Can venous saturations from the central venous line and the venous side of the heart–lung machine be interchangeable with mixed venous saturation from the pulmonary artery in children undergoing open-heart surgery?

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Background
Mixed venous oxygen saturation has been advocated as an indirect index of tissue oxygenation. This study evaluated whether venous oxygen saturation from the central venous line (CVL) or the venous side of the cardiopulmonary bypass (CPB) was interchangeable with mixed venous oxygen saturation from the pulmonary artery in children undergoing cardiac surgery for correction of congenital heart defects.

Patients and methods
Forty children ranging in age from 1 to 15 years undergoing correction for congenital heart procedures with CPB were included in this study. Simultaneous samples were taken from the CVL, the pulmonary artery, and from the venous side of the CPB after 10 min on full CPB and at the end of surgery before weaning from CPB. Bland and Altman's analysis was carried out to study the agreement between different venous oxygen saturation.

Results
Insignificant correlations were observed between venous oxygen saturation from the pulmonary artery, the CVL, and the venous site of the CPB. Wide limits of agreements were observed between the venous oxygen saturation in the pulmonary artery with that in the CVL (14.21−−15.32), and also with that in the venous side of the CPB (34.34−−33.18). A wide limit of agreement was observed between venous oxygen saturation in the venous side of the CPB with that in the CVL (28.24−−31.67).

Conclusion
Venous saturations from the CVL, and from venous side of CPB are not interchangeable with mixed venous saturation from the pulmonary artery in children undergoing open-heart surgery.

Keywords:
children, congenital, defects, heart, oxygen, venous

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Introduction

Mixed venous oxygen saturation (SvO_2) refers to the hemoglobin oxygen saturation of blood drawn from the proximal pulmonary artery and reflects the oxygen balance of the entire body [1–3]. SvO_2 was proposed as an indicator of the balance between systemic oxygen delivery and oxygen consumption and thus can be used to assess the adequacy of tissue oxygenation [1,2,4]. Mixed venous oxygen saturation monitoring requires the introduction of a pulmonary artery catheter which carried significant complications [5,6]. Venous oxygen saturation from the internal jugular vein ($ScvO_2$) refers to a hemoglobin oxygen saturation of blood from the superior vena cava [2–4,7–10]. This measurement reflects the venous oxygen saturation of blood from the brain and the upper body but neglects venous blood from the lower body [2,7–10]. Monitoring of the $ScvO_2$ was suggested as safer and more cost-effective than the SvO_2 [7–10]. Also, insertion of the central venous line (CVL) is used routinely in adults and children undergoing open-heart surgery with cardiopulmonary bypass (CPB). However, there has been a major debate in the recent literature on the use of $ScvO_2$ as an alternative to SvO_2 in septic patients or during different surgical procedures [1–4,7–10]. During cardiac surgery, venous oxygen saturation from the venous side of the heart–lung machine has been used to express mixed venous oxygen saturation [11–13]. There is little appeared in the literature on the relationship between mixed venous oxygen saturation from the pulmonary artery, and venous oxygen saturation from the CVL and that from the venous side of the heart–lung machine in children undergoing open-heart surgery for correction of congenital heart defects. This study aimed to examine the relationship between venous oxygen saturation from the CVL and the venous side of the heart–lung machine and also their interchangeability with mixed venous oxygen saturation from the pulmonary artery in children undergoing open-heart surgery.

Patients and methods

The study is a prospective one and was approved by the Local Ethics Committee of the Faculty of Medicine, Assiut University and was registered with ClinicalTrials.gov (Clinicaltrial.gov identifier: NCT02498626). A written parents' informed consent was obtained. Forty children ranging in the age from 1 to 15 years and scheduled for surgical closure of the different congenital heart defects with CPB in the period from July 2009 until January 2016 were studied. Patients with hepatic or renal impairment, and emergency surgery or reoperation were excluded. Preoperative preparation, induction, and maintenance of anesthesia, patient monitoring, and a CPB technique have been described in a previous paper [11]. A radial artery catheter and central venous catheter were inserted after induction of anesthesia. Two-lumen indwelling catheters were used for central venous catheterization (double-lumen 5 Fr ARROW Blue Catheters, 8 or 13 cm, Blue FlexTip; B. Braun Melsungen AG, Melsungen, Germany). Chest radiography was performed to confirm the position of the internal jugular catheter in the superior vena cava in all cases.

Study measurements

Samples from three sites for venous oxygen saturation (pulmonary artery by the surgeon through direct access by a very small needle, internal jugular vein, and from the venous blood of the CPB) were obtained 10 min after full-flow CPB and another sample was obtained before weaning from CPB. Samples were analyzed using a blood gas analyzer (EDAN i15-FCC: SMQi15EDAN-China).

Statistical analysis

Sample size calculation was based on a power of 80% to detect differences between pairs of measurements and an α error of 5%. This yielded a sample of 72 pairs of measurements in 36 patients, and 80 pairs of measurements were included from 40 patients to compensate for any dropouts during the study. All results were analyzed using SPSS version 20 for Windows (SPSS Inc., Chicago, Illinois, USA). Correlations and Bland and Altman analysis with limits of agreement 14 were carried out to study the relationship between venous saturations from the three sites. Mean difference (bias), a SD of this difference (precision), confidence interval, and limits of agreement between venous saturation measurements were reported.

