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ORIGINAL ARTICLE

# Is venous oxygen saturation a predictor of optimal oxygen delivery in adult patients undergoing cardiac surgery, with the use of extracorporeal circulation and mild hypothermia at 34°C?

*¿Es la saturación venosa de oxígeno un predictor de óptima entrega de oxígeno, en pacientes adultos sometidos a cirugía cardíaca con el uso de circulación extracorpórea e hipotermia leve a 34°C?*

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## ABSTRACT

Specifically, venous oxygen saturation during extracorporeal circulation indicates the relationship between the supply and consumption of oxygen in the body. Normal values are between 70% and 80%, until now it is an indicator of adequate tissue perfusion during extracorporeal circulation. But even in situations where venous oxygen saturation is within normal limits, this value could be masking a silently or hidden hypoperfusion, so we would be facing an increase in serum lactate concentration and little oxygen delivery to all organs.

**Objective:** To determine whether venous oxygen saturation is a predictor of optimal oxygen delivery in adult patients undergoing cardiac surgery using extracorporeal circulation and mild hypothermia at 34°C

**Method:** The study included all adult patients who met the inclusion criteria in the period from January to May 2021. Blood sampling, for arterial and venous blood gases, were taken simultaneously at the time of reaching the temperature at 34°C, and after cardiac arrest with the cardioplegic solution. Once these two results were obtained, they were compared and the arterial oxygen saturation, venous oxygen saturation, both arterial and venous oxygen pressure were measured, these results were processed in the application of the Latin American Perfusion Association and we also verified manually with the Fick equation.

**Results:** The data was analyzed with the statistical software IBM SPSS version 2.5, the Shapiro-Wilk test was used to demonstrate the normal distribution of variables. The Pearson correlation test to relate the variables and the student's t-test to assess statistical significance.

**Conclusions:** LVenous oxygen saturation can be considered a good predictor of adequate oxygen delivery in adult patients if this value is around 80%, and perfusion is performed at a cardiac index greater or equal to 2.32 $L/min/m^2$ in during the entire extracorporeal circulation at 34°C. Reducing flow or cardiac index below 2.32 $L/min/m^2$ does not guarantee optimal oxygen delivery and reduces venous oxygen saturation despite temperature reduction to 34°C. Adult patients with a temperature of 34°C should be perfused with flows used in normothermia.

**Key Words**: **Venous oxygen saturation, oxygen consumption, tissue perfusion, cardiac index.**

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## ABSTRACT

Específicamente la saturación venosa de Oxígeno durante la circulación extracorpórea nos indica la relación del suministro y consumo de oxígeno del organismo. Los valores normales están comprendidos entre el 70% y el 80%, hasta ahora es un indicador de la adecuada perfusión tisular durante la circulación extracorpórea. Pero aún en situaciones donde la saturación venosa de oxígeno se encuentra en límites normales, este valor podría estar enmascarando una hipoperfusión silente u oculta, por lo que estaríamos frente a un aumento de la concentración de lactato sérico y poca entrega de oxígeno a todos los órganos.

**Objetivo:** Determinar si la saturación venosa de oxígeno es un predictor de óptima entrega de oxígeno en pacientes adultos sometidos a cirugía cardíaca con el uso de circulación extracorpórea e hipotermia leve a 34°C.

**Método:** El estudio incluyó todos los pacientes adultos que cumplieron con el criterio de inclusión en el periodo de enero a mayo del 2021. La toma de muestras de sangre, para las gasometrías arteriales y venosas se realizaron de forma simultánea: en el momento en que se alcanza la temperatura de 34°C y depués de haber logrado parar el corazón, con la solución cardiopléjica, una vez obtenidos estos dos resultados se los comparó y se midió la saturación arterial de oxígeno, saturación venosa de oxígeno, presión de oxígeno, tanto arterial como venosa, estos resultados se procesaron con la aplicación de la Asociación Latinoamericana de Perfusión y además, los resultados se verificaron de forma manual con la fórmula de Fick.

**Resultados:** Los datos se analizaron con el software estadístico IBM SPSS versión 2.5. Se utilizó la prueba de Shapiro-Wilk para demostrar la normalidad de las variables, la prueba de correlación de Pearson para relacionar las variables y la prueba t de student para valorar la significancia estadística.

