BRIEF REPORT

The changes in the oxygen saturations in the superior vena cava and the pulmonary artery are not the same during cardiac surgery

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Abstract

Objective: To evaluate the changes over time (trend) in sign and magnitude for $S_{vO_2}$ and $S_{O_2}$ during and after cardiac surgery.

Patients and methods: A prospective and observational study was conducted on 34 cardiac surgery patients. Venous blood samples were taken simultaneously from the introductory ($S_{vO_2}$) and distal ($S_{O_2}$) port of the pulmonary artery catheter at predefined intervals. Systemic and pulmonary hemodynamic variables were measured at the same time. The trend was calculated as the difference between 2 consecutive measurements ($t_{SO_2}$). Data were processed with ANOVA for multiple comparisons, Pearson correlation coefficient and Bland–Altman analysis.

Results: There was a significant correlation between $S_{vO_2}$ and $t_{SO_2}$ ($R^2=0.55$), the mean of the differences was $0.36 \pm 7.75\%$, and the limits of agreement ranged from $-15.1$ to $15.9\%$. The sign of the trend was similar in 85.1% of the paired data. However, the magnitude of the changes in $t_{SO_2}$ and $S_{O_2}$ were not always equivalent. Between 0 and 5% of the change in the $S_{vO_2}$ was coincident with only 44.7% of the $S_{O_2}$. A wide variation was found between both trends when the signs and magnitudes of the changes were taken into account.

Conclusions: When considering the sign and magnitude, the change over time of central venous $O_2$ saturations were not interchangeable in cardiac surgery patients. Clinical decisions based exclusively on $t_{SO_2}$ monitoring should be taken with caution.

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Las tendencias en el tiempo de las saturaciones de oxígeno en la vena cava superior y la arteria pulmonar no son equivalentes en cirugía cardiaca

Resumen

Objetivo: Comparar los cambios de signo y magnitud de las tendencias (tSO₂) de las saturaciones venosas de arteria pulmonar (tSO₂O₂) y de vena cava superior (tSO₂VC) en pacientes sometidos a cirugía cardiaca.

Pacientes y métodos: Realizamos un estudio prospectivo y observacional en 34 pacientes sometidos a cirugía cardiaca. Las medidas hemodinámicas y las extracciones de sangre se realizaron a intervalos predefinidos. Se extrajeron muestras simultáneamente del puerto distal del catéter pulmonar (tSO₂O₂) y del introductor del mismo (tSO₂VC). Las tSO₂ se calcularon como la diferencia entre 2 medidas consecutivas. Los datos fueron procesados por test ANOVA, correlación de Pearson y análisis de Bland-Altman.

Resultados: Las tSO₂ de ambos ambas mostraron una correlación positiva (R² = 0,55), siendo la diferencia de las medias de 0,36 ± 7,75% y los límites de discordancia desde −15,1 a 15,9%. La probabilidad de que un cambio direccional en tSO₂VC pueda ser seguido de un cambio similar en tSO₂O₂, mostró que el signo de las mismas coincidió en el 85,1%. Sin embargo, la magnitud del cambio coincidió en un porcentaje menor, dependiendo del considerado. Entre 0 y 5% de cambio en la tSO₂VC, se encontró coincidencia con la tSO₂O₂ en el 44,7% de los casos.

Conclusiones: Considerando que el signo y magnitud de las tendencias de ambas SO₂ no son intercambiables, las decisiones terapéuticas basadas en la consideración de estos parámetros deben hacerse con precaución.

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Introduction

There is strong evidence to suggest that absolute central venous saturation levels (SVC) do not match mixed venous oxygen saturation (SvO₂) levels, and clinicians should not base their decisions on the latter. An alternative approach is to consider the changes over time or trend of these variables instead of their absolute value. Ducek et al. found that SVC (tSVC) trends could replace those of SvO₂ (tSvO₂), based purely on directional changes (rise/fall), without considering the magnitude of such changes. These findings, however, were not confirmed in other studies.

The aim of our study was to compare changes in SVC and SvO₂ and the magnitude of such changes in patients undergoing heart surgery (i.e.).

