither reached nor being effectively extracted by cells, probably because of arteriovenous shunting or abnormalities in cellular metabolism (distributive shock) (2). In response to shock, three systems are stimulated to maintain CO by maintaining preload: sympathetic stimulation, release of vasopressin, and formation of angiotensin II. The resulting action is increased venoconstriction and heart rate. However, these compensatory systems fail overtime due to an inflammatory process with vasodilatation. The microcirculation is adversely affected, with maldistribution of blood flow. Organ blood flow and organ perfusion pressure are regulated by two control mechanisms. The first, extrinsic, involves a complex interaction of vasomotor effects between opposing neurohormonal system. The second, intrinsic mechanism, organ autoregulation, depends on changes in afferent arteriolar tone in response to the organ perfusion pressure itself. Below the autoregulatory thresholds, organ blood flows become linearly dependent on perfusion pressure. Because hemodynamic factors such as volume depletion, low cardiac output or inappropriate vasodilatation resulting in systemic hypotension may directly produce organ hypoperfusion through in organ perfusion pressure, organ autoregulation is disturbed in shock patients especially during sepsis. Therefore, therapy of patients in shock should be aimed at restoring an adequate organ perfusion pressure (3). In summary, the perfusion pressure is an important determinant of regional blood flow. Despite evident limitations, inadequate tissue perfusion

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leads to formation of serum lactate. Reduction in lactate levels reflects probably the restoration of organ blood flow, and is a good surrogate for one of the best level of blood pressure in shock state.

Although there are other, more sophisticated, definitions of shock – hypoperfusion and hypotension are key aspects of syndrome. Measurement and monitoring of arterial blood pressure are therefore intrinsic to the diagnosis and treatment of shock.

In modern critical care practice virtually all shocked patients have invasive arterial blood pressure monitoring.

APPROACHES TO MEASURING ABP

- Indirect (non – invasive) methods:
  - Sphygmomanometry:
    - palpatory method
    - auscultatory method
  - Oscillometric technique
  - Finger plethysmography
  - External tonometry

- Direct (invasive) methods:
  - Intra-arterial catheter
    - widely used in modern intensive care
    - radial artery the most common site
    - femoral artery increasingly used
    - brachial and axillary vessels sometime used
    - used with modern high - fidelity disposable transducers
  - Regarded as "GOLD STANDARD"
  - Catheter type – transducers also available

OBJECTIVES FOR MEAN ARTERIAL PRESSURE

Objectives in Hemorrhagic Shock

The best level of blood pressure has never been defined in hemorrhagic shock. However, the natural course of hemorrhagic shock can be divided in a pre-intervention phase and a post-intervention phase. During the pre-intervention phase, because the bleeding is uncontrolled, fluid resuscitation may be detrimental. Hypotensive resuscitation is preferred for patients with penetrating injuries. Indeed, in a prospective clinical trial, patients with penetrating torso injuries who presented a prehospital systolic blood pressure below 90 mmHg were assigned to an immediate-resuscitation group aimed at maintaining systolic blood pressure above 100 mmHg, hematocrit above 25%, and urinary output above 50 mL versus a delayed-resuscitation group receiving cannulation but no fluid resuscitation until they reached the operating room (4). Systolic blood pressure was kept at 79 ± 46 mmHg in the immediate-resuscitation group, as compared with 72 ± 43 mmHg in the delayed-resuscitation group (P = 0.02). Seventy percent of the patients in the delayed-resuscitation group survived, as compared with 62% of those in the immediate-resuscitation group (P = 0.04). The duration of hospitalization was shorter in the delayed-resuscitation group. The results of this study have confirmed those obtained in experimental studies (5,6). Interestingly, in a swine model of penetrating liver injury with loss of 40% of estimated whole blood volume within 30 minutes, mean arterial pressure was significantly higher after vasopressin versus epinephrine versus saline placebo (7). All epinephrine and saline placebo-treated animals died within 15 minutes after drug administration, whereas all vasopressin-treated animals survived. It was concluded that vasopressin improved short-term survival after liver injury when surgical intervention and fluid replacement were delayed. Despite several limitations, these experiments deserve an assessment in clinical practice (8), since increasing blood pressure with certain vasopressors seems efficient on the survival.

