



**HAL**  
open science

## 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:

Zaccaria Ricci, Cristiana Garisto, Isabella Favia, Ulrike Schloderer, Chiara Giorni, et al.. Cerebral NIRS as a marker of superior vena cava oxygen saturation in neonates with congenital heart disease. *Pediatric Anesthesia*, 2010, 20 (11), pp.1040. 10.1111/j.1460-9592.2010.03430.x . hal-00587983

**HAL Id: hal-00587983**

**<https://hal.science/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.

# Pediatric Anesthesia

## Cerebral NIRS as a marker of superior vena cava oxygen saturation in neonates with congenital heart disease

Journal:	<i>Pediatric Anesthesia</i>
Manuscript ID:	PAN-2010-0248.R2
Manuscript Type:	Original Paper
Date Submitted by the Author:	10-Aug-2010
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

1  
2  
3 **Cerebral NIRS as a marker of superior vena cava oxygen saturation in neonates with**  
4  
5  
6 **congenital heart disease**  
7  
8  
9

10  
11  
12 Authors

13  
14  
15  
16 Zaccaria Ricci<sup>1</sup>, Cristiana Garisto<sup>1</sup>, Isabella Favia<sup>1</sup>, Ulrike Schloderer<sup>1</sup>, Chiara Giorni<sup>1</sup>, Tiziana  
17  
18 Fragasso<sup>1</sup>, Sergio Picardo<sup>1</sup>.  
19

20  
21  
22 1) Department of Pediatric Cardiology, Bambino Gesù Hospital, Rome, Italy  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41

42 Word count: 2800  
43  
44

45 Key words: Near Infrared Spectroscopy, Pediatric Cardiac Surgery, venous oxygen saturation,  
46  
47  
48 low cardiac output syndrome.  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 Abstract  
4  
5  
6

7 Objectives: to investigate the correlation between cerebral NIRS (rSO<sub>2</sub>c) and superior vena cava  
8 venous oxygen saturation (ScvO<sub>2</sub>) in newborn patients with congenital heart disease (CHD).  
9

10  
11 Background: Near infrared spectroscopy (NIRS) is a non invasive method to monitor  
12 hemoglobin oxygen saturation using non pulsatile oximetry. Methods: We retrospectively  
13 analyzed perioperative data from 100 newborn patients who underwent cardiac surgery for  
14 CHD. RSO<sub>2</sub>c, ScvO<sub>2</sub> from 24 hours before to 72 hours after surgery were recorded. Results:  
15 rSO<sub>2</sub>c had a fair correlation with ScvO<sub>2</sub> (r 0,37; p<0.001). The relationship between rSO<sub>2</sub>c and  
16 ScvO<sub>2</sub> did not change when analyzed between patients with cyanotic or acyanotic CHD. During  
17 the preoperative period rSO<sub>2</sub>c levels overestimated ScvO<sub>2</sub>; in the first 18 postoperative hours  
18 rSO<sub>2</sub>c underestimated ScvO<sub>2</sub>; after that period they showed very close trends. Hypocapnia  
19 caused rSO<sub>2</sub>c to underestimate ScvO<sub>2</sub>; in normocapnic patients rSO<sub>2</sub>c-ScvO<sub>2</sub> average  
20 differences were close to zero; in hypercapnic neonates rSO<sub>2</sub>c tended to overestimate ScvO<sub>2</sub>.  
21 The best performance of rSO<sub>2</sub>c as a surrogate of ScvO<sub>2</sub> was found in the venous saturation  
22 ranges from 40 to 60% (r 0.3, p: 0.03). Conclusions: rSO<sub>2</sub>c in newborn patients with cyanotic  
23 and acyanotic CHD provides a continuous non invasive information with a fair correlation with  
24 ScvO<sub>2</sub> %: some predictable variables (i.e. time from surgery, carbon dioxide and venous  
25 saturation levels), should guide the operators in order to adjust rSO<sub>2</sub>c values in terms of  
26 ScvO<sub>2</sub>. Serial measures of ScvO<sub>2</sub> seem recommended in order to tailor rSO<sub>2</sub>c information on  
27 actual venous saturation percentage.  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 Introduction.

