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Assessment of global tissue perfusion and oxygenation in neonates and infants after open-heart surgery†

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Abstract

OBJECTIVES: Monitoring and preserving adequate perfusion and oxygen balance is a primary objective of critical care. This prospective observational study aimed to assess the relationship between global haemodynamic parameters and variables reflecting tissue oxygenation during the early period following corrective cardiac surgery in neonates and infants. The postoperative time course of oxygen delivery and consumption was evaluated. As surrogate markers of oxygen balance, the central venous oxygen saturation ($ScvO_2$) and venoarterial PCO_2 difference ($PvaCO_2$) were thoroughly investigated.

METHODS: Thirteen children <1 year of age who underwent open-heart surgery were prospectively enrolled. In addition to conventional postoperative monitoring, transpulmonary thermodilution (TPTD) was used to monitor cardiac output and calculate oxygen delivery and consumption. In parallel with each TPTD measurement, arterial and central venous blood gas values were recorded. Global haemodynamic parameters and oxygenation measurements were compared with weighted linear regression statistics and Pearson's correlation coefficient.

RESULTS: Data from 145 TPTD measurements and 304 blood gas samples were recorded. The early postoperative period was characterized by a supply-dependent oxygen consumption, as demonstrated by the direct correlation between the change in oxygen delivery and consumption ($r = 0.62$, $P < 0.001$). Regarding haemodynamic parameters, none of the heart rate, mean arterial pressure or cardiac index correlated with the measured $ScvO_2$. However, the $ScvO_2$ and $PvaCO_2$ were found to correlate significantly ($r = -0.49$, $P < 0.001$), and both strongly related to oxygen extraction.

CONCLUSIONS: Both the $ScvO_2$ and $PvaCO_2$ are reliable and comparable parameters in following tissue oxygen balance during the early postoperative course after open-heart surgery in neonates and infants. As part of multiparameter monitoring, our data highlight the importance of regular $ScvO_2$ measurements and $PvaCO_2$ calculations in paediatric intensive care.

Keywords: Haemodynamics • Thermodilution • Oxygen consumption • Critical care

INTRODUCTION

Maintaining adequate tissue oxygenation has particular priority in critical care. The basic concept of closely controlling the appropriate balance between systemic oxygen delivery (DO_2) and consumption (VO_2) evolved early from animal studies [1, 2]. Later, when investigating high-risk surgical patients postoperatively, improved survival was found when higher oxygen delivery and cardiac index (CI) values were targeted [3]. However, the benefit of maintaining supranormal DO_2 values has been questioned in many studies [4]. The goals of haemodynamic optimization in critically ill patients are still an ongoing matter of discussion [5, 6].

In conventional monitoring, pressure-based haemodynamic parameters and heart rate (HR) are influenced by many factors that are not specific and sensitive variables to follow tissue oxygenation [7]. Volumetric parameters give a more complex picture of haemodynamics, but cardiac output (CO) in small children varies over a wide range depending on the actual needs, and normal values can be difficult to define. Concerning the adequacy of a measured CO, many factors should be considered. Global blood flow should always be interpreted in conjunction with oxygen balance.

The central venous oxygen saturation ($ScvO_2$) has become an important and widely accepted indicator of the balance between oxygen supply and demand. Targeting $ScvO_2 > 70\%$ is recommended in both adult and paediatric sepsis guidelines as a therapeutic goal [8, 9]. In paediatric patients, the global oxygen consumption is influenced by the higher basal metabolic rate, and different haemodynamic compensatory mechanisms are applied.

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Moreover, in children with cyanotic congenital heart disease, the necessary adaptations for substantially decreased oxygen supply should also be considered.

Data regarding the relationship between $ScvO_2$ and global circulatory parameters in paediatric patients, particularly in small children, are scarce. The aim of this prospective observational study was to evaluate the global indices of tissue perfusion and oxygenation in the early postoperative period following open-heart surgery in neonates and infants. In particular, the $ScvO_2$ and venoarterial PCO_2 difference ($PvaCO_2$) was tested as a surrogate marker of oxygen balance.

