

Venous oximetry

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ABSTRACT

Tissue hypoxia is the central pathophysiological process in shock and an important co-factor in the development of organ dysfunction. Hemodynamic parameters, usually used to assess the perfusion of organs and tissues, like arterial blood pressure, heart rate, urine output and blood gases can be normal in the presence of tissue hypoxia and cannot rule out imbalances between global oxygen supply and demand. Mixed venous oxygen saturation (SvO₂) is a sensitive indicator of the adequacy of whole-body tissue oxygenation. However, it requires the placement of a pulmonary artery catheter, which is an invasive procedure with the possibility of numerous complications and is increasingly questioned due to the lack of evidence that it improves outcome. Central venous oxygen saturation (ScvO₂) requires the insertion of a central venous catheter, which is routinely used in most critically ill patients, but it reflects the adequacy of oxygenation in the brain and upper part of the body and differs from SvO₂. Still, it can be used as a surrogate for mixed venous oxygen saturation because the changes and trends of both variables parallel each other. Both variables are used extensively in the treatment of patients with severe sepsis, shock and trauma. In combination with other hemodynamic and biochemical parameters, they have diagnostic and prognostic value and allow for rational treatment of critically ill patients.

Key words: mixed venous oxygen saturation, central venous oxygen saturation, physiological monitoring, shock

Introduction

The basic role of the cardiorespiratory system is to supply oxygen to the tissues. The reduction of oxygen availability to the tissues, on a global or regional scale is the most frequent cause of physiological decompensation. The other, less frequent, causes are deficit in glucose supply, accumulation of metabolic waste products (carbon dioxide and lactate) and metabolic poisoning which interferes with the cellular utilization of oxygen (carbon monoxide, cyanide and possibly sepsis).

The oxygen partial pressure at mitochondrial level would be the ideal variable to monitor but it is impossible in the clinical setting. The more practical way of gaining an insight into the balance between oxygen supply and demand is measurement of venous oxygen saturation. A rise in venous saturation indicates a rise in supply relative to

demand and a fall in venous saturation indicates the opposite. Readings of venous oximetry may be monitored continuously with a fiberoptic catheter (1) or intermittently by blood sampling and co-oximetry. Fiberoptic monitoring is based on the presence of an optical fibre built into the catheter for measuring hemoglobin saturation. Light is transmitted into the blood, reflected off red blood cells and read by a photo detector. Continuous monitoring allows for prompt detection in changes of oxygen saturation and for easy observation of trends. The sampling method is more feasible and may be used in intensive care unit (ICU) patients or outside the ICU setting.

Recently, an alternative method for measuring mixed venous saturation was described where the oxymeter probe was placed in the trachea of anesthetized patients, adjacent to the pulmonary artery. The readings had excellent correlation with readings determined by co-oximetry from samples taken simultaneously from the pulmonary artery (2) Venous oxygen saturation may be used

to monitor individual organs, like the brain in a head trauma patient, by placing a catheter in the internal jugular vein. More commonly, it is used to monitor the global oxygen balance by catheter placement in the pulmonary artery or central vein. However, the global oxygen balance does not necessarily reflect the oxygenation status of individual organs (3)

When taking blood samples, blood needs to be aspirated very slowly because high negative pressures in the syringe can lower gas tensions and may lead to air entering the sample. When fiberoptic monitoring is used there is a possibility of interference from other optically active compounds (carboxyhemoglobin, very high bilirubin levels). There is also the need for recalibration against a co-oximeter every 4-6 hours.

Physiology and pathophysiology of venous oximetry

Venous oximetry reflects the balance between oxygen supply or delivery (DO₂) and oxygen consumption (VO₂). DO₂ is dependent on cardiac output

(CO) and oxygen content in arterial blood (CaO_2) which is the sum of oxygen bound to hemoglobin product of hemoglobin concentration (Hb) and arterial O_2 saturation (SaO_2) and physically dissolved oxygen (PaO_2), according to the following formulas:

$$DO_2 = CO \times CaO_2$$

$$CaO_2 = (Hb \times 1,36 \times SaO_2) + (PaO_2 \times 0,0031)$$

The amount of physically dissolved oxygen is small and can be neglected for practical purposes. Thus, oxygen delivery is defined mostly by CO, Hb and SaO_2 . Clinical conditions that can affect DO_2 are low cardiac output, anemia and hypoxia (decreased DO_2) and high cardiac output or CaO_2 which increase DO_2 (Table 1).