4  
5  
6 Cerebral hemoglobin oxygen saturation measured with near-infrared spectroscopy (NIRS) is  
7  
8 used to monitor and titrate brain oxygen delivery preoperatively, during cardiopulmonary  
9  
10 bypass and postoperatively in the pediatric cardiac intensive care unit (PCICU) [1]. It has also  
11  
12 been evaluated as a surrogate measure of superior vena cava oxygen saturation (ScvO<sub>2</sub>), in  
13  
14 order to non-invasively assess adequacy of oxygen delivery and consumption [2, 3, 4, 5].  
15  
16

17  
18 Somatic NIRS has also been proposed, as an estimate of somatic oxygen delivery and as a  
19  
20 measure of optimized systemic perfusion, coupled with cerebral NIRS (rSO<sub>2</sub>c) [6]. Different  
21  
22 locations have been described for NIRS sensors: typically, cerebral sensor is positioned on the  
23  
24 right forehead and somatic sensor is placed on the flank at the T10-12 vertebrae level, in order  
25  
26 to theoretically measure renal oxygen saturation (rSO<sub>2</sub>r).  
27  
28  
29  
30  
31

32  
33 Initial studies on correlation between rSO<sub>2</sub>c and ScvO<sub>2</sub> saturation have showed conflicting  
34  
35 results [7, 8], due to wide limits of agreement between the two methods presumably due to  
36  
37 individual features (such as age), specific cardiovascular disease (cyanotic or acyanotic), or  
38  
39 clinical condition (arterial blood pressure and PaCO<sub>2</sub>): these considerations lead to the  
40  
41 conclusion that rSO<sub>2</sub>c monitoring might be more suitable to monitor ScvO<sub>2</sub> trends than  
42  
43 absolute values.  
44  
45  
46  
47

48  
49 The management of neonates with congenital heart diseases (CHD) who are candidates for  
50  
51 early surgery is challenging and perioperative cerebral blood flow and oxygen delivery  
52  
53 monitoring is mostly important due to neurological impairment that may occur in these  
54  
55 children [9]. Furthermore, anatomical considerations, such as their limited skull thickness and  
56  
57  
58  
59  
60

1  
2  
3 their relatively high cerebral blood flow, make rSO<sub>2</sub>c monitoring potentially applicable in this  
4  
5 population [9]. Finally, previous studies pooled in the same analysis neonates and infants [10].  
6  
7  
8 Since these age groups are so different in terms of surgery and cerebral physiopathology, they  
9  
10 should probably be examined separately.  
11  
12

13  
14 No studies are reported, so far, on correlation between rSO<sub>2</sub>c and ScvO<sub>2</sub> saturation in a large  
15  
16 cohort of exclusively newborn patients with CHD. This retrospective study had two objectives:

17  
18 a) to evaluate the relationship of changes in rSO<sub>2</sub>c and rSO<sub>2</sub>r with changes in ScvO<sub>2</sub> in this  
19  
20 specific subgroup of children with CHD and eventually confirm NIRS reliability as a surrogate  
21  
22 non-invasive measure of ScvO<sub>2</sub>; b) to examine the impact of different clinical variables (type of  
23  
24 CHD, perioperative period, venous saturation level and carbon dioxide partial pressure) on such  
25  
26 correlation.  
27  
28  
29  
30  
31  
32  
33  
34  
35

36 Patients and methods.

37  
38  
39 We retrospectively reviewed data from newborn patients who underwent cardiac surgery for  
40  
41 CHD from January 2007 to December 2009. Enrolled patients diagnoses were transposition of  
42  
43 the great arteries (TGA), hypoplastic left heart syndrome (HLHS), tetralogy of Fallot (TOF) and  
44  
45 other less frequent CHD (atrioventricular canal, aortic arch interruption, truncus arteriosus,  
46  
47 aortic coarctation with ventricular septal defect). According to our institutional protocol on  
48  
49 newborn patients' monitoring, after induction of anesthesia, neonatal sensors for the INVOS  
50  
51 System (Model 5100C, Somanetics, Troy, Michigan, USA) for rSO<sub>2</sub>c (right forehead) and rSO<sub>2</sub>r  
52  
53 (left flank) were placed and an arterial cannula was inserted for the measurement of invasive  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 blood pressure. A central venous catheter (CVC) was positioned in the superior vena cava.

