Continuous Central Venous Saturation Measurement in Pediatric Patients undergoing Cardiac Surgery

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INTRODUCTION

Mixed venous saturation (SvO_2) has been widely studied and accepted as a marker of global tissue perfusion in cardiac surgery patients both in the operating room (OR) and the intensive care unit (ICU). However, measurement of SvO_2 requires the placement of a pulmonary artery (PA) catheter, which is highly invasive and not feasible in certain patient populations, especially children. Central venous saturation ($ScvO_2$), which can be obtained from a central venous catheter (CVC), has been studied as a surrogate to SvO_2. While there has ben debate over the correlation between $ScvO_2$ and SvO_2, it has ben clearly shown that $ScvO_2$ is superior to vital signs alone for assessing global perfusion. Unfortunately, very little literature exists on the use of $ScvO_2$ in children. Continuous $ScvO_2$ measurement for pediatric patients is under development and warrants study. We determined the accuracy of a novel pediatric CVC with integrated fiberopic oximetry, correlated the readings with hemodynamics in anesthetized pigs, and tested its feasibility in pediatric patients undergoing open cardiac surgery.

METHODS

A CVC capable of continuous $ScvO_2$ monitoring by infrared oximetry (pediaSat© oximetry catheter, Edwards Lifesciences, shown in **Figure 1**) was placed in in 5 anesthetized pigs (experimental protocol). Cardiac index (CI), heart rate (HR), mean arterial pressure (MAP), mean pulmonary artery pressure (MPAP), central venous pressure (CVP) and fiberoptic oximetric $ScvO_2$ ($ScvO_2$-cath) were measured every 5 minutes at baseline conditions, during preload reduction by compression of the inferior vena cava (IVC), during dopamine infusion, and at a return to baseline conditions. $ScvO_2$ by blood gas co-oximetry ($ScvO_2$-blood) was measured every 10 minutes. A catheter was also placed in 10 pediatric patients (clinical protocol) who underwent open cardiac surgery with cardiopulmonary bypass (CPB). Catheter size was chosen based on patient size. $ScvO_2$ was continuously monitored throughout surgery and for 48 hours following surgery in the ICU. Seven central venous blood samples were drawn perioperatively: two in the OR (pre-CPB and post-CPB) and five in the ICU (1 hr, 3 hrs, 6 hrs, 12 hrs, and 24 hrs postoperatively). HR, MAP, CVP, inspired oxygen concentration (FIO_2), arterial oxygen partial pressure (PaO_2), hemoglobin concentration (Hb), and oxygen saturation by pulse oximetry (SaO_2), were also measured at these times. Correlation of experimental and clinical $ScvO_2$-cath measurements with simultaneously measured hemodynamic and laboratory data (CI, MAP, HR, Hb, and $ScvO_2$-blood) was calculated using the Pearson's correlation coefficient (Pr), and regression analysis was performed. A Bland-Altman analysis was used for determination of systematic error (bias).

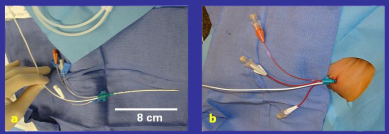

FIGURE 1 - PediaSat© oximetry catheter, Edwards Lifesciences - Photographs showing a 5.5-Fr (8cm length), triple lumen central venous catheter with an integrated fiberoptic oximetry probe (white cable) before (a) and after (b) percutaneous placement into the superior vena cava via the right internal jugular vein of a 4 year old patient (15 kg).

