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SjO_2/SvO_2 correlation during pediatric cardiac surgery with cardiopulmonary bypass

Correlação entre a SvO_2 e SjO_2 durante a cirurgia cardíaca com circulação extracorpórea em crianças

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Abstract

Objectives: **To compare the SjO_2 (cerebral oxygenation indicator) and SvO_2 (cardiac output indicator) during pediatric cardiac surgery with cardiopulmonary bypass (CPB).**

Methods: **Retrospective study. Data of SjO_2 and SvO_2 measured simultaneously at critical time periods during cardiac surgery with CPB were analyzed by the Spearman correlation test and Bland- Altman plot.**

Results: **Regression analysis of the pooled data showed poor correlation between SjO_2 and SvO_2 (r^2=0.14, *P*=0.03) and Bland- Altman plot had a high bias (-7.9), indicating independency of the two variables. SjO_2<50% (indicative of cerebral ischemia-hypoxia) were observed in 50% of the measurements after rewarming during hypothermic CPB.**

Conclusions: **SvO_2 is not a good predictor of SjO_2 during pediatric cardiac surgery with CPB, and low SjO_2 can be undetected measuring SvO_2 only.**

Descriptors: **Extracorporeal circulation. Child. Oxygenation. Jugular veins.**

Resumo

Objetivos: **Analisar a correlação entre a SvO_2 (indicador do débito cardíaco) e a SjO_2 (indicador da oxigenação cerebral) durante cirurgias cardíacas com circulação extracorpórea (CEC) em crianças.**

Métodos: **Estudo retrospectivo. Dados da SjO_2, SvO_2 e SaO_2, mensurados simultaneamente em momentos críticos da cirurgia cardíaca com CEC, em 12 crianças, foram**

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analisados pelo teste de correlação de Spearman e pela representação gráfica de Bland-Altman.

Resultados: **Foram encontrados baixa correlação entre a SjO_2 e a SvO_2 (r^2=0,14, *P*=0,03) e um viés alto (-7,8) na plotagem de Bland-Altman, indicando independência entre as duas variáveis. SjO_2 < 50% (indicativo de isquemia-hipoxia cerebral) foi observada em cerca de 50% das medidas após o reaquecimento no final da CEC hipotérmica.**

Conclusões: **A medida de SvO_2 não é preditiva da SjO_2 durante a cirurgia cardíaca com CEC em crianças e baixa SjO_2 pode deixar de ser detectada medindo-se apenas a SvO_2.**

Descritores: **Circulação extracorpórea. Criança. Oxigenação. Veias jugulares.**

INTRODUCTION

The hemoglobin saturation of blood from the internal jugular vein (SjO_2), particularly near the jugular bulb, is an objective measure of oxygen delivery to the brain, the quality of neuroprotection during cardiopulmonary bypass (CPB) in cardiac surgery and allows the immediate detection of cerebral hypoxia-ischemia [1-3].

The hemoglobin saturation of central venous blood (SvO_2), near the right atrium, is commonly used as an indicator of the adequacy of cardiac output and oxygenation throughout the body [4,5], however, it does not reflect the oxygenation of specific organs, particularly the brain [6]. The desaturation (SjO_2 <50%) of hemoglobin in the jugular vein, commonly observed during the rewarming period, is not reflected in SvO_2, and also it would not be detected without the monitoring of specific SjO_2 [1-3].

Similar prospective studies in adults and a few retrospective pediatric studies show a weak correlation between SvO_2 and SjO_2 during CPB, especially after rewarming [1 to 3.7]. Intermittent collections of jugular blood samples can provide useful information for the proper management of cerebral perfusion and oxygenation, particularly when regional cerebral oxygenation (NRS-near-infrared spectroscopy) or venous co-oximetry are not available.

In the present study, we evaluated data from SjO_2 and SvO_2 of pediatric patients undergoing surgery for correction of congenital heart disease with CPB, which had the right internal jugular vein (central venous catheter) and left internal jugular vein (jugular cephalic catheter) cannulated. The SjO_2 and SvO_2 were correlated at successive times during cardiac surgery.

