

Correlation between central venous oxygen saturation and oxygen delivery changes following fluid therapy

A. YAZIGI, H. ABOU-ZEID, S. MADI-JEBARA, F. HADDAD, G. HAYEK and K. JABBOUR

Department of anesthesia and surgical intensive care, Hotel-Dieu de France hospital, Saint-Joseph University, Beirut, Lebanon

Background: The rationale for using central venous oxygen saturation (ScvO₂) in various clinical scenarios is that it reflects the balance between oxygen delivery (DO₂) and demands. In this study, we evaluated the correlation between ScvO₂ and DO₂ changes (Δ DO₂, Δ ScvO₂) in patients receiving fluid therapy following coronary surgery. We also correlated the changes of mean arterial pressure (Δ MAP) and central venous pressure (Δ CVP), with Δ DO₂.

Methods: Sixty consecutive sedated and mechanically ventilated adult patients, with cardiac index ≤ 2.3 L/min/m² and a pulmonary artery occlusion pressure ≤ 12 mmHg following coronary surgery, were included. Concomitant hemodynamic parameters, arterial and venous blood gases were measured before (T0) and after (T1) administration of a 500 ml bolus of an isotonic crystalloid solution over 30 min. The correlations between Δ DO₂ and Δ ScvO₂, Δ MAP or Δ CVP were evaluated by linear regression analysis and Pearson test.

Results: Cardiac index (1.9 ± 0.2 vs 2.3 ± 0.5 ml/min/m²), MAP (83 ± 11 vs 94 ± 13 mmHg) and CVP (5.7 ± 3 vs 7.1 ± 3 mmHg) were significantly higher at T1 compared with T0. The correlation of Δ DO₂ with Δ ScvO₂ was positive, significant ($r = 0.41$; $P = 0.004$) and superior to its correlation with Δ MAP ($r = 0.30$; $P = 0.01$) or Δ CVP ($r = 0.03$; $P = 0.78$).

Conclusion: A significant correlation between ScvO₂ and DO₂ changes was found in patients receiving fluid therapy following coronary surgery. ScvO₂ could be used as an indicator to track DO₂ and to guide volume loading.

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THE usefulness of central venous oxygen saturation (ScvO₂) measurement is evaluated in various clinical scenarios. Abnormally low ScvO₂ values have been found to be associated with global tissue hypoxia and elevated blood lactate levels in patients presenting in shock,¹ decompensated chronic heart failure² and trauma.³ Early goal-directed therapy, which included treatment goals for ScvO₂, has increased survival in septic patients.^{4,5} Central venous oxygen saturation is also of prognostic significance after major surgery,⁶ during cardiopulmonary resuscitation^{7,8} and in unplanned admission to ICU.⁹

The rationale for using ScvO₂ in critically ill patients is that it reflects indirectly the balance between systemic oxygen delivery (DO₂) and demands.¹⁰ A recent animal study has documented a strong correlation between ScvO₂ and DO₂ values under different cardiovascular conditions.¹¹ In this study, we evaluated the correlation between ScvO₂ and DO₂ changes in patients receiving fluid therapy

following coronary surgery. In comparison, we correlated the changes of mean arterial pressure (MAP) and central venous pressure (CVP), with DO₂. A positive correlation between DO₂ and ScvO₂ changes would make ScvO₂ a valuable indicator to track DO₂ and to guide volume loading.

Methods

This prospective observational study was approved by our institutional review board and all participants gave an informed written consent. Two hundred and fifty adult patients underwent elective coronary surgery in our department over a period of 6 months. Anesthesia was induced and maintained using etomidate 0.3 mg/kg, pancuronium 0.2 mg/kg, midazolam 0.1 mg/kg/h, fentanyl 5 μ g/kg/h and isoflurane up to 1 minimum alveolar concentration. Invasive hemodynamic monitoring was achieved with a 20 G radial

artery catheter, a 7.5 French pulmonary artery catheter (Edwards Lifesciences, Irvine, CA) inserted through the right internal jugular vein and a 7 French central venous catheter (Arrow-Howes, Reading, PA) inserted through the right subclavian vein. A cardiopulmonary bypass was performed under hemodilution and mild hypothermia, using a membrane oxygenator primed with a crystalloid solution. Myocardial preservation was achieved with a cold cardioplegia solution containing 30 mM of potassium per liter. Coronary anastomoses were performed under total aortic cross clamping.