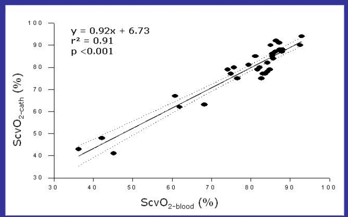

FIGURE 2a - Experimentally acquired paired data sets (n=34) comparing $ScvO_2$-cath $ScvO_2$-blood during various hemodynamic states (dashed line: 95% confidence interval)

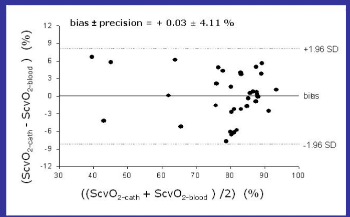

FIGURE 2b - Bland-Altman analysis of $ScvO_2$-cath and $ScvO_2$-blood shows a low bias (+0.03%; solid line) with a ±4.11% precision. The lower and upper limits of agreement (bias ± 1.96 x standard deviation (SD)) were -8.02% and +8.09% (dotted lines). respectively

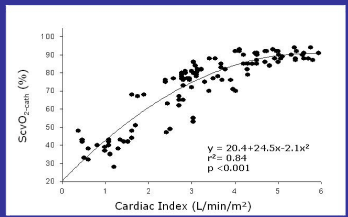

FIGURE 2c - Scatter plot demonstrating non-linear curve-fitting of the correlation between $ScvO_2$-cath and CI (119 paired data sets) during experimentally induced hemodynamic alterations

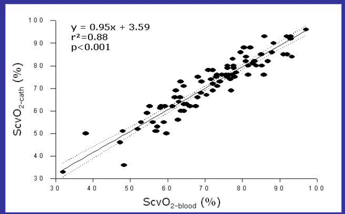

FIGURE 3a - Paired data sets (n=99) $ScvO_2$-cath and $ScvO_2$-blood acquired during the perioperative period of patients undergoing cardiac surgery for congenital heart disease (dashed line: 95% confidence interval

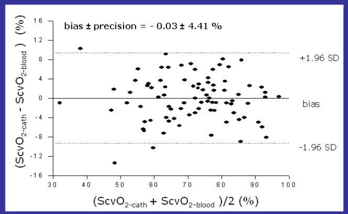

FIGURE 3b - Bland-Altman analysis of $ScvO_2$-cath and $ScvO_2$-blood revealed a low bias (-0.03%; solid line) with a ±4.41% precision.

Variable	Baseline	IVC Occlusion	Dopamine	End
HR (bpm)	115 ± 16	119 ± 17	147 ± 10	117 ± 11
MAP (mmHg)	69 ± 15	32 ± 12	116 ± 29	66 ± 12
MPAP (mmHg)	15 ± 4	9 ± 2	17 ± 2	13 ± 4
CVP (mmHg)	4 ± 1	3 ± 1	5 ± 2	4 ± 2
CI (L/min/m²)	3.7 ± 0.7	0.8 ± 0.4	5.3 ± 0.4	3.3 ± 0.5
PaO_2 (mmHg)	199 ± 24	-	-	200 ± 12
Hb (g/dL)	10.8 ± 0.4	-	-	10.6 ± 1.5
SpO_2 (%)	99 ± 2	98 ± 2	98 ± 3	99 ± 3
$ScvO_2$-cath (%)	81 ± 7	39 ± 7	91 ± 3	75 ± 8
$ScvO_2$-blood (%)	82 ± 5	41 ± 5	92 ± 2	73 ± 11

TABLE 1 - Experimental hemodynamic, oximetric, and laboratory data at baseline, during occlusion of the IVC, during dopamine infusion, and at the return to baseline (n=5). Data are mean ± SD.

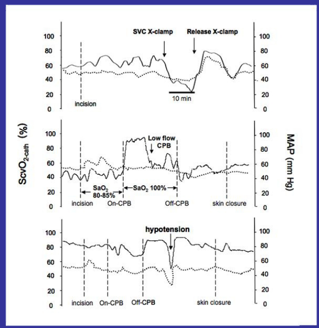

FIGURE 3c - Temporal intraoperative changes of $ScvO_2$-cath. Solid line represents continuous $ScvO_2$ (%), and dotted line represents MAP (mmHg)

Upper graph: Decrease in $ScvO_2$ occurs during partial cross-clamping of the superior vena cava (SVC) following an inadvertent surgical tear in a 2 year old patient with pulmonary atresia. Note that $ScvO_2$ decreased substantially as a result of SVC flow occlusion even though MAP remained relatively unchanged. $ScvO_2$ promptly improves upon release of cross-clamp.