Patients and methods

We carried out a prospective, observational study in the Hospital Universitario de Clínicas and the Sanatorio Americano in Montevideo. The study was approved by the Independent Ethics Committee of both hospitals, and patients were asked to give their informed consent. HS patients with indication for pulmonary artery catheter (PAC) were included; patients with tricuspid regurgitation or cardiac shunt were excluded. Prior to anesthesia induction, the left radial artery was catheterized and a PAC (7.5 G, Biosensors International Pvt Ltd., Singapore) was placed in the right internal jugular vein. During the immediate postoperative period the position of the catheter and the distal port of the introducer were confirmed by chest X-ray. Patients with PAC malposition were excluded. Hemodynamic measurements and blood samples were taken simultaneously: (a) following anesthesia induction; (b) immediately after surgery; (c) on transfer to the Intensive Care Unit; (d and e) at 12 and 36 h following transfer. Blood samples were taken simultaneously from the distal port of the PAC (SvO₂), from the introductor (SVC), and from the radial artery. Each sample was measured twice, and the mean measurement was calculated (ABL 700 series, Radiometer, Copenhagen, Denmark). Changes over time in both saturation levels (tSO₂) were taken to be the difference between 2 consecutive measurements.

Statistical analysis

Hemodynamic data were compared by one-way repeated measures ANOVA. Post hoc Newman–Keuls was used to evaluate differences between individual measurements, whenever necessary. The unpaired t-test with the Bonferroni correction was used to compare both saturation levels at different time periods. Paired SO₂ and tSO₂ samples were analyzed using the Pearson correlation coefficient and the Bland-Altman test. The sample size was sufficient for the purposes of the study (α = 0.05, power 80%).

Results

Thirty-four patients were included in the study, 21 were men, and mean age was 64 ± 9 years. Of the total number of patients, 26 underwent coronary artery bypass graft,
Table 1  Hemodynamic variables.

<table>
<thead>
<tr>
<th></th>
<th>Anesthesia induction</th>
<th>End of surgery</th>
<th>Transfer to ICU</th>
<th>ICU, 12 h</th>
<th>ICU, 36 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (h)</td>
<td>-</td>
<td>3.4 ± 1.0</td>
<td>8.5 ± 2.0</td>
<td>17.3 ± 3.8</td>
<td>28.3 ± 4.0</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>75 ± 19</td>
<td>81 ± 14</td>
<td>89 ± 14</td>
<td>86 ± 20</td>
<td>92 ± 18</td>
</tr>
<tr>
<td>MAP (mmHg)</td>
<td>75 ± 19</td>
<td>71 ± 12</td>
<td>79 ± 15</td>
<td>86 ± 14</td>
<td>85 ± 9</td>
</tr>
<tr>
<td>MPAP (mmHg)</td>
<td>22 ± 8</td>
<td>24 ± 5</td>
<td>19 ± 5</td>
<td>19 ± 5</td>
<td>20 ± 6</td>
</tr>
<tr>
<td>Pcap (mmHg)</td>
<td>14 ± 5</td>
<td>15 ± 4</td>
<td>10 ± 3</td>
<td>12 ± 4</td>
<td>12 ± 5</td>
</tr>
<tr>
<td>CVP</td>
<td>9 ± 5</td>
<td>11 ± 5</td>
<td>9 ± 3</td>
<td>10 ± 4</td>
<td>10 ± 4</td>
</tr>
<tr>
<td>CI (b/min/m²)</td>
<td>2.0 ± 0.6</td>
<td>2.7 ± 0.6</td>
<td>2.8 ± 0.7</td>
<td>2.8 ± 1.1</td>
<td>2.9 ± 0.6</td>
</tr>
<tr>
<td>SVRI (dynes/s/cm²)</td>
<td>2730 ± 961</td>
<td>1739 ± 441</td>
<td>2145 ± 619</td>
<td>2169 ± 846</td>
<td>1996 ± 646</td>
</tr>
<tr>
<td>Hemoglobin (g/dl)</td>
<td>11.8 ± 2.0</td>
<td>9.9 ± 1</td>
<td>10.0 ± 1</td>
<td>10.4 ± 2</td>
<td>10.0 ± 3</td>
</tr>
<tr>
<td>Lactate (mmol/L)</td>
<td>1.09 ± 0.36</td>
<td>3.22 ± 1.37</td>
<td>4.25 ± 3.50</td>
<td>3.50 ± 4.01</td>
<td>2.36 ± 3.31</td>
</tr>
</tbody>
</table>

