



Queensland University of Technology
Brisbane Australia

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CENTRAL VENOUS OXYGEN SATURATION MONITORING

ABSTRACT

It has been established that mixed venous oxygen saturation (SvO₂) reflects the balance between systemic oxygen delivery and consumption. Literature indicates that it is a valuable clinical indicator and has good prognostic value early in patient course. This article aims to establish the usefulness of SvO₂ as a clinical indicator. A secondary aim was to determine whether central venous oxygen saturation (ScvO₂) and SvO₂ are interchangeable. Of particular relevance to cardiac nurses is the link between decreased SvO₂ and cardiac failure in patients with myocardial infarction, and with decline in myocardial function, clinical shock and arrhythmias. While absolute values ScvO₂ and SvO₂ are not interchangeable, ScvO₂ and SvO₂ are equivalent in terms of clinical course. Additionally, ScvO₂ monitoring is a safer and less costly alternative to SvO₂ monitoring. It can be concluded that continuous ScvO₂ monitoring should potentially be undertaken in patients at risk of haemodynamic instability.

KEY WORDS

Oxygen saturation; monitoring; blood gases.

KEY POINTS

- Venous oxygen saturation has been advocated as an indirect index of tissue oxygenation.
- It is generally accepted that venous oxygen saturation reveals a discrepancy between oxygen supply and oxygen demand thus indicating global tissue hypoxia.
- Mixed venous oxygen saturation monitoring can detect tissue ischaemia at an early stage, and thus is a valuable indicator of clinical course.
- Central venous oxygen saturation and mixed venous oxygen saturation are interchangeable in the course of clinical decision making.

- Continuous central venous oxygen saturation monitoring should be undertaken in patients at risk of haemodynamic instability and low cardiac output.

Background

Haemodynamic monitoring is an assessment cornerstone for all critically ill patients in the intensive care unit. It will identify haemodynamic instability, indicate its cause and monitor the patient's response to therapy (Pinsky, 2007). Sustained tissue hypoxia is one of the principle factors in multi-organ failure, and thus recognition, treatment and prevention of tissue hypoxia is an essential component of care (Reinhart and Bloos, 2005; Marx and Reinhart, 2006; Bracht et al, 2007). Venous oximetry is used in this capacity and has been shown to identify global tissue hypoxia in patients with otherwise normal observations and vital signs (Ander et al, 1998).

Venous oximetry encompasses measurements of mixed venous oxygen saturations (SvO₂) and central venous oxygen saturations (ScvO₂) (Bracht et al, 2006; Marx and Reinhart, 2006). SvO₂ refers to the haemoglobin saturation of blood drawn from the proximal pulmonary artery, and reflects the oxygen balance of the whole body (Reinhart and Bloos, 2005; Varpula et al, 2006). ScvO₂ refers to the haemoglobin saturation of blood from the superior vena cava (Marx and Reinhart, 2006; Bracht et al, 2007). This measurement reflects the venous oxygen saturations of blood from the brain and upper body, but neglects venous blood from the lower body (Rivers et al, 2001a; Turnaoglu et al, 2001). It has been proposed that ScvO₂ provides a mirror of SvO₂ and consequently that the two measures are interchangeable.

Applications of mixed venous oxygen saturations (SvO₂)

SvO₂ has been proposed as an indicator of the balance between systemic oxygen delivery and consumption and thus can be used to assess the adequacy of tissue oxygenation (Pearse et al, 2005; Bracht et al, 2006; Marx and Reinhart, 2006; Ramakrishna et al, 2006). Blood contained in the pulmonary artery consists of mixed

venous blood from organ systems and regions of the body. Thus, SvO₂ reflects the average venous oxygen saturation of the whole body as measurements are obtained via the pulmonary artery (Turnaoglu et al, 2001).

SvO₂ can be measured intermittently by blood sampling and co-oximetry or continuously by a spectrophotometric catheter (Pearse et al, 2005). Low SvO₂ values indicate a mismatch between oxygen delivery and oxygen requirements and can occur when systemic oxygen delivery has been compromised or demands have exceeded supply (Rivers et al, 2001a; Marx and Reinhart, 2006). The normal range of SvO₂ is 65-75% and reflects the balance between systemic oxygen delivery and consumption (Rivers et al, 2001a; Marx and Reinhart, 2006).

Occult tissue hypoxia occurs when there is an imbalance of tissue oxygen demand and tissue oxygen delivery (Pinsky, 2007). The ability to detect occult tissue hypoxia early in the course of care while it is still potentially responsive to treatment is a huge benefit of SvO₂ measurement (Kupeli and Satwicz, 1989; Rivers et al, 2001a; Pinsky, 2007). SvO₂ is advocated as an early indicator of increased oxygen consumption and inadequate oxygen delivery when other vital signs are within a normal range (Kupeli and Satwicz, 1989; Reinhart and Bloos, 2005).

