Cerebral NIRS as a marker of superior vena cava oxygen saturation in neonates with congenital heart disease
Zaccaria Ricci, Cristiana Garisto, Isabella Favia, Ulrike Schloderer, Chiara Giorni, Tiziana Fragasso, Sergio Picardo

To cite this version:

HAL Id: hal-00587983
https://hal.archives-ouvertes.fr/hal-00587983
Submitted on 22 Apr 2011

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Cerebral NIRS as a marker of superior vena cava oxygen saturation in neonates with congenital heart disease

<table>
<thead>
<tr>
<th>Journal:</th>
<th>Pediatric Anesthesia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manuscript ID:</td>
<td>PAN-2010-0248.R2</td>
</tr>
<tr>
<td>Manuscript Type:</td>
<td>Original Paper</td>
</tr>
<tr>
<td>Date Submitted by the Author:</td>
<td>10-Aug-2010</td>
</tr>
</tbody>
</table>
| Complete List of Authors: | ricci, zaccaria; Ospedale Bambino Gesù, Department of pediatric cardiac surgery  
|                     | Garisto, Cristiana; Ospedale Bambino Gesù, Department of pediatric cardiac surgery  
|                     | Favia, Isabella; Ospedale Bambino Gesù, Department of pediatric cardiac surgery  
|                     | Schloderer, Ulrike; Ospedale Bambino Gesù, Department of pediatric cardiac surgery  
|                     | Giorni, Chiara; Ospedale Bambino Gesù, Department of pediatric cardiac surgery  
|                     | Fragasso, Tiziana; Ospedale Bambino Gesù, Department of pediatric cardiac surgery  
|                     | Picardo, Sergio; Ospedale Bambino Gesù, Department of pediatric cardiac surgery  |
| Key Words:        | neonate < Age, congenital heart disease < Cardiac, near infrared spectroscopy, venous oxygen saturation |
Cerebral NIRS as a marker of superior vena cava oxygen saturation in neonates with congenital heart disease

Authors

Zaccaria Ricci\textsuperscript{1}, Cristiana Garisto\textsuperscript{1}, Isabella Favia\textsuperscript{1}, Ulrike Schloderer\textsuperscript{1}, Chiara Giorni\textsuperscript{1}, Tiziana Fragasso\textsuperscript{1}, Sergio Picardo\textsuperscript{1}.

\textsuperscript{1) Department of Pediatric Cardiology, Bambino Gesù Hospital, Rome, Italy}

Word count: 2800

Key words: Near Infrared Spectroscopy, Pediatric Cardiac Surgery, venous oxygen saturation, low cardiac output syndrome.
Abstract

Objectives: to investigate the correlation between cerebral NIRS (rSO2c) and superior vena cava venous oxygen saturation (ScvO2) in newborn patients with congenital heart disease (CHD).

Background: Near infrared spectroscopy (NIRS) is a non invasive method to monitor hemoglobin oxygen saturation using non pulsatile oximetry. Methods: We retrospectively analyzed perioperative data from 100 newborn patients who underwent cardiac surgery for CHD. RSO2c, ScvO2 from 24 hours before to 72 hours after surgery were recorded. Results: rSO2c had a fair correlation with ScvO2 (r 0.37; p<0.001). The relationship between rSO2c and ScvO2 did not change when analyzed between patients with cyanotic or acyanotic CHD. During the preoperative period rSO2c levels overestimated ScvO2; in the first 18 postoperative hours rSO2c underestimated ScvO2; after that period they showed very close trends. Hypocapnia caused rSO2c to underestimate ScvO2; in normocapnic patients rSO2c-ScvO2 average differences were close to zero; in hypercapnic neonates rSO2c tended to overestimate ScvO2. The best performance of rSO2c as a surrogate of ScvO2 was found in the venous saturation ranges from 40 to 60% (r 0.3, p: 0.03). Conclusions: rSO2c in newborn patients with cyanotic and acyanotic CHD provides a continuous non invasive information with a fair correlation with ScvO2 %: some predictable variables (i.e. time from surgery, carbon dioxide and venous saturation levels), should guide the operators in order to adjust rSO2c values in terms of ScvO2. Serial measures of ScvO2 seem recommended in order to tailor rSO2c information on actual venous saturation percentage.
Introduction.