HR: heart rate; CI: cardiac index; SVRI: systemic vascular resistance index; MAP: mean arterial pressure; Pcap: pulmonary capillary pressure; MPAP: mean pulmonary artery pressure; CVP: central venous pressure; time: time in hours from anesthesia induction; ICU: intensive care unit.

Data expressed as mean ± standard deviation.

* p < 0.05 comparing changes over time.

and 18 underwent mitral or aortic valve replacement. Mean EuroSCORE was 7.4 ± 4.9%. Mean cardiopulmonary bypass (CPB) time was 143 ± 8 min, and cross-clamp time was 78 ± 28 min. Table 1 shows the hemodynamic variables, noting low systemic vascular resistance following removal of CPB, characterized by a systemic vascular resistance index below 1800 dynes/s/cm² and a higher cardiac index with respect to baseline levels. Lactate levels increased significantly (p < 0.05). At T0, most patients (26/34) did not require any type of vasoactive or vasopressor drugs, since all surgeries were elective. At T1 and T2, however, most (22/34) patients required such therapy; the most commonly administered drug was norepinephrine (12/22). At 12 h, 16 (47%) patients were already extubated, and at 36 h, 28 were breathing spontaneously (82%). Six patients continued with mechanical ventilation for over 36 h, and 2 patients died after this time. Of 170 blood samples taken for $S_vO_2$ and $S_vO_2$ measurements, valid results were obtained from 136. Both levels fell significantly during the postoperative period (p < 0.05) (Table 2). A positive correlation between $S_vO_2$ and $I_aS_vO_2$ ($R^2 = 0.69$, p = 0.001) was observed. The Bland–Altman test showed a mean difference of 2.49 ± 6.1%, with 95% limits of agreement ranging from −9.61 to 14.6%.

### Correlation between trends in central venous and pulmonary artery oxygen saturation

We compared 101 paired $T_vO_2$ measurements, all of which showed a positive correlation ($R^2 = 0.55$; p < 0.001) (Fig. 1, Panel A). The Bland–Altman test showed a mean difference of 0.36 ± 7.75%, with 95% limits of agreement ranging from −15.1 to 15.9% (Fig. 1, Panel B). The rise and fall in both variables and the magnitude of the change showed that the greatest decrease in saturation levels occurred in the first 2 measurements taken in the Intensive Care Unit (p < 0.05). Following this, we studied the probability of a rise or fall in $T_vO_2$ being followed by a similar change in $T_sO_2$. Taking all samples, the direction (rise or fall) of the change was mirrored in 85.1% of all paired samples. In terms of magnitude, however, the match rate, based on the data ranges taken into consideration, was far lower and more variable (Table 3). Changes in $T_vO_2$ ranging from 0 to 5% were matched by only 44.7% of all $T_vO_2$ levels in terms of both direction of change (rise/fall) and magnitude. Agreement in direction and magnitude of change in $T_vO_2$ saturation levels improved as the range increased, reaching 82.2% for $T_vO_2$ changes ranging from 0 to 20%.

Table 2  Hemoglobin saturation levels.