As early as the 1960s, decreased SvO₂ was found to be indicative of imminent or current cardiac failure in patients with myocardial infarction (Goldman et al, 1968a). Similarly, SvO₂ declines have been found to precede the decline of myocardial functioning, the onset of clinical shock, and arrhythmias, even when physiological signs were within normal limits (Rivers et al, 2001a; Ramakrishna et al, 2006). Absolute values differ among patient groups and study populations, but SvO₂ levels less than 65-70% indicate increased tissue oxygen extraction and thus inadequate systemic oxygen delivery (Pinsky, 2007). Research has also found SvO₂ to be superior to mean arterial pressure and heart rate in predicting declines in cardiac surgical patients (Rivers et al, 2001a). Furthermore, SvO₂ has been found to carry prognostic significance as a predictor for death and has been shown to reduce

morbidity and healthcare resource consumption in postoperative cardiac patients (Rivers et al, 2001a).

SvO2 as a clinical indicator

A number of observational and prospective clinical studies have demonstrated the prognostic significance of SvO2. These studies have encompassed a variety of patient groups including general surgical, cardiac surgical, myocardial infarction and cardiac disease, cardiogenic shock, and severe sepsis and septic shock. A small study found SvO2 correlated well with the duration of cardiac arrest (Van Riper et al, 1988). SvO2 was found to correlate well with clinical course and be of prognostic value in patients in cardiogenic and septic shock and in postoperative cardiac surgery patients (Edwards, 1991; Svedjeholm et al, 1999). Polonen and Ruokonen (2000) also examined SvO2 in cardiac surgery patients. Findings indicated that patients treated with a goal of SvO2 above 70% had a shorter hospital stay and lower morbidity than patients provided with standard treatment (Polonen et al, 2000). Overwhelmingly, evidence from observational and prospective clinical studies indicates that SvO2 correlates well with clinical course and is a valuable clinical indicator.

Potential problems measuring SvO2

Measurement of SvO2 involves the placement of a pulmonary artery catheter. The controversy surrounding these catheters when they were introduced 30 years ago remains today (Harvey et al, 2005; Marx and Reinhart, 2006). Health risks associated with insertion of a pulmonary artery catheter and later complications include arrhythmias, catheter knotting, pulmonary artery perforation and infection (Bowdle, 2002; Reinhart and Bloos, 2005; Marx and Reinhart, 2006; Yazigi et al, 2008). Observational studies suggest increased mortality levels are associated with pulmonary artery catheter usage (Connors et al, 1996). However, two large scale randomized control trials found no difference in hospital mortality between patients with a pulmonary artery catheter and those without (Sandham et al, 2003; Harvey et al, 2005). As a result of conflicting findings controversy surrounding the use of pulmonary artery catheters remains. Furthermore, increasing doubt exists regarding

whether the advantages of pulmonary artery catheters outweigh the potential risks. Research indicates however, that ScvO₂ mirrors SvO₂. Thus ScvO₂ may be considered as a safer alternative to SvO₂ for monitoring tissue oxygenation (*Table 1*).

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Central venous oxygen saturations versus mixed oxygen saturations

Monitoring ScvO₂ has been suggested as a safer and more cost effective alternative to monitoring SvO₂ (Ramakrishna et al, 2006; Yazigi et al, 2008). A central venous catheter is routinely inserted in patients admitted to the intensive care unit, thus all patients eligible for a central venous catheter may theoretically benefit from ScvO₂ monitoring (Reinhart and Bloos, 2005; Bracht et al, 2006; Marx and Reinhart, 2006). Variations in regional perfusion and oxygen consumption between different organ systems result in different venous oxygen saturation levels (Marx and Reinhart, 2006; Yazigi et al, 2008). In healthy, functioning people ScvO₂ is generally 2-5% lower than SvO₂, as the brain extracts more oxygen than organ systems in the lower body (Kupeli and Satwicz, 1989; Reinhart et al, 2004; Marx and Reinhart, 2006). However, differences between the two values are not constant and may be affected by various conditions that induce haemodynamic instability, including general anaesthetic, head injury and redistribution of blood flow as occurs in shock (Reinhart and Bloos, 2005; Bracht et al, 2006).