Cerebral hemoglobin oxygen saturation measured with near-infrared spectroscopy (NIRS) is used to monitor and titrate brain oxygen delivery preoperatively, during cardiopulmonary bypass and postoperatively in the pediatric cardiac intensive care unit (PCICU) [1]. It has also been evaluated as a surrogate measure of superior vena cava oxygen saturation (ScvO2), in order to non-invasively assess adequacy of oxygen delivery and consumption [2, 3, 4, 5].

Somatic NIRS has also been proposed, as an estimate of somatic oxygen delivery and as a measure of optimized systemic perfusion, coupled with cerebral NIRS (rSO2c) [6]. Different locations have been described for NIRS sensors: typically, cerebral sensor is positioned on the right forehead and somatic sensor is placed on the flank at the T10-12 vertebrae level, in order to theoretically measure renal oxygen saturation (rSO2r).

Initial studies on correlation between rSO2c and ScvO2 saturation have showed conflicting results [7, 8], due to wide limits of agreement between the two methods presumably due to individual features (such as age), specific cardiovascular disease (cyanotic or acyanotic), or clinical condition (arterial blood pressure and PaCO2): these considerations lead to the conclusion that rSO2c monitoring might be more suitable to monitor ScvO2 trends than absolute values.

The management of neonates with congenital heart diseases (CHD) who are candidates for early surgery is challenging and perioperative cerebral blood flow and oxygen delivery monitoring is mostly important due to neurological impairment that may occur in these children [9]. Furthermore, anatomical considerations, such as their limited skull thickness and
For Peer Review

their relatively high cerebral blood flow, make rSO2c monitoring potentially applicable in this population [9]. Finally, previous studies pooled in the same analysis neonates and infants [10]. Since these age groups are so different in terms of surgery and cerebral physiopathology, they should probably be examined separately.

No studies are reported, so far, on correlation between rSO2c and ScvO2 saturation in a large cohort of exclusively newborn patients with CHD. This retrospective study had two objectives: a) to evaluate the relationship of changes in rSO2c and rSO2r with changes in ScvO2 in this specific subgroup of children with CHD and eventually confirm NIRS reliability as a surrogate non-invasive measure of ScvO2; b) to examine the impact of different clinical variables (type of CHD, perioperative period, venous saturation level and carbon dioxide partial pressure) on such correlation.

Patients and methods.

We retrospectively reviewed data from newborn patients who underwent cardiac surgery for CHD from January 2007 to December 2009. Enrolled patients diagnoses were transposition of the great arteries (TGA), hypoplastic left heart syndrome (HLHS), tetralogy of Fallot (TOF) and other less frequent CHD (atrioventricular canal, aortic arch interruption, truncus arteriosus, aortic coarctation with ventricular septal defect). According to our institutional protocol on newborn patients’ monitoring, after induction of anesthesia, neonatal sensors for the INVOS System (Model 5100C, Somanetics, Troy, Michigan, USA) for rSO2c (right forehead) and rSO2r (left flank) were placed and an arterial cannula was inserted for the measurement of invasive
blood pressure. A central venous catheter (CVC) was positioned in the superior vena cava.

Central venous access was achieved by a 4 Fr bilumen catheter. If, after chest X ray verification,
CVC was not correctly positioned in the superior vena cava, patients were excluded from the
study. Data collection started 24 hours before transport to the operatory room (T0 and T1, after
12 hours) if the patient required intubation before the scheduled surgery. Thereafter, data
collection was achieved after anesthesia induction (T2), at ICU admission (T3) and successively
after 6, (T4), 12 (T5), 18 (T6), 24 (T7), 48 (T8) and 72 hours (T9). At each data point, rSO2c,
rSO2r, ScvO2 were recorded; ScvO2 was measured by co-oximetry and arterial carbon dioxide
partial pressure (PaCO2) was also registered together with all blood gas analysis parameters.

Patient age, diagnosis and surgical procedure were reported.

Statistical analysis.

Kolmogorv-Smirnov test was used to test sample deviation from Gaussian distribution. Pearson
test was chosen for correlation estimation. Bland Altman analysis was used to verify bias and
agreement of correlated variables. Results are expressed as mean (standard deviation). A p
value less than 0.05 was considered significant. Statistical analysis was performed with the
GraphPad Prism 4.00 software package (GraphPad Software, San Diego, CA, USA).

Institutional review board approved the study and waived the need for informed consent due
to the observational nature of the research.

