

Theory and Clinical Application of Continuous Fiberoptic Central Venous Oximetry (ScvO₂) Monitoring

Physiology and Venous Oximetry

Maintaining the balance between oxygen delivery (DO₂) and consumption (VO₂) to the tissues is essential for cellular homeostasis and preventing tissue hypoxia and subsequent organ failure. Traditional monitoring parameters (HR, blood pressure, CVP, and SpO₂) have been proven to be poor indicators of oxygen delivery secondary to compensatory mechanisms (Figure 1).¹ Moreover, patients have demonstrated continued signs of tissue hypoxia (increased lactate, low ScvO₂) even after they have been resuscitated to normalized vital signs.²

ScvO₂ = Early Warning and Prevention

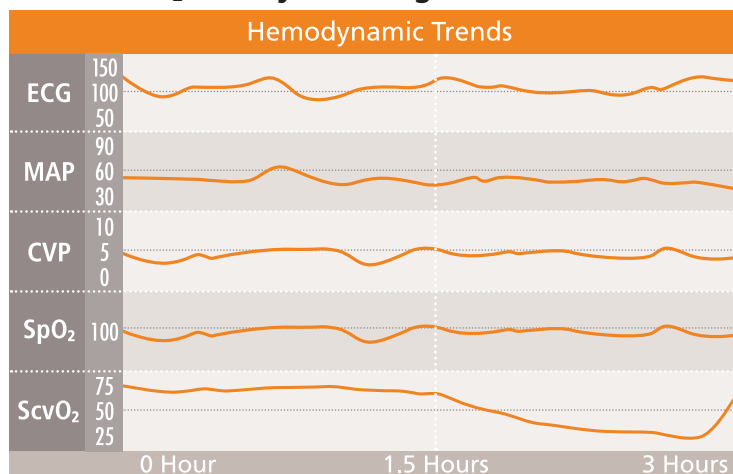


Figure 1. Traditional monitoring parameters failed to alert clinicians to cardiac tamponade in this case.¹

Continuous fiberoptic venous oximetry is a valuable tool for monitoring the balance between oxygen delivery and consumption at the bedside.³ Continuous venous oximetry is a sensitive real-time indicator of this balance, which can be applied as a global or regional indicator – with mixed venous oxygen saturation (SvO₂) and central venous oxygen saturation (ScvO₂) being the most commonly monitored. SvO₂ is a true reflection of the global balance between oxygen delivery and consumption since it is measured in the pulmonary artery, where venous blood returning to the right heart from the superior vena cava (SVC), inferior vena cava (IVC) and the coronary sinus (CS) have mixed. SvO₂ has been extensively studied and used clinically to monitor the global balance between DO₂ and VO₂.^{2,3,4} SvO₂ monitoring has been available through either co-oximetry laboratory analysis or through continuous fiberoptic monitoring with advanced technology pulmonary artery catheters since the 1970s and mid-1980s, respectively.

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Continuous fiberoptic ScvO₂ monitoring became available in 2003 on an 8.5F central venous catheter platform (PreSep catheter). This capability is also available via 4.5F and 5.5F central venous oximetry catheters (PediaSat catheter) for pediatric use (Figure 2). With the tip of the PediaSat central venous catheter placed in the SVC, ScvO₂ can be measured and displayed on either a Vigileo or Vigilance monitor.