MATERIALS AND METHODS

Thirteen children undergoing complete surgical correction of congenital heart defects with cardiopulmonary bypass were enrolled consecutively in this prospective observational study. Each patient was under 1 year of age and weighed <10 kg. The study was approved by the Ethics Committee of Gottsegen György Hungarian Institute of Cardiology, and parental informed consent was obtained for each patient.

After anaesthetic induction, a right internal jugular vein catheter (4–5 Fr) and a 3-Fr thermistor-tipped fibreoptic femoral arterial catheter (PVPK2013L07-N, Pulsion Medical Systems, Munich, Germany) were inserted according to anatomic landmark orientation. CO and complex volumetric monitoring was carried out using transpulmonary thermodilution (TPTD) with PiCCO-plus bedside haemodynamic monitor (V4.12, Pulsion Medical Systems, Munich, Germany). Intraoperative data were collected from the overview of the surgical and anaesthesia reports.

After admission to the postoperative paediatric intensive care unit, conventional haemodynamic parameters were continuously monitored (two-channel electrocardiogram, HR, mean arterial pressure [MAP], central venous pressure [CVP], pulse oximetry [SpO_2] [Philips Medical Systems, Andover, MA, USA]).

TPTD measurements were performed at least once in every 6 h. For TPTD, the mean of three consecutively repeated tests with bolus injections of 3 ml of cold (T < 8°C) saline was calculated and registered. We recorded the CI, stroke volume index, global end-diastolic volume index, extravascular lung water index, systemic vascular resistance index (SVRI) and core temperature (T).

In parallel with each TPTD measurement, arterial and central venous blood gas samples were drawn and analysed (Cobas b 221, Roche Ltd, Basel, Switzerland). The arterial and venous oxygen partial pressure (PaO_2, PvO_2), carbon dioxide partial pressure ($PaCO_2$, $PvCO_2$), oxygen saturation (SaO_2, $ScvO_2$), pH, base excess and haemoglobin concentration (Hgb) were recorded. According to standard formulae, the following derived variables were calculated:

(i) CaO_2 (arterial oxygen content) = 1.34 × Hgb × SaO_2 + 0.0031 × PaO_2,
(ii) CvO_2 (venous oxygen content) = 1.34 × Hgb × $ScvO_2$ + 0.0031 × PvO_2,
(iii) $CavO_2$ (arterio-venous oxygen content difference) = CaO_2 – CvO_2,
(iv) DO_2i (oxygen delivery indexed for body surface area) = CO × CaO_2/BSA,
(v) VO_2i (oxygen consumption indexed for body surface area) = CO × (CaO_2 – CvO_2)/BSA and
(vi) Oxygen extraction (OER) = 100 × VO_2i/DO_2i.

Inotropic support was quantified according to the modification of a cumulative inotrope index previously proposed by Wernovsky *et al.* [10]: dopamine (μg/kg/min) + dobutamine (μg/kg/min) + 100 × epinephrine (μg/kg/min) + 100 × norepinephrine (μg/kg/min) + 20 × milrinone (μg/kg/min).

During the investigated postoperative period, assisted conventional ventilation was applied with positive end-expiratory pressure of 4–6 cmH_2O; FiO_2 40–75%; tidal volume 8 ml/kg and targeted $PaCO_2$ 35–40 mmHg. None of the enrolled children required invasive mechanical ventilation due to pulmonary complications. The main ventilation parameters (inspired fraction of oxygen [FiO_2], positive end-expiratory pressure and peak inspiratory pressure) were recorded. Derived indices assessing oxygen uptake in the lungs, including the PaO_2/FiO_2 and alveolar-arterial oxygen difference, were also calculated. An institutional protocol was used for weaning. Pulmonary hypertension requiring therapy did not occur. Children presenting with relevant postoperative intracardiac shunt or significant valve dysfunction were excluded using intra- and postoperative echocardiography.

STATISTICS

The results are reported as the means ± standard deviations (SDs). For multiple comparisons of repeated measurements, the parameters were compared using repeated measures analysis of variance (ANOVA) with *post hoc* Bonferroni correction. In parallel with each TPTD measurements, a single measure of conventional haemodynamic variables (MAP, CVP and HR) and blood gas parameters were collected and correlated. The pair-wise relationships between the parameters were evaluated using Pearson's correlation coefficient. To avoid violating the test assumption for independent measurements, a weighted linear regression analysis was also applied after the means of the parameters for each subject had been calculated. Delta values (Δ) referring to the percentage change between two consecutive measurements of each parameter were also calculated. Statistical significance was defined at a *P*-value of <0.05. For statistical evaluation, SPSS for Windows 11.5.0 (SPSS, Inc., Chicago, IL, USA) was used.

