Continuous SvO₂ Monitoring:
Theory & Applications
A Professional Education Teaching Tool
Provided by
Edwards Lifesciences
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Program Objectives

- This program will provide the learner with information regarding:
  - Oxygen delivery physiology
  - Oxygen supply and demand dynamics
  - Interrelationships of SvO₂ with its determinants
  - Clinical application of continuous SvO₂ monitoring
Learning Objectives

- Upon completion of this module, the learner will be able to:

  - Understand the concepts of oxygen delivery and consumption
  - List four factors that influence oxygen balance
  - Define $SvO_2$
  - Discuss the clinical significance of $SvO_2$
Pre Test

1. The normal range for $\text{SvO}_2$ is:
   a. 60-80%
   b. 40-60%
   c. 80-100%
   d. Below 40%
Pre Test

2. The most common reason for an elevated \( \text{SvO}_2 \) value is?

   a. Hypovolemia
   b. Sepsis
   c. LV dysfunction (e.g. MI)
   d. Exercise
Pre Test

3. Lower than normal SvO₂ may indicate:

a. Increase in oxygen demand/consumption
b. Decrease in oxygen delivery
c. Both
d. Neither
Pre Test

4. Changes in $\text{SvO}_2$ can reflect changes in:
   
   a. $\text{SaO}_2$
   b. CO
   c. Hb
   d. All of the above
   e. a and c only
5. The primary determinant of oxygen delivery (DO$_2$) is:

   a. PO$_2$
   b. a-vO$_2$ difference
   c. CO
   d. Oxyhemoglobin
6. The two primary compensatory mechanisms of the body which help maintain the balance between oxygen supply and demand are:

a. Increased cardiac output and tachycardia
b. Hyperthermia and tachypnea
c. Increased oxygen extraction and hypothermia
d. Increased CO and increased oxygen extraction
Pre Test

7. If $\text{SvO}_2$ falls, it may be indicative of:

a. Increase in VO$_2$
b. Decrease in CO
c. Decrease in Hb
d. Increase in SaO$_2$
e. a, b, and c
f. b, c, and d
Pre Test

8. To prevent oxygen imbalance, it is important that:

   a. Oxygen demand equals oxygen consumption
   b. Oxygen consumption exceeds oxygen demand
   c. Oxygen demand exceeds oxygen consumption
   d. None of the above
Pre Test

9. SvO\textsubscript{2} can be used to:
   a. Assist in interpreting other indirect measurements of oxygen supply/demand; i.e. CO
   b. Directly assess the balance between oxygen delivery and consumption
   c. Assess the effect and adequacy of therapeutic interventions; i.e., vasoactive drugs, PEEP
   d. Identify changes in patient status earlier
   e. Determine selective need for further measurements such as cardiac output and arterial blood gases

   1. b, c, d
   2. a, b, e
   3. a, b, c, d
   4. All of the above
A major goal of managing critically ill patients is to ensure adequate tissue oxygenation.

Hemodynamic monitoring assists the clinician in meeting that goal.
A major component of hemodynamic monitoring is the continuous assessment of \( \text{SvO}_2 \). The addition of this hemodynamic parameter allows for a more comprehensive approach to management of the critically ill.
Fundamentals of Oxygen Delivery
Components of Oxygen Delivery

- **Oxygen Content**
  - Hemoglobin
  - Saturation of hemoglobin with oxygen
  - Dissolved oxygen
- **Cardiac Output**

Oxygen delivery, or oxygen transport, reflects the amount of oxygen that leaves the heart to be delivered to the tissues. It is dependent upon oxygen content and cardiac output. Each of the components of oxygen delivery will be discussed in the following slides.
Oxygen content is the total amount of oxygen in the blood. It is the sum of oxyhemoglobin plus the amount of oxygen dissolved in the plasma. The first component of oxygen content to be discussed is hemoglobin.
Hemoglobin