4  
5  
6 Central venous access was achieved by a 4 Fr bilumen catheter. If, after chest X ray verification,  
7  
8 CVC was not correctly positioned in the superior vena cava, patients were excluded from the  
9  
10 study. Data collection started 24 hours before transport to the operating room (T0 and T1, after  
11  
12 12 hours) if the patient required intubation before the scheduled surgery. Thereafter, data  
13  
14 collection was achieved after anesthesia induction (T2), at ICU admission (T3) and successively  
15  
16 after 6, (T4), 12 (T5), 18 (T6), 24 (T7), 48 (T8) and 72 hours (T9). At each data point, rSO<sub>2c</sub>,  
17  
18 rSO<sub>2r</sub>, ScvO<sub>2</sub> were recorded; ScvO<sub>2</sub> was measured by co-oximetry and arterial carbon dioxide  
19  
20 partial pressure (PaCO<sub>2</sub>) was also registered together with all blood gas analysis parameters.  
21  
22 Patient age, diagnosis and surgical procedure were reported.  
23  
24  
25  
26  
27  
28

29 Statistical analysis.

30  
31  
32 Kolmogorov-Smirnov test was used to test sample deviation from Gaussian distribution. Pearson  
33  
34 test was chosen for correlation estimation. Bland Altman analysis was used to verify bias and  
35  
36 agreement of correlated variables. Results are expressed as mean (standard deviation). A p  
37  
38 value less than 0.05 was considered significant. Statistical analysis was performed with the  
39  
40 GraphPad Prism 4.00 software package (GraphPad Software, San Diego, CA, USA).  
41  
42  
43  
44

45  
46 Institutional review board approved the study and waived the need for informed consent due  
47  
48 to the observational nature of the research.  
49

50  
51 Results.  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 One hundred and sixty-two neonates with CHD were admitted to our intensive care unit within  
4  
5 the studied period. Of these, 12 were not surgical patients, in 10 cases CVC was not correctly  
6  
7 positioned in superior vena cava and 40 had a femoral vascular access. One hundred neonates  
8  
9 with superior vena cava vascular access and NIRS monitoring were examined. Ages, diagnoses  
10  
11 and surgical procedures are summarized in table 1. We retrieved 890 of 1000 expected data  
12  
13 points and in 110 cases data have been missed: 30 patients were not intubated before surgery  
14  
15 and were not monitored in the T0-T1 period (60 data points); in 10 cases 72 hours of full  
16  
17 monitoring were not reached (15 data points); in few occasions it was not possible to achieve  
18  
19 simultaneous NIRS and ScvO<sub>2</sub> data (35 data points). The analyzed data had Gaussian  
20  
21 distribution. Bland Altman plot confirmed a fair correlation between rSO<sub>2</sub>c and ScvO<sub>2</sub> with a  
22  
23 bias of 0.049 and a 95% agreement of 25% to -25% (figure 1). Correlation between ScvO<sub>2</sub> and  
24  
25 rSO<sub>2</sub>c resulted significant ( $p < 0.001$ ) with an  $r$  of 0,37 (figure 2). RSO<sub>2</sub>C/ScvO<sub>2</sub> correlation  
26  
27 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  $r$   
28  
29 of 0.30 ( $p$  0.03) in TOF patients (table 2). Correlations of subgroups divided per preoperative  
30  
31 (T0-T2), early postoperative (T3-T6) and late postoperative periods (T7-T9) resulted,  
32  
33 respectively, of 0.24 ( $p$ : 0.05), 0.34 ( $p < 0.01$ ) and 0.50 ( $p < 0.001$ ) (table 2). Interestingly, Bland  
34  
35 Altman analysis revealed that surgical operation significantly affected precision of ScvO<sub>2</sub> and  
36  
37 rSO<sub>2</sub>c correlation: during the preoperative period bias was 1.5, indicating that average rSO<sub>2</sub>c  
38  
39 tended to overestimate ScvO<sub>2</sub>; during the early postoperative period bias was -1.2 because  
40  
41 average rSO<sub>2</sub>c levels underestimated ScvO<sub>2</sub>; finally, in the late postoperative period bias  
42  
43 reduced to 0.1 meaning that rSO<sub>2</sub>c and ScvO<sub>2</sub> average difference tended to normalization.  
44  
45 However, trends of average values of rSO<sub>2</sub>c and ScvO<sub>2</sub> % showed a good correlation (figure 3):  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60