Results.
One hundred and sixty-two neonates with CHD were admitted to our intensive care unit within the studied period. Of these, 12 were not surgical patients, in 10 cases CVC was not correctly positioned in superior vena cava and 40 had a femoral vascular access. One hundred neonates with superior vena cava vascular access and NIRS monitoring were examined. Ages, diagnoses and surgical procedures are summarized in table 1. We retrieved 890 of 1000 expected data points and in 110 cases data have been missed: 30 patients were not intubated before surgery and were not monitored in the T0-T1 period (60 data points); in 10 cases 72 hours of full monitoring were not reached (15 data points); in few occasions it was not possible to achieve simultaneous NIRS and ScvO2 data (35 data points). The analyzed data had Gaussian distribution. Bland Altman plot confirmed a fair correlation between rSO2c and ScvO2 with a bias of 0.049 and a 95% agreement of 25% to –25% (figure 1). Correlation between ScvO2 and rSO2c resulted significant (p< 0.001) with an r of 0.37 (figure 2). RSO2C/ScvO2 correlation achieved an r of 0.31 (p<0.001) in TGA patients, an r 0.37 of (p<0.001) in HLHS patients and an r of 0.30 (p 0.03) in TOF patients (table 2). Correlations of subgroups divided per preoperative (T0-T2), early postoperative (T3-T6) and late postoperative periods (T7-T9) resulted, respectively, of 0.24 (p: 0.05), 0.34 (p < 0.01) and 0.50 (p<0.001) (table 2). Interestingly, Bland Altman analysis revealed that surgical operation significantly affected precision of ScvO2 and rSO2c correlation: during the preoperative period bias was 1.5, indicating that average rSO2c tended to overestimate ScvO2; during the early postoperative period bias was -1.2 because average rSO2c levels underestimated ScvO2; finally, in the late postoperative period bias reduced to 0.1 meaning that rSO2c and ScvO2 average difference tended to normalization. However, trends of average values of rSO2c and ScvO2 % showed a good correlation (figure 3):
when the differences of average rSO2c values between consecutive time points (T_{x+1}-T_x) were calculated and correlated with the same differences of average ScvO2 values, an r of 0.8 was found (p<0.005). Correlations of subgroups divided per PaCO2 < 31 mmHg, PaCO2 >31 and < 41 mmHg and PacO2 > 41 mmHg resulted, respectively, of 0.34 (p: 0.02), 0.39 (p < 0.001) and 0.39 (p<0.001) (table 2). Again, Bland Altman analysis revealed that PaCO2 altered mean error of ScvO2 and rSO2c correlation: in the hypocapnic group bias was -5, indicating that rSO2c tended to underestimate ScvO2; in the normocapnic group bias was -0.15 because rSO2c-ScvO2 average differences were likely close to zero; in the in the hypercapnic group bias was 2, because rSO2c overestimated ScvO2. We also tried to explore the correlation existing between high (90 to 61 %), medium (60 to 41 %) and low (< 40 %) ScvO2 saturations and rSO2c: the high group showed an r of 0.1 (p 0.8), the medium level group showed an r of 0.3 (p 0.03) and the low group showed an r of 0.25 (p 0.05) (table 2).

Discussion.

Near-infrared spectroscopy is a noninvasive, continuous monitoring technique using nonpulsatile oximetry to determine a venous-weighted oxyhemoglobin saturation of the underlying regional tissue. NIRS emits photons into the underlying capillary vascular bed, which readily transmit through skin, bone, and fat. Chromophores such as hemoglobin absorb some photons, causing wavelength-dependent changes in those photons to be reflected back to the detector. By analyzing this spectral absorption pattern, the oxygenation of the underlying tissue is determined [9]. Being primarily venous, the regional oxygen saturation drops –and NIRS % accordingly falls- when regional oxygen delivery is impaired and/or regional oxygen extraction
increases. Tissue beds with high oxygen consumption (brain) have a lower baseline saturation, whereas tissue with little metabolic demand (kidney) has a higher baseline value [6]. NIRS sensors placement has not been clearly standardized yet: whereas cerebral cortex capillary vascular bed lies few millimeters beyond forehead skin, making a strong rationale for rSO2c evaluation, especially in neonates, it is less clear which is the position and the indication for the somatic sensor [11, 12]. In our institution two site NIRS (cerebral-renal) monitoring has become a standard since three years: the aim of this retrospective analysis was to examine the clinical variables that mostly influence correlation of NIRS saturation with systemic oxygen delivery in a large homogeneous cohort of newborn patients. To our knowledge, this study is the first specifically addressing NIRS utilization in neonates with CHD: for anatomical reason, this is an ideal population where to validate rSO2c/ScvO2 correlation since cerebral blood flow is relatively high with respect to other tissue beds drained by superior vena cava. Furthermore, finding a non-invasive surrogate to central venous blood withdrawal has great clinical and practical implications.