RESULTS

The major demographic and perioperative characteristics of the 13 enrolled children are presented in Table 1**.** The patients underwent surgical correction at a mean age of 128 (SD: 126) days and weighing 4.6 ± 1.3 kg. The mean postoperative paediatric intensive care unit observation time was 8 (SD: 4.4) days. During the study period, data from 145 TPTD measurements and 304 blood gas samples were recorded. The average time of weaning from ventilation was 127 h (SD: 81), and none of the children required reintubation.

The summary of the first postoperative 48-h basic haemodynamic parameters, volumetric measurements, blood gas values, derived tissue oxygenation indices and cumulative inotropic score are presented in a 6-h time frame in Table 2. Concerning the haemodynamic parameters, the MAP, CVP, CI and stroke volume index showed a tendency towards a significant increase during this early period. In the investigated group of patients, a mildly decreased overall DO_2i was calculated, but the VO_2i was found to be relatively stable. Oxygen delivery rose without changes in oxygen consumption and extraction. In parallel with these changes, the $PvaCO_2$ tended to decrease significantly, and the

Table 1: Basic characteristics and perioperative data of patients

Patient number	Female/ male	Age (days)	Weight (kg)	Diagnosis of CHD	Operation time (min)	CPB time (min)	Cross-clamp time (min)	ICU (days)	Time to extubation (h)	TPTD (*n*)
1	F	239	5.2	VSD + PH	135	60	32	3	21	10
2	M	285	6.5	BWG, DCM	155	91	41	17	278	10
3	M	9	3.4	TGA	250	162	109	6	97	15
4	M	196	6.4	CAVD	160	100	67	5	81	11
5	M	102	3.7	CAVD	200	100	57	8	129	11
6	F	11	3.8	TGA	275	161	102	17	302	8
7	M	5	3.4	TGA	345	192	102	8	77	19
8	M	254	6.4	TOF	170	98	56	7	112	8
9	M	9	2.9	TGA	260	179	117	10	164	1
10	F	13	4.0	TGA + VSD	285	196	101	4	68	13
11	F	196	4.5	VSD + PH	135	73	33	5	98	15
12	M	340	6.0	VSD + PH	160	76	38	6	83	7
13	M	10	4.1	TGA	215	134	65	8	136	17

CHD: congenital heart disease; VSD: ventricular septal defect; PH: pulmonary hypertension; BWG: Bland–White–Garland syndrome; DCM: dilated cardiomyopathy; TGA: transposition of great arteries; CAVD: complete atrioventricular septal defect; TOF: tetralogy of Fallot; CPB time: cardiopulmonary bypass time; TPTD: transpulmonary thermodilution.

Table 2: Results of haemodynamic parameters, TPTD-derived indices, blood gas data, calculated oxygenation variables and cumulative inotropic index in a 6-h time frame following admission to the paediatric intensive care unit

