

Clinical Superiority of Three-Wavelength Venous Oximetry vs. Conventional Two-Wavelength Technologies

INTRODUCTION

Accurate venous oximetry measurements are key to understanding a patient's true oxygenation status. Other objective measures used to assess the perfusion of organs and tissues—like mean arterial pressure, heart rate, urine output, and arterial oxygen saturation (SaO_2 or SpO_2)—can be normal in the presence of global tissue hypoxia and cannot rule out imbalances between oxygen supply and demand. Decreasing or low values for mixed venous oxygen saturation (SvO_2) or central venous oxygen saturation (ScvO_2) signal a decrease in oxygen delivery or an increase in oxygen consumption consistent with hypovolemic shock, while increasing $\text{SvO}_2/\text{ScvO}_2$ indicate either an increase in oxygen delivery or a decrease in oxygen consumption consistent with sepsis.¹

SvO_2 is measured at the tip of a pulmonary artery catheter and includes all of the venous blood returning from the head and arms (via superior vena cava), the gut and lower extremities (via the inferior vena cava), and the coronary veins (via the coronary sinus). By the time the blood reaches the pulmonary artery, all venous blood has “mixed” to reflect the average amount of oxygen remaining after all tissues in the body have removed oxygen from the hemoglobin. The mixed venous sample captures the blood before it is reoxygenated in the pulmonary capillary.

ScvO_2 is the oxygen saturation of central venous blood only. This value is obtained by placing a fiber optic venous catheter into the superior vena cava and reflects oxygen saturation of blood returning from the upper body, indicating the balance between oxygen delivery and oxygen consumption in the upper portion of the body, including the brain.

Although SvO_2 values are generally lower than ScvO_2 , the two values have been shown to track with one another over a variety of changing clinical conditions, making ScvO_2 an acceptable surrogate for SvO_2 .^{2,3,4,5,6}

Both ScvO_2 and SvO_2 can be measured using either two- or three-wavelength reflectance spectrophotometry technologies. While traditional two-wavelength oximetry has been used more frequently, three-wavelength technology (ICU Medical, Inc., San Clemente CA) has been shown in multiple clinical studies to provide a greater level of accuracy and eliminate the need for daily hemoglobin calibrations associated with conventional two-wavelength systems.

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TWO- VS. THREE-WAVELENGTH OXIMETRY

Hemoglobin oxygen saturation is measured using reflectance spectrophotometry, in which either two or three wavelengths of light are transmitted down a fiber optic filament in the catheter to the blood flowing past the catheter tip. An additional fiber optic filament transmits the reflected light back to a photodetector located in the optical module. Because oxyhemoglobin (hemoglobin containing bound oxygen molecules) and deoxyhemoglobin (hemoglobin not bound with oxygen molecules) absorb light at different wavelengths, this reflected light is analyzed to determine SvO_2 or ScvO_2 and then displayed for the clinician on a monitor. Various physiologic factors impact the integrity of the light absorption reflected back through the fiber optic filament. Changes in blood pH, hematocrit, and blood flow velocity can affect the color of blood, and consequently they affect the relationship between oxygen saturation and light intensity ratio.

Changes in hemoglobin (Hb) levels can impact the accuracy of two-wavelength reflectance spectrophotometry and require frequent calibration due to drift that occurs with changing Hb and other adverse conditions. Application of three-wavelength reflectance spectrophotometry alleviates the need for calibration and filters artifact caused by blood cell orientation, vessel wall reflections, and changes in blood pH.

CLINICAL ADVANTAGES OF THREE-WAVELENGTH TECHNOLOGY

The current body of literature suggests multiple advantages of three-wavelength technology over two-wavelength systems, including improved accuracy and the elimination of the need for routine calibration. The following is a summary of keystone research providing evidence for the superior accuracy and efficiency of three-wavelength technology.

Superior Accuracy

An in vivo animal study documented the accuracy of three-wavelength technology when compared to the readings of a co-oximeter control over a 10-hour period.⁷ The validation methodology included a comparative analysis of a two-wavelength system. Each test subject was given three

levels of inspired oxygen. Readings were obtained from the catheters and then blood was drawn for the controls. In all cases, the error of the three-wavelength was less than the error of the two-wavelength predicate device [Table 1].

Another study performed a clinical evaluation on postoperative cardiac patients of the comparative accuracy of continuous monitoring systems to reflect SvO₂ values over a 24-hour period.⁸ After random assignment to either a two- or three-wavelength continuous SvO₂ catheter for postoperative monitoring, the researchers analyzed mixed venous blood samples with a co-oximeter and compared readings with the monitor value of the SvO₂ catheter. SvO₂ measured by the three-wavelength system aligned with reference SvO₂ measurement, while SvO₂ measured by the two-wavelength system was significantly lower than the co-oximeter measurement within four hours of admission to the critical care unit and

remained significantly lower throughout the 24-hour study period.

An analysis of the accuracy and the stability of three commercially available systems for measuring SvO₂ (two two-wavelength systems and one three-wavelength system) determined that the spontaneous drifts in the two-wavelength systems were significantly higher than the spontaneous drift in the three-wavelength system [Figure 1].⁹ This comparative assessment, performed in critically ill

patients with acute respiratory failure and circulatory shock over a 24-hour period, also showed that the drift in the two-wavelength system persists in the presence of a stable hematocrit value.

