The Hemodynamic and Physiological Relevance of Continuous Central Venous Oxygenation Monitoring: It’s Not Just for Sepsis

Eric Reyer, DNP, ACNP, CCNS, 2013

OVERVIEW

SvO₂/ScvO₂ (mixed or central venous oxygen saturation) is an important yet frequently misunderstood hemodynamic parameter. Specifically, its use in patients other than those in cardiac surgery and with sepsis has not been widely understood as a useful tool in decision-making with critically ill patients. This paper covers tissue oxygenation and the role of continuous central venous oxygenation monitoring in the assessment of both potential oxygen delivery and consumption in the typical critical care patient.

MEASURING POTENTIAL OXYGEN DELIVERY

The normal oxygenation cycle begins with deoxygenated blood entering the right side of the heart. As hemoglobin molecules pass out of the right side of the heart and through the lungs/alveoli, four molecules of oxygen become attached to each individual hemoglobin molecule. This oxygenated blood then passes through the left side of the heart and out to the tissue. Upon reaching the capillary beds, an average patient extracts one molecule of oxygen from each hemoglobin molecule, leaving the red blood cells 75% saturated with oxygen as they return back to the right side of the heart.¹

The amount of oxygen saturation in the arterial system as it passes into the capillary bed is referred to as potential oxygen delivery (DO₂), as extraction has not yet occurred. In the early days of measuring DO₂, blood had to be sampled directly from an artery and the amount of oxygen/saturation was measured through instrumentation outside the body.² Continuous pulse oximetry, or SpO₂, was widely used in the operating room beginning in the 1980s.

As the technology was simplified, its use in critical care areas emerged in the early to mid-1990s. Because of the cost of this technology, most hospitals only acquired a handful of these monitors in their ICUs and emergency departments. Medical staff would use the same monitor and go bed to bed at specified times, obtaining a reading of each patient’s arterial oxygen saturation.

This snapshot in time was quickly recognized to be unacceptable because a patient’s physiology is constantly changing, sometimes rapidly. Continuous SpO₂ monitoring was adopted as a standard in all ICU patients in the mid to late 1990s as clinicians learned that one value obtained at regular intervals was not sufficient to treat serious and critically ill patients.³
INCREASING POTENTIAL OXYGEN DELIVERY: FOUR METHODS

Measuring $DO_2$ is dependent upon hemoglobin/hematocrit, cardiac output, and saturation of the individual hemoglobin molecules. Increasing potential oxygen delivery can be achieved in four ways:

1. The first, and simplest, form is to increase inspired oxygen or $FiO_2$. Assuming that a disease process is not inhibiting the transfer of oxygen in the alveolar beds, there should be a rise in partial pressure of oxygen and subsequent saturation of hemoglobin molecules.\(^1,^2,^4,^5\)

2. Mechanical ventilation can be used for patients who require assistance in either the movement of oxygen into the lungs or who require more pressure for oxygen to transfer across the alveolar membranes. BiPAP, endotracheal intubation, and advanced ventilator modes such as Airway Pressure Release Ventilation (APRV) and oscillation increase the movement of $O_2$, including controlling pressure both during inspiration and at end expiration. Using mechanical ventilation, Positive End Expiratory Pressure (PEEP) can be increased, stretching alveoli to maximize their surface area and resulting in increased oxygen transference into the blood.\(^2,^5\)

3. Though recent research has shown that blood transfusions may increase mortality in many patient populations, increasing hemoglobin levels through transfusion of packed red blood cells may result in extra oxygen-carrying capacity. In simple terms, if you increase the amount of hemoglobin molecules crossing the capillary beds, there is more potential for oxygen to be extracted because more oxygen molecules are present. This treatment should be reserved for disease processes shown to require transfusion rather than being based on lab values alone, as blood is a liquid transplant and has many adverse effects.\(^2,^6\)

4. The final way to increase potential oxygen delivery is to deliver more blood volume directly to the tissues. Increasing cardiac output (CO) does this by maximizing the amount of blood exiting the left side of the heart that is directly pumped to the capillary beds. CO is composed of stroke volume (the amount of blood pumped from the left ventricle during each cardiac cycle) times heart rate: $CO = SV \times HR$.