- A role of hemoglobin is to carry oxygen
  - Oxygen is carried on binding sites
  - Not all sites are bound with oxygen
- Fully saturated hemoglobin can carry 1.38 ml of oxygen per gram of hemoglobin
The next component of oxygen content is arterial oxygen saturation ($\text{SaO}_2$).
Oxygen Saturation ($SO_2$) reflects the percentage of hemoglobin that is saturated with oxygen in either the arterial ($SaO_2$) or mixed venous blood ($SvO_2$). Saturation is expressed as a percentage when multiplied by 100.
The reversible binding of oxygen to the hemoglobin molecule is important in oxygen delivery. This reversible binding allows for loading of oxygen in the lungs and unloading of oxygen to the tissues.
There are two ways that oxygen is carried by the blood. The majority of oxygen is combined with hemoglobin. A much smaller percentage is dissolved in the plasma.
Arterial blood (SaO₂) is 95-100% saturated with oxygen while mixed venous blood (SvO₂) is 60-80% saturated with oxygen. A normal resting individual uses approximately 25% of the available oxygen, with 75% being returned to the lungs.
The last component of oxygen content is dissolved oxygen (PaO₂) in the arterial blood.
The partial pressure of oxygen reflects the pressure that oxygen exerts when it is dissolved in the plasma. \( \text{PO}_2 \) is measured in mm Hg.
The partial pressure on the arterial side ($\text{PaO}_2$) is normally 80-100mmHg while $\text{PO}_2$ on the venous side ($\text{PvO}_2$) is much lower at 35-45mmHg. The partial pressure affects the ability of oxygen to combine with hemoglobin in the lungs and the ability of oxygen to be released to the tissues.
The previous slides have taken a closer look at the individual components of oxygen content. Let’s now look more specifically at oxygen content of the arterial and venous blood.
Arterial blood content (CaO$_2$) represents the total amount of oxygen in the arterial blood. Content is measured in volume % and represents the amount of oxygen in 100ml of blood (dl).

- **Total amount of oxygen in the arterial blood**
- **Measured in ml O$_2$/dl of blood (volume %)**
- **CaO$_2$=(1.38 x Hb x SaO$_2$)+ 0.0031 x PaO$_2$**
- **Normal Range: 17-20 ml/dl**
As discussed in the previous slide, arterial blood oxygen content is the total amount of oxygen in the arterial blood.

• The greatest contributor of the three components of arterial blood oxygen content (hemoglobin, saturation of hemoglobin with oxygen and dissolved oxygen) is the patient’s hemoglobin level.

• The percentage of hemoglobin saturated with oxygen (SaO₂) also contributes to the arterial blood oxygen content, but to a lesser degree.

• The third, and most minor, component is the amount of oxygen dissolved in blood at body temperature and varies directly with the partial pressure of oxygen (PaO₂).

Thus, it is important to remember that changes in the patient’s hemoglobin level have the greatest effects on arterial blood oxygen content. For example, an anemic patient may manifest inadequate CaO₂ in the presence of a normal arterial saturation and partial pressure of oxygen (PaO₂).
Venous oxygen content ($CvO_2$) represents the total amount of oxygen in the venous blood. Content is measured in volume % and represents the amount of oxygen in 100ml of blood (dl).
As discussed in the previous slide, venous blood oxygen content is the total amount of oxygen in the venous blood.

- The greatest contributor of the three components of venous blood oxygen content (hemoglobin, saturation of hemoglobin with oxygen and dissolved oxygen) is the patient’s hemoglobin level.
- The percentage of hemoglobin saturated with oxygen (SvO₂) also contributes to the venous blood oxygen content, but to a lesser degree.
- The third, and most minor, component is the amount of oxygen dissolved in blood at body temperature.

Thus, similar to the discussion of arterial blood oxygen content, it is important to remember that changes in the patient’s hemoglobin level also have the greatest effects on venous blood oxygen content.
Hemoglobin, oxyhemoglobin and PO₂ levels combine to equal arterial and venous oxygen carrying capacity.
The last component of oxygen delivery we will discuss is cardiac output (CO).
Cardiac output (CO) is one of the major determinants of oxygen delivery. The primary determinants of cardiac output are stroke volume (SV) and heart rate (HR).
Cardiac output (CO) is determined by stroke volume (SV) and heart rate (HR). Stroke volume is influenced by preload, afterload and contractility.
Arterial oxygen delivery (DO₂) is the amount of oxygen delivered to the tissues. It is measured in ml O₂/minute. The normal value is approximately 1000 ml O₂/min.
The formula for oxygen delivery is cardiac output (CO) times the oxygen content. (The factor of 10 necessary to convert the cardiac output measured in liters/minute and oxygen content measured in 100 ml (1 deciliter) of blood cell to a common denominator of ml/minute.) Arterial oxygen delivery (DaO₂) can be calculated using the formulas found on this slide.
The units of measurement for each component of oxygen delivery is shown on this slide.
Oxygen consumption (VO$_2$) is the amount of oxygen consumed by the tissues. It is measured in ml O$_2$/minute.
Oxygen consumption is derived from the difference between arterial oxygen delivery and venous oxygen delivery. This difference between the oxygen delivered in the arterial circulation and returned by the venous system reflects the amount of oxygen consumed by tissues. Normal oxygen consumption is within the range of 200-250 ml O₂/minute.
SvO₂ reflects the percentage of hemoglobin that is saturated with oxygen in the mixed venous blood. It is a global indicator of the balance between oxygen delivery and consumption. This represents the oxygen “reserve” – the amount of oxygen that can be utilized in periods of increased demand.