<table>
<thead>
<tr>
<th></th>
<th>Anesthesia induction</th>
<th>End of surgery</th>
<th>Transfer to ICU</th>
<th>ICU, 12 h</th>
<th>ICU, 36 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_vO_2$, %</td>
<td>76.3 (9.9)</td>
<td>77.9 ** (7.4)</td>
<td>68.2 ** (8.8)</td>
<td>66.1 ** (9.3)</td>
<td>64.3 (8.9)</td>
</tr>
<tr>
<td>$S_vO_2$, %</td>
<td>74.7 (10.2)</td>
<td>75.7 (7.2)</td>
<td>65.4 (9.8)</td>
<td>62.3 (8.6)</td>
<td>61.7 (9.6)</td>
</tr>
<tr>
<td>$S_vO_2$−$S_vO_2$, %</td>
<td>1.2 (9.5)</td>
<td>2.2 (4.2)</td>
<td>2.9 (5.1)</td>
<td>3.8 (3.7)</td>
<td>3.0 (5.3)</td>
</tr>
<tr>
<td>$T_vO_2$, %</td>
<td>−</td>
<td>1.5 (11.4)</td>
<td>−9.5 (10.7)</td>
<td>−3.0 (9.2)</td>
<td>0.2 (5.8)</td>
</tr>
<tr>
<td>$S_vO_2$, %</td>
<td>−</td>
<td>1.1 (7.83)</td>
<td>−10.2 (10.3)</td>
<td>−3.1 (9.4)</td>
<td>1.3 (8.1)</td>
</tr>
</tbody>
</table>

$S_vO_2$: mixed venous oxygen saturation; $S_vO_2$: central venous oxygen saturation; $T_vO_2$: difference between two consecutive measurements of mixed venous oxygen saturation; $T_vO_2$: difference between two consecutive measurements of central venous oxygen saturation; ICU: intensive care unit.

Data expressed as mean ± standard deviation.

* p < 0.05 comparing $S_vO_2$ with $S_vO_2$.

** p < 0.05 compared with baseline levels.
The changes in the oxygen saturations are not the same during cardiac surgery

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Different central venous saturation ranges measured over time showing trends in variables.</th>
</tr>
</thead>
<tbody>
<tr>
<td>tS\textsubscript{VC}\textsubscript{O}2 range (%)</td>
<td>Paired samples</td>
</tr>
<tr>
<td>0-5</td>
<td>38/101 (37.6%)</td>
</tr>
<tr>
<td>0-10</td>
<td>65/101 (64.4%)</td>
</tr>
<tr>
<td>0-15</td>
<td>82/101 (81.2%)</td>
</tr>
<tr>
<td>0-20</td>
<td>90/101 (89.1%)</td>
</tr>
<tr>
<td>All samples</td>
<td>101/101 (100.0%)</td>
</tr>
</tbody>
</table>

\(tS\textsubscript{O}2\): changes in mixed venous oxygen saturation over time (%); tS\textsubscript{VC}\textsubscript{O}2: changes in central venous oxygen saturation over time (%). The match probability was analyzed first in terms of change of direction (rise/fall), and then in both change of direction and magnitude. The analysis was repeated for different tS\textsubscript{VC}\textsubscript{O}2 ranges: 0-5%, 0-10%, 0-15%, 0-20% and for all samples. Data are presented as mean ± standard deviation and percentages.

found a good correlation between both variables \(R^2 = 0.69\), a more detailed study using Bland–Altman analysis showed differences in limits of agreement ranging from −9.61 to 14.6%. This means that for a hypothetical \(S\textsubscript{VC}\textsubscript{O}2\) level of 70%, \(S\textsubscript{V}O\textsubscript{2}\) levels could vary by 60.4–84.6%. These findings are largely similar to those of earlier studies by other investigators.\(^1\)\(^2\)\(^3\)\(^4\)\(^5\)\(^6\) The lack of equivalence between these saturation levels is due to blood from the territory of the superior vena cava mixing with less saturated blood from the inferior vena cava or from the coronary sinus. Oxygen saturation and metabolic response to anesthesia and normal postoperative hemodynamic changes differ in these territories, and therefore, estimations of \(S\textsubscript{V}O\textsubscript{2}\) changes should not be based on changes measured in \(S\textsubscript{VC}\textsubscript{O}2\).