Postoperative time	T1 (0–6 h)	T2 (6–12 h)	T3 (12–18 h)	T4 (18–24 h)	T5 (24–30 h)	T6 (30–36 h)	T7 (36–42 h)	T8 (42–48 h)	ANOVA (*P*-value)
MAP (mmHg)	57 ± 4	60 ± 4	58 ± 5	56 ± 4	66 ± 13	67 ± 13	68 ± 13	73 ± 9[a]	0.001
HR (bpm)	151 ± 18	145 ± 12	148 ± 21	143 ± 17	144 ± 10	145 ± 9	139 ± 14	138 ± 11	0.54
CVP (mmHg)	7.6 ± 3.3	9.1 ± 2.7	9.6 ± 2.2	9.0 ± 2.3	10.7 ± 2.7	11.3 ± 2.2	10.7 ± 1.9[a]	11.7 ± 3.0	0.039
CI (l/min/m^2)	3.17 ± 0.6	3.24 ± 0.9	3.07 ± 0.9	3.12 ± 0.9	3.78 ± 1.3	3.96 ± 1.3	4.17 ± 1.2[a]	4.08 ± 1.1[a]	0.009
SVI (ml/m^2)	20.2 ± 3.8	22.3 ± 8.2	22.0 ± 9.3	24.9 ± 12.4	25.8 ± 9.1	27.3 ± 9.6	29.4 ± 9.2	30.0 ± 7.4[a]	0.037
GEDVI (ml/m^2)	311 ± 112	307 ± 104	338 ± 180	329 ± 161	359 ± 152	346 ± 141	384 ± 146	350 ± 118	0.09
ELWI (ml/kg)	24.1 ± 9.0	21.6 ± 10.2	21.1 ± 7.1	22.8 ± 9.6	21.6 ± 8.5	20.8 ± 8.3	24.3 ± 10.4	22.8 ± 10.5	0.62
$ScvO_2$ (%)	73.3 ± 8.6	69.2 ± 3.5	68.7 ± 3.5	67.3 ± 5.2	70.7 ± 6.0	74.8 ± 5.5	70.4 ± 6.8	76.1 ± 4.8	0.23
$PvaCO_2$ (mmHg)	10.1 ± 4.6	11.3 ± 3.3	11.3 ± 1.6	11.1 ± 2.5	10.0 ± 1.7	9.3 ± 2.3	9.5 ± 2.7	6.8 ± 2.5[a a]	0.047
pH	7.35 ± 0.09	7.38 ± 0.06	7.34 ± 0.06	7.37 ± 0.08	7.37 ± 0.05	7.38 ± 0.03	7.39 ± 0.04	7.39 ± 0.03	0.37
BE (mmol/l)	−4.0 ± 3.2	−3.5 ± 2.8	−4.6 ± 2.8	−3.3 ± 3.1	−3.2 ± 2.4	−2.8 ± 2.7	−0.6 ± 3.2[a]	−0.5 ± 2.0[a]	0.012
Hgb (g/l)	98 ± 16	123 ± 18[a]	120 ± 9	114 ± 14	121 ± 11	119 ± 10	118 ± 15	117 ± 6	0.037
$CavO_2$ (ml/100ml)	42 ± 17	50 ± 10	45 ± 12	44 ± 13	47 ± 17	40 ± 11	40 ± 7	34 ± 9	0.13
DO_2i (ml/min/m^2)	400 ± 41	488 ± 170	496 ± 137	477 ± 117	551 ± 166	606 ± 211[a]	654 ± 198[a]	628 ± 191[a]	0.004
VO_2i (ml/min/m^2)	95 ± 25	144 ± 35	141 ± 21	142 ± 46	156 ± 79	133 ± 60	172 ± 51	136 ± 65	0.73
OER (%)	25% ± 8%	30% ± 4%	30% ± 3%	29% ± 5%	28% ± 7%	22% ± 5%	28% ± 8%	21% ± 5%	0.25
Inotropic index	23.3 ± 15	20.1 ± 12	18.9 ± 10	18.7 ± 9	20.5 ± 9	19.4 ± 8	18.2 ± 7	17.6 ± 7	0.93

Data are expressed as the mean ± SD. Repeated measures ANOVA with *post hoc* Bonferroni correction was applied to compare the consecutive data.
[a]Significant differences compared with the baseline (T1) measurement.
MAP: mean arterial pressure; HR: heart rate; CVP: central venous pressure; CI: cardiac index; SVI: stroke volume index; GEDVI: global end-diastolic volume index; ELWI: extravascular lung water index; $ScvO_2$: central venous saturation; $PvaCO_2$: venoarterial PCO_2 difference; BE: base excess; Hgb: haemoglobin level; $CavO_2$: arterio-venous oxygen content difference; DO_2i: oxygen delivery indexed for body surface area; VO_2i: oxygen consumption indexed for body surface area; OER: oxygen extraction.

base excess was also found to improve considerably. A significant increase in the Hgb level was found between T1 and T2.

According to the relationship between the ΔDO_2i, ΔVO_2i and ΔOER, the early postoperative period was characterized by oxygen supply dependency (Figs 1A and B).