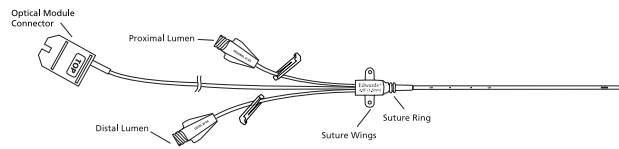


Figure 2. PediaSat oximetry catheter, 4.5F 5cm 20/23 gauge

Difference Between SvO₂ and ScvO₂

Since SvO₂ and ScvO₂ are affected by the same four factors (cardiac output, hemoglobin, oxygenation, and oxygen consumption), and trend together clinically, they are considered nearly interchangeable.^{3,5} The exception is when calculating global physiologic profiles that use SvO₂, such as VO₂.⁴

SvO₂ is a global indicator of the balance between DO₂ and VO₂ as it is a reflection of all venous blood; IVS, SVC, and CS. ScvO₂ is a regional reflection (head and upper body) of that balance. Under normal conditions ScvO₂ is slightly lower than SvO₂ due in part to the mixing and amount of venous blood returning. In hemodynamically unstable patients, this relationship changes with ScvO₂ being higher than SvO₂ by approximately 7%.

This difference can widen in shock states, up to 18%, but the values trend together more than 90% of the time.^{3,5,6}

Global Venous Oximetry

SvO₂ – mixed venous oximetry

Regional Venous Oximetry

ScvO₂ – head and upper extremities⁷

SpvO₂ – peripheral venous oximetry

Organ Specific Venous Oximetry

SjvO₂ – cranial jugular bulb oximetry⁸

ShvO₂ – hepatic venous oximetry⁹

ScsO₂ – coronary sinus oximetry¹⁰

Continuous ScvO₂ Monitoring Technology

All venous oximetry is measured through reflection spectrophotometry. Light is emitted from an LED through one of the two fiberoptic channels into the venous blood; some of this light is reflected back and received by another fiberoptic channel, which is read by a photodetector. The amount of light that is absorbed by the venous blood (or reflected back) is determined by the amount of oxygen that is saturated or bound to hemoglobin. This information is processed by the oximetry monitor, and updated and displayed every two seconds as a percent value on the monitor (Figure 3).³

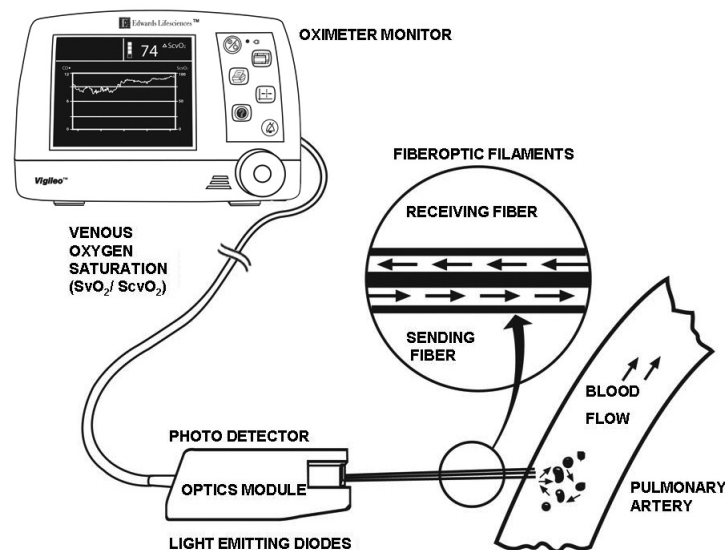


Figure 3. Venous Oximetry System

Accuracy of Edwards Fiberoptic Continuous ScvO₂ Compared to Co-oximetry

In a laboratory bench environment continuous fiberoptic venous oximetry monitoring accuracy is approximately $\pm 2\%$ at oximetry range of 30-99% as compared to a co-oximeter.¹¹ With oxygen saturations from 9% to 100%, the results of the fiberoptic oximetry systems correlated significantly ($P < 0.0001$) with the standard blood gas co-oximetry system ($r = 0.99$).¹² In an animal model, fiberoptic ScvO₂ technology correlated significantly ($Pr = 0.96$, $P < 0.001$) and had a close linear relationship as determined by regression analysis ($r^2 = 0.91$, $P < 0.001$). Bland-Altman analysis revealed a $+ 0.03\%$ difference of means (bias) with $+ 4.11\%$ precision. Clinical comparison measurements also showed a significant correlation ($Pr = 0.94$, $P < 0.001$) and close linear relationship as determined by regression analysis ($r^2 = 0.88$, $P < 0.001$). Difference of means (bias) was $- 0.03\%$ with a $+ 4.41\%$ precision.¹³