Many methods exist to increase CO depending upon the patient’s hemodynamic status, overall condition, and disease process. The appropriate method/intervention should be chosen based on current physiological needs.\(^5,^7\)

MEASURING VENOUS OXYGENATION

As blood returns to the right side of the heart, venous oxygenation can be measured through saturation of the hemoglobin molecules. This was first done, just as with arterial oxygenation, by obtaining a blood sample from the central circulation and measuring the oxygen level, the partial pressure, and/or hemoglobin saturation.

Many clinicians still use this outdated practice of measuring central venous oxygen saturation, giving them only a snapshot in time. As we learned with arterial saturation ($SpO_2$), this method of monitoring does not give a clinician enough information to make good decisions because a patient’s condition may vary from minute to minute.\(^3,^5,^7\)

The intermittent measurement of a patient’s central venous oxygen saturation does not give a clinician enough information to make good decisions because the saturation levels may vary from minute to minute.\(^3,^5,^7\)
Continuous SvO₂/ScvO₂ is measured through technology similar to SpO₂. Various wavelengths of light are emitted from the tip of a catheter that is located in the pulmonary artery using a PA catheter (SvO₂), or the superior vena cava using a central line (ScvO₂). As these wavelengths of light are reflected back to the receiver on the tip of the catheter, venous oxygen saturation is measured and displayed continuously in real time.

Because the normal oxygen cycle delivers one molecule of oxygen in the capillary bed, the average healthy person should have a venous oxygenation saturation of around 70 to 80%. ScvO₂ measures oxygen saturation returning from the upper body.¹⁻³⁻⁷ The value runs approximately 5 to 10% higher than SvO₂. SvO₂ measures saturation of blood returning from both the lower and upper body mixed with coronary return.

Research has proven that these values correlate exactly, thus allowing ScvO₂ to be utilized in a less invasive manner as a replacement, or surrogate, for the more invasive SvO₂. Most critically ill patients require the use of a central venous catheter. Continuous ScvO₂ monitoring can be easily achieved through the use of the same invasive practice (triple-lumen central venous catheter) currently accepted as the standard of care in critically ill patients.⁸ This means that no other devices need to be placed.⁴⁻⁹ The following graphic shows venous saturation by minutes for ScvO₂ and SvO₂.

Venous Saturation
Although ScvO₂ values run approximately 5 to 10% higher than SvO₂, research has proven that these values correlate exactly, thus allowing ScvO₂ to be utilized in a less invasive manner as a replacement, or surrogate, for the more invasive SvO₂.
COMPARING FIBER OPTIC TECHNOLOGIES FOR GATHERING ScvO\textsubscript{2} AND SvO\textsubscript{2} DATA

Several fiber optic technologies are available in the medical industry to gather SvO\textsubscript{2}/ScvO\textsubscript{2} data. The first uses only two wavelengths of light, resulting in limited capability because it requires the hemoglobin level to be constant. This forces the user to calibrate the catheter at least daily, including entering frequent hemoglobin values. The other limiting factor with this method is that the value measured can be inaccurate if there is a small change in hemoglobin, which is frequent in critical care patients.\textsuperscript{10-12}

The more accurate technology monitors central venous oxygenation independent of hemoglobin levels using three wavelengths of light instead of two, making calibration unnecessary except when first taking it out of the package.

It is available as both an integrated model (built into a standard triple-lumen central venous catheter) or as a small probe that can be easily advanced down the distal lumen of a previously inserted dwelling central venous catheter.\textsuperscript{10-12}

In addition, a new technology utilizing the same three-wavelength fiber optic bundle delivered less invasively through a peripherally inserted cardiac catheter (known as a PICC line) is pending FDA 510(k) clearance and may allow for more widespread adoption of ScvO\textsubscript{2} monitoring outside the OR and ICU.