It has been suggested therefore, that the response to fluid resuscitation in blunt trauma with solid-organ injuries is inherently different from that in penetrating trauma with large-vessel injury. To prove this hypothesis, a rat model of standardized liver injury was developed, and resuscitation was achieved with various fluid

regimens, including lactated Ringer' solution, hypertonic sodium acetate (9). Survival time was significantly longer in animals treated with hypertonic saline, while no difference was observed between animals receiving no resuscitation and those treated with different volumes of lactated Ringer's solution. In this model, blood pressure was higher in the animals treated with hypertonic saline. In contrast using a massive splenic injury leading to uncontrolled hemorrhagic shock in adult male rats, the mean survival time, if untreated, was approximately 127 minutes while infusion of bolus of fluid was followed by a significant increase in blood loose from the injured spleen and a significant decrease in survival time. The authors concluded that splenic injuries mimic large-vessel injuries. However, in their experiments, mean arterial pressure was similar in untreated and treated animals (10). In conclusion, it is unclear which is the best level of blood pressure for the patients with hemorrhagic shock due to solid-organ injuries.

The optimal level of blood pressure for trauma patients during their intensive care unit stay has never been investigated. Nevertheless, 75 severely injured patients with shock resulting from bleeding and without major intracranial or spinal cord trauma were randomized to resuscitation, starting immediately after admission, to either normal values of systolic blood pressure, urine output, base deficit, hemoglobin, and cardiac index (control group) or optimal values (cardiac index >4.5 L/min/m^2, ratio of transcutaneos oxygen tension to fractional inspired oxygen > 200, oxygen delivery index >600mL/min/m^2, and oxygen consumption index >170 mL/min/m^2; (optimal group) (11). Despite these optimal values in the optimal group, the levels of blood pressure were similar in both groups. There was no difference in rates of death, organ failure, sepsis, or the length of intensive care unit or hospital stay between the two groups.

In conclusion, there is a lack of firm data that delineate the best level of blood pressure in hemorrhagic shock. However, regarding the results of studies on penetrating trauma, hypotension should be respected until bleeding was controlled.

Objectives in Cardiogenic Shock

The clinical definition of cardiogenic shock is decreased output and evidence of tissue hypoxia in the presence of adequate intravascular volume. Hemodynamic criteria are sustained hypotension (systolic blood pressure < 90 mmHg for at least 30 minutes or mean arterial pressure < 30 mmHg below baseline value) and reduced cardiac index (< 2.2 L/min/m^2) in the presence of elevated pulmonary capillary occlusion pressure (>15 mmHg) (12). In fact, under normal conditions, the upstream pressure for perfusion of coronary arteries is aortic diastolic pressure. The effective downstream or critical closing pressure in the coronary circulation in unclear. For the left ventricle subendocardium, the left ventricle end-diastolic pressure may be an accurate reflection of the downstream pressure. Consequently, aortic diastolic pressure should be adjusted for maintaining at least an adequate coronary perfusion pressure. Probably, blood pressure should be maintained at the level which makes it possible to decrease the serum lactate level without increasing the cardiac load work (13). In practice, guidelines for the management of patients with ST elevation recommend a systolic blood pressure above 100 mmHg (14). Both, inotropic and vasopressor agents have to be used if systolic blood pressure is below 80 mmHg (12).

Objectives in Septicc Shock

Septic shock is defined by sepsis-induced hypotension requiring for vasopressors despite adequate fluid resuscitation. From the Surviving Sepsis Campaign guidelines, the end-points for initial resuscitation are: central venous pressure from 8 to 12 mmHg, mean arterial pressure ≥ 65 mmHg, urine output ≥ 0,5 mL/kg/h, and central venous (superior vena cava) or mixed venous oxygen saturation ≥ 70% (15).

Unfortunately, there is a lack of end-point for resuscitation during the following hours. Vasopressors may be required when hypotension is persisting despite adequate fluid resuscitation using dynamic parameters. Increase blood pressure may restore organ blood flow by

improving perfusion pressure. On the other hand, one can hypothesize that stimulation of alpha receptors leads to endothelial cell apoptosis, worsening the picture of septic shock (16). However, this issue remains conflicting since when the endothelial cells die, they detach from the vessel and are cleared from the circulation. Therefore it is difficult to determine how extensive endothelial cell death really is.

