Continuous Measurement of Central Venous Oxygen Saturation in Critically Ill Patients

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Learning Objectives
Upon completion of this learning activity, the participant will be able to:
1. Describe the technology that is used to measure central venous oxygen saturation (ScvO2).
2. Discuss the correlation between mixed venous oxygen saturation (SvO2) and ScvO2.
3. Identify clinical indications for use of continuous ScvO2 monitoring.

Current hemodynamic technology allows critical care practitioners to continuously monitor and evaluate tissue oxygenation at the bedside by using a fiberoptic pulmonary artery catheter that measures mixed venous oxygen saturation (SvO2). Placement of a pulmonary artery catheter to measure SvO2 may not always be feasible early in resuscitation or outside the intensive care unit (ICU). A new technology that uses a modified central venous catheter with fiberoptic technology has recently been introduced into clinical practice. It is now being used before, or as an alternative to, placement of a pulmonary artery catheter. This new catheter measures central venous oxygen saturation (ScvO2), which has been shown to trend with SvO2. ScvO2 provides clinicians with a real-time, continuous parameter for evaluating tissue oxygenation at the bedside. Similar to continuous SvO2, ScvO2 monitoring enables early warning and surveillance for changes in a patient’s ability to provide sufficient oxygen to meet metabolic demands. ScvO2 monitoring also provides immediate feedback on the effectiveness of therapies.

The purpose of this article is to introduce critical care practitioners to this new technology that enables tissue oxygenation to be evaluated at the bedside.

Overview
A fundamental understanding of the principles of oxygen delivery and consumption is needed in order to appreciate the clinical significance of ScvO2 monitoring.

Oxygen delivery is the amount of oxygen being delivered to the tissues. The major determinants of oxygen delivery are cardiac output, hemoglobin level, and arterial oxygen saturation (SaO2).

Oxygen consumption is the amount of oxygen that is actually being used by the tissues. The balance between oxygen delivery and consumption is what maintains homeostasis in the body. This delicate balance is threatened when either oxygen supply (delivery) is decreased or oxygen demand (consumption) is increased. When supply decreases or demand increases, compensatory mechanisms are activated to ensure sufficient oxygen is available to meet the metabolic demands of the tissues. Immediately available compensatory mechanisms include increased cardiac output and increased oxygen extraction. Critically ill patients with compromised cardiac function may not be able to increase cardiac output enough to meet the metabolic needs of the tissues. In this situation, oxygen extraction at the tissue level increases and less oxygen is present in the blood that returns to the lungs to be reoxygenated, reflected as a decreasing SvO2. SvO2 decreases when oxygen demands exceed supply or when oxygen delivery is compromised. If compensatory mechanisms fail to restore the balance between oxygen supply and demand, anaerobic metabolism, lactic acidosis, and global tissue hypoxia result. Therefore, SvO2 may serve as an indicator of the balance between oxygen delivery and demand.

This new central venous catheter with fiberoptic capabilities is being used in many settings, including the emergency department and outside the traditional ICU. Central venous catheterization is easier to perform and has fewer inherent risks than does placement of a pulmonary artery catheter. This new catheter measures ScvO2 in the superior vena cava. Continuous monitoring of SvO2 and ScvO2 has proven beneficial in the early identification of global tissue hypoxia and the treatment of such patients even when vital signs have appeared to be normal.

DEFINITIONS
ScvO2 is the oxygen saturation of central venous blood. This value is obtained by placing a fiberoptic central venous catheter into the superior vena cava. ScvO2 reflects oxygen saturation of blood returning from the upper body and indicates the balance between oxygen delivery and oxygen consumption in the cranial portion of the body, including the brain.

SvO2, on the other hand, is obtained from a pulmonary artery catheter and reflects overall SvO2 of blood returning from the upper body, the lower body, and the heart via the coronary sinus. Variations in regional blood flow from the upper body, lower body, and heart will affect the absolute values for ScvO2 and SvO2.