ICU Medical’s TriOx™ central venous oximetry catheter and probe are currently the only technologies providing three-wavelength oximetry for greater accuracy in assessing real-time tissue oxygenation status.
MAKING DECISIONS IN TREATMENT AND PLAN OF CARE

Continuous measurement of both ScvO\textsubscript{2} and SpO\textsubscript{2} allows us to calculate oxygen consumption by subtracting the two values. In a normal patient, there is 25% extraction of oxygen based on the normal values of each of these monitoring techniques. Through interpretation of these values, ScvO\textsubscript{2} can indicate a change in either oxygen delivery or consumption. As stated earlier, oxygen delivery is composed of CO, hemoglobin, and SpO\textsubscript{2}.

Changes in oxygen consumption can be from metabolic rate, oxygen extraction rate, or many other physiologic processes that will be discussed shortly\textsuperscript{5-7,9} As with all hemodynamic monitoring, a value must be interpreted through analyzing all the parameters together, including the patient’s condition, to make much earlier and better decisions in treatment and plan of care.

When oxygen demand increases in a healthy person, the body attempts to maximize delivery by increasing cardiac output and respiratory rate. ScvO\textsubscript{2} values should remain in the normal range as the person compensates for this increased demand. If the body is unable to compensate because of disease processes or other physiologic problems, tissues extract more than one oxygen molecule, resulting in lower venous oxygenation saturation as evidenced by a decrease in ScvO\textsubscript{2}\textsuperscript{2,4,7,13}

Clinicians must keep in mind that patients compensate differently. A person who is athletic and exercises regularly will have a more increased stroke volume over heart rate. A sedentary individual will increase his or her heart rate, as he or she is unable to increase stroke volume because of lack of cardiac muscle and training. Interpreting compensation must take into account the individual patient and other hemodynamic values\textsuperscript{2,4,7,13}

The first sign that a patient is beginning to decompensate will be a decrease in ScvO\textsubscript{2}, prior to other hemodynamic or lab values changing. This early detection makes continuous ScvO\textsubscript{2} an invaluable tool in the monitoring and treatment of the critically ill patient. ScvO\textsubscript{2} monitoring is simply about meeting the oxygen demand by determining the cause of changes in either delivery or extraction \textsuperscript{4,7,13}Causes of decreased ScvO\textsubscript{2} are listed in the following table:

<table>
<thead>
<tr>
<th>Causes of Decreased ScvO\textsubscript{2}</th>
<th>Examples</th>
</tr>
</thead>
</table>
| Increased O\textsubscript{2} consumption  | Hyperthermia  
Shivering  
Infection  
Seizures  
Pain  
Trauma  
Head injury |
| Decreased CO/Cl                          | Negative inotropic agents  
Decreased preload/increased afterload  
Hypovolemia  
Sepsis  
MODS |
| Decreased O\textsubscript{2} supply      | Respiratory failure  
Ventilatory changes  
Suctioning  
Airway obstruction  
Increased WOB  
Decreased alveolar/arterial oxygenation |
| Nursing Interventions                    | Position changes  
CPT  
EKG  
Visitors  
Bathing (25%) |
SUMMARY

Treating low ScvO$_2$ is done by first determining the cause. The clinician must analyze the patient’s overall condition, ScvO$_2$, and other hemodynamic values before determining the next therapeutic intervention. After examining the patient’s data and referring to the above table, one of the four causes should be apparent. The exact cause is then determined and a treatment course set and implemented.

The four basic treatment regimens include the following:

1. Decreasing metabolic demand (need for extraction)
2. Increasing oxygen delivery/saturation of hemoglobin
3. Increasing circulating hemoglobin
4. Increasing cardiac output

Note that cardiac output and blood pressure are not synonymous. Utilizing ScvO$_2$ may show that a lower CO or MAP is acceptable to meet the current metabolic demands of the patient, resulting in lower use of pressors, oxygen/mechanical ventilation, blood products, and/or inotropes. ScvO$_2$ can also be used for real-time weaning of pressors, inotropes, and ventilator support.$^{1,2,4,5,7,9,13}$

The following table evidences increased ScvO$_2$:

<table>
<thead>
<tr>
<th>Causes of Increased SvO$_2$</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease in O$_2$ Demand</td>
<td>Hypothermia</td>
</tr>
<tr>
<td></td>
<td>NMB</td>
</tr>
<tr>
<td></td>
<td>Anesthesia</td>
</tr>
<tr>
<td></td>
<td>Relaxation/sedation</td>
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<tr>
<td></td>
<td>Sepsis</td>
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<td></td>
<td>Pressure support ventilation</td>
</tr>
<tr>
<td></td>
<td>A-V shunting</td>
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<tr>
<td>Increased CO/CI</td>
<td>Positive inotropic agents</td>
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<tr>
<td></td>
<td>Afterload reduction</td>
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<tr>
<td></td>
<td>Fluid administration</td>
</tr>
<tr>
<td></td>
<td>IABP</td>
</tr>
<tr>
<td>Increased O$_2$ Supply</td>
<td>Increased FiO$_2$</td>
</tr>
<tr>
<td></td>
<td>Increased SaO$_2$</td>
</tr>
<tr>
<td></td>
<td>Increased PaO$_2$</td>
</tr>
</tbody>
</table>

RESPONDING TO TREATMENT

Increased ScvO$_2$ may indicate either a positive response to current treatments or that oxygenation extraction has decreased because of blockages such as micro-clotting in sepsis or AV shunting. Increased ScvO$_2$ may be used (after cause is determined) to alter treatment such as weaning the ventilator or decreasing inotropes and pressors, remembering
that typical hemodynamic goals such as a MAP greater than 60, CI \( \geq 2 \), HGB \( \geq 7 \), and PaO\(_2\) >60 may not be required in a particular patient because of his or her decreased metabolic demand.\(^1\) \(^2\) \(^4\) \(^5\) \(^7\) \(^9\) \(^13\)

Intervention should be done when ScvO\(_2\) moves out of the normal 70 to 80% range or when there is a change of plus or minus 10% for more than 5 to 10 minutes. The trend of ScvO\(_2\) should be taken into account, especially with patients that present with atypical hemodynamic values.

The following table represents standard accepted values of ScvO\(_2\). Please note that the ideal time to intervene is when the patient’s ScvO\(_2\) is in the 50 to 70% range. At this point, the patient is in a compensatory mode with little variation in other parameters being monitored. As ScvO\(_2\) drops below 50%, other hemodynamic monitoring values will begin to be apparent. Unfortunately, damage is already being done to the tissues once you see a change in other monitoring values.\(^2\) \(^4\) \(^5\) \(^7\) \(^9\) \(^13\) \(^14\)

<table>
<thead>
<tr>
<th>ScvO(_2)/SvO(_2)</th>
<th>Oxygenation Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>70-80%</td>
<td>Normal extraction</td>
</tr>
<tr>
<td></td>
<td>( \text{DO}_2 &gt; \text{VO}_2 )</td>
</tr>
<tr>
<td>50-70%</td>
<td>Increasing ( \text{VO}_2 ) or decreasing ( \text{DO}_2 )</td>
</tr>
<tr>
<td></td>
<td>Compensatory ( \text{O}_2 ) extraction</td>
</tr>
<tr>
<td>30-50%</td>
<td>Exhausting of extraction</td>
</tr>
<tr>
<td></td>
<td>Beginning of lactic acidosis</td>
</tr>
<tr>
<td>25-30%</td>
<td>Severe lactic acidosis</td>
</tr>
<tr>
<td>&lt;25%</td>
<td>Cellular death</td>
</tr>
</tbody>
</table>

Patients who may benefit from continuous ScvO\(_2\) monitoring may include myocardial infarction (risk for drop in cardiac output), sepsis (as evidenced by the surviving sepsis campaign), trauma/GI bleed or other bleeding diathesis (which can cause abrupt changes in hemoglobin but is not recognized for hours until another H&H is drawn), shock of any kind, or basically any critical care patient with potential for acute changes in hemoglobin, oxygen consumption/demand, or cardiac output.

Continuous ScvO\(_2\) should be considered in all critically ill patients, especially those who require use of a central venous or peripherally inserted cardiac catheter.
References