At the end of surgery, all patients were kept anesthetized and transferred to the cardiac surgery unit. Arterial, pulmonary artery and CVPs were displayed on an electronic monitor (Hellige SMU 611, Freiburg, Germany) and measured at end-expiration. Cardiac output was obtained by the thermodilution technique. The cardiac index (CI) was computed by averaging three consecutive measurements of cardiac output divided by the patient body surface area. The position of the pulmonary artery catheter was confirmed by the transduced waveforms. The location of the central venous catheter tip 2–3 cm underneath the clavicle was shown by chest radiography.

Patients were consecutively included in the study if they had, at the time of admission in the cardiac surgery unit, a $CI \leq 2.31/\text{min}/\text{m}^2$ associated with a pulmonary artery occlusion pressure (PAOP) and a CVP ≤ 12 mmHg. Patients were excluded from the study if they had a left ventricular ejection fraction $\leq 40\%$, intracardiac shunting, valvular disease, active bleeding, inotropic drugs or an intra aortic balloon pump. Patients included in the study had a 500-ml bolus of an isotonic crystalloid solution administered over 30 min. Fluid therapy was stopped if PAOP reached 18 mmHg.

Concomitant hemodynamic and blood gas measurements were taken in included patients before starting fluid therapy (T0) and repeated at the end of the maneuver (T1). Blood samples of 2 ml were simultaneously obtained from the radial artery catheter and from the central venous catheter after withdrawal of dead space blood and flushing fluid. All samples were withdrawn over 30 s, using a low-negative pressure technique. Samples were immediately analyzed for blood gas variables, using a blood gas analyzer (ABL, Radiometer, Copenhagen, Denmark), along with central venous and arterial hemoglobin oxygen saturation mea-

sured by oxymetry. The reproducibility of the measurements made with our instrument was found, on duplicated determination, to be $\pm 2\%$ for oxygen saturation between 35% and 100%. The oximeter was calibrated using standards supplied with the machine. Hemodynamic measurements included CI, MAP, mean pulmonary artery pressure (MPAP), CVP, PAOP and systemic vascular resistance index (SVRI). Concomitant arterial hemoglobin concentration and rectal temperature were also recorded. During the study period, patients were sedated with midazolam 0.1 mg/kg/h and paralyzed with vecuronium 0.02 mg/kg/h. Mechanical ventilation was provided with a tidal volume of 10 ml/kg, an FIO_2 of 60% and a respiratory rate of 12/min. Body temperature was maintained with a warming blanket.

On the basis of a preliminary investigation that showed a correlation coefficient of 0.3 between DO_2 and $ScvO_2$ changes following fluid therapy, it was determined that a sample of 60 patients is needed to demonstrate a significant correlation, with a power of 80% and an α coefficient of 0.05, between the two primary evaluated parameters in our study. The DO_2 was calculated as: $DO_2 (\text{ml}/\text{min}/\text{m}^2) = CI \times 10 \times (Hg \times SaO_2 \times 1.36 + PaO_2 \times 0.003)$. All data were checked for normal distribution by a one-sample Kolmogorov–Smirnov test and are presented as mean \pm SD unless otherwise indicated. Normally distributed variables were compared by paired Student's *t*-test, whereas nonparametric variables were compared by Wilcoxon's Signed test by ranks. The changes in individual values of DO_2 and $ScvO_2$ were recorded as ΔDO_2 and $\Delta ScvO_2$. The correlation between ΔDO_2 and $\Delta ScvO_2$ was evaluated by linear regression analysis and Pearson's test. The changes in individual values of MAP and CVP were expressed as ΔMAP and ΔCVP . The correlations between ΔDO_2 and ΔMAP or ΔCVP were also evaluated by linear regression analysis and Pearson's test. Statistical evaluations were performed using the SPSS (version 13.0) statistical package. $P \leq 0.05$ was considered to be statistically significant.