Effects of shock, sepsis and septic shock

Shock involves a critical reduction in systemic oxygen delivery resulting in inadequate tissue perfusion. The body compensates by increasing systemic oxygen extraction to maintain perfusion, resulting in increased oxygen consumption in non-vital organs thus altering the values of SvO₂ and ScvO₂ (Edwards, 1991). In critically ill patients ScvO₂ is often higher than SvO₂, suggesting pathologic ScvO₂ indicates even lower SvO₂ (Reinhart and Bloos, 2005). Different organ systems extract different amounts of oxygen thus absolute values of ScvO₂ and SvO₂ are not

interchangeable (Turnaoglu et al, 2001; Bracht et al, 2007). However, the literature overwhelmingly indicates that changes in ScvO₂ correlate well with SvO₂ and that the two are equivalent provided absolute values are not required (Scheinman et al, 1969; Martin et al, 1992; Turnaoglu et al, 2001; Bracht et al, 2006; Marx and Reinhart, 2006; Varpula et al, 2006; Bracht et al, 2007). It has been found that although values are not *exactly* equivalent they are *pathologically* equivalent with low values of both ScvO₂ and SvO₂ associated with high morbidity and mortality (Rivers et al, 2001a). Additionally, positive changes in SvO₂ due to therapeutic interventions are well reflected in ScvO₂ with changes occurring in a parallel manner (Reinhart and Bloos, 2005; Marx and Reinhart, 2006).

The general consensus in the literature is that trends in SvO₂ are mirrored in ScvO₂ and thus are interchangeable so long as absolute values are not required (Dueck et al, 2005). As early as the 1960s, observational and prospective clinical studies examining whether ScvO₂ and SvO₂ are interchangeable have been conducted. Seminal studies performed in 1968 and 1969 found a correlation between changes in ScvO₂ and SvO₂ in critically ill cardiac patients with myocardial infarction, congestive heart failure and cardiogenic shock (Goldman et al, 1968a; Scheinman et al, 1969). Interest in this area continued, and was examined in a heterogeneous group of ICU patients. Lee et al (1972) found ScvO₂ to be a good reflection of SvO₂ in patients not in shock, but found an unreliable correlation in septic shock patients. Similarly, Varpula and Karlsson (2006) found that ScvO₂ and SvO₂ only changed in the same direction approximately half of the time, and thus could not be considered equivalent. However, Martin et al (1992) and Turnaoglu et al (2001) found ScvO₂ paralleled changes in SvO₂ in severe sepsis and septic shock patients. The discrepancy in findings may be attributed to the fact that the populations examined were admitted to the intensive care unit and thus were in advanced stages of sepsis and septic shock. In an advanced state of sepsis or septic shock, all organ systems extract greater amount of oxygen, resulting in hugely varied ScvO₂ and SvO₂ values (Varpula et al, 2006).

Postoperative patients

Surgical patients are a further subpopulation that has been focused on in determining the interchangeability of ScvO₂ and SvO₂. Two studies have examined postoperative cardiac surgical patients. Both found large variation between individual values of ScvO₂ and SvO₂ but showed a positive, significant correlation between changes in the values (Ramakrishna et al, 2006; Yazigi et al, 2008). Neurological surgical patients have also been examined in this context. Dueck et al (2005) found agreement between ScvO₂ trends and SvO₂ trends across changing hemodynamic conditions in these patients. In addition to specific clinical subpopulations, heterogeneous populations have also been examined. A number of studies have found differences in absolute values of ScvO₂ and SvO₂ but found agreement in trends in populations encompassing cardiac disease, cardiac surgery, severe sepsis and septic shock, trauma and mechanically ventilated patients (Berridge, 1992; Ladakis et al, 2001; Reinhart et al, 2004). Thus, evidence indicates that while ScvO₂ and SvO₂ can not be substituted for one another in terms of absolute values, they are interchangeable with regard to trends. An exception to this is the later treatment of severe sepsis and septic shock as controversy and uncertainty remains in this population. However, on the whole ScvO₂ is equivalent to SvO₂ in the course of clinical decisions provided absolute values are not required (Ramakrishna et al, 2006).