METHODS

We selected 18 children aged between 3 and 120 months, submitted to heart surgery with CPB between July and December 2009, in which it was possible cannulation of right internal jugular vein with double-lumen catheter Fr5 designed for junction between the vena cava and the right atrium, left internal jugular vein in cephalic direction (jugular bulb) from the cricoid ring with venous catheter 20G and radial or femoral artery. In 12 patients, the data were able to be analyzed at all protocol times of the study. This retrospective cohort study of data from selected patients, which were monitored the SjO_2, was authorized by the Ethics Committee in Research of the Hospital das Clínicas of Ribeirão Preto-USP. We excluded patients who underwent reoperation, which required the use of a pacemaker after CPB, presented preoperative hemodynamic instability and bronchospasm, and it was not possible to collect all scheduled blood samples.

Anesthesia consisted of fentanyl (20 $\mu g.kg^{-1}$, followed by 5 $\mu g.kg^{-1}.h^{-1}$), midazolam (0.2 $mg.kg^{-1}$) in the induction and initiation of CPB, supplemented with isoflurane for control of hyperdynamic responses (increases in blood pressure and heart rate greater than 30%). Vecuronium (0.4 $mg.kg^{-1}$) was used for intubation. Milrinone (50 $\mu g . Kg^{-1}$, followed by 0.7 $\mu g.kg^{-1}.min.^{-1}$) and adrenalin (0.03 – 0.05 $\mu g.kg^{-1}.min.^{-1}$) was initiated in start of rewarming. The rate of infusion of adrenaline was set up at the end of CPB. Noradrenalin (0.03 – 0.05 $\mu g.kg^{-1}.min^{-1}$) was used temporarily to raise blood pressure in some patients.

The fractional concentration of O_2 (FiO_2) was maintained between 0.6 to 1.0 and $P_{ET}CO_2$ between 35 and 45 mmHg and PEEP at 2-5 cmH_2O. During CPB, the perfusion flow was 2.5 to 3 $L.min^{-1}.mm^2$, hematocrit was maintained between 25 to 30% and the pH was handled by the alpha-stat strategy, the mean arterial pressure was maintained between 30 to 70 mmHg and the temperature reduced to values between 26 to 32ºC (at the criterion of the surgeon). The flow of perfusion and / or mean arterial pressure were adjusted to maintain $SvO_2 \geq 70\%$.

Samples of arterial blood (SaO_2), central venous blood (SvO_2) and jugular blood (SjO_2) were collected immediately after cannulation (time CAN) before the start of CPB

(moment BCPB), after reaching the minimum nasopharyngeal temperature during cooling of CPB (moment TM), after rewarming (moment RQ) and after protamine administration after leaving CPB (moment PROTA). In addition to the saturation of hemoglobin, blood glucose levels and concentrations of lactate were recorded. The correlation between SvO_2 and SjO_2 was analyzed by Spearman correlation test and Bland-Altman plot. Data are presented as means and standard deviations. Statistical significance was set at $P < 0.05$.

RESULTS

The demographic data, congenital heart defects diagnosed by ultrasound, CPB and aortic clamping times and rate of infusion of vasoactive drugs at surgery of 12 pediatric patients are presented in Table 1. There was wide age range (3-120 months) and weights (4.1 to 33.6 kg). In all patients, it was possible the rapid cannulation in the cephalic direction of the left internal jugular vein without complications, particularly hematomas. Atrioventricular septal defect was the most prevalent defect of this series of patients assigned.

The average of SjO_2 tended to be lower than those of SvO_2 at all times recorded, however, there was statistically significant difference only after the end of CPB (moment PROTA). The lowest values of SjO_2 and SvO_2 were observed after rewarming (moment RQ) (Figure 1). Values of SjO_2 <50%, indicative of cerebral hypoxia-ischemia were detected more frequently (50% of measurements) in moment RQ (Figure 1). On the other hand, values indicative of lush cerebral blood flow (SjO_2> 75%) were detected at all times, particularly at moment PROTA, and, except at moment RQ.