Results

Sixty consecutive adult patients, 41 male and 19 female, requiring fluid therapies upon their admission in CSU, were included in this study. Acute physiology and chronic health evaluation II (APACHE) score ranged between 10 and 15. All

Table 1

Hemodynamic parameters, arterial blood gases, rectal temperature and arterial haemoglobin concentration at T0 and T1.

	T0	T1	P
Cardiac index (ml/min/m ²)	1.9 ± 0.2	2.3 ± 0.5	0.001
Mean arterial pressure (mmHg)	83 ± 11	94 ± 13	0.05
Pulmonary artery occlusion pressure (mmHg)	8.0 ± 1.9	10.5 ± 2.3	0.001
Central venous pressure (mmHg)	5.7 ± 3.0	7.1 ± 3.1	0.001
Systemic vascular resistance index(dyne/s/cm ⁵ /m ²)	3150 ± 730	2632 ± 762	0.001
Heart rate (beats/min)	91 ± 9	90 ± 8	NS
Arterial pH	7.44 ± 0.5	7.43 ± 0.6	NS
PaO ₂ (mmHg)	221 ± 88	224 ± 89	NS
PaCO (mmHg)	34 ± 4	36 ± 2	NS
Bicarbonates concentration (mEq/l)	23 ± 4	24 ± 4	NS
Rectal temperature (°C)	36.1 ± 0.8	36.1 ± 0.9	NS
Haemoglobin concentration (g/dl)	11.5 ± 1.4	10.9 ± 1.5	0.001

Data expressed in mean ± standard deviation; T0, before fluid therapy; T1, after fluid therapy.

Table 2

Central venous oxygen saturation and oxygen delivery at T0 and T1.

	T0	T1	P
ScvO ₂ (%)	55 ± 10	59 ± 10	0.001
DO ₂ (ml/min/m ²)	312 ± 57	357 ± 82	0.001

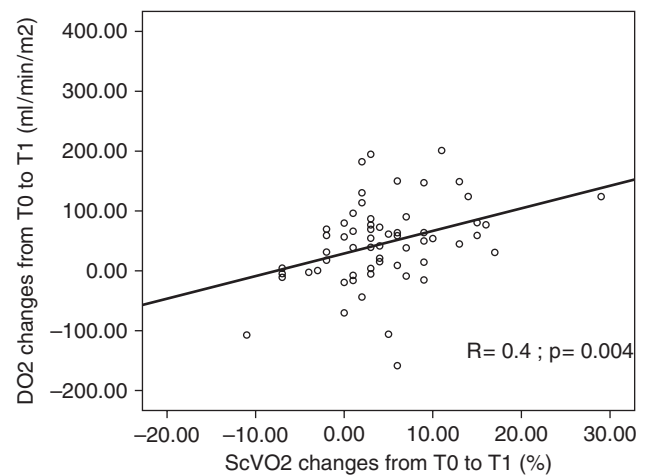
NB, data expressed in mean ± SD; T0, before fluid therapy; T1, after fluid therapy; ScvO₂, central venous oxygen saturation; DO₂, oxygen delivery.

patients responded to volume loading without increasing PAOP above 18 mmHg. CI, MAP, CVP and PAOP were higher at T1 compared with T0 (Table 1). SVRI and arterial hemoglobin concentration were lower at T1 compared with T0 (Table 1).

Recorded values of ScvO₂ and DO₂ at T0 and T1 are presented in Table 2. There was a significant increase in ScvO₂ and DO₂ at T1 compared with T0. The correlation between Δ ScvO₂ and Δ DO₂, shown in Fig. 1, was positive and significant ($r = 0.41$; $P = 0.004$). The correlation between Δ MAP and Δ DO₂ was also significant ($r = 0.30$; $P = 0.01$), whereas changes in DO₂ did not correlate with Δ CVP ($r = 0.03$; $P = 0.78$).

Discussion

The current study measured ScvO₂ and DO₂ changes in patients presenting a low CI and filling pressures following coronary artery bypass grafting. This hemodynamic scenario is common after cardiac surgery and is caused by a reduced vascular volume or blood sequestration into the venous compartment.¹² The management of this hemodynamic scenario usually includes fluid therapy to

Fig. 1. The correlation between ScvO₂ and DO₂ changes from T0 to T1.

expand the intravascular compartment and increase venous return.¹² In patients receiving fluid therapy following coronary surgery, ScvO₂ and DO₂ increased significantly. The correlation of Δ DO₂ with Δ ScvO₂ was significant and superior to its correlation with Δ MAP and Δ CVP.