1  
2  
3 when the differences of average rSO<sub>2</sub>c values between consecutive time points ( $T_{x+1}-T_x$ ) were  
4  
5 calculated and correlated with the same differences of average ScvO<sub>2</sub> values, an r of 0.8 was  
6  
7 found ( $p<0.005$ ). Correlations of subgroups divided per PaCO<sub>2</sub> < 31 mmHg, PaCO<sub>2</sub> >31 and < 41  
8  
9 mmHg and PaCO<sub>2</sub> > 41 mmHg resulted, respectively, of 0.34 ( $p: 0.02$ ), 0.39 ( $p < 0.001$ ) and 0.39  
10  
11 ( $p<0.001$ ) (table 2). Again, Bland Altman analysis revealed that PaCO<sub>2</sub> altered mean error of  
12  
13 ScvO<sub>2</sub> and rSO<sub>2</sub>c correlation: in the hypocapnic group bias was -5, indicating that rSO<sub>2</sub>c tended  
14  
15 to underestimate ScvO<sub>2</sub>; in the normocapnic group bias was -0.15 because rSO<sub>2</sub>c-ScvO<sub>2</sub>  
16  
17 average differences were likely close to zero; in the in the hypercapnic group bias was 2,  
18  
19 because rSO<sub>2</sub>c overestimated ScvO<sub>2</sub>. We also tried to explore the correlation existing between  
20  
21 high (90 to 61 %), medium (60 to 41 %) and low (< 40 %) ScvO<sub>2</sub> saturations and rSO<sub>2</sub>c: the high  
22  
23 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  
24  
25 low group showed an r of 0.25 ( $p 0.05$ ) (table 2).  
26  
27  
28  
29  
30  
31  
32  
33

#### 34 Discussion.

35  
36  
37 Near-infrared spectroscopy is a noninvasive, continuous monitoring technique using  
38  
39 nonpulsatile oximetry to determine a venous-weighted oxyhemoglobin saturation of the  
40  
41 underlying regional tissue. NIRS emits photons into the underlying capillary vascular bed, which  
42  
43 readily transmit through skin, bone, and fat. Chromophores such as hemoglobin absorb some  
44  
45 photons, causing wavelength-dependent changes in those photons to be reflected back to the  
46  
47 detector. By analyzing this spectral absorption pattern, the oxygenation of the underlying tissue  
48  
49 is determined [9]. Being primarily venous, the regional oxygen saturation drops –and NIRS %  
50  
51 accordingly falls- when regional oxygen delivery is impaired and/or regional oxygen extraction  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 increases. Tissue beds with high oxygen consumption (brain) have a lower baseline saturation,  
4  
5  
6 whereas tissue with little metabolic demand (kidney) has a higher baseline value [6]. NIRS  
7  
8  
9 sensors placement has not been clearly standardized yet: whereas cerebral cortex capillary  
10  
11 vascular bed lies few millimeters beyond forehead skin, making a strong rationale for rSO<sub>2c</sub>  
12  
13 evaluation, especially in neonates, it is less clear which is the position and the indication for the  
14  
15 somatic sensor [11, 12]. In our institution two site NIRS (cerebral-renal) monitoring has become  
16  
17 a standard since three years: the aim of this retrospective analysis was to examine the clinical  
18  
19 variables that mostly influence correlation of NIRS saturation with systemic oxygen delivery in a  
20  
21 large homogeneous cohort of newborn patients. To our knowledge, this study is the first  
22  
23 specifically addressing NIRS utilization in neonates with CHD: for anatomical reason, this is an  
24  
25 ideal population where to validate rSO<sub>2c</sub>/ScvO<sub>2</sub> correlation since cerebral blood flow is  
26  
27 relatively high with respect to other tissue beds drained by superior vena cava. Furthermore,  
28  
29 finding a non-invasive surrogate to central venous blood withdrawal has great clinical and  
30  
31 practical implications.  
32  
33  
34  
35  
36  
37  
38

39 Our results are in line with previous descriptions, remarking that also in newborn patients a  
40  
41 significant correlation between rSO<sub>2c</sub> and ScvO<sub>2</sub> exists, even if with wide limits of agreement.  
42  
43  
44 Our analysis also showed that performance of rSO<sub>2c</sub> is not apparently affected by the CHD  
45  
46 diagnosis, whether it is a cyanotic or an acyanotic syndrome. Cerebral NIRS monitoring showed  
47  
48 an optimal correlation to ScvO<sub>2</sub> in the crucial venous saturation range from 40 to 60%, where  
49  
50 timely diagnosis of low oxygen delivery might rapidly improve clinical conditions by early  
51  
52 therapy. Furthermore, our data suggest that before cardiac surgery venous cerebral blood flow  
53  
54 is less desaturated than ScvO<sub>2</sub>, maybe due to relative redundancy of blood flow, especially  
55  
56  
57  
58  
59  
60