RELATIONSHIP BETWEEN SvO2 AND ScvO2
Many studies have examined the relationship between SvO2 and ScvO2. ScvO2 is usually slightly lower than SvO2 in healthy persons. However, in pathologic states such as circulatory shock, cardiac shock, severe sepsis, heart failure, and head injury, this relationship changes and ScvO2 is generally higher than SvO2. These studies suggest that the presence of a low ScvO2 indicates an even lower SvO2.

Although ScvO2 and SvO2 values do not absolutely correlate, more importantly, they have been shown to track with one another over a variety of changing clinical conditions. Timely
clinical decision making is enhanced by having a continuous, graphic recording of ScvO₂. In many cases, clinical changes occur so quickly that treatment would be delayed without the use of real-time, continuous monitoring of ScvO₂. Use of continuous ScvO₂ monitoring as a surrogate for SvO₂ enhances decision making in nontraditional settings where pulmonary artery catheters are not routinely placed, such as the emergency department.

MEASUREMENT

Components needed to measure continuous ScvO₂ include a fiberoptic central venous catheter, an optic module, and a specialized computer (Figure 1). This technology is based on reflection spectrophotometry. A modified, fiberoptic triple-lumen central venous catheter is placed in the superior vena cava. This catheter is 20 cm long and also allows for pressure measurement and fluid administration. Selected wavelengths of light are transmitted down a fiberoptic filament in the catheter to the blood flowing past the catheter tip in the superior vena cava. A second fiberoptic filament transmits the reflected light back to a photodetector located in the optic module. The reflected light can be analyzed to determine ScvO₂ because oxyhemoglobin and hemoglobin absorb light at different wavelengths. A real-time, on-line continuous reading of ScvO₂ is then displayed on the computer screen.

CLINICAL APPLICATION

Measurement of ScvO₂ has been used in a variety of settings for early management of patients with severe sepsis and septic shock,¹⁰ acutely decompensated congestive heart failure,¹¹ cardiac arrest,¹²,¹³ and traumatic and hemorrhagic shock,⁵,¹⁵ as well as following resuscitation after cardiac arrest.¹

Severe Sepsis and Septic Shock

Global tissue hypoxia develops before severe sepsis, septic shock, multiorgan failure, and death.¹⁶ Persistent global tissue hypoxia usually cannot be detected by means of traditional measurement parameters such as vital signs and hemodynamic pressures.⁴

Rivers et al¹⁰ recently studied continuous ScvO₂ monitoring as a resuscitation endpoint in the management of severe sepsis and septic shock. In their study, a systematic approach to the management of patients with sepsis in the emergency department was evaluated by using early goal-directed therapy (EGDT) beginning before ICU admission (Figure 2). Restoration of the balance between systemic oxygen delivery and demand is the primary goal of EGDT. Patients coming to the emergency department with severe sepsis and septic shock were randomized to receive either 6 hours of standard sepsis care or 6 hours of EGDT. Therapeutic goals for both groups included achieving a central venous pressure of 8 to 12 mm Hg and a mean arterial pressure greater than 65 mm Hg. In addition, those in the group receiving EGDT were also resuscitated to an ScvO₂ greater than 70%. Study results included a reduction of in-hospital mortality by 16%, shortening of the length of stay by approximately 4 days, and a reduction in total charges of $12,000 per discharge.

Acutely Decompensated Congestive Heart Failure

Ander et al¹¹ studied the use of lactic acid levels and continuous measurement of ScvO₂ as a way to stratify and manage patients with acutely decompensated, end-stage, chronic congestive heart failure (ejection fraction <0.30) who came to the emergency department. Global tissue hypoxia is caused by shock when myocardial function is deteriorating. Initial lactic acid levels were measured, and patients were managed by using continuous ScvO₂ monitoring based on a standardized protocol. Ander et al found that therapeutic interventions that were guided by ScvO₂ monitoring resulted in a significant decrease in lactic acid levels, indicating that global tissue hypoxia was resolving. They concluded that use of continuous ScvO₂ monitoring and measurement of lactic acid levels in this population was superior to assessment of vital signs for identifying and managing global tissue hypoxia that indicates occult cardiogenic shock. Timely recognition of occult cardiogenic shock while patients are in the emergency department will make it possible to use early, aggressive management strategies aimed at resolution of global tissue hypoxia.