Several studies report a significant increase in ScvO₂ following volume loading both in animals¹¹⁻¹⁴ and in humans.^{1,2} The increase in ScvO₂ was associated with an increase in cardiac output and in oxygen delivery to tissues.^{14,15} However, the correlation of ScvO₂ with DO₂ or with one of its components, as blood volume or cardiac output, was not frequently documented. Osthaus et al.¹¹ reported a strong and significant correlation ($r^2 = 0.9$; $P < 0.0001$) of ScvO₂ with DO₂ in anesthetized piglets under different cardiovascular conditions, including volume loading. A positive correlation between ScvO₂ and the percentage of

blood loss was found in trauma patients ($r^2 = 0.43$)³ and in unanesthetized mongrel dogs ($r = 0.82$).¹⁶ Madsen et al.¹⁷ reported that, in healthy volunteers placed in a head-up tilt position, ScvO₂ was not consistently correlated with cardiac output. In critically ill patients, the correlation between ScvO₂ and cardiac output changes after therapy was found to be positive but poor ($r = 0.27$).¹⁸ The current study evaluated the correlation between changes of ScvO₂ and DO₂ following fluid therapy in humans. The results validated, in the clinical setting of cardiac surgery, the significant correlation between DO₂ and ScvO₂ reported in the anesthetized piglets' model.¹¹

The correlation between DO₂ or one of its components and heart rate, MAP or CVP has been assessed in comparison with ScvO₂. Osthaus et al.¹¹ showed in their animal model that the correlation of DO₂ with ScvO₂ was superior to its correlation with heart rate or MAP. The correlation of central blood volume with ScvO₂ was found to be superior to its correlation with CVP, heart rate and MAP in awake dogs,¹⁶ healthy volunteers¹⁷ and trauma patients.³ In the current study, the higher correlation of Δ DO₂ with Δ ScvO₂, compared with Δ MAP or Δ CVP, is in agreement with the reported data. Mean arterial and CVP are affected by several factors whereas, in anesthetized patients with stable oxygen consumption, ScvO₂ is directly related to DO₂.

The results of this study have clinical implications. In patients requiring fluid therapy following coronary surgery, an insufficient increase in DO₂ related to hemodilution or to inadequate myocardial function may lead to global tissue hypoxia.¹⁴ Changes in DO₂ and in tissues' oxygen extraction during cardiac surgery are ideally monitored by mixed venous oxygen saturation measured by a pulmonary artery catheter.¹⁹ However, the insertion of these catheters is associated with inherent risks^{20,21} and their systematic use is currently a matter of debate in patients undergoing cardiac surgery.^{22,23} Central venous oxygen saturation is obtained in a less risky manner from a central venous catheter. The results of our study indicated that, in the absence of a pulmonary artery catheter, measurement of ScvO₂ changes is valuable as trend monitoring of DO₂ changes following fluid therapy. Furthermore, ScvO₂ is superior to MAP and CVP in predicting DO₂ response to fluid loading. An inadequate increase in ScvO₂ after volume expansion may indicate the need for alternative therapies as blood transfusion or inotrope drugs. Several authors suggested, outside the context of cardiac

surgery, that ScvO₂ changes could be used to assess the impact of various hemodynamic therapeutic modalities.^{4,5,7,10,24}