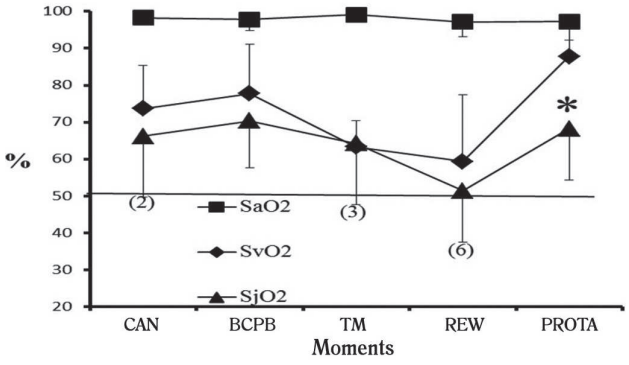

*Fig 1 - saturation of arterial, central venous and internal jugular hemoglobin measured simultaneously during cardiac surgery with cardiopulmonary bypass (CPB) in children at the following times: CAN - right after artery cannulation, central vein, jugular vein in cephalic, BCPB - before the start of CPB; TM - upon reaching the minimum nasopharyngeal temperature (26-32 ° C) RQ - after rewarming on CPB; PROTA after administration of protamine-out of the CPB. * Statistically significant difference (P> 0.05) between SvO_2 and SjO_2*

Table 1. Data of pediatric patients (P) undergoing cardiac surgery for correction of congenital heart disease with CPB, which were correlated in the SjO_2 SvO_2 at successive times and surgery.

P	CongenitalCardiopathy	Weight (kg)	Age (months)	CBP	PAo	ADR	NOR
1	AVSD	8.7	9	90	0	0.03	0
2	PS	15	36	90	55	0.05	0
3	AVSD	3.5	6	110	85	0.04	0
4	VSD	6.6	12	72	62	0	0
5	ASD	34.8	108	50	29	0	0.03
6	AOS	33.6	120	95	74	0	0.04
7	VSD	6.9	9	65	51	0.03	0
8	AVSD, VSD	16.9	72	112	79	0	0.03
9	ASD, VSD, PDA	6.5	9	70	45	0.04	0
10	ASD, PS	12.3	24	174	127	0	0
11	ASD,VSD, PDA, AVSD	4.3	3	128	93	0.04	0
12	TA	14.7	60	81	0	0.03	0.03

SjO2 = saturation of hemoglobin in the blood of the internal jugular vein; SvO2 = saturation of hemoglobin in the central venous blood; AVSD = atrioventricular septal defect, PS = pulmonary stenosis, VSD = ventricular septal defect, ASD = atrial septal defect; AOS = aortic stenosis; PDA = patent ductus arteriosus, TA = tricuspid atresia. Time (minutes) CPB (cardiopulmonary bypass) and Cao (aortic clamping). Infusion rate (microg.kg-1.min-1) of adrenaline (ADR) and noradrenaline (NOR) at the end of surgery. Note: All patients were receiving milrinone at surgery

The Spearman regression analysis, of all values of SvO_2 and SjO_2 grouped, showed low correlation between SvO_2 and SjO_2 ($r^2 = 0.14$, $P = 0.03$). The Bland-Altman plot (mean x difference) showed a bias (-7.9) considered high, confirming the independence between the simultaneous measurements of SvO_2 and SjO_2, that is, or low predictive value of SvO_2 to detect cerebral hypoxia-ischemia during CPB with hypothermia.

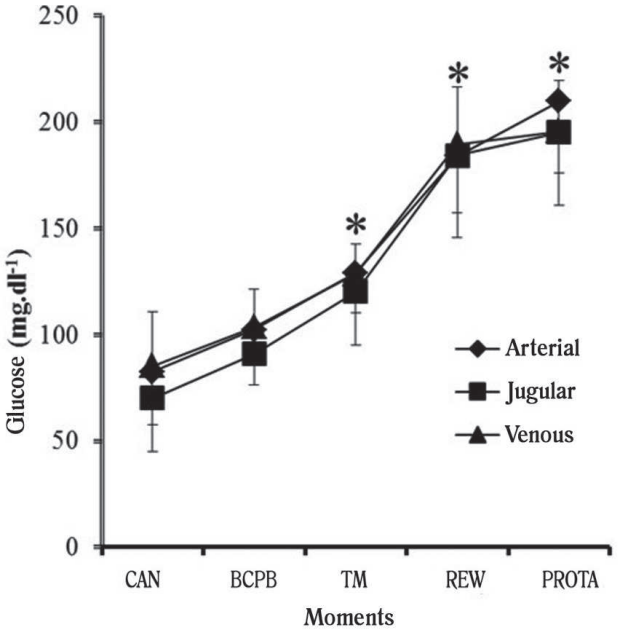

*Fig 2 – Hyperglycemia: pressure, central venous (vein) and left internal jugular vein (jugular). * Statistically significant difference (P> 0.05) in relation to the moment CAN. Moments equal to Figure 1*