Middle graph: $ScvO_2$ trend plotted during the intraoperative course of a patient undergoing surgery for d-TGA. SaO_2 and $ScvO_2$ rapidly improve with the initiation of CPB.

Lower graph: Rapid drop in $ScvO_2$ occurs in conjunction with a hypotensive episode during the post-CPB period in a patient undergoing a VSD repair.

Age (months)	8.4 (2.5 mo – 11 yr)
Sex	Male 6/15 (37%) Female 9/15 (63%)
Body Weight (kg)	8.0 (5.0-37.1)
Diagnosis -TOF - VSD, ASD - Other*	 6/15 (37%) 4/15 (26%) 6/15 (37%)
*AV Canal, Pulmonary Atresia, Aortic Insufficiency, DORV, Tricuspid Atresia, TGA (each 1/16)	

TABLE 2 - Preoperative characteristics of pediatric patients (n=16). Data are given as median value and range. TOF: tetralogy of Fallot; VSD: ventricular septal defect; ASD: atrial septal defect; AV: atrio-ventricular; AR: aortic regurgitation; DORV: double-outlet right ventricle; TGA: transposition of the great arteries.

RESULTS

There were no catheter-related complications. Experimental hemodynamic, oximetric, and laboratory data is shown in **Table 1**. There was significant decrease in MAP, CI, CVP and MPAP after IVC-occlusion ($p<0.05$) and increase of MAP, HR, and CI with dopamine support ($p<0.05$) when compared to baseline (**Table 1**). Hemodynamics returned to baseline values at the end of the protocol. Analysis of 34 paired data sets of $ScvO_2$-cath and $ScvO_2$-blood measurements showed a significant correlation (Pr= 0.96, $p<0.001$) and close linear relationship as determined by regression analysis ($y=0.92x+6.73$, $r^2=0.91$, $p<0.001$; **Figure 2a**). Bland-Altman analysis revealed a +0.03% difference of means (bias) with ±4.11% precision (**Figure 2b**). ScvO2-cath correlated with cardiac index (Pr= 0.87, $p<0.001$) showing a polynomial regression ($y = 20.4+24.5x-2.1x2$, r2= 0.84, $p <0.001$; **Figure 2c**) in a total of 119 paired data sets. Correlations of $ScvO_2$-cath with MAP (Pr= 0.59, $p<0.001$), MPAP (Pr=0.44, $p<0.001$) and CVP (Pr=0.38, $p<0.001$) were also found. When compared to $ScvO_2$-cath, correlations of hemodynamic parameters to cardiac index were weaker, including MAP (Pr=0.61, $p<0.001$), MPAP (Pr=0.38, $p<0.001$), CVP (Pr=0.35, $p<0.001$) and HR (Pr=0.25, $p<0.05$). Demographic data of the 16 pediatric patients can be found in **Table 2**. Analysis of 99 paired data sets of $ScvO_2$-cath and $ScvO_2$-blood measurements showed a significant correlation (Pr= 0.94, $p<0.001$) and close linear relationship as determined by regression analysis ($y = 0.95x+3.59$, $r^2=0.88$, $p<0.001$; **Figure 3a**). Differences of means (bias) was -0.03% with ±4.41% precision (**Figure 3b**). Correlations of $ScvO_2$-cath were found with PaO_2 (Pr= 0.46, $p<0.001$) and SpO_2 (Pr=0.35; $p<0.001$), but not with other hemodynamic variables. However, in the intraoperative period, continuous $ScvO_2$-cath

CONCLUSION

We have demonstrated the accuracy of a novel oximetric continuous $ScvO_2$ CVC during a wide range of experimentally controlled hemodynamic changes and in pediatric patients undergoing surgery for congenital heart disease. Additionally, $ScvO_2$ accurately reflected changes in CI in anesthetized pigs and was found to be superior when compared to routine hemodynamic parameters. There appears to be low risk associated with the placement of oximetirc CVCs, and $ScvO_2$ monitoring appears feasible for pediatric patients undergoing open cardiac surgery with CPB.

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