Interference with ScvO₂ Readings

Technical issues and therapeutic interventions may affect fiberoptics. Both the large distal lumen and the sending/receiving optics reside at the tip of the catheter. Therefore, tip position may influence signal quality (SQI) and readings if the tip is positioned against a vessel wall. Fluids infused through the distal lumen may also influence SQI and readings (e.g., lipids such as TPN or propofol, green or blue dyes, and crystalloid infusions at high flow rates). Catheter kinking may also result in a high SQI.

Interpreting Venous Oximetry (SvO₂ and ScvO₂) Values

Normal range values for SvO₂ are 60-80% and 70% for ScvO₂. ScvO₂ usually runs 7% higher than SvO₂ in critically ill patients.

Low oximetry readings usually indicate either low oxygen delivery (DO₂) or an increase in consumption (VO₂).² However, patients with cyanotic hearts may have extremely low ScvO₂ levels, therefore it is important to establish a baseline for each patient.

Significantly elevated levels ($>80\%$) may indicate an inability to use oxygen delivered oxygen, significant shunting, significantly high cardiac output, or technical errors.

When is Change Significant?

ScvO₂ and SvO₂ values are not static and fluctuate approximately $\pm 5\%$. These values may show significant changes with activities or interventions such as suctioning; however, the values should recover within seconds. Slow recovery is an ominous sign of the cardiopulmonary system's struggle to respond to a sudden increase in oxygen demand. When monitoring ScvO₂, clinicians should look for changes of $\pm 5 - 10\%$ that are sustained for more than 3-5 minutes and then investigate each of the four factors that influence ScvO₂:

- Cardiac output
- Hemoglobin
- Arterial oxygen saturation (SaO₂) and
- Oxygen consumption

The first three (above) are indicators of DO₂, while the fourth is an indicator of VO₂.

Clinical Applications of ScvO₂

ScvO₂ and SvO₂ are affected by the same four factors and trend together more than 90% of the time. Thus most of the research and clinical applications documented for SvO₂ should apply to ScvO₂. Figure 4 provides examples of clinical situations where ScvO₂ monitoring may be helpful in identifying imbalances between DO₂ and VO₂.⁴

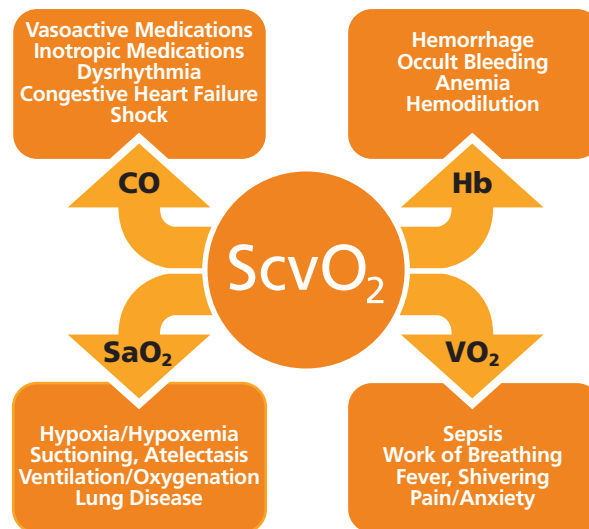


Figure 4. Clinical uses of ScvO₂ monitoring.⁴

ScvO₂ is best used adjunctively with cardiac output monitoring, allowing the clinician to determine the adequacy of oxygen delivery and to differentiate between issues of oxygen delivery vs. oxygen consumption (Figure 5).