1  
2  
3 when the patient is sedated and in stable hemodynamic conditions: this might explain rSO<sub>2c</sub>  
4  
5 overestimation of ScvO<sub>2</sub> in this phase. After surgery, especially when prolonged  
6  
7 cardiopulmonary bypass times and/or deep hypothermic circulatory arrest are required,  
8  
9 cerebral oxygen consumption to blood flow ratio is probably less favorable, and ScvO<sub>2</sub> tends to  
10  
11 be higher than rSO<sub>2c</sub>. This phenomenon reaches an equilibrium after 18 hours where  
12  
13 rSO<sub>2c</sub>/ScvO<sub>2</sub> difference is no more so evident and rSO<sub>2c</sub>/ScvO<sub>2</sub> correlation highest. PaCO<sub>2</sub> is  
14  
15 well known to affect cerebral vascular resistances and flow: in case of hypocapnia and cerebral  
16  
17 vasoconstriction, a reduction of cerebral oxygen delivery might decrease brain venous  
18  
19 saturation due to constant consumption in the face of decreased supply (low rSO<sub>2c</sub>  
20  
21 saturations). Probably for this reason low rSO<sub>2c</sub> values underestimated ScvO<sub>2</sub> in neonates with  
22  
23 a PaCO<sub>2</sub> level below 31 mmHg, whereas in normocapnic patients rSO<sub>2c</sub>/ScvO<sub>2</sub> seemed to be  
24  
25 optimized. Hypercapnia (and relative cerebro-vascular vasodilation), on the other side, induced  
26  
27 a rSO<sub>2c</sub> tendency to overestimate ScvO<sub>2</sub>. As a matter of fact, however, rSO<sub>2c</sub> is only a fair  
28  
29 surrogate of ScvO<sub>2</sub> values and its measures are probably more suitable as a trend for single  
30  
31 cases and not reliable for pooled evaluation of a large cohort of subjects and, differently from  
32  
33 ScvO<sub>2</sub>, a rSO<sub>2c</sub> value considered low for somebody might appear adequate in another patient:  
34  
35 inter-individual values are widely variable, also when age and diagnosis are considered as  
36  
37 confounding variables. Nevertheless, rSO<sub>2c</sub> and ScvO<sub>2</sub> trends showed to have a significant  
38  
39 correlation, confirming that, in our neonates with CHD, rSO<sub>2c</sub> is at least able to show ScvO<sub>2</sub>  
40  
41 tendency. From our analysis, moreover, it was not possible to find specific diagnostic  
42  
43 indications from rSO<sub>2r</sub> (data not shown). Its correlation to ScvO<sub>2</sub> is similar to rSO<sub>2c</sub>, but not  
44  
45 better.  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 Our study has several limitations. This is a retrospective analysis of data collected during a  
4 relatively wide perioperative period. Time points were pre-defined without any specific  
5 rationale: such “raw” information registration of a continuous signal might have missed specific  
6 perioperative moments when significant hemodynamic events occurred (i.e delayed sternal  
7 closure, vasopressors dose modifications, periods of hypotension, etc) where oxygen delivery  
8 monitoring was mostly important. Furthermore, wrong NIRS values coming from artifacts and  
9 partial sensor detachment might have occurred in our routine clinical NIRS utilization. Finally,  
10 missing data might have affected our results. Nevertheless, ten time points should adequately  
11 cover a 96 hours perioperative time lapse and more then 800 data points should reliably  
12 minimize any hypothetical wrong information. We did not examine the impact of different  
13 ventilation modalities, sedation and hemoglobin variations that may modify rSO<sub>2</sub>c value  
14 independently or differently from ScvO<sub>2</sub> %. However, these have been already illustrated [3]  
15 and the analysis of confounding factors secondary to non-hemodynamic therapy modifications  
16 was beyond the scope of our analysis that approached NIRS as a surrogate of ScvO<sub>2</sub>.  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38

39 Conclusion.

40  
41  
42 We examined rSO<sub>2</sub>c/ScvO<sub>2</sub> correlation in the largest cohort of neonates evaluated so far. Our  
43 study confirmed existing data and allowed to refine some information in the specific setting of  
44 CHD: rSO<sub>2</sub>c monitoring in CHD newborn patients during the perioperative period did not  
45 provide an absolute oxygen saturation value that could reliably be considered a marker of  
46 ScvO<sub>2</sub> and serial measures of ScvO<sub>2</sub> seem recommended in order to tailor rSO<sub>2</sub>c information  
47 on actual venous saturation percentage. The continuous rSO<sub>2</sub>c monitoring in neonates,  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

nevertheless, trends with ScvO<sub>2</sub>, and is best with normocapnia, in ScvO<sub>2</sub> ranges of 40-60%, and in the later postoperative period. Furthermore it showed to be consistent both in cyanotic and acyanotic CHD.