Results

Forty children who underwent correction of different congenital heart diseases were studied. Patient characteristics are presented in Table 1. Various congenital heart defects are shown in Table 2. No significant correlations were observed between venous oxygen saturation in the pulmonary artery, in the CVL, and in the venous site of the heart–lung machine (Table 3). A wide limit of agreements occured between venous oxygen saturation in the pulmonary artery with that in the CVL (14.21–−15.32), and also with that in the venous side of the heart–lung machine (34.34–−33.18) (Table 3 and Figs 1–3). Also, a wide limit of agreement was observed after analyzing data from patients with noncyanotic lesions (23 patients) and those with cyanotic lesions (17 patients) (Tables 4 and 5).

Discussion

In this study, venous oxygen saturation from the internal jugular vein ($ScvO_2$) or from that of the venous blood of the CPB is not in agreement with mixed venous oxygen saturation from the pulmonary artery (SvO_2). The lack of this agreement was also found on analyzing of the results for cyanotic and noncyanotic lesions. Several studies have used the

Table 1 Patient characteristics

Variables	Mean (SD)
Age (months)	54.42 (36.72)
Weight (kg)	21.52 (10.61)
Sex (male/female)	22/18
CPB time (min)	79.60 (37.22)
Ischemic time (min)	54.65 (28.54)

CPB, cardiopulmonary bypass.

Table 2 Type of congenital heart lesions

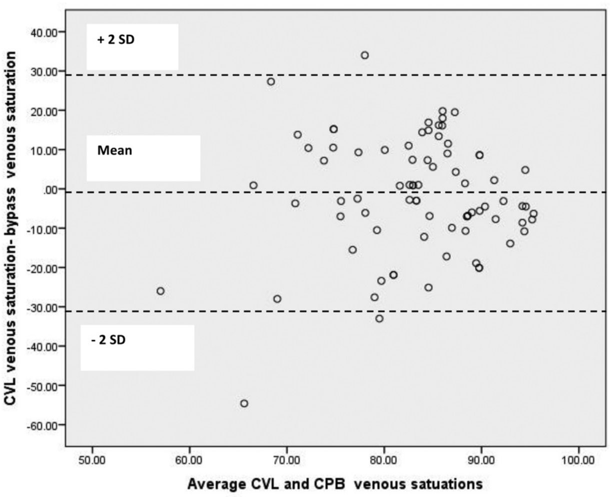
Types of lesion	Number
Atrial septal defect	9
Ventricular septal defect	8
Tetralogy of Fallot	17
Subaortic membrane	2
Partial atrioventricular canal	3
Atrial septal defect, ventricular septal defect	1

Table 3 Correlations and limits of agreement between venous saturations of the central venous line, pulmonary artery and venous blood of cardiopulmonary bypass (sample size=80)

	r^2	Mean difference (bias)	SD of the mean difference (precision)	Limits of agreement	
				Upper	Lower
Pulmonary artery and CVL venous saturations	0.089	−0.56	7.38	14.2	−15.32
Pulmonary artery and CPB venous saturations	0.007	0.58	16.88	34.34	−33.18
CPB and CVL venous saturations	0.013	−1.716	14.98	28.24	−31.67

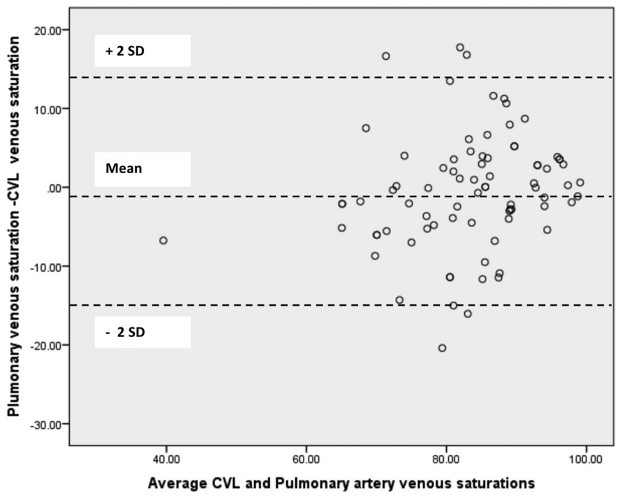
Limits of agreement and correlations by Bland and Altman analysis. CPB, cardiopulmonary bypass; CVL, central venous line.

Figure 1



Bland and Altman plot of venous oxygen saturations from the venous side of the heart–lung machine and the central venous line.