The best level of mean arterial pressure of 65 mmHg has been shown to be physiologically equivalent to higher pressure (17,18). Indeed, in a prospective, randomized, 14 septic shock patients were randomly treated to achieve a mean arterial pressure of 65 mmHg by increasing the dose of norepinephrine for a 4 hour-period (18). Increasing mean arterial pressure from 65 mmHg to 85 mmHg with norepinephrine resulted in a significant increase in cardiac index from 4.8 to 5.8 L/min/m^2. Arterial lactate and oxygene consumption did not change, as well as renal function variables. In conclusion, mean arterial pressure can be maintained at 65 mmHg in septic shock patients. One should remind the limitations of this clinical study. First, with longer periods of evaluation, a time effect with spontaneous improvement of the studied variables related to the natural history of the disease cannot be ruled out, altthough the use of control group strengthens the findings of the present study since patients in this group had an evolution that was similar to that of the treated patiens. Secondly, the findings of the present study may not be applicable to all patients. Older patients, patients with a prior history of severe atherosclerosis, or those with severe hypertension may have a wider range of pressure-dependent perfision. Organ perfusion could be pressure-dependent over the range of 65-85 mmHg, and it is possible that this group of patients could benefit from higher (e" 90 mmHg) levels of mean arterial pressure. Thirdly, another limitation to the study is the sample size studied. The sample size studied was appropriate to test our hypothesis on the physiologic variables evaluated. A far greater number of patients should be evaluated to determine whether the level of mean arterial pressure reached has any influence on the survival of patients in septic shock.

HOW CAN I ASSES WHETHER THE CARDIAC OUTPUT IS APPROPRIATE FOR MY PATIENT?

Circulatory shock is defined by inadequate oxygen availability in the cell, and to appropriately answer the title question, we must therefore focus on the circulation rather than on the heart. In other words, the interpretation of the cardiac output, the question is less whether the heart functions well enough to provide an adequate cardiac output than whether the cardiac output produced enables adequate blood flow to supply enough oxygen to the cells. The interpretation of an appropriate cardiac output value will therefore include a number of peripheral, as well as central elements.

In fact, the appropriateness of the cardiac output response can be assessed by considering the response to three clinical and three biological questions:

Clinical

1. How is the cutaneous perfusion? If blood flow to the skin is decreased, the skin will be vasoconstricted, mottled and cyanotic.

2. How is the mental status? Cerebral hypoperfusion is typically manifest by obtundation and confusion (that are acute and otherwise unexplained)

3. How is the urine output? Decreased renal blood flow is an early sign of inadequate cardiac output, and is associated with reduced diuresis.

Biological

1. What is the blood lactate level? In severe shock, anaerobic metabolism will develop and results in hyperlactatemia associated with metabolic acidosis (due to the release of H^+ ions during ATP degradation). The normal lactate concentration is around 1 mEq/L, and hyperlactatemia is associated with a lactate concentration above 1.5 to 2 mEq/L.

Importantly, hyperlactatemia per se does not mean that cardiac output is inadequate, as other

abnormalities may contribute to hyperlactatemia in septic shock. However, where shock is present, an inadequate cardiac output, if severe, is always associated with hyperlactatemia. The presence of hyperlactatemia should, therefore, act as a warning signal of a potentially inadequate output.

2. What is the mixed venous saturation (SvO_2)? SvO_2 or its surrogate, central venous oxygen saturation ($ScvO_2$), is typically low (below its normal value of around 70%) when cardiac output is inadequate.(19) It is important to keep in mind that a low SvO_2 may be due to other factors, including hypoxemia, and does not necessarily mean that cardiac output is inadequate. However, a low cardiac output is always associated with increased oxygen extraction (i.e., a low SvO_2). Importantly, the decrease in SvO_2 associated with a low cardiac output occurs earlier than the hyperlactatemia, providing a more valuable monitor of initial condition and response to treatment.

3. What are the biological signs of organ dysfunction? Biological signs of organ dysfunction, e.g., altered renal function (urea, creatinine), liver function (liver enzymes, bilirubine) etc., suggest that organ perfusion is reduced and organ function is suffering. However, none of these is specific and many take some time to develop, thus limiting their usefulness in the acute situation and in following response to treatment.

Clearly, a single cardiac output value taken out of the context of the whole patient picture provides little information about whether or not cardiac output is adequate for the patient. Indeed, a low cardiac output may be adequate when oxygen needs are reduced (a hibernating organism has very low cardiac output!). Conversely, cardiac output should be high when requirements are elevated as in exercise or in sepsis. Likewise, evaluating the cardiac output response to an intervention like fluid administration or dobutamine administration does not help either, as the cardiac output of normal individuals may respond differently to these interventions. The adequacy of cardiac output is therefore best assessed by a combined clinical and biological review of the individual patient. Techniques are being developed to enable us to better visualize the microcirculation and better assess tissue oxygenation (20), and may in the future help in our assessment of the adequacy of cardiac output.

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