The current study has several limitations. First, it was undertaken in sedated, paralyzed and ventilated patients with stable oxygen consumption and the results may not be valid in awake and spontaneously breathing patients. Mechanical ventilation may have caused some central venous depletion and contributed to the required fluid therapy. Moreover, Pearse et al.⁶ evaluated changes in ScvO₂ following major surgery and found that tissues' oxygen consumption is an important determinant of ScvO₂. Second, this study was based on spot *in vitro* measurements of ScvO₂. Several authors have used central venous fiberoptic oxygen saturation catheters to assess the clinical usefulness of ScvO₂.^{4,7,10,13} These catheters provided an accurate continuous monitoring of central venous oxygen saturation, a large number of measurements and a close tracking of ScvO₂ changes across a wide range of hemodynamic conditions. However, fiberoptic catheters have a high cost and a limited availability. Third, the correlation of DO₂ with ScvO₂ was not assessed in comparison with standard base excess and serum lactate. These parameters were used, in association with ScvO₂, to evaluate the adequacy of tissues' oxygenation in critically ill patients.^{1,2,5,7,25,26} It would be interesting to clarify whether base excess and serum lactate changes are valuable as trend monitoring of DO₂ following fluid therapy in cardiac surgery. Finally, this study was not designed to clarify whether ScvO₂ monitoring is beneficial in terms of outcome in the specific context of cardiac surgery. Recently, Kapoor et al.²⁷ showed that an early goal-directed therapy including ScvO₂ optimization may have some benefits in moderate- to high-risk cardiac surgery patients.

We concluded that, in patients receiving fluid therapy following coronary surgery, the correlation of Δ DO₂ with Δ ScvO₂ was superior to its correlation with Δ MAP and Δ CVP. These data indicate that, in the absence of a pulmonary artery catheter, measurement of ScvO₂ changes is valuable as trend monitoring of DO₂ to guide volume loading.