We investigated the relationship between conventional haemodynamic parameters, TPTD-derived values and parameters reflecting global tissue oxygenation. None of the HR, MAP, CVP or volumetric parameters proved to correlate with the tissue oxygenation variables (Table 3). Similar results were found when examining the relationships between the percentage changes between two consecutive measurements of these parameters. Accordingly, the ΔCI and $\Delta ScvO_2$ ($r = 0.09$, $P = 0.33$) showed no significant association.

The calculated inotropic index did not prove to have relevant, direct impact on the VO_2i ($r = 0.02$, $P = 0.96$), OER ($r = 0.21$, $P = 0.49$), $ScvO_2$ ($r = 0.19$, $P = 0.51$) and $PvaCO_2$ ($r = 0.43$, $P = 0.14$).

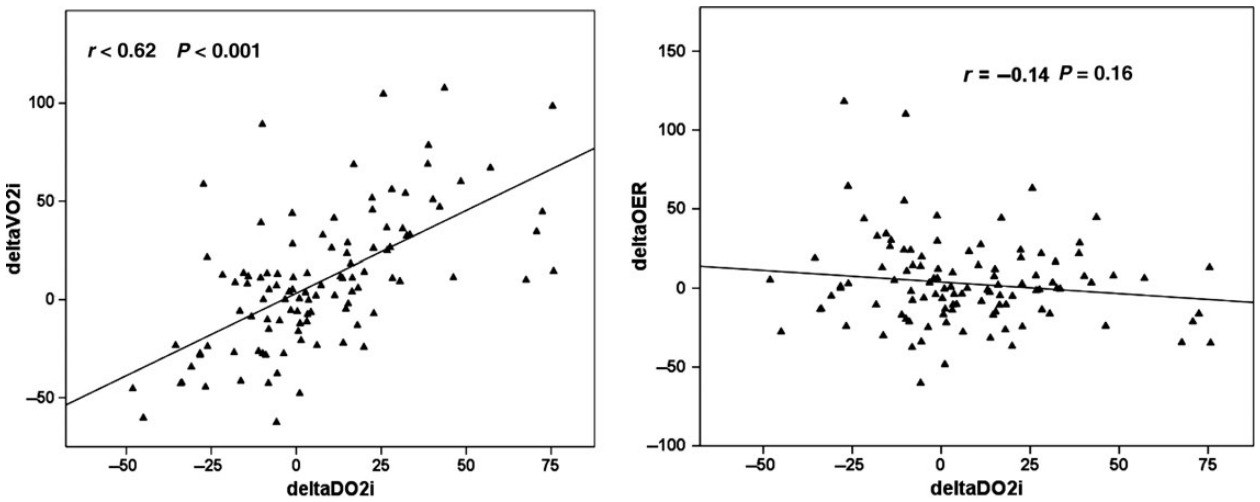

Figure 1: (**A** and **B**) Relationship between the percentage change in oxygen delivery index (ΔDO_2i) and consumption index (ΔVO_2i), oxygen extraction (ΔOER).

Table 3: Relationship between haemodynamic parameters and variables reflecting oxygen balance

	$ScvO_2$		$PvaCO_2$		BE		$CavO_2$		OER	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value
MAP	0.48	0.10	0.23	0.45	0.33	0.27	0.54	0.06	0.36	0.23
HR	0.48	0.09	0.03	0.92	0.14	0.64	0.43	0.14	0.43	0.15
CVP	0.31	0.31	0.30	0.33	0.11	0.72	0.35	0.24	0.33	0.28
CI	0.24	0.43	0.18	0.55	0.52	0.07	0.18	0.55	0.22	0.48
GEDVI	0.06	0.85	0.07	0.81	0.48	0.10	0.01	0.97	0.01	0.97
SVRI	0.52	0.07	0.36	0.23	0.44	0.14	0.50	0.08	0.51	0.08

Data are expressed as regression coefficients (*r*) and *P*-values.
MAP: mean arterial pressure; HR: heart rate; CVP: central venous pressure; CI: cardiac index; GEDVI: global end-diastolic volume index; SVRI: systemic vascular resistance index; $ScvO_2$: central venous saturation; $PvaCO_2$: venoarterial PCO_2 difference; BE: base excess; $CavO_2$: arterio-venous oxygen content difference; OER: oxygen extraction.