When oxygen demand increases, the body attempts to increase delivery, primarily through an increase in cardiac output. In this situation, the SvO₂ may remain unchanged. If delivery does not increase in response to the increased demand, the tissues will extract a larger amount of oxygen from the available supply (delivered amount). This is reflected by a decrease in SvO₂. A drop in SvO₂ is a warning sign of a potential threat to tissue oxygenation (that oxygen demand is exceeding oxygen consumption).
As discussed in the previous slide, SvO₂ reflects the amount of oxygen remaining in the blood after the tissues have extracted the needed amount of oxygen. SvO₂ represents the difference between oxygen delivery (DO₂) and oxygen consumption (VO₂).

The entire process can be described as follows:

1) Oxygen loading onto hemoglobin occurs in the lungs (SaO₂).
2) The oxygen on Hb is delivered by blood flow (CO) to the tissues.
3) At the tissue level oxygen is removed and utilized (VO₂).
4) SvO₂ reflects the difference between oxygen delivery (CO, SaO₂, Hb) and oxygen consumption (VO₂).
Why Measure $\text{SvO}_2$?
Typically a decrease in SvO₂ is one of the earliest indicators of the threat to tissue oxygenation.
Continuous SvO₂ can alert the clinician to a change in the patient’s condition sooner than other parameters. The sooner changes in the patient's status are detected, the earlier appropriate interventions can be made.
The normal range for SvO₂ is 60-80%. If the SvO₂ is within this normal range, global tissue oxygenation is usually adequate. However, at the higher levels of normal, other assessments of tissue oxygenation may be necessary.
SvO₂ monitoring can alert the clinician to a change in patient condition sooner than traditional parameters. When a change in SvO₂ occurs, it is important to examine each of the components of oxygen delivery (CO, Hb, SaO₂) and oxygen consumption. Determination of the cause of the altered SvO₂ will allow for prompt identification of appropriate interventions.
Abnormally low ranges of SvO₂, specifically below 60% can result from any of the major determinants of SvO₂. Hence, either a decrease in oxygen delivery as a consequence of either a fall in the patient’s hemoglobin level, a decrease in the patient’s arterial oxygen saturation, or a decrease in cardiac output, or an increase in oxygen consumption can lead to a SvO₂ < 60%.

When the balance between oxygen supply and demand is threatened, the body mobilizes its compensatory mechanisms to ensure adequate oxygen availability. The two most important mechanisms are an increase in cardiac output and an increase in oxygen extraction.
This slide further defines some of the clinical conditions that can contribute to a decrease in oxygen delivery.

- A fall in the patient’s hemoglobin concentration due to either existing anemia or an acute loss of blood/hemorrhage with a compromised cardiovascular system can decrease oxygen delivery to the tissues.
- Hypoxemia and lung disease can decrease oxygen saturation in the arterial blood and hence cause a decrease in oxygen delivery.
- A fall in the patient’s cardiac output, for example, due to cardiogenic shock, left ventricular dysfunction or other causes.
In addition to problems with oxygen delivery, an increase in oxygen consumption (also known as oxygen demand) can also lead to a decrease in the (mixed) venous saturation to below 60%.