For Peer Review

## References

- 
- 1) Hirsch JC, Charpie JR, Ohye RG, Gurney JG. Near-infrared spectroscopy: what we know and what we need to know--a systematic review of the congenital heart disease literature. *J Thorac Cardiovasc Surg* 2009; 137:154-9.
  - 2) Tortoriello TA, Stayer SA, Mott AR, McKenzie ED, Fraser CD, Andropoulos DB, Chang AC. A noninvasive estimation of mixed venous oxygen saturation using near-infrared spectroscopy by cerebral oximetry in pediatric cardiac surgery patients. *Paediatr Anaesth* 2005; 15:495-503.
  - 3) McQuillen PS, Nishimoto MS, Bottrell CL, Fineman LD, Hamrick SE, Glidden DV, Azakie A, Adatia I, Miller SP. Regional and central venous oxygen saturation monitoring following pediatric cardiac surgery: concordance and association with clinical variables. *Pediatr Crit Care Med* 2007; 8:154-60.
  - 4) Bhutta AT, Ford JW, Parker JG, Prodhan P, Fontenot EE, Seib PM, Stroope BI, Frazier EA, Schmitz ML, Drummond-Webb JJ, Morrow WR. Noninvasive cerebral oximeter as a surrogate for mixed venous saturation in children. *Pediatr Cardiol* 2007; 28: 34-41.
  - 5) Tyree K, Tyree M, DiGeronimo R. Correlation of brain tissue oxygen tension with cerebral near-infrared spectroscopy and mixed venous oxygen saturation during extracorporeal membrane oxygenation. *Perfusion* 2009; 24: 325-31.

1  
2  
3  
4  
5 6) Hanson SJ, Berens RJ, Havens PL, Kim MK, Hoffman GM. Effect of volume resuscitation on  
6  
7 regional perfusion in dehydrated pediatric patients as measured by two-site near-infrared  
8  
9 spectroscopy. *Pediatr Emerg Care* 2009; 25:150-3.  
10

11  
12  
13 7 ) Dullenkopf A, Baulig W, Weiss M, Schmid ER. Cerebral near-infrared spectroscopy in adult  
14  
15 patients after cardiac surgery is not useful for monitoring absolute values but may reflect  
16  
17 trends in venous oxygenation under clinical conditions. *J Cardiothorac Vasc Anesth* 2007; 21:  
18  
19 535-9  
20  
21

22  
23  
24 8 ) Knirsch W, Stutz K, Kretschmar O, Tomaske M, Balmer C, Schmitz A, Berger F, Bauersfeld U,  
25  
26 Weiss M; Working Group on Non-Invasive Haemodynamic Monitoring in Paediatrics. Regional  
27  
28 cerebral oxygenation by NIRS does not correlate with central or jugular venous oxygen  
29  
30 saturation during interventional catheterisation in children. *Acta Anaesthesiol Scand* 2008; 52:  
31  
32 1370-4.  
33  
34

35  
36  
37 9 ) Chakravarti S, Srivastava S, Mittnacht AJ. Near infrared spectroscopy (NIRS) in children.  
38  
39 *Semin Cardiothorac Vasc Anesth* 2008; 12: 70-9.  
40  
41

42  
43 10 ) Weiss M, Dullenkopf A, Kolarova A, Schulz G, Frey B, Baenziger O. Near-infrared  
44  
45 spectroscopic cerebral oxygenation reading in neonates and infants is associated with central  
46  
47 venous oxygen saturation. *Paediatr Anaesth* 2005; 15: 102-9.  
48  
49

50  
51 11 ) Chakravarti SB, Mittnacht AJ, Katz JC, Nguyen K, Joashi U, Srivastava S. Multisite near-  
52  
53 infrared spectroscopy predicts elevated blood lactate level in children after cardiac surgery. *J*  
54  
55 *Cardiothorac Vasc Anesth* 2009; 23:663-7.  
56  
57  
58  
59  
60

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.