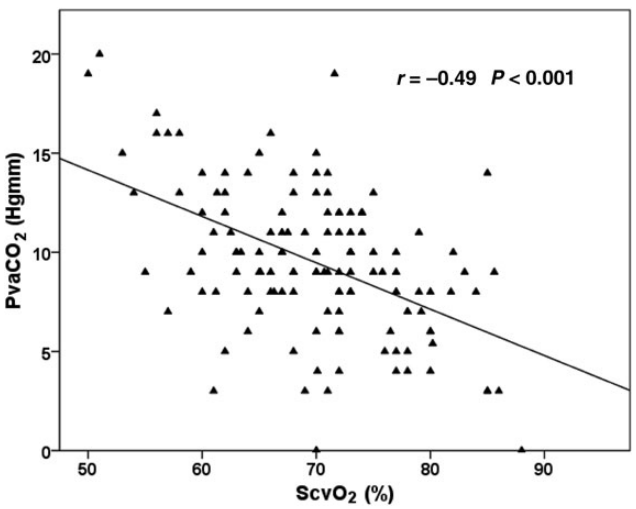

Figure 2: Relationship between $ScvO_2$ and $PvaCO_2$.

However, $ScvO_2$ and $PvaCO_2$ were found to correlate significantly and to change in parallel (Fig. 2). Both parameters showed strong correlations with OER (Table 4).

In the investigated group, the haemoglobin values proved to have a remarkable impact on the $ScvO_2$ ($r = 0.74$, $P = 0.004$) and OER ($r = 0.69$, $P = 0.008$). The core temperature was not related to the $ScvO_2$, $PvaCO_2$, VO_2i or OER.

Concerning the relationship between arterial and venous oxygenation, neither the SaO_2 ($r = 0.32$, $P = 0.29$) nor the PaO_2 ($r = 0.17$, $P = 0.11$) showed any significant association with the $ScvO_2$.

The measured extravascular lung water index (ELWI) values were considerably higher compared with the normal adult range. The change in ELWI did not correlate with the functional parameters of the lung: the alveolar-arterial oxygen difference ($r = 0.03$, $P = 0.71$) or PaO_2/FiO_2 ($r = -0.04$, $P = 0.65$).

DISCUSSION

Proper balance of oxygen supply and demand is determined by respiratory, haemodynamic and local metabolic variables. An additional important factor is the oxygen-carrying capacity of the blood, which is influenced mostly by the haemoglobin concentration [11]. In our study, various global haemodynamic parameters

Table 4: Relationship between $ScvO_2$, $PvaCO_2$ and other parameters influencing or related to tissue oxygenation

	DO_2i		VO_2i		OER		pH		BE		T	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value	R	*P*-value	*r*	*P*-value	*r*	*P*-value
$ScvO_2$	0.55	0.05	0.38	0.19	0.96	<0.001	0.04	0.88	0.22	0.47	0.10	0.76
$PvaCO_2$	0.40	0.18	0.33	0.27	0.81	0.001	0.41	0.15	0.52	0.07	0.16	0.58

Data are expressed as regression coefficients (*r*) and *P*-values. DO_2i: oxygen delivery indexed for body surface area; VO_2i: oxygen consumption indexed for body surface area; OER: oxygen extraction; BE: base excess; T: core temperature.

were tested to follow the oxygen balance in neonates and infants following open-heart surgery. PiCCO provides complex haemodynamic assessment, including volumetric cardiac performance, preload and afterload monitoring. The reliability of CO measured by TPTD in a paediatric population has been successfully validated with the direct Fick method [12], pulmonary artery catheter [13] and indicator dilution [14]. However, tissue perfusion and oxygen balance can be sufficient despite low CO, and vice versa.

Echocardiography is an essential non-invasive tool in perioperative haemodynamic monitoring, but it cannot be applied for continuous measurements. In paediatric cardiac intensive care practice, echocardiography provides a lot of information about malformations, valve function and global cardiac performance, but it is less informative and specific regarding the changes in global tissue perfusion.

In paediatric clinical practice, there is often a lack of strict and valuable target values for haemodynamic and oxygenation variables. The VO_2i is considered an important index of adequate cardiac performance that can be directly measured by respiratory mass spectrometry or calculated from the CO and $CavO_2$ [15]. Both methods require considerable technical background. Thus, in practice the VO_2 is usually estimated according to the LaFarge equation [16]. Recent paediatric data have shown that the estimation of oxygen consumption generates significant errors, particularly in children <3 years of age with congenital heart disease [17].