**Correlation between trends in central venous and pulmonary artery oxygen saturation**

In a study of 70 patients undergoing neurosurgery in the sitting position, Dueck et al.\(^7\) took 502 simultaneous paired samples of \(S\textsubscript{VC}\textsubscript{O}2\) and \(S\textsubscript{V}O\textsubscript{2}\) in different hemodynamic situations. Their findings showed a moderate \(R^2 = 0.57\) correlation between tS\textsubscript{VC}\textsubscript{O}2 and tS\textsubscript{V}O\textsubscript{2}. In over 80% of cases, directional changes (rise/fall) in one sample were matched in the other, although neither absolute values nor magnitude were measured. Reinhart et al.\(^8\) reported similar findings in a study of 29 postoperative cardiovascular and sepsis patients, in which changes were matched in 88.3% of cases. These findings, however, were not confirmed by other authors. Varpula et al.\(^9\) in a study of sepsis patients, and Sander et al.\(^1\) in HS patients, found lower match rates for consecutive measurements of both saturation levels. Our study has shown a significant correlation between both trends (tS\textsubscript{VC}\textsubscript{O}2 and tS\textsubscript{V}O\textsubscript{2}, \(R^2 = 0.55\)). The Bland–Altman test, which evaluates whether 2 measurement methods are clinically useful and exchangeable, showed a difference of 0.36 ± 7.75% between measurements, although the limits of agreement range (from −15.1 to 15.9%) were too wide to be clinically useful. The change in direction (rise/fall) was matched in 85% of cases. However, when magnitude was added to this analysis, we again found significant discrepancies between paired tS\textsubscript{VC}\textsubscript{O}2 and tS\textsubscript{V}O\textsubscript{2} levels. For tS\textsubscript{VC}\textsubscript{O}2 levels ranging from 0 to 5%, changes in direction and magnitude matched in less than half the pairs studied (44%). It was only when

**Discussion**

Our findings confirm the hypothesis that there is no equivalence between absolute \(S\textsubscript{VC}\textsubscript{O}2\) and \(S\textsubscript{V}O\textsubscript{2}\) values. Although we

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**Figure 1** Panel A: correlation between tS\textsubscript{V}O\textsubscript{2} and tS\textsubscript{VC}\textsubscript{O}2 \((R^2 = 0.55, p < 0.001)\). Panel B: Bland–Altman analysis. The 95% limits of agreement for tS\textsubscript{V}O\textsubscript{2} and tS\textsubscript{VC}\textsubscript{O}2 ranged from −15.1 to 15.9%, with a 0.36 ± 7.75% difference in measurement.
the range was increased that the rate of coincidence in both direction and magnitude of these variables improved. Therefore, in terms of clinical usefulness, we can say that the correlation between trends in both saturation levels varies greatly, and that slight or moderate changes in trend found in central venous levels are not followed by similar changes in pulmonary artery saturation levels. This leads us to the conclusion that therapeutic measurements should not be based on these trends, particularly in the case of slight or moderate changes.

Recent studies have suggested that the difference or gradient between these measurements (∆SO₂ = SVcO₂ - SVO₂) could be clinically useful, particularly in HS.⁹¹ Ten due to blood from the coronary sinus.

Although an evaluation of the clinical usefulness of SVcO₂ values by themselves is beyond the scope of this study, very low, or very high levels, particularly when associated with high lactate levels, can be valuable in predicting outcomes in high-risk surgical patients.¹³ Our research, in this case, was limited to exploring the possibility of replacing one measurement (absolute values or trends) with the other.

Limitations of the study

(1) We did not take serial measurements of both saturation levels to analyze changes in magnitude. This could have shed more light on the discrepancies found in each range.

(2) The study was performed in a homogenous group of patients undergoing HS with CPB, and therefore cannot be extrapolated to other patient groups and surgical procedures.

We conclude that changes in direction (rise/fall) and magnitude over time in SVcO₂ and SVO₂ are not interchangeable, and caution should be taken when basing therapeutic decisions on these parameters.

The study was approved by the independent ethics committee of the hospitals involved in accordance with the rules of the World Medical Association and the Declaration of Helsinki.

Conflict of interests

The authors declare they have no conflicts of interest.

References