*Pediatr Crit Care Med* 2008; 9:62-8.

## 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 decoarctation without interventricular septum closure (3 pts), aortic decoarctation 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 (ScvO<sub>2</sub>). TGA: transposition of the great arteries, HLHS: hypoplastic left heart

syndrome, TOF: tetralogy of Fallot. T0-T2 indicate preoperative phase, T3-T5 indicate early



1  
2  
3  
4 postoperative phase and T6-T9 indicate late postoperative phase. PaCO<sub>2</sub>: arterial partial  
5  
6  
7 pressure of carbon dioxide.  
8  
9

## FIGURES

### Figure 1

10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20 Bland Altman plot showing Cerebral Near Infrared Spectroscopy (rSO<sub>2</sub>c) and Superior Vena  
21  
22 Cava Venous Oxygen Saturation (ScvO<sub>2</sub>) difference vs average. Dotted lines show 95% limits of  
23  
24 agreement.  
25  
26

### Figure 2

27  
28  
29  
30  
31  
32  
33  
34  
35 Correlation and linear regression analysis of Cerebral Near Infrared Spectroscopy (rSO<sub>2</sub>c) and  
36  
37 Superior Vena Cava Venous Oxygen Saturation (ScvO<sub>2</sub>):  $r$  0.37,  $p < 0.001$ .  
38  
39  
40  
41  
42  
43

### Figure 3

44  
45  
46  
47  
48 Mean and standard deviation values of Cerebral Near Infrared Spectroscopy (rSO<sub>2</sub>c) and Superior  
49  
50 vena cava Venous Oxygen Saturation (ScvO<sub>2</sub>) at different time points (T0-T9). Light gray bars  
51  
52 indicate preoperative phase, dark gray bars indicate early postoperative phase and white bars  
53  
54 indicate late postoperative phase. Bars filled with horizontal lines refer to ScvO<sub>2</sub> and empty  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5 bars refer to NIRS. Mean rSO<sub>2</sub>c values showed very close trends to ScvO<sub>2</sub> % in the evaluated  
6  
7 perioperative period but tended to overestimate ScvO<sub>2</sub> in the preoperative period and to  
8  
9 underestimate it in the early postoperative period.  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

For Peer Review

Table 1

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

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

Table 2

	Group definition	Number of examined pairs	r	p
<b>All data points</b>	ALL	890	0.37	<0.001
<b>Diagnostic subgroups</b>	TGA	333	0.31	<0.001
	HLHS	168	0.37	<0.001
	TOF	164	0.3	0.03
<b>ScvO2% subgroups</b>	<40%	196	0.25	0.05
	41-60%	394	0.3	0.03
	61-90%	300	0.1	0.8
<b>Period subgroups</b>	T0-T2	215	0.24	0.05
	T3-T5	385	0.34	<0.001
	T6-T9	290	0.50	<0.001
<b>PaCO2 subgroups</b>	< 31 mmHg	284	0.34	0.02
	>31 and < 41 mmHg	316	0.39	<0.001
	> 41 mmHg	290	0.39	<0.001

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

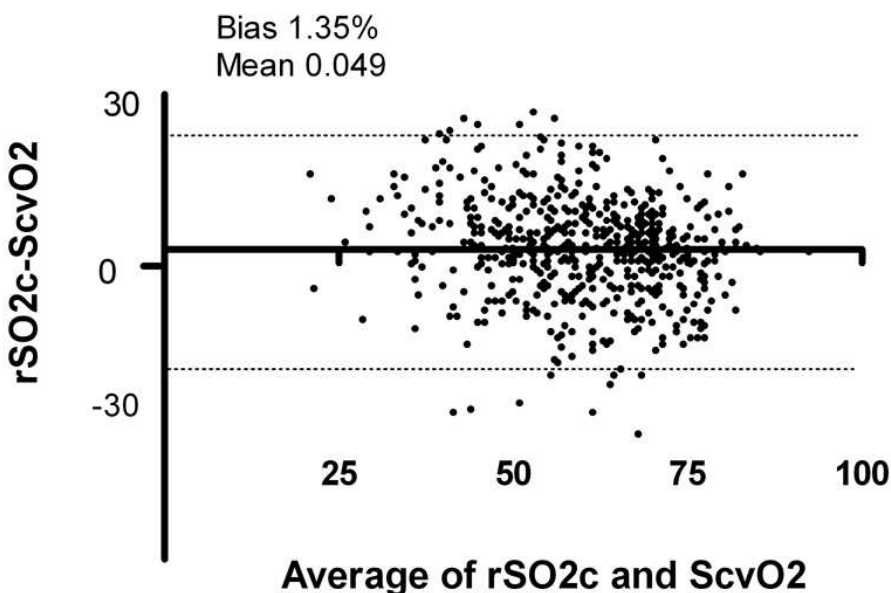


figure 1  
144x94mm (150 x 150 DPI)