Oxygen demand or whole-body oxygen consumption (VO_2) can be expressed by the product of CO and arteriovenous O_2 content difference ($CaO_2 - CvO_2$) which is known as the Fick principle:

$$VO_2 = CO \times (CaO_2 - CvO_2) \text{ or rearranged}$$

$$CvO_2 = CaO_2 - VO_2 / CO$$

That means that mixed venous oxygen content (CvO_2) reflects the relation between whole body oxygen consumption and cardiac output under conditions of constant CaO_2 . CvO_2 can also be expressed by the equation:

$$CvO_2 = (Hb \times 1,36 \times SvO_2) + (PvO_2 \times 0,0031)$$

As physically dissolved oxygen can be neglected, the principal determinants of CvO_2 are Hb and SvO_2 . Since Hb is usually constant in a certain period of time, CvO_2 is mostly determined by SvO_2 . SvO_2 is inversely related to the VO_2 / CO ratio. Clinical conditions that can affect VO_2 are stress, pain, hyperthermia and shivering (increase O_2 consumption) or analgesia, sedation, mechanical ventilation and hypothermia which decrease O_2 consumption (Table 1).

Oxygen delivery and consumption are linked by a simple relationship:

$$VO_2 = DO_2 \times ERO_2 \text{ or}$$

$$ERO_2 = VO_2 / DO_2$$

where ERO_2 represents oxygen extraction ratio as a percentage. Normally ERO_2 is about 25% which means that 25% of delivered oxygen is taken up by tissues and 75% returns to the lungs. ERO_2 is inversely related to SvO_2 , which is shown in the equation:

$$SvO_2 = 1 - ERO_2$$

Therefore, normal ERO_2 of 25% corresponds to SvO_2 of 75%, and ERO_2 of 60% matches SvO_2 of 40%. Under normal conditions VO_2 is independent of DO_2 because tissues can meet their needs for oxygen by increasing extraction. When this compensation is exhausted at critical DO_2 , VO_2 becomes dependent of DO_2 . Anaerobic metabolism occurs and lactates begin to rise.

Oxygen delivery and consumption vary during physiological (exercise) and clinical conditions. The normal cardiovascular response to increasing VO_2 is to increase ERO_2 and cardiac output. SvO_2 normally decreases during exercise because the increased cardiac output cannot match completely the increased O_2 demand. Therefore, a drop in SvO_2 does not necessarily mean that tissue hypoxia is occurring but represents increased metabolic stress.

The extent of the SvO_2 drop denotes the magnitude of the stress (4) (Table 2).

In a healthy person anaerobic metabolism usually occurs when SvO_2 drops below 40% for a substantial period of time. In patients with severe heart disease the ERO_2 is increased at rest and they can live with SvO_2 in the low range without apparent hypoxia because they have adapted to hypoxia (rightward shift of oxyhemoglobin dissociation curve, adaptation of peripheral microvasculature).

In a septic patient misdistribution of blood flow and the disturbance of mitochondrial oxygen utilization may cause anaerobic metabolism in the presence of normal or even high SvO_2 . In that case blood lactate levels and base deficit will be high.

The normal values of SvO_2 are considered to be between 60 and 80%. Examples from above show that SvO_2 values should be interpreted carefully in the context of a wider clinical and biochemical picture.

The relationship between mixed venous oxygen saturation and central venous oxygen saturation

Obtaining mixed venous oxygen saturation levels requires pulmonary artery catheterization with a risk-benefit relationship that is still a matter of controversy. Central venous oxygen saturation may be obtained through a central venous catheter which is commonly placed in critically ill patients for a variety of reasons like central venous pressure monitoring, parenteral nutrition and catecholamine infusion. Therefore,

Table 1: Clinical conditions that affect DO_2 , VO_2 and venous oxymetry

Decrease in $SvO_2/ScvO_2$		Increase in $SvO_2/ScvO_2$	
O_2 consumption ↑	O_2 delivery ↓	O_2 consumption ↑	O_2 delivery ↓
- stress	- anemia	- analgesia	- high CaO_2
- pain	- hypoxia	- sedation	- high CO
- hyperthermia	- low CO	- mechanical ventilation	
- shivering		- hypothermia	

Table 2: The magnitude of SvO₂ drop related to physiological consequences

SvO ₂	Oxygenation status
> 75%	Normal extraction DO ₂ >VO ₂
75-50%	Increasing VO ₂ or decreasing DO ₂ Compensatory O ₂ extraction
50-30%	Exhausting of extraction Beginning of lactic acidosis DO ₂ <VO ₂
30-25%	Severe lactic acidosis
< 25%	Cellular death

ScvO₂ measurement seems to be an attractive alternative to SvO₂ monitoring. However, it has been questioned whether ScvO₂ may be used instead of SvO₂ especially under various clinical conditions.