**Conclusiones:** La saturación venosa de oxígeno puede considerarse un buen predictor de adecuada entrega de oxígeno en pacientes adultos, siempre y cuando este valor se encuentre alrededor de 80%, y la perfusión se realice a índices cardiacos mayores o iguales a 2,32 $l/min/m^2$, en toda la conducción de la circulación extracorpórea a 34°C. Reducir el flujo o índices cardiacos a valores por debajo de 2,32 $l/min/m^2$ no garantizan una entrega óptima de oxígeno y reduce la saturación venosa de oxígeno, a pesar de la reducción de la temperatura a 34°C. Los pacientes adultos con temperatura de 34°C deberían ser perfundidos con flujos utilizados en normotermia.

**Palabras Clave:** **saturación venosa de oxígeno, consumo de oxígeno, perfusión tisular, índice cardiaco.**

## INTRODUCTION

Back in May 6, 1953, John Gibbon successfully accomplished the work a lifetime when he closed—for the first time ever—the interatrial communication in a young woman. In this procedure he used a heart-lung machine. However, the surgery had previously explored other approaches to operate on the heart such as hypothermia that consisted on lowering the patient's body temperature by putting the patient in a tub with cold water to later perform surgical correction of a heart malformation in the shortest time possible.

One year later, Walton Lillehei introduced the method of "controlled cross-circulation," in which a patient, usually a child, was connected to a "donor," often the father or mother, whose heart and lungs served as oxygenators so that the patient could undergo open-heart surgery.[1] The parameters measured in extracorporeal circulation usually are: the use of safety systems, pressure sensors, gas systems of the ECC machine, gases in lines, venous and arterial blood gas tests, temperature control, use of vaporizators, and coagulation times.[2] The hypothermia techniques during the application of cardiac shunt in different cardiovascular surgical treatments depend on the complexity of the anatomy and the pathophysiology of surgical correction.

Several aspects should be assessed such as: aortic clamping time with coronary flow interruption and subsequent ischemia, the patient's weight, age and hemodynamic stability.[3] Specifically, venous oxygen saturation ($SvO_2$) during extracorporeal circulation is indicative of the correlation between the body's oxygen supply and consumption. Normal values go from 70% to 80% so far it has been considered an indicator of suitable tissue perfusion during extracorporeal circulation. However, even in situations where $SvO_2$ is within normal limits, this value could be masking a silent or hidden hypoperfusion. Therefore, we would be in the presence of a situation of an increased concentration of serum lactate and little oxygen delivery to all the organs. This often happens when the oxygen demand of the tissues is greater than the supply.[4] Therefore, it is classed as a late marker of tissue hypoxia or hypoperfusion. Delivered oxygen ($DO_2$) is the volume of oxygen delivered to the tissues per unit of time. It is expressed in mL/min and is often corrected by body mass in (mL/kg/ min) or the body surface area (mL/min/$m^2$).

An increased level of blood lactate has traditionally been associated with anaerobic metabolism due to insufficient $DO_2$ regarding tissue requirements. $DO_2$ is the product of cardiac output (CO) and arterial oxygen content ($CaO_2$), which is expressed by the following formula $DO_2$= (CO x $CaO_2$ x 10). In physiological conditions oxygen demand is equal to consumption (2.4 mL/kg/min). Delivered oxygen is generally greater than consumption ($VO_2$), which in turn adapts to tissue demand. In clinical practice, $SvO_2$ assesses the $DO_2/VO_2$ ratio. According to the Fick equation, tissue $VO_2$ is proportional to cardiac output and this way $CvO_2$ represents the total venous return.[5]

| Table 1. Temperature levels associated with cardiac index | | |
|---|---|---|
| Category | Temperature | C. I. |
| Severe Hypothermia | < 14 °C | 0.4 L/min/$m^2$ |
| Deep Hypothermia | 14.1 °C to 20 °C | 1.0 L/min/$m^2$ |
| Moderate Hypothermia | 20.1 °C to 28 °C | 1.8 L/min/$m^2$ |
| Mild Hypothermia | 28.1°C to 34 °C | 2.4 L/min/$m^2$ |

On the other hand, $VO_2$ of a resting adult usually goes from 3 mL/kg/min to 3.5 mL/kg/min. During intense exercise, $VO_2$ can reach up to 60 to 70 mL/kg/min in healthy athletes.6 In hypothermia, the aforementioned value drops down to 50%. In moderate hypothermia, 28°C, it drops down to 60%. We should say that the induction of deeper levels of