Cardiac Arrest

Currently, during cardiac arrest, vital signs and findings on the physical examination are used as guides to therapy. Several studies have shown the usefulness of ScvO₂ monitoring as a diagnostic and treatment adjunct for patients in cardiac arrest.¹²,¹³ ScvO₂ values during resuscitation of patients in cardiac arrest were between 5% and 20%. A mortality rate of 100% was found in patients whose ScvO₂ value failed to reach 40%.

In another study, Paradis et al¹⁴ examined the use of ScvO₂ monitoring to confirm the presence of sustainable cardiac activity during electromechanical dissociation or a pulseless idioventricular rhythm. They concluded that if ScvO₂ was greater than 60%, return of spontaneous circulation was likely to occur, and that an ScvO₂ value greater than 72% was associated with a return...
of spontaneous circulation.

**Following Resuscitation After Cardiac Arrest**

It is well known that after cardiac arrest, patients are at risk for re-arrest because of continuing hemodynamic instability. ScvO\textsubscript{2} monitoring is useful in detecting ongoing oxygen imbalances that might not have been fully resolved during resuscitation. Rivers et al\textsuperscript{1} state that if ScvO\textsubscript{2} decreases below 40% to 50%, the patient is at risk for re-arrest. When the ScvO\textsubscript{2} increases above 60% to 70%, the patient is considered to be hemodynamically stable. In the presence of a low oxygen delivery, an ScvO\textsubscript{2} value greater than 80% indicates impaired systemic oxygen consumption and is associated with a poor prognosis.

**Trauma and Hemorrhagic Shock**

Traditionally, assessment of vital signs such as blood pressure and pulses has been used to detect and treat shock states in trauma patients. Several studies\textsuperscript{5,15} of critically ill patients have shown that vital signs are unreliable resuscitation endpoints. Several authors\textsuperscript{5,16} advocate that if ScvO\textsubscript{2} is less than 65%, additional resuscitation or surgical interventions may be required in patients with trauma and hemorrhagic shock.

**CONCLUSIONS**

One of the major goals of treatment for critically ill patients is to restore the balance between oxygen delivery and demand.\textsuperscript{10,17} Continuous S\textsubscript{v}O\textsubscript{2} monitoring allows clinicians to routinely monitor tissue oxygenation at the bedside. Unfortunately, insertion of a pulmonary artery catheter is not possible in many situations. Although S\textsubscript{v}O\textsubscript{2} and ScvO\textsubscript{2} values do not absolutely correlate, they do trend with one another. Continuous ScvO\textsubscript{2} monitoring is currently being used in a variety of nontraditional settings where insertion of a pulmonary artery catheter is not feasible, such as early or during resuscitation and in the emergency department. In these settings, central venous catheters are commonly placed and used to manage patients.

Vital signs and other hemodynamic parameters have proven inadequate as indicators of existing imbalances between oxygen delivery and consumption.\textsuperscript{5,10,15} Use of continuous ScvO\textsubscript{2} monitoring will enable clinicians to detect early alterations in tissue oxygenation so that therapeutic interventions aimed at restoring oxygen balance can be instituted promptly. In addition, continuous monitoring of ScvO\textsubscript{2} will allow continuous evaluation of patients’ responses to interventions and nursing care.

**Author Disclosure**

Cynthia Goodrich is a senior education consultant for Edwards Lifesciences, Irvine, Calif.

**References**

Table Causes of Altered Central and Mixed Venous Oxygen Saturation

Low $Svo_2$/$ScvO_2$
- Decreased oxygen delivery
  - Cardiac output
  - Hemoglobin level
  - Arterial oxygen saturation
- Increased oxygen consumption
  - Fever, pain, agitation, shivering
  - Seizures, increased work of breathing

High $Svo_2$/$ScvO_2$
- Increased oxygen delivery
  - Cardiac output
  - Hemoglobin level
  - Arterial oxygen saturation
- Decreased oxygen consumption
  - Hypothermia, anesthesia, late sepsis
  - Pharmacological paralysis

Symbols: ↓, decreased; ↑, increased