There are normal, physiological differences between SvO₂ and ScvO₂. Venous oxygen saturation differs among organ systems because they extract different amounts of oxygen.

The central venous catheter tip resides in the superior vena cava which collects blood from the brain and upper part of the body. The pulmonary artery catheter sampling site is in the pulmonary artery which collects mixed venous blood that drains from the whole body. The blood that drains from the lower part of the body into the inferior vena cava has a higher venous saturation level than the blood in the superior vena cava mostly due to highly saturated (92%) renal venous blood. Renal

blood flow uses blood for non-oxidative phosphorylation needs and oxygen extraction is relatively low. Since the pulmonary artery contains a mixture of blood from both the superior and inferior vena cava, SvO₂ is greater than ScvO₂ by about 2-3%. (5)

The tip of the central venous catheter may also be positioned in the right atrium or at the junction of the superior vena cava and right atrium. Furthermore, the catheter can move due to a change in position of the patient (6) The sampled blood may contain, to some degree, blood from the inferior vena cava which can decrease the difference between SvO₂ and ScvO₂.

The relationship between the two variables may also be affected by various clinical situations and has been investigated in many experimental and clinical studies with different conclusions.

Several studies demonstrated the reversed relationship of SvO₂ and ScvO₂ in shock (7,8).

During cardiogenic and hypovolemic shock mesenteric and renal flow decreases followed by an increase in oxygen extraction. During septic shock, regional oxygen consumption by the gastrointestinal tract increases to a greater extent than blood flow. In both situations the blood in the inferior vena cava is desaturated and SvO₂ is lower than ScvO₂. Thus, during shock the low ScvO₂ implies even lower SvO₂. The difference is 5-18% (9), and a ScvO₂ value of 50% is considered critical.

During anesthesia ScvO₂ also exceeds SvO₂ by up to 6% due to the effects of inhalational anesthetics which increase cerebral blood flow and decrease oxygen extraction in the brain. (10)

A similar effect can be induced by cerebral trauma and barbiturate coma. Patients with elevated intracranial pressure have the highest difference between SvO₂ and ScvO₂ (11)

There has been considerable debate about whether ScvO₂ may substitute SvO₂ due to considerable differences. Edwards et al. in their prospective clinical investigation (12), compared oxyhemoglobin saturation in blood samples taken only once during insertion of the

pulmonary artery catheter from the superior vena cava, right atrium and pulmonary artery in thirty consecutive patients in severe shock. They found no statistical correlation between single measurements.

Reinhart et al. (13) examined the correlation between SvO₂ and ScvO₂ over a broad range of cardiorespiratory conditions in anesthetized dogs. The SvO₂ and ScvO₂ values and changes in values induced by experimental interventions were generally in close accordance throughout all of the experimental conditions. The same author, in another clinical study (11), explored the course of continuous and parallel measurements of SvO₂ and ScvO₂ in high risk patients in an interdisciplinary ICU. The results of this study confirmed the findings of others, namely that in patients with circulatory failure, ScvO₂ is generally higher than SvO₂, but also that changes in values were parallel in direction and similar in size.

Dueck et al. (14), in a prospective clinical trial, compared the oxyhemoglobin saturation in blood from the superior vena cava, right atrium and pulmonary artery during various hemodynamic situations. Correlation between single values was interpreted as clinically unacceptable, whereas, correlation between changes of oxygen saturation at various sampling sites was interpreted as clinically acceptable.

From these and other studies it may be concluded that there is an inconstant difference between absolute values of SvO₂ and ScvO₂ during shock, anesthesia and cerebral trauma and ScvO₂ cannot be used instead of SvO₂ for calculation of derived variables like oxygen consumption, extraction ratio or pulmonary shunt. The changes and trends of SvO₂ are closely mirrored by changes in ScvO₂ and there is parallel tracking of both variables during various hemodynamic conditions. The presence of a pathologically low ScvO₂ (implying an even lower SvO₂) is more clinically important than whether the values are equal. That makes ScvO₂ a satisfactory substitute for SvO₂ in a hemodynamically unstable patient.

Clinical application of venous oxymetry

When dealing with hemodynamically unstable patients in ICU the treatment is usually centered on optimizing cardiac output. At the beginning of resuscitation the clinician relies on hemodynamic variables like arterial blood pressure, central venous pressure, urine output and arterial blood gases which can all be normal despite tissue hypoxia. When cardiac output is monitored, usually by transpulmonary or transarterial thermodilution insight into only half of the picture is obtained, i.e. oxygen delivery. The relationship between oxygen delivery and oxygen consumption cannot be seen from cardiac output alone. High cardiac output values during severe sepsis and septic shock may be associated with tissue hypoxia.