Review

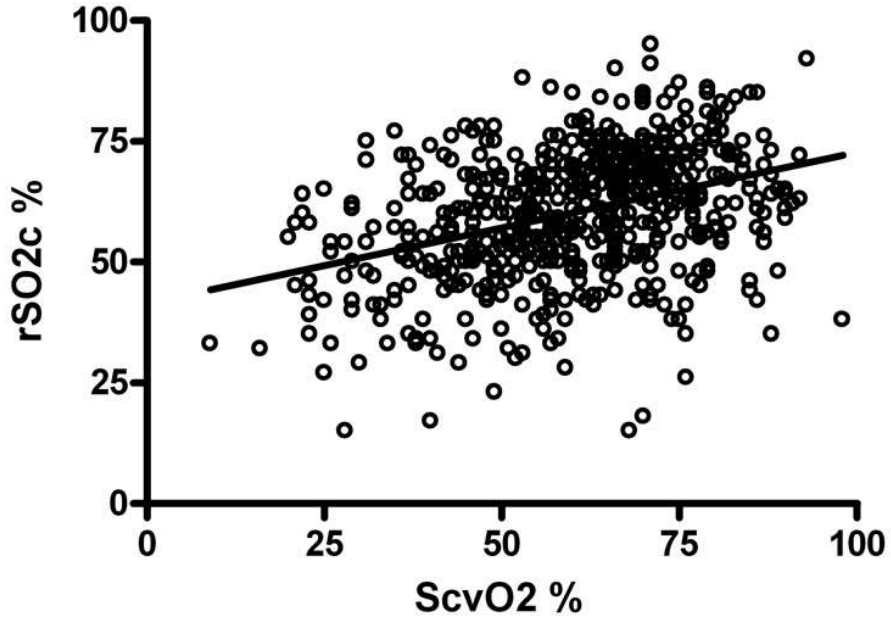


figure 2  
139x97mm (150 x 150 DPI)

review

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

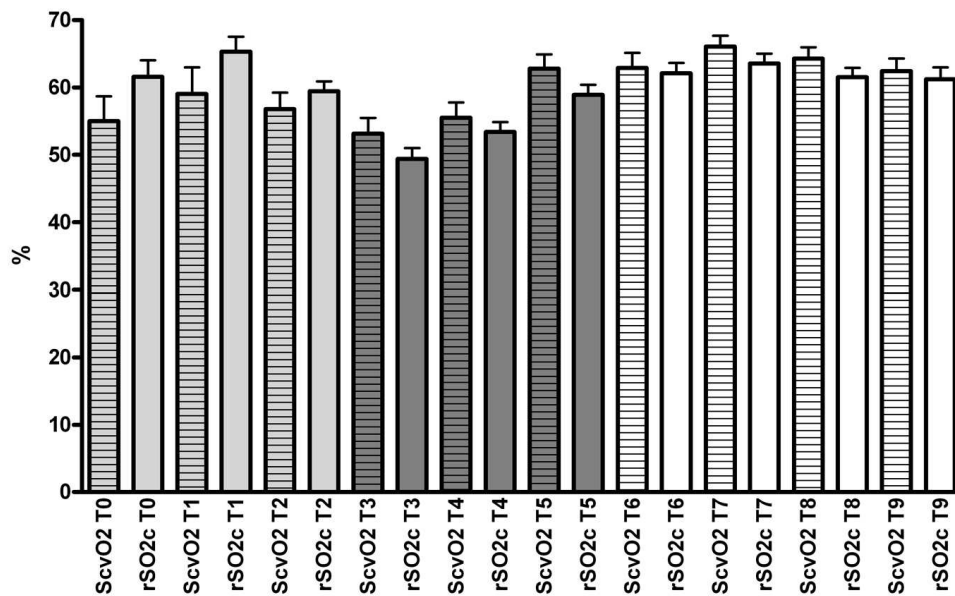


figure 3  
240x150mm (150 x 150 DPI)

Review