There are also large fluctuations in the two-wavelength reflected light signal due to the motion of the catheter tip relative to

TABLE 1. CORRELATION BETWEEN IN VIVO AND IN VITRO SATURATIONS⁷

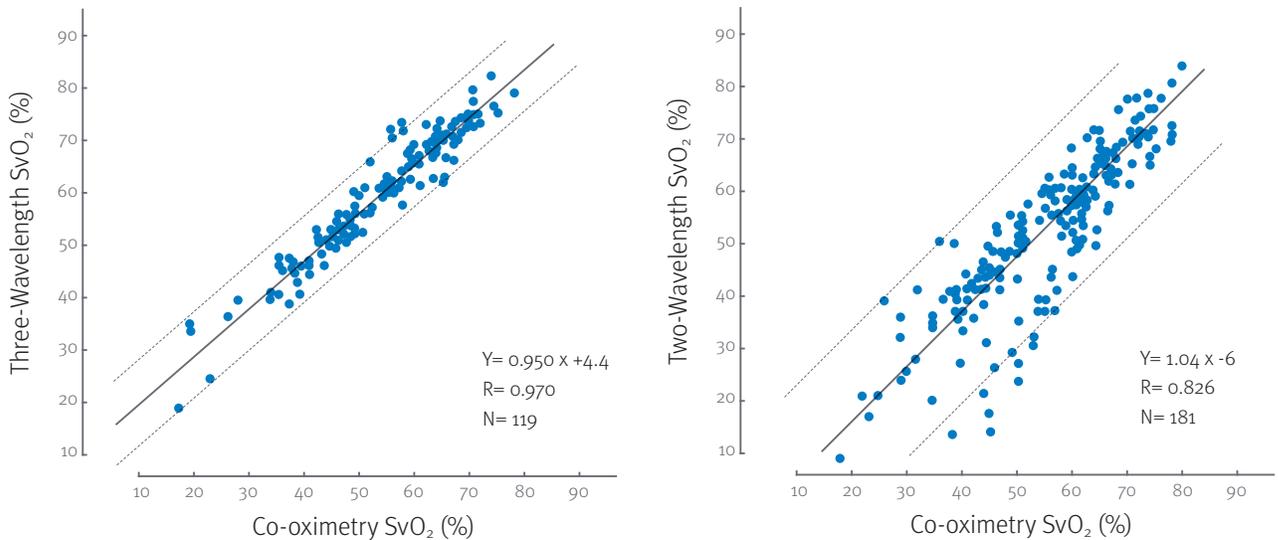
SvO ₂ Range	Three-wavelength, R (N)	Two-wavelength, R (N)	Significance*
ALL	0.994 (88)	0.808 (77)	P < 0.001
IL <46%	0.949 (30)	0.603 (38)	P < 0.001
IL 46-60%	0.909 (20)	0.268 (21)	P < 0.001
IL >60%	0.987 (38)	0.789 (18)	P < 0.001

* Fisher's Z test used to compare differences in correlation between catheters

N – number of observations per group IL – reference co-oximeter

Three-wavelength oximetry technology delivers more accurate ScvO₂ and SvO₂ measurements than two-wavelength technologies, helping clinicians in their efforts to restore the balance between oxygen delivery and demand in critically ill patients.

FIGURE 1. REGRESSION ANALYSIS SHOWING GREATER ACCURACY OF THREE VS. TWO-WAVELENGTH ScvO₂ ⁹



the vessel walls.¹⁰ The light reflected from the vessel wall is not related to any light absorption by the blood and therefore creates artifact. In patients who are under continuous positive pressure ventilation and hemodynamically unstable, these sources of error from two-wavelength readings could impose risk when continuous monitoring is needed. The researchers concluded that errors due to changes in blood flow velocity or wall artifact—two factors commonly seen in ventilated critically ill patients with shock and respiratory failure—might contribute to the observed difference in the accuracy of each catheter.

The greater accuracy documented by numerous studies is in part due to the three-wavelength technology's digital filtering, which removes artifact in the returning fiber optic transmission that can be caused by cell orientation, vessel wall reflection and changes in pH. Filtering provides for a more accurate trend line presentation to clinicians.

Eliminating the Need for Daily Calibration

Small fluctuations in hemoglobin levels can produce inaccurate oximetry measurements.^{7,9,11} Because these hemoglobin fluctuations are common in critically ill patients, two-wavelength oximetry monitoring technologies require constant hemoglobin calibration to maintain accuracy; an aspect described in multiple studies as a limitation of two-wavelength oximetry sensors.^{9,12} Daily calibrations are time consuming and require clinicians to order unscheduled blood tests to enter updated hemoglobin values.

In contrast, use of three selected wavelengths enables oximetry catheters to obtain sufficient data to eliminate the dependence on hemoglobin, allowing saturation to be calculated directly from reflected light intensity ratios with no additional user input. As a result, three-wavelength oximetry catheters are able to accurately measure abrupt changes in key oxygenation indicators related to therapeutic interventions independent of hemoglobin. In fact, with three-wavelength technology, calibration is unnecessary except when first taking the catheter from the package. This eliminates the need for and cost of recurrent laboratory updates of hemoglobin.

CONCLUSION

Three-wavelength oximetry monitoring technology (ICU Medical, Inc., San Clemente CA) delivers more accurate ScvO₂ and SvO₂ measurements than two-wavelength technologies, helping clinicians in their efforts to restore the balance between oxygen delivery and demand in critically ill patients. Additionally, by reducing artifact caused by vessel wall reflections and eliminating the reliance on hemoglobin, three-wavelength oximetry has been shown to be clinically superior to two-wavelength technologies.

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