Clinical conditions that can lead oxygen demand to exceed oxygen supply are those that increase muscle activity and metabolic rate including include fever, sepsis, and seizures.
Due to micro capillary obstruction, arterial blood is shunted past the capillaries and into the venous blood. This shunting effect may cause SvO₂ levels to rise in patients with sepsis.
When the PA Catheter is wedged the SvO₂ can elevate. Blood in front of the catheter mixes with capillary blood causing the oxygen saturation to increase.
How is $\text{SvO}_2$ Measured?
The SvO₂ level can be measured from the distal tip of the PA Catheter (e.g. Edwards CCOmbo Swan-Ganz Catheter), either continuously or intermittently. It is also possible to measure ScVO₂ from the distal tip of the triple lumen catheter (e.g. Edwards PreSep Central Venous Catheter with Oximetry).
SvO₂ measurements are obtained from blood in the pulmonary artery, which is the best location for determining a (mixed) venous saturation.
Reflection Spectrophotometry
When is a Change in SvO₂ Clinically Important?
When using continuous SvO₂ monitoring, clinicians should note when measurements move outside the normal range. Any deviation greater than 10% from baseline (even within normal limits) should be considered significant if it persists for longer than 3-5 minutes.
This slide provides an overview for managing changes in SvO₂. If SvO₂ remains unchanged monitoring should continue. When a change occurs in SvO₂, the clinician should assess the patient and examine each of the components of oxygen delivery (CO, Hb, SaO₂) and oxygen consumption. Appropriate interventions can than be identified and implemented.
Clinical Applications of Continuous SvO₂ Monitoring
Principal Clinical Applications

- Monitoring and early warning system
- Guide for adjusting and assessing interventions
- Means for interpreting other variables
Continuous $\text{SvO}_2$ as a Monitoring and Early Warning System
SvO₂ and CO will parallel each other when a decrease in blood flow causes a deficiency in oxygen delivery. The seriousness of the drop in blood flow can be seen by the degree of decrease in the SvO₂ value.

In this case, a 69 year old male with an acute episode of CHF complains of difficulty in breathing at 0315. Note the drop in CO and corresponding decrease in SvO₂. This sharp decrease in SvO₂ indicates a serious threat to tissue oxygenation caused by the decrease in CO.
In this case, the change in $\text{SvO}_2$ toward the normal range did not herald the patient’s survival. Peripheral shunting involved in septic shock caused arterial blood to be diverted into the venous circulation. The net result is an increase in $\text{SvO}_2$.

In this case, a 56 year old male is admitted to the MICU with hypotension and loss of sensation in both lower legs. He had a hip replacement three days earlier. He was febrile (39.9), tachycardic (142) and tachypneic (39) on admission. In a very short time, his $\text{SvO}_2$ continued to climb and he died within 18 hours.
Continuous SvO₂ Monitoring as a Guide for Adjusting/Assessing Interventions
When fluid therapy is given, the end points are better blood flow (stroke index) and improved tissue oxygenation.

In this case, the fluid bolus produced both an increase in stroke index and $\text{SvO}_2$. These increases signaled the success of the fluid therapy.
When vasopressors are administered, the goal is to improve tissue oxygenation by improving blood flow and blood pressure. However, increases in blood pressure may not always be correlated with an increase in blood flow. Therefore, it is advisable to monitor the effect of vasopressors with SvO₂ response.

In this case, a 66 year old female with the diagnosis of pneumonia develops respiratory distress and requires intubation. She becomes hypotensive and remains so despite repeated fluid bolus therapy. Dopamine is initiated at 8mcg/kg/min. Within 90 minutes, the blood pressure, cardiac output and SvO₂ indicate a good response to this therapy. However, since the SvO₂ and cardiac output are still somewhat low, further treatment may be indicated.
When administering blood, the goal is to improve tissue oxygenation. While the hemoglobin level is an indicator of greater oxygen carrying capacity, the $\text{SvO}_2$ is a better indicator of the adequacy of tissue oxygenation. In this case, the moderate increase in $\text{SvO}_2$ (to near normal levels) indicates a very good response to this blood transfusion.
Continuous $\text{SvO}_2$ Monitoring as a Means for Interpreting Other Variables
Blood pressure may remain stable despite threats to tissue oxygenation. In this case, a 59 year old male is in the ICU following a CABG and heart valve replacement. Note the stable blood pressure and cardiac output but a decrease in $\text{SvO}_2$ during a weaning attempt. The drop in $\text{SvO}_2$ is likely explained by an increase in $\text{VO}_2$. The key point of this case is the ability of $\text{SvO}_2$ to reflect changes in tissue oxygenation that would be undetected by blood pressure or cardiac output.
One of the advantages of \( \text{SvO}_2 \) is to give the clinician additional perspectives on patient assessment.