In the investigated group of neonates and infants, during the early postoperative period, oxygen consumption was found to depend on oxygen delivery, which indicated partial oxygen supply insufficiency. Accordingly, OER changed in parallel with the VO_2i, but the DO_2i showed no correlation with OER. At the same time, the overall VO_2i was not seriously depressed in our study. Both the $ScvO_2$ and $PvaCO_2$ proved to be reliable clinical variables to follow OER. However, in these haemodynamically compromised children, neither CI nor conventional pressure-based circulatory variables were directly associated with the $ScvO_2$ and OER. It can be hypothesized that there is a non-linear relationship between the CI and $ScvO_2$, and during the perioperative period, many confounding factors are present. Most of the children enrolled to our study were preoperatively cyanotic or had significant left-to-right shunt fraction and required anticongestive therapy due to heart failure. Presumably, their preoperative oxygen delivery was significantly impaired and they were preconditioned for hypoxia. It should always be remembered that children, particularly neonates and infants, have enhanced tolerance towards hypoxic states and are able to considerably increase oxygen extraction. When evaluating the $ScvO_2$ as a recognized variable of global oxygen balance in this patient population, these factors need to be considered.

In our results, the $PvaCO_2$ proved to be an easy-to-measure and comparable parameter with the $ScvO_2$ in assessing tissue perfusion [18]. $PvaCO_2$ of >6 mmHg has been proposed in previous studies as an independent risk factor for impaired systemic blood flow [19]. Furthermore, during anaerobic metabolism, it is assumed that the VO_2 decreases more than the CO_2 production (VCO_2) [20, 21]. In the case of hypoxic conditions, the $PvaCO_2$ is most likely more sensitive to changes in perfusion than the $ScvO_2$ [22]. Therefore, in children with cyanotic heart defects in whom the impact of the SaO_2 on the $ScvO_2$ should be more pronounced, measuring the $PvaCO_2$ can add to the adequate monitoring of tissue perfusion [23, 24].

A further possible advantage of the $PvaCO_2$ is that the $ScvO_2$ is likely to be more dependent on the actual haemoglobin level. The $PvaCO_2$ is likely influenced more independently by perfusion, although this hypothesis needs further investigation.

We tested whether the ELWI values reflect respiratory functional and ventilation parameters, but no significant correlations were found. The relatively high measured ELWI values are most likely age-related characteristics.

STUDY LIMITATIONS

Our results are limited by the relatively small number of enrolled patients, but the study group was reasonably homogeneous. The intensive care physicians were not blinded to the results of the TPTD measurements or the $ScvO_2$ data. Obviously, this knowledge might have influenced therapy compared with routine treatment.

The validity of the $ScvO_2$ in assessing the mixed venous oxygen saturation is a matter of debate, but with some limitations the $ScvO_2$ has been found to be a reliable surrogate marker [25]. In small children, the proportion of the upper body is relatively higher, and thus blood samples from the superior vena cava correlate more closely with the mixed venous blood. To obtain valid measurements, central venous catheters were inserted through the right internal jugular vein, ending close to the cavoatrial junction. Blood samples were consistently taken from the distal line of the catheters.

Measuring serum lactate levels could have added more information to our findings, but it was not technically feasible during our study.

CONCLUSIONS

In conclusion, we have found that both the $ScvO_2$ and $PvaCO_2$ are reliable and comparable parameters in following tissue oxygen

balance during the early postoperative course after open-heart surgery in neonates and infants. However, the correlations between conventional or volumetric haemodynamic parameters and tissue oxygenation were poor. According to our results, oxygen consumption in these paediatric patients is characterized by substrate dependency but maintained on a reasonable level. As part of multiparameter monitoring, our data highlight the importance of regular $ScvO_2$ measurements and $PvaCO_2$ calculations in paediatric intensive care. The advantage of the $PvaCO_2$ over the $ScvO_2$ in hypoxic patients, particularly in children with cyanosis, requires further investigation.

Conflict of interest: none declared.

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