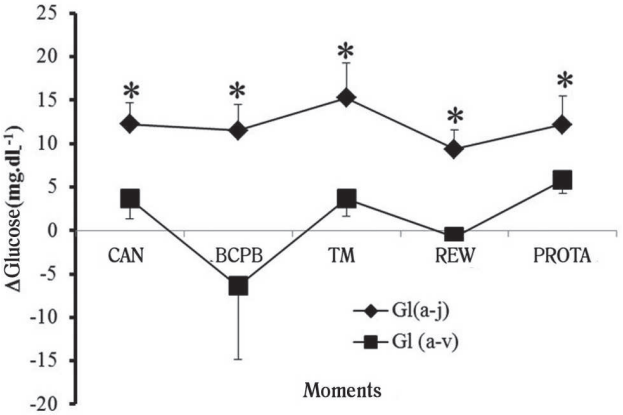

*Fig 3 - Arterio-jugular difference [cerebral extraction of glucose (G (a-j)] and central venous-arterial difference [G (a-v)] glucose. * Statistically significant difference (P> 0.05) G (a-j) and G (a-v) each time. There are no differences between successive moments in G (a-j). Moments similar to Figure 1*

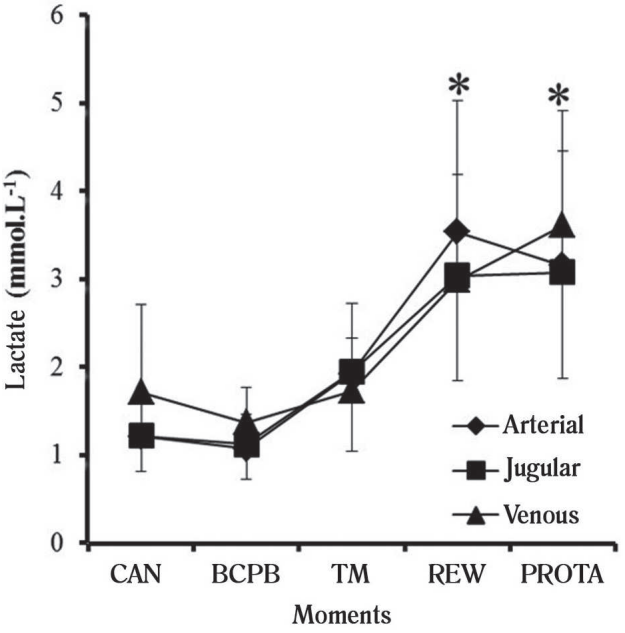

*Fig 4 – Concentrations: pressure, central venous and jugular (venous) of lactate. Moments equal to Figure 1. * Statistically significant difference (P> 0.05) in relation to the moment CAN*

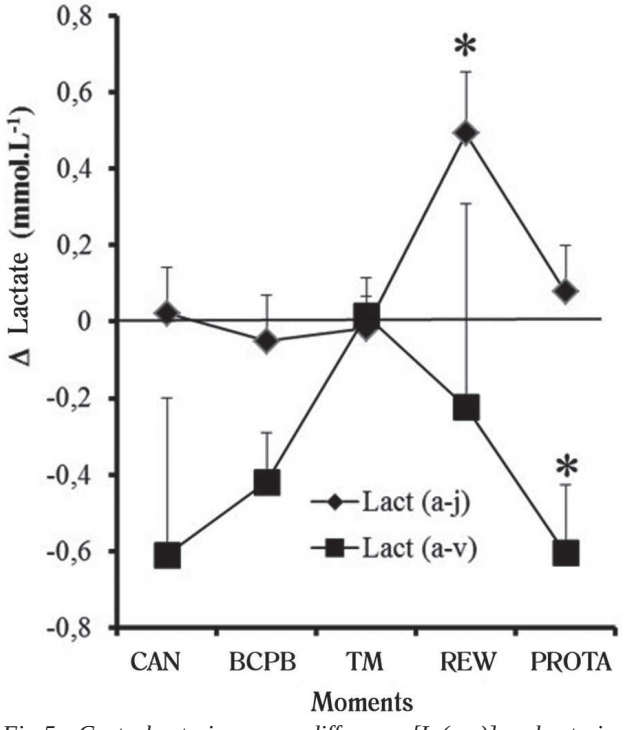

*Fig 5 - Central arterio-venous difference [L (a-v)] and arterio-jugular [L (a-j)] of lactate. Moments equal to Figure 1. * Statistically significant difference when compared to the moment CAN*