In this case, a 71 year old male with CHF is in the CCU. AT 0300, he has a decrease in cardiac output. No patient symptoms have occurred. However, the stable \( \text{SvO}_2 \) indicates this drop in cardiac output is either clinically insignificant or due to measurement variability. The patient does not require treatment based on the stable \( \text{SvO}_2 \).
Post Test

1. The normal range for SvO₂ is:
   a. 60-80%
   b. 40-60%
   c. 80-100%
   d. Below 40%
2. The most common reason for an elevated SvO₂ value is?
   a. Hypovolemia
   b. Sepsis
   c. LV dysfunction (e.g. MI)
   d. Exercise
Post Test

3. Lower than normal $\text{SvO}_2$ may indicate:

a. Increase in oxygen demand/consumption
b. Decrease in oxygen delivery
c. Both
d. Neither
Post Test

4. Changes in $\text{SvO}_2$ can reflect changes in:
   a. $\text{SaO}_2$
   b. $\text{CO}$
   c. $\text{Hb}$
   d. All of the above
   e. a and c only
Post Test

5. The primary determinant of oxygen delivery (DO₂) is:

a. PO₂
b. a-vO₂ difference
c. CO
d. Oxyhemoglobin
Post Test

6. The two primary compensatory mechanisms of the body which help maintain the balance between oxygen supply and demand are:

a. Increased cardiac output and tachycardia
b. Hyperthermia and tachypnea
c. Increased oxygen extraction and hypothermia
d. Increased CO and increased oxygen extraction
Post Test

7. If $\text{SvO}_2$ falls, it may be indicative of:

a. Increase in $\text{VO}_2$
b. Decrease in $\text{CO}$
c. Decrease in $\text{Hb}$
d. Increase in $\text{SaO}_2$
e. a, b, and c
f. b, c, and d
Post Test

8. To prevent oxygen imbalance, it is important that:

a. Oxygen demand equals oxygen consumption
b. Oxygen consumption exceeds oxygen demand
c. Oxygen demand exceeds oxygen consumption
d. None of the above
9. \( \text{SvO}_2 \) can be used to:

a. Assist in interpreting other indirect measurements of oxygen supply/demand; i.e., CO
b. Directly assess the balance between oxygen delivery and consumption
c. Assess the effect and adequacy of therapeutic interventions; i.e., vasoactive drugs, PEEP
d. Identify changes in patient status earlier
e. Determine selective need for further measurements such as cardiac output and arterial blood gases

1. b, c, d
2. a, b, e
3. a, b, c, d
4. All of the above
Test Answers
SvO₂ represents the oxygen “reserve” – the amount of oxygen that returns to the heart and would be available for use in periods of increased demand.
In sepsis, blood flow is obstructed. The result is arterial blood being emptied into the venous blood (with the result of an increase in $\text{SvO}_2$).
The cells have the ability to extract oxygen at greater levels than normal when either oxygen supply is reduced or oxygen consumption is increased.
SvO₂ levels, while not directly reflecting changes in other parameters, will identify when changes in blood flow (cardiac output) or arterial oxygenation (hemoglobin, SaO₂) may be clinically abnormal.

**Post Test**

4. Changes in SvO₂ can reflect changes in:
   
   d. All of the above
Blood flow is the most important component of oxygen delivery. Changes in blood flow alter oxygen delivery and can affect venous saturation.
When cells require more oxygen, there are two main adaptation mechanisms. One is to increase blood flow to deliver more oxygen. Second, the cells can increase extraction of oxygen off of hemoglobin.

Post Test

6. The two primary compensatory mechanisms of the body which help maintain the balance between oxygen supply and demand are:

   d. Increased CO and increased oxygen extraction
Changes in extraction of oxygen from hemoglobin can be affected by an increase in oxygen demand (VO$_2$), a drop in blood flow (CO) or a decrease in oxygen carrying capacity (Hgb).
Oxygen demand must equal oxygen consumption to maintain organism homeostasis.
SvO₂ levels help in identifying the impact of therapies and putting into perspective other parameters (e.g. cardiac output and blood pressure). However, it does not replace the need to measure other parameters.
Test Answer Key

1. a   2. b   3. c   4. d   5. c   6. d   7. e   8. a   9. 3
Evaluation

Your feedback is important!
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that your suggestions can be
incorporated into future programming...