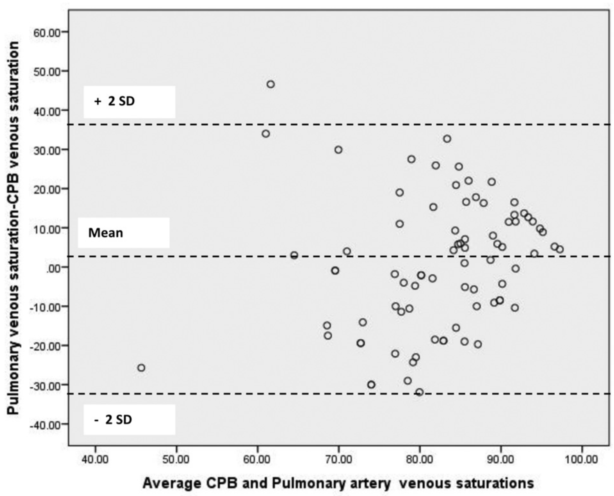
Figure 2



Bland and Altman plot of venous oxygen saturations from pulmonary artery and the central venous line.

central venous saturation as an alternative to mixed venous saturation from the pulmonary artery in patients with different medical conditions, and the results are conflicting [3,14–21]. Vapula *et al.* [3] found broad limits of agreement (−8.1–16.5%) between SvO_2 and $ScvO_2$ in septic patients.

Figure 3



Bland and Altman plot of venous oxygen saturations from pulmonary artery and the venous side of the heart–lung machine.

They concluded that a mixed venous oxygen saturation caught not be estimated by $ScvO_2$. Kopterides *et al.* [15] and Ho *et al.* [16] reported similar findings. They found that the limits of agreement were −20.2–3.3% and −5.0–18.8; in both studies respectively. The same results were found during and after cardiac surgery in adult patients, where the mean bias between SvO_2 and $ScvO_2$ was 4.4%, and the limits of agreement were −13.6–22.3% [17]. The previous reports are in agreement with our study, where limits of agreement were −15.3–14.2%). Such differences and the lack of agreement between SvO_2 and $ScvO_2$ could be explained by the blood coming from the pulmonary artery reflects venous saturation throughout the entire body including that from the superior vena cava [2], whereas $ScvO_2$ mainly reflects blood drained from the brain and upper parts of the body [7–10]. In contrast to our findings, other studies reported that $ScvO_2$ measurements were closely related to SvO_2 [18,19]. Interestingly, in this study, venous oxygen saturation from the venous side of the CPB was not related to SvO_2 from the pulmonary artery, as it had limits of agreement ranging from −33.18 to 34.34%. In one animal study, oxygen saturation from the venous side of the CPB did

Table 4 Correlations and limits of agreement between venous saturations of the central venous line, pulmonary artery and venous blood of cardiopulmonary bypass for the patients with noncyanotic lesions (sample size=46)

	r^2	Mean difference (bias)	SD of the mean difference (precision)	Limits of agreement	
				Upper	Lower
Pulmonary artery and CVL venous saturations	0.096	1.63	15.64	32.91	−29.92
Pulmonary artery and CPB venous saturations	0.022	−0.08	16.87	33.66	−33.82
CPB and CVL venous saturations	0.018	1.55	15.37	32.29	−29.19

Limits of agreement and correlations by Bland and Altman analysis. CPB, cardiopulmonary bypass; CVL, central venous line.

Table 5 Correlations and limits of agreement between venous saturations of the central venous line, pulmonary artery and venous blood of cardiopulmonary bypass for the patients with cyanotic lesions (sample size=34)

	r^2	Mean difference (bias)	SD of the mean difference (precision)	Limits of agreement	
				Upper	Lower
Pulmonary artery and CVL venous saturations	0.077	−0.046	13.67	26.88	−27.8
Pulmonary artery and CPB venous saturations	0.002	1.48	17.1	35.68	−32.72
CPB and CVL venous saturations	0.071	−1.95	14.66	27.37	−31.27

Limits of agreement and correlations by Bland and Altman analysis. CPB, cardiopulmonary bypass; CVL, central venous line.

not reflect regional venous oxygen saturation from the portal vein or that from the sagittal sinus. Ten SvO_2 did not indicate brain oxygen saturation. Brain oxygen saturation is monitored by jugular bulb oximetry [12] or near-infrared spectroscopy [22] in patients undergoing cardiac surgery with CBP. It is clear that regional oxygen saturation cannot be reflected by monitoring venous oxygen saturation from the heart–lung machine or that from the pulmonary artery [2,12,22,23]. This can be explained in part by the poor agreement between venous oxygen saturation from the internal jugular vein and the venous side of the heart–lung machine with mixed venous oxygen saturation from the pulmonary artery in our study. Moreover, Kakuta *et al.* [24] found parallel changes between $ScvO_2$ from the internal jugular vein with regional brain oxygen saturation measured by near-infrared spectroscopy (rSO_2) despite the marked differences in $ScvO_2$ in patients undergoing a bidirectional Glenn shunt. However, the authors did not use Bland and Ataman [25] analysis to test the agreement between the two measurement tools.

The fact that this study was carried out only during the CPB period and that only intermittent samples were obtained can be considered limitations of this study.

Conclusion

It appears that venous saturations from the CVL and from the venous side of the heart–lung machine cannot substitute for or be interchange with mixed venous saturation from the pulmonary artery in children undergoing open-heart surgery.

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Conflicts of interest

There are no conflicts of interest.

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