Application of central venous oxygen saturation measurement

ScvO₂ represents the reserve oxygen supply of the region from which the blood is drained, thus providing the rationale for evaluating ScvO₂ as a goal (Varpula et al, 2006; Bracht et al, 2007). ScvO₂ provides a method of assessing the adequacy of tissue oxygenation and detecting occult tissue hypoxia early in the course of care (Rivers et al, 2001a; Pearse et al, 2005; Bracht et al, 2006; Marx and Reinhart, 2006; Ramakrishna et al, 2006). It has been demonstrated in canine experimental models that changes in ScvO₂ closely reflect circulatory disturbances during periods of hypoxia, haemorrhage and resuscitation (Scalea et al, 1988; Reinhart et al, 1989). Goldman et al (1968b) conducted a seminal study in this area, finding a correlation between ScvO₂ and clinical course in patients with myocardial infarction. Goldman et al (1968b) found patients not in heart failure had a mean ScvO₂ of 70%, those in

heart failure a mean of 56% and those in heart failure and clinical shock a mean of 43%. However, despite these positive findings, interest in ScvO₂ waned with research focusing on instead on SvO₂. Rivers et al (2001b) conducted a large scale, prospective randomized study returning to ScvO₂ as a haemodynamic parameter of interest. The study examined patients with severe sepsis or septic shock admitted to the emergency department. Patients in the treatment group underwent six hours of early goal-directed therapy with an aim to keep ScvO₂ above 70%. It was found that mortality was reduced by 15% in patients who met ScvO₂ goals as opposed to the control group who received standard treatment (Rivers et al, 2001b). These findings led to a renewed interest in ScvO₂ as a clinical parameter, resulting in a number of large scale, observational studies. Three studies found ScvO₂ values less than 70% preoperatively and intraoperatively predicted an increased risk of postoperative complications in high risk patients undergoing general surgery (Pearse et al, 2005; Bracht et al, 2006; Baulig et al, 2008). Additionally, Pearce et al (2005) found patients with ScvO₂ values greater than 75% postoperatively did not develop postoperative complications. While a number of studies examining the role of ScvO₂ as a clinical indicator have been conducted, few interventional studies have been undertaken. However overwhelming evidence from these interventional studies and from observational and prospective studies indicates that ScvO₂ has prognostic significance.

Recommendations

ScvO₂ can be measured intermittently by drawing repeated blood samples from the central venous catheter and measuring the oxygen saturation via co-oximetry. This approach provides only intermittent information, increases health staff workload and results in unnecessary blood loss (Baulig et al, 2008). Alternatively, ScvO₂ can be measured continuously via a spectrophotometric catheter. Advantages of continuous measurement include the provision of continuous data, decreased risk of infection as compared with intermittent sampling and conservation of time (Molnar et al, 2007; Muller et al, 2007; Baulig et al, 2008). Molnar et al (2007) found continuous ScvO₂ monitoring yielded results comparable with those obtained by intermittent blood sampling and co-oximetry. Consequently, the use of continuous monitoring of ScvO₂ is recommended as opposed to intermittent sampling.

Support for ScvO₂ as a clinical indicator exists across a number of patient groups including general and cardiac surgical, myocardial infarction and cardiac disease, cardiogenic shock, and severe sepsis and septic shock. It is therefore suggested that ScvO₂ be monitored continuously in patients from these groups who are at risk of haemodynamic instability and low cardiac output and that are eligible for a central venous catheter (Muller et al, 2007). Information regarding cutoff values for ScvO₂ varies between patient groups and studies, however ScvO₂ levels below 70% have been found to be associated with increased morbidity and mortality (Polonen et al, 2000; Rivers et al, 2001a; Pinsky, 2007). Thus treatment should be directed towards keeping ScvO₂ levels above 70%.

Conclusions

The use of ScvO₂ as a haemodynamic goal is becoming increasingly popular (Bracht et al, 2007). While SvO₂ has been found to be a good clinical indicator of patient condition, evidence indicates ScvO₂ and SvO₂ to be interchangeable as long as absolute values are not required (Goldman et al, 1968; Rivers et al, 2001a; Dueck et al, 2005; Marx and Reinhart, 2006). Given these findings it would appear that ScvO₂ is a valuable method of directing treatment in a range of patient groups. Furthermore, these findings suggest further research into the use of ScvO₂ as a clinical indicator in other clinical subpopulations would be of merit.

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Table 1: Summary of mixed versus central oxygen saturation monitoring.

Measurement	Mixed venous oxygen saturations	Central venous oxygen saturations
Abbreviation:	Svo2	Scvo2
Blood drawn from:	Proximal pulmonary artery	Superior vena cava
Clinical picture:	<ul style="list-style-type: none">• Average venous oxygenation• Balance between systemic delivery and consumption	<ul style="list-style-type: none">• Venous oxygen saturations of blood from brain of whole body and upper body but not lower body
Advantages:	Systemic picture	No pulmonary artery catheter required Patients in ICU routinely already have central venous catheter in place
Disadvantages:	Possible complications include arrhythmias, catheter knotting in patients, perforation of pulmonary artery, infection	Unreliable correlation with systemic oxygenation in advanced sepsis/septic shock