On the other hand, $VO_2$ of a resting adult usually goes from 3 mL/kg/min to 3.5 mL/kg/min. During intense exercise, $VO_2$ can reach up to 60 to 70 mL/kg/min in healthy athletes.6 In hypothermia, the aforementioned value drops down to 50%. In moderate hypothermia, 28°C, it drops down to 60%. We should say that the induction of deeper levels of hypothermia decrease $VO_2$ in approximately 9% for every degree centigrade of temperature dropped.[7]

Metabolic processes depend on temperature; a temperature decrease in homoeothermic beings entails a lower use of energy. Q10 is the increase or decrease of the speed of metabolic processes in relation to temperature for a change of 10°C.8 Ischemia periods are variable depending on the different organs. The kidney can tolerate between 50 to 60 min, the liver between 20 and 30 min, and the spinal cord between 30 and 45 min. However, cerebral cortex can only tolerate between 2 and 4 min, pupillary centers 5 to 10 min and the cerebellum, 10 to 15 min.[7]

Reduction of temperature down to 30°C entails a drop in metabolism of 50% and at 23°C oxygen consumption drops down to 25%. Despite these theoretical advantages, hypothermia has a series of consequences and effects in different parts of the body. The final objective of systemic perfusion of the entire body during routine cardiopulmonary bypass is to satisfy the metabolic needs of the anesthetized cardiac patient. Previous publications have shown that cardiac index should remain between 2.8 L/min/$m^2$ and 3.0 L/min/$m^2$ at rest and that it can go up to 15 L/min/$m^2$ during exercise.[9] These reference values were obtained measuring blood that flows in resting patients who are not anesthetized.

Optimal systemic blood flow in anesthetized patients is calculated by the perfusionist based on theoretical calculations. The patient's height and weight are used to obtain the body surface area, the most often used cardiac index during cardiopulmonary bypass, in adult patients, ranges between 2.2 L/min/$m^2$ and 2.4 L/min/$m^2$. This value is believed to be close to the cardiac index of a normal resting person in normothermia. Hemodilution started shortly after the discovery of blood type groups. Pánico and Neptune described the hemodilution technique in a heart surgery around 1959, the hemodilution intended for ECC .[10]

Hemodilution plays a very important role in extracorporeal circulation, and it has three aspects: the first reduces blood oxygen carrying capacity, the second reduces blood viscosity, and the third one increases cardiac output as a compensatory effect for hematocrit drop. Since hematocrit value is the parameter that better reflects the association between plasma and blood cells, it is preferred to determine the degree of hemodilution. The degrees of hemodilution can be divided into mild, 25% to 30%,; moderate, 20% to 25%, and extreme, < 20%.[11] Blood dilution up to a hematocrit value of 20% to 25% is called moderate hemodilution, and when hematocrit drops down to values of around 10%, it is referred to as extreme dilution expressed in other medical literature.[12]

Goal-directed therapy (GDT) has adapted to the field of perfusion, and many of the physiological parameters in previous GDT studies are similar to those monitored by perfusionists during extracorporeal circulation. This new application has been called "goal-directed perfusion" (GDP), and was first described by Philip de Somer, who led a multicenter trial based on Ranucci's finding.

In GDP, we take the conventional terms of optimal perfusion and add concepts from cellular respiration: Delivered oxygen ($DO_2$), oxygen consumption ($VO_2$), carbon dioxide output ($VCO_2$) and oxygen extraction rate ($O_2ER$ or $VO_2/DO_2$) to reach a more physiological perfusion.[13] $DO_2$ levels above the critical value > 272 mL/min/m², minimizing hemodilution, and keeping hematocrit values > 26% decrease acute kidney injury. $VCO_2$ > 60 mL/min/m² and a $DO_2/VCO_2$ ratio < 5 are predictors of hyperlactatemia. $SvO_2$ and $O_2ER$ are the best predictors of transfusion during extracorporeal circulation, and they are even more important than the hemoglobin value.[14]

$SvO_2$ has been used over the past few years as a marker of optimal perfusion and values ≥ 75% are accepted as suitable by the community of surgeons, perfusionists, and anesthesiologists including the protocols of our center. Although there is another type of literature where $SvO_2$ levels under the aforementioned reference value are considered normal and despite of this, they continued to be ranked as normal.[15,16]

We should mention that certain studies mention $SvO_2$ values < 75% as normal, which could mask silent or hidden hypoperfusion causing hyperlactatemia and kidney failure.[17]

Traditionally, the estimates used to determine perfusion flows prior to the start of cardiopulmonary bypass are performed using the patient's weight and height according to Mosteller formula that underestimates body surface in adult patients.18 Low output and hypoperfusion are causes of ventricular dysfunction, alterations of circulatory state at the peripheral level, and oxygen extraction. Something similar happens at tissue perfusion level, $SVO_2$, blood lactate, and the $CO_2$ veno-arterial gradient (V-A $CO_2$) have been postulated as markers of tissue perfusion in patients undergoing heart surgery.