Our results are in line with previous descriptions, remarking that also in newborn patients a significant correlation between rSO2c and ScvO2 exists, even if with wide limits of agreement. Our analysis also showed that performance of rSO2c is not apparently affected by the CHD diagnosis, whether it is a cyanotic or an acyanotic syndrome. Cerebral NIRS monitoring showed an optimal correlation to ScvO2 in the crucial venous saturation range from 40 to 60%, where timely diagnosis of low oxygen delivery might rapidly improve clinical conditions by early therapy. Furthermore, our data suggest that before cardiac surgery venous cerebral blood flow is less desaturated than ScvO2, maybe due to relative redundancy of blood flow, especially
when the patient is sedated and in stable hemodynamic conditions: this might explain rSO2c overestimation of ScvO2 in this phase. After surgery, especially when prolonged cardiopulmonary bypass times and/or deep hypothermic circulatory arrest are required, cerebral oxygen consumption to blood flow ratio is probably less favorable, and ScvO2 tends to be higher than rSO2c. This phenomenon reaches an equilibrium after 18 hours where rSO2c/ScvO2 difference is no more so evident and rSO2c/ScvO2 correlation highest. PaCO2 is well known to affect cerebral vascular resistances and flow: in case of hypocapnia and cerebral vasoconstriction, a reduction of cerebral oxygen delivery might decrease brain venous saturation due to constant consumption in the face of decreased supply (low rSO2c saturations). Probably for this reason low rSO2c values underestimated ScvO2 in neonates with a PaCO2 level below 31 mmHg, whereas in normocapnic patients rSO2c/ScvO2 seemed to be optimized. Hypercapnia (and relative cerebro-vascular vasodilation), on the other side, induced a rSO2c tendency to overestimate ScvO2. As a matter of fact, however, rSO2c is only a fair surrogate of ScvO2 values and its measures are probably more suitable as a trend for single cases and not reliable for pooled evaluation of a large cohort of subjects and, differently from ScvO2, a rSO2c value considered low for somebody might appear adequate in another patient: inter-individual values are widely variable, also when age and diagnosis are considered as confounding variables. Nevertheless, rSO2c and ScvO2 trends showed to have a significant correlation, confirming that, in our neonates with CHD, rSO2c is at least able to show ScvO2 tendency. From our analysis, moreover, it was not possible to find specific diagnostic indications from rSO2r (data not shown). Its correlation to ScvO2 is similar to rSO2c, but not better.
Our study has several limitations. This is a retrospective analysis of data collected during a relatively wide perioperative period. Time points were pre-defined without any specific rationale: such “raw” information registration of a continuous signal might have missed specific perioperative moments when significant hemodynamic events occurred (i.e., delayed sternal closure, vasopressors dose modifications, periods of hypotension, etc) where oxygen delivery monitoring was mostly important. Furthermore, wrong NIRS values coming from artifacts and partial sensor detachment might have occurred in our routine clinical NIRS utilization. Finally, missing data might have affected our results. Nevertheless, ten time points should adequately cover a 96 hours perioperative time lapse and more than 800 data points should reliably minimize any hypothetical wrong information. We did not examine the impact of different ventilation modalities, sedation and hemoglobin variations that may modify rSO2c value independently or differently from ScvO2%. However, these have been already illustrated [3] and the analysis of confounding factors secondary to non-hemodynamic therapy modifications was beyond the scope of our analysis that approached NIRS as a surrogate of ScvO2.

Conclusion.

We examined rSO2c/ScvO2 correlation in the largest cohort of neonates evaluated so far. Our study confirmed existing data and allowed to refine some information in the specific setting of CHD: rSO2C monitoring in CHD newborn patients during the perioperative period did not provide an absolute oxygen saturation value that could reliably be considered a marker of ScvO2 and serial measures of ScvO2 seem recommended in order to tailor rSO2c information on actual venous saturation percentage. The continuous rSO2c monitoring in neonates,
nevertheless, trends with ScvO2, and is best with normocapnia, in ScvO2 ranges of 40-60%, and in the later postoperative period. Furthermore it showed to be consistent both in cyanotic and acyanotic CHD.
References


12) Kaufman J, Almodovar MC, Zuk J, Friesen RH. Correlation of abdominal site near-infrared
spectroscopy with gastric tonometry in infants following surgery for congenital heart disease.