References

1. Rady MY, Rivers EP, Nowak RM. Resuscitation of the critically ill in the ED: responses of blood pressure, heart

- rate, shock index, central venous oxygen saturation, and lactate. *Am J Emerg Med* 1996; **14**: 218–25.
2. Ander DS, Jaggi M, Rivers E, Rady MY, Levine TB, Levine AB, Masura J, Gryzbowski M. Undetected cardiogenic shock in patients with congestive heart failure presenting to the emergency department. *Am J Cardiol* 1998; **82**: 888–91.
 3. Scalea TM, Hartnett RW, Duncan AO, Atweh NA, Phillips TF, Sclafani SJ, Fuortes M, Shaftan GW. Central venous oxygen saturation: a useful clinical tool in trauma patients. *J Trauma* 1990; **30**: 1539–43.
 4. Rivers E, Nguyen B, Havstad S, Ressler J, Muzzin A, Knoblich B, Peterson E, Tomlanovich M. Early goal-directed therapy collaborative group. Early goal-directed therapy in the treatment of severe sepsis and septic shock. *N Engl J Med* 2001; **345**: 1368–77.
 5. Nguyen HB, Corbett SW, Steele R, Banta J, Clark RT, Hayes SR, Edwards J, Cho TW, Wittlake WA. Implementation of a bundle of quality indicators for the early management of severe sepsis and septic shock is associated with decreased mortality. *Crit Care Med* 2007; **35**: 1105–12.
 6. Pearse R, Dawson D, Fawcett J, Rhodes A, Grounds RM, Bennett ED. Changes in central venous saturation after major surgery, and association with outcome. *Crit Care* 2005; **9**: R694–9.
 7. Snyder AB, Salloum LJ, Barone JE, Conley M, Todd M, DiGiacomo JC. Predicting short-term outcome of cardiopulmonary resuscitation using central venous oxygen tension measurements. *Crit Care Med* 1991; **19**: 111–3.
 8. Rivers EP, Martin GB, Smithline H, Rady MY, Schultz CH, Goetting MG, Appleton TJ, Nowak RM. The clinical implications of continuous central venous oxygen saturation during human CPR. *Ann Emerg Med* 1992; **21**: 1094–101.
 9. Bracht H, Hänggi M, Jeker B, Wegmüller N, Porta F, Tüller D, Takala J, Jakob SM. Incidence of low central venous oxygen saturation during unplanned admissions in a multidisciplinary intensive care unit: an observational study. *Crit Care* 2007; **11**: R2.
 10. Rivers EP, Ander DS, Powell D. Central venous oxygen saturation monitoring in the critically ill patient. *Curr Opin Crit Care* 2001; **7**: 204–11.
 11. Osthaus WA, Huber D, Beck C, Roehler A, Marx G, Hecker H, Sümpelmann R. Correlation of oxygen delivery with central venous oxygen saturation, mean arterial pressure and heart rate in piglets. *Paediatr Anaesth* 2006; **16**: 944–7.
 12. Bojar RM. Early postoperative care: basic pathophysiology and common scenarios. In: Bojar RM, ed. *Manual of perioperative care in cardiac and thoracic surgery*. Oxford: Blackwell Science, 1994:61–79.
 13. Hirschl RB, Palmer P, Heiss KF, Hultquist K, Fazzalari F, Bartlett RH. Evaluation of the right atrial venous oxygen saturation as a physiologic monitor in a neonatal model. *J Pediatr Surg* 1993; **28**: 901–5.
 14. Krantz T, Warberg J, Secher NH. Venous oxygen saturation during normovolaemic haemodilution in the pig. *Acta Anaesthesiol Scand* 2005; **49**: 1149–56.
 15. Goldman RH, Braniff B, Harrison DC, Spivack AP. The use of central venous oxygen saturation measurements in a coronary care unit. *Ann Intern Med* 1968; **68** (6): 1280–7.
 16. Scalea TM, Holman M, Fuortes M, Baron BJ, Phillips TF, Goldstein AS, Sclafani SJ, Shaftan GW. Central venous blood oxygen saturation: an early, accurate measurement of volume during hemorrhage. *J Trauma* 1988; **28**: 725–32.
 17. Madsen P, Iversen H, Secher NH. Central venous oxygen saturation during hypovolaemic shock in humans. *Scand J Clin Lab Invest* 1993; **53**: 67–72.
 18. Lee J, Wright F, Barber R, Stanley L. Central venous oxygen saturation in shock: a study in man. *Anesthesiology* 1972; **36**: 472–8.
 19. O'Connor JP, Townsend GE. Perioperative continuous monitoring of mixed venous oxygen saturation should be routine during high-risk cardiac surgery. *J Cardiothorac Vasc Anesth* 1990; **4**: 647–50.
 20. Weil MH. The assault on the Swan-Ganz catheter: a case history of constrained technology, constrained bedside clinicians, and constrained monetary expenditures. *Chest* 1998; **113**: 1379–86.
 21. Kelso LA. Complications associated with pulmonary artery catheterization. *New Horiz* 1997; **5**: 259–63.
 22. Djaiani G, Karski J, Yudin M, Hynninen M, Fedorko L, Carroll J, Poonawala H, Cheng D. Clinical outcomes in patients undergoing elective coronary artery bypass graft surgery with and without utilization of pulmonary artery catheter-generated data. *J Cardiothorac Vasc Anesth* 2006; **20**: 307–10.
 23. Kastrup M, Markewitz A, Spies C, Carl M, Erb J, Grosse J, Schirmer U. Current practice of hemodynamic monitoring and vasopressor and inotropic therapy in post-operative cardiac surgery patients in Germany: results from a postal survey. *Acta Anaesthesiol Scand* 2007; **51**: 347–58.
 24. Goldman RH, Klughaupt M, Metcalf T, Spivack AP, Harrison DC. Measurement of central venous oxygen saturation in patients with myocardial infarction. *Circulation* 1968; **38**: 941–6.
 25. Park M, Azevedo LC, Maciel AT, Pizzo VR, Noritomi DT, da Cruz Neto LM. Evolutionary standard base excess and serum lactate level in severe sepsis and septic shock patients resuscitated with early goal-directed therapy: still outcome markers? *Clinics* 2006; **61**: 47–52.
 26. Shah NS, Kelly E, Billiar TR, Marshall HM, Harbrecht BG, Udekwu AO, Peitzman AB. Utility of clinical parameters of tissue oxygenation in a quantitative model of irreversible hemorrhagic shock. *Shock* 1998; **10**: 343–6.
 27. Kapoor PM, Kakani M, Chowdhury U, Choudhury M, Lakshmy R, Kiran U. Early goal-directed therapy in moderate to high-risk cardiac surgery patients. *Ann Card Anaesth* 2008; **11**: 27–34.

Address:
 Alexandre Yazigi
 Department of anesthesia and surgical intensive care
 Hotel-Dieu de France hospital
 Saint-Joseph University
 Beirut
 Lebanon
 e-mail: ritalama@idm.net.lb