A correct, early diagnosis of each of these alterations facilitates timely, and effective treatment.[19] Management of metabolism plays an important role during ECC. There are different devices integrated to heart-lung machines for metabolic monitorization. The metabolic goals that are most often used and accepted are indexed oxygen delivery ($DO_2i$) which should be > 280 mL/min/m² and cardiac index (CI) 2.4 L/min/m². These can be managed independently or together with other metabolic parameters.[20]

$SvO_2$ can drop down to 30%-50% before tissue oxygen extraction is depleted and onset of anaerobic metabolism occurs. Venous oximetry is a parameter used for early goal-directed therapy, and is useful in critical conditions like in the period of sepsis. Monitoring changes to $SvO_2$ makes it possible to act in a quick and timely manner and perform interventions to improve the patient's critical condition.21 There are studies where the effect of an increased oxygen carrying is assessed until $SvO_2$ ≥ 70% is achieved on the morbimortality of patients who underwent heart surgery with the use of ECC.[22]

## METHOD

The study included all the adult patients who met the inclusion criterion at the Centro de Diagnóstico de Medicina Avanzada y Telemedicina (CEDIMAT) from January through May, 2021, in Santo Domingo, Dominican Republic. It was approved by the Ethics Committee of this center. The study data were obtained from a consolidated database through the perfusion register with its different variables: age, sex, hematocrit, body mass index (BMI), diabetic patients, extracorporeal circulation pump flow, cardiac indexes, arterial and venous blood gas tests, $DO_2$ and $VO_2$ while the mean arterial pressure (MAP) was registered as a hemodynamic parameter.

According to the protocol of the Adult Perfusion Department at CEDIMAT the model and brand of the oxygenator is selected depending on the flow required by the patient. Among them, Livanova-Sorin Inspire 6-Fr and 8-Fr, Euroset Horizon and Terumo RX 15 and FX 25. 3/8 G and 1/2 G Arteriovenous lines of are often used, respectively, as well as the use of a hemoconcentrator. Blood samples were drawn simultaneously to run the arterial and venous blood gas tests when a temperature of 34°C was reached, around 20 min after extracorporeal circulation is started and after stopping the heart with the use of the Del Nido cardioplegic solution.

Once these two results were obtained, they were compared, and arterial and venous oxygen saturations were measured as well as arterial and venous oxygen pressure. These results were entered into the application of the Latin American Perfusion Association (ALAP). In addition, they were verified manually with the Fick principle. Through these 2 methods the values of the patient's oxygen delivery and consumption were obtained. These data were registered in an Excel spreadsheet for data collection.

## RESULTS

Table 2. Correlation between SvO2 and DO2 between group #1 and group #2.

| | Group #1 | Group #2 |
|---|---|---|
| $SvO_2/DO_2$ ratio | -0.12 | 0.615 |
| *P* value | 0.567 | 0.567 |

Table 2 shows the correlation differences between $SvO_2$ and $DO_2$ in both study groups; group #1 shows a weak negative correlation that is not statistically significant between $SvO_2$ and $DO_2$ unlike patients from group #2 who show a moderate positive correlation, which is statistically significant.

Table 3. Correlation between SvO2 and flow, groups #1 and #2.

| | Group #1 | Group #2 |
|---|---|---|
| $SvO_2$/Flow ratio | 0.271 | 0.560 |
| *P* value | 0.190 | 0.004 |

Table 4 shows differences in the correlation between $SvO_2$ and age in both groups studied. Group #1 shows a weak negative correlation between $SvO_2$ and age unlike patients from group #2 who show a moderate positive correlation, which is not statistically significant in both study groups.