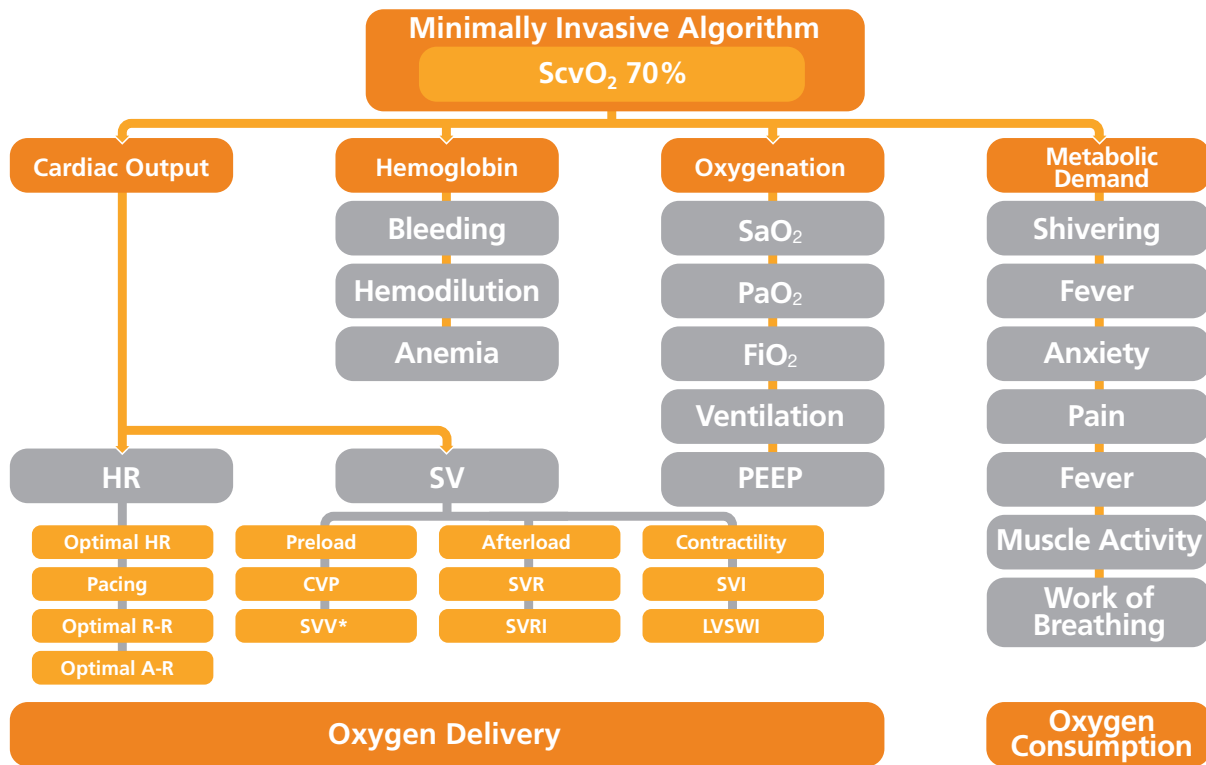


Figure 5. Minimally invasive algorithm breaking down components of oxygen delivery and consumption followed by sub-components investigating root cause of imbalance.

Summary

Continuous venous oximetry (ScvO₂) monitoring is an early, sensitive, and real-time indicator of the balance between DO₂ and VO₂ that can alert clinicians to an imbalance when traditional vital signs may not. ScvO₂ monitoring with the PreSep or PediaSat catheter is a practical tool which is no more invasive than a traditional central venous catheter. Venous oximetry is best used in conjunction with cardiac output monitoring. Moreover, keeping ScvO₂ values above 70% has been proven to lead to better patient outcomes.¹⁴

Prepared By

John Frazier RN RRT, Critical Care Marketing and Education, Edwards Lifesciences, Irvine, California

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* SVV is an indicator of preload responsiveness.

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