Venous oxygen saturation provides information about the second part of the picture – adequacy of oxygen supply. Monitoring of SvO₂ and ScvO₂, together with other hemodynamic and biochemical variables, allows for a rational approach to the management of critically ill patients. Measures may be undertaken to increase DO₂ by increasing cardiac output, Hb or PaO₂. In the same time VO₂ may be decreased by sedation, analgesia, antipyretics and mechanical ventilation.

Target SvO₂ depends on the clinical situation. In high output states it is higher (SvO₂ 70%) but in low-output states it is lower and usually 60% is accepted.

The importance of SvO₂ monitoring has been originally proposed in cardiology patients. (15) Since then, indications for this monitoring have extended to other areas and it was used extensively in various clinical scenarios.

Gattinoni et al. in a large multicentre trial (16) resuscitated critically ill patients to an SvO₂ >70% and could not find any difference in morbidity and mortality between treated and control patients. However, the anticipated goal was only achieved in one third of the patients and who were included only 48 hours after admission to the ICU. Since hemodynamic resuscitation should have been

applied during the first hours after admission it is difficult to draw conclusions regarding the quality of venous oxymetry from this study.

The beneficial effect of continuous measurement of ScvO₂ was demonstrated by Rivers et al. in a prospective randomized study in patients with severe sepsis and septic shock (17). It was used as a hemodynamic goal during early and aggressive resuscitation. The maintenance of ScvO₂ above 70% in addition to maintaining mean arterial blood pressure above 65 mmHg, central venous pressure between 8-12 mmHg and urine output above 0,5 ml/kg/h reduced absolute mortality by 15%. In this study ScvO₂ was monitored fibreoptically.

Whether intermittent sampling would have had the same results remains to be demonstrated. The results of this important study are incorporated in the Surviving Sepsis campaign guidelines.

The care of severely traumatized patients includes early and aggressive resuscitation followed by early surgical intervention. Studies have shown that vital signs like blood pressure, heart rate and central venous pressure are insensitive end-points and that 50% of patients had insufficient ScvO₂ after initial resuscitation. (18) Patients with ScvO₂ lower than 65% after initial resuscitation needed additional interventions. The same cut-off value was able to detect initially hemodynamically stable patients in need of blood transfusion. (19)

Heart failure is a state of limited cardiac output. Therefore, such patients cannot sufficiently increase cardiac output during a rise of oxygen demand. Those changes can only be covered by increasing O₂ extraction. Therefore, in these patients SvO₂ is tightly correlated with cardiac output and a drop in SvO₂ is a good marker of cardiac deterioration.

Those patients can live with low SvO₂ values without tissue hypoxia, and the rise of lactate may be the first sign of decompensation. Patients with an ScvO₂ below 60% are usually in cardiogenic shock (20)

ScvO₂ has been shown to have diagnostic, prognostic and therapeutic use in patients who have an acute myocardial infarction (15,21)

Continuous fibreoptic ScvO₂ monitoring may be very helpful during cardiopulmonary Resuscitation (CPR). During cardiac arrest venous blood is desaturated to very low values (<20%). Successful chest compressions increase ScvO₂ above 40% (22). It also has predictive value: in all patients who reached ScvO₂ >72% during CPR, spontaneous circulation was observed (23) In the immediate post resuscitation period patients are often hemodynamically unstable. The decrease of ScvO₂ to <40-50% indicates the likelihood of re-arrest. Sustained, extreme elevation of ScvO₂ above 80% is an unfavorable predictor of outcome. These very high values may be indicative of impairment of tissue oxygen utilization (24)

The successful use of ScvO₂ as a hemodynamic goal in the management of early sepsis has led to interest in the use of this parameter in surgical patients. Pearse et al. demonstrated that applying goal directed therapy in the intensive care unit can be successfully initiated after major surgery (25) During this study they also measured ScvO₂ in order to assess the efficacy of goal directed therapy. The analysis suggests that ScvO₂ may have prognostic significance after major surgery. In their cohort of patients the ScvO₂ cut-off value of 64,4% discriminated patients with a complicated and uncomplicated postoperative course (26).

Conclusion

Venous oxymetry gives essential information about tissue oxygenation. Measurement of ScvO₂ is simple, feasible in every ICU and may give almost the same information as SvO₂. Its value is recognized by clinicians and is used extensively in various clinical settings. It should be interpreted carefully, taking into account the complexity of patients and diseases, combined with other clinical, hemodynamical and biochemical variables.

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