Table 4. Correlation between $SvO_2$ and age, groups #1 and #2.

| | Group #1 | Group #2 |
|---|---|---|
| $SvO_2$/Age ratio | -0.085 | 0.269 |
| *P* value | .686 | 0.193 |

Table 5 shows differences in the correlation between mean arterial pressure (MAP) and $SvO_2$ between both groups studied. Group #1 shows a moderate negative correlation between $SvO_2$ and MAP unlike patients from group #2 who show a weak positive correlation, which turned out to be not statistically significant in both study groups.

Table 5. Correlation between $SvO_2$ and mean arterial pressure, groups #1 and #2.

| | Group #1 | Group #2 |
|---|---|---|
| MAP/$SvO_2$ ratio | -0.515 | 0.146 |
| *P* value | 0.487 | 0.008 |

Table 6 shows that there is a perfect positive correlation between $SvO_2$ values, measured using the Irma gasometer (Trupoint Lifehealth, United States) by a blood sample obtained from the venous line of the extracorporeal circuit, and those obtained through the gas measuring device in the B-Care5 venous line. This correlation was statistically significant.

## DISCUSSION

We should mention that, lately, $SvO_2$ has become a forgotten measure of tissue oxygenation. In the bibliographic quotations in the introduction to this study, we found $SvO_2$

Correlation between the $SvO_2$ values obtained from the blood gas test and the B-Care 5 system, groups #1 and #2.

| | Groups #1 and #2 |
|---|---|
| $SvO_2$/B-CARE5 ratio | 1.00 |
| *P* value | 0.000 |

values considered normal when they fall within the range of 65% to 75%.[22] However, based on the results of this study these "normal" values could be masking not optimal oxygen delivery to the tissues. The standards of goal-directed perfusion on proper $DO_2$ should be above the critical value of 272 mL/min/m$^2$. In this study we wanted to relate $SvO_2$ with $DO_2$.

Comparing the groups studied group #1 shows no correlation between $SvO_2$ and $DO_2$ parameters, the mean $SvO_2$ was 77.07% for this group. Unlike group #2 which showed a correlation between $SvO_2$ and $DO_2$. The mean $SvO_2$ for this group was 80.57%, which is higher than the percentage for the other group. Starting from this correlation a venous oxygen saturation of approximately 5% above the values reported as normal (75%) was necessary. The increased $SvO_2$ of group #2, unlike group #1, could be due to the fact that patients from group #2 were managed with a 97% pump flow, that is, they were perfused at an average cardiac index of 2.[32] L/min/m$^2$ vs 1.9 L/min/m$^2$, which is consistent with a 18% reduction of pump flow in group #1 compared to group #2.

This result can suggest that higher $SvO_2$ values should be managed in extracorporeal circulation since they are associated with optimal oxygen delivery. However, to achieve this it is necessary to maintain pump flow and cardiac index > 2.[32] L/min/m$^2$ and temperature of 34°C. We should mention that the hematocrit used in this study for groups #1 and #2 was around 29% without ever being any statistical differences between them. This means that according to these findings reducing ECC flow down to a cardiac index of 1.9 L/min/m$^2$ at 34°C is ill-advised, as it was revealed in thi study group #1 even if venous saturation is > 75%, since adequate oxygen delivery could be compromised.

In relation to the flow of the heart-lung machine and $SvO_2$, the latter played an important role maintaining $SvO_2$ values within the parameters recommended in this study (80%). Knowing that cardiac index in extracorporeal circulation should be 2.4 L/min/m$^2$, and pump flow 100% in adult patients26 we could determine that for a flow of 2.32 L/min/m$^2$ at 34°C with 80% of $SvO_2$, oxygen delivery is optimal at 34°C.

## CONCLUSIONS

This research paper described the behavior of $SvO_2$ in relation to optimal oxygen delivery in adult patients that underwent heart surgery connected to an extracorporeal circulation machine. As the main final results of this study we should mention that:

Venous oxygen saturation can be considered a good predictor of proper oxygen delivery in adult patients, provided that this value is around 80% and perfusion is performed at cardiac indexes > 2.32 L/min/m$^2$ throughout the ECC at a temperature of 34°C.

Reducing the flow or cardiac indexes to values < 2.32 L/min/m$^2$ does not guarantee optimal $O_2$ delivery and reduces $SvO_2$ despite the fact that temperature is reduced to 34°C.

Adult patients with temperatures of 34°C should be perfused with the same flows used in normothermia.

Variations regarding age and mean arterial pressure are not associated with $SvO_2$ values or $O_2$ delivery.

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