Blood glucose increased significantly from the moment TN in CPB and reached an average of 209 ± 34 $mg.dL^{-1}$ at the moment PROTA. The central venous blood, arterial blood and jugular blood glucose were similar (Figure 2). The cerebral glucose extractions (arterio-jugular difference) were significantly higher than the systemic extraction (arterio-venous difference), and remained constant at all times recorded (Figure 3). The jugular lactate rose similarly in the three sources of blood, from the moment RQ (Figure 4). The arterio-venous differences of lactate [L (a-v)] showed clear lung extraction after removal of CPB and the arterio-jugular difference [L (a-j)] also revealed distinct cerebral extraction during rewarming (moment PROTA) (Figure 5).

DISCUSSION

This retrospective study investigated the correlation between SvO_2 and SjO_2 of pediatric patients during cardiac surgery with hypothermic CPB. The linear regression analysis of all data recorded in the moments considered critical revealed a weak correlation between two variables. SjO_2 <50%, understood as an indicator of cerebral hypoxia-ischemia, was observed more frequently after reheating at the end of CPB, and not accompanied by similar reductions of SvO_2. The primary working hypothesis was confirmed, in which the SvO_2 is not predictive of SjO_2, and its single measure as an indicator of oxygenation throughout the body, may leave undetected cerebral hypoxia-ischemia. Other markers of ischemia, such as jugular artery difference of lactate and glucose showed no clinically significant changes.

Monitoring of cerebral oxygenation during cardiac surgery with CPB can be performed in continuous mode (co-oximetry with catheter in the jugular vein, regional oximetry, -NIRS) or intermittently by collecting frequent jugular venous blood, disposing the venous catheter tip near the jugular bulb. The intermittent monitoring has some disadvantages, such as not being constant, invasive, leading to blood loss and complications such as hematoma and infection. However, it is feasible when there is blood gas analysis readily available and it is inexpensive. The SjO_2 is a reliable marker, or indicator of global cerebral oxygenation. Reflects the balance between supply, which is the product of cerebral blood flow (CBF) and oxygen content of arterial blood (CaO_2, ml/100 ml) and the demand (oxygen consumption - $CMRO_2$: "Cerebral metabolic rate for oxygen"), and defined by the formula SjO_2á CBF/ $CMRO_2$.

Serial measurements of SjO_2 (every 5-10 min.) provide information, though indirect, on cerebral oxygenation, effectiveness and consistency of the complete cooling of the brain, neuroprotection quality and depth of anesthesia; it guides also the effectiveness of clinical interventions (increase of CBF, $PaCO_2$, hypothermia and anesthesia) designed to prevent or manage conditions of risk of cerebral hypoxia-ischemia. Normal values are between 55% -75%, which are always smaller than the simultaneous SvO_2. It is a global measure, and it may not reflect hypoperfusion (focal ischemia), therefore, normal or lower values do not necessarily ensure adequate oxygenation, on the other hand, low values (<50-54%) indicate focal or global ischemia severe enough to cause low SjO_2, associated with postoperative neurological deficits [1-3,8,9].

There are few studies, mostly retrospective and with limited sample size, especially in children, correlating SjO_2 and SvO_2 during heart surgery with CPB [1-3,8,9-11]. Similar to adults, discrepancies between the two variables are consistently observed. In the present study, this low correlation was confirmed, although the averages differ only after the end of CPB. The rewarming period is the highest risk for cerebral hypoxia-ischemia, defined as SjO_2 <50% associated with normal systemic oxygenation (SvO_2> 60%), and this phenomenon seems consistent with our clinical data. Invariably, rewarming at the end of CPB has been identified as the period of greatest risk for cerebral hypoperfusion.

There is an increased oxygen consumption associated with increased brain temperature, which temporarily exceeds the increased circulatory supply of oxygen during rewarming. This imbalance seems to be due to: the impaired primary autoregulation, cerebral vasoconstriction consequent to the nonpulsatile flow of CPB, microemboli, low hematocrit, hypocapnia [1-3,7-12,15]. The relative ischemia resulting from global cerebral vasoconstriction seems to be the main mechanism in pediatric patients, particularly neonates [11.13-15]. In contrast, the increase of SjO_2 (> 75%) when reaching the hypothermia temperature routinely observed [12,15,16], was not confirmed in all patients. Maybe it is due to the practice of establishing a flow based on age, temperature and mean arterial pressure, and then correct it by SvO2. On the other hand, important CBF (SjO_2> 75) was found in several patients after the end of CPB, which seems to be a consequence of vasoactive support initiated during reheating.