**TABLES**

**Table 1**

Demographic characteristics of evaluated sample. Age, weight and RACHS are expressed as
mean (standard deviation). TGA: transposition of the great arteries, HLHS: hypoplastic left heart
syndrome, TOF: tetralogy of Fallot, RACHS: Risk Adjusted classification for Congenital Heart
Surgery. *) at the time of surgical procedure. §) other diagnoses: Truncus arteriosus (3 pts),
anomalous left coronary artery from pulmonary artery (1 pt), Aortic coarctation and
interventricular septal defect (4 pts), aortopulmonary window (1pt), aortic arch interruption (2
pts). £) other procedures: correction of truncus arteriosus (3 pts), correction of TOF (16 pts),
aortic deoarctation without interventricular septum closure (3 pts), aortic deoarctation with
interventricular septum closure (1 pt), correction of anomalous left coronary artery from
pulmonary artery (1 pt), aortopulmonary window (1pt) and aortic arch interruption (2 pts).

**Table 2**

Correlation (r) between cerebral Near Infra Red Spectroscopy and Superior Vena Cava Venous
Oxygen Saturation (ScvO2). TGA: transposition of the great arteries, HLHS: hypoplastic left heart
syndrome, TOF: tetralogy of Fallot. T0-T2 indicate preoperative phase, T3-T5 indicate early
postoperative phase and T6-T9 indicate late postoperative phase. PaCO2: arterial partial pressure of carbon dioxide.

FIGURES

Figure 1

Bland Altman plot showing Cerebral Near Infrared Spectroscopy (rSO2c) and Superior Vena Cava Venous Oxygen Saturation (ScvO2) difference vs average. Dotted lines show 95% limits of agreement.

Figure 2

Correlation and linear regression analysis of Cerebral Near Infrared Spectroscopy (rSO2c) and Superior Vena Cava Venous Oxygen Saturation (ScvO2): r 0.37, p< 0.001.

Figure 3

Mean and standard deviation values of Cerebral Near Infrared Spectroscopy (rSO2c) and Superior vena cava Venous Oxygen Saturation (ScvO2) at different time points (T0-T9). Light gray bars indicate preoperative phase, dark gray bars indicate early postoperative phase and white bars indicate late postoperative phase. Bars filled with horizontal lines refer to ScvO2 and empty
bars refer to NIRS. Mean rSO2c values showed very close trends to ScvO2 % in the evaluated perioperative period but tended to overestimate ScvO2 in the preoperative period and to underestimate it in the early postoperative period.
### Table 1

| Diagnosis                | TGA: 39 pts  
|                         | HLHS and UVH: 26 pts  
|                         | TOF: 24 pts  
|                         | Other*: 11 pts  
|                         | Total: 100 pts  
| Age* (days)             | 13 (10)  
| Sex                     | Males 62  
|                         | Females 38  
| Weight (kg)             | 3.3 (0.9)  
| RACHS                   | 4.3 (1.4)  
| Surgical procedure      | Arterial Switch operation: 39 pts  
|                         | Norwood I stage: 26 pts  
|                         | Blalock Taussig shunt: 8 pts  
|                         | Other*: 27 pts  

<table>
<thead>
<tr>
<th>Group definition</th>
<th>Number of examined pairs</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>All data points</td>
<td>ALL</td>
<td>890</td>
<td>0.37</td>
</tr>
<tr>
<td>Diagnostic</td>
<td>TGA</td>
<td>333</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>HLHS</td>
<td>168</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>TOF</td>
<td>164</td>
<td>0.3</td>
</tr>
<tr>
<td>ScvO2% subgroups</td>
<td>&lt;40%</td>
<td>196</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>41-60%</td>
<td>394</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>61-90%</td>
<td>300</td>
<td>0.1</td>
</tr>
<tr>
<td>Period subgroups</td>
<td>T0-T2</td>
<td>215</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>T3-T5</td>
<td>385</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>T6-T9</td>
<td>290</td>
<td>0.5</td>
</tr>
<tr>
<td>PaCO2 subgroups</td>
<td>&lt; 31 mmHg</td>
<td>284</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>&gt;31 and &lt; 41 mmHg</td>
<td>316</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>&gt; 41 mmHg</td>
<td>290</td>
<td>0.39</td>
</tr>
</tbody>
</table>
Bias 1.35%
Mean 0.049

Average of rSO2c and ScvO2
figure 2
139x97mm (150 x 150 DPI)
figure 3
240x150mm (150 x 150 DPI)