Cerebral monitoring, particularly oxygenation, has became mandatory in routine cardiac surgery, whereas postoperative neurological sequelae are minimized with early detection of the occurrence of cerebral hypoxia [12]. Until the establishment of routine use of noninvasive cerebral oximetry (NIRS) measurements of SjO_2 and cerebral extraction of oxygen (SaO_2-SjO_2) represented reliable indirect indicators of the efficiency of brain cooling and neuroprotection quality and depth of anesthesia [9.12 , 13].

Cephalic catheterization of the internal jugular vein of children, preferably near the jugular bulb, is now used only

for research, which can be performed by percutaneous puncture or surgical approach through the superior vena cava with co-oximetry catheter (continuous hemoglobin saturation), which also allows measurement of other markers of adequate cerebral oxygenation such as lactate and glucose (glucose extraction), which can provide relevant information to the therapeutic management of ischemia or prevention of risk, particularly children during CPB with behaviors such as increased cardiac output (perfusion in CPB) and $PaCO_2$ in order to maintain the relationship $CBF/CMRO_2$ normal, in addition to these indicators having high prognostic value of neurological sequelae in children [10,14,15,17].

In our study, the extraction of glucose was constant during CPB, and showed no evidence, however, the expected reduction in cooling time and the production of lactate was the expected [10]. Several prospective studies of selective cerebral perfusion, with demonstrated efficacy in the prevention of neurological sequelae [18,19], and reviews about intraoperative neuroprotection, particularly during CPB do not emphasize the brain monitoring as a means of evaluating the quality of neuroprotection in real or capable time [20,21]. Certainly this is due to the unavailability in the domestic market and high cost of brain monitors, however, as frequent measurement of SjO_2 may be feasible and useful.

The limited sample size (cases) and retrospective observational design are the main limitations of this study. Despite the success of 18 technical cannulations of the internal jugular vein on the cephalic direction (of the jugular bulb), the procedure is time consuming and requires a specific skill, offers difficulty keeping the catheter patent for obtaining samples in the critical moments of brain ischemia / hypoxia during CPB and carries risks of complications. Only in 12 patients it was possible the fulfillment of the research protocol, however, about 100 paired data were generated for statistical analysis with significance in tests of correlation. During data analysis, study in children undergoing cardiac surgery with CPB showed a close correlation between the saturation of hemoglobin in the superior vena cava ($SvcsO_2$) and $rcSO_2$ (NIRS brain) [22].

Although mixing with blood from extra-cerebral structures and upper limbs, analysis of blood samples taken from the superior vena cava is a reliable representation of the metabolic state (oxygenation and the occurrence of anaerobic metabolism) of the brain and they are predictive of rcSO2 in real time . This reciprocal correlation and predictive value of static and dynamic (acute variations) between the SvcsO2 rcSO2 and were recently confirmed in another similar study [23]. The sample sizes in these two studies are similar to ours. In our current routine, supported by the arguments exposed, we used samples of the superior vena cava in the monitoring of cerebral oxygenation, and correction (increase of perfusion and $PaCO_2$ and/ or deeper anesthesia) of any low cerebral perfusion. It would be desirable to classify patients on the cardiac output and severity of postoperative neurological sequelae to quantify the predictive value, specificity and sensitivity of measures of SjO_2 or the difference between SvO_2 and SjO_2 on the neurological outcome. This was not possible in our study, since all patients in our series were discharged without any apparent neurological alteration.

Currently, few patients transported to the PICU with low output, and developing gross neurological injuries, which, of course, is due to the quality of cardiac protection during cardiopulmonary bypass and surgical repair, and possibly the neuroprotection. The subtle neurological sequelae are feasible to study after 1 year of age, and they require the participation of trained neurologists and psychologists (not available in our area) and a large number of patients [15].

CONCLUSION

In conclusion, this study suggests that it is possible to predict the value of SjO_2 thus cerebral oxygenation, based on measurements of SvO_2. The period of greatest risk of desaturation in the jugular blood during rewarming was the end of CPB and routine vasoactive support which can produce increased brain blood flow after CPB.

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