Original Article

Clinical Comparisons of Continuous Venous Oxygen Saturation and Hematocrit Monitors in Pediatric Surgery

Denise Bennett, BS, CPT, Jeff Burnside, BS, CCP, Jim Langwell, CPT and Philip D. Beckley, PhD

Department of Cardiovascular Perfusion, Children's Hospital, Columbus, Ohio

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ABSTRACT

Continuous venous oxygen saturation and hematocrit values are important parameters in assessing patient status while on cardiopulmonary bypass. Two devices used to measure continuous venous oxygen saturation while on cardiopulmonary bypass were compared to a control. The Bentley Oxysat meter and the Medtronic MX2 Oxygen Saturation and Hematocrit System were compared to the ABL500 blood gas monitor. The continuous hematocrit readings from the MX2 system were compared to spun hematocrits. Twenty-nine pediatric patients ranging from 2.3kg - 43.3kg were randomly selected. In-line optical transmission cells used were 1/4" or 3/8" depending upon the patient's blood flow requirements. A total of 163 data points were analyzed at different blood flow rates, temperatures, and hematocrits. The venous oxygen saturation values obtained from the Oxysat and the MX2 devices correlated well with the ABL500 over the entire range of blood flows, temperatures, and hematocrits. All correlation coefficients were greater than 0.89. The correlation betweeen the MX2 device and the spun hematocrit varied with temperature ranges. The correlation coefficient tended to decrease with decreasing temperature. We conclude that these devices are important adjuncts to bypass as long as their limitations are understood.

Address correspondence to:
Denise Bennett, BS, CPT
Cardiovascular Perfusion, J-260
Children's Hospital
700 Children's Drive
Columbus, OH 43205

INTRODUCTION

Continuous measurement of venous oxygen saturation (SVO_2) affords important methods of assessing adequate oxygen delivery to tissues and organs during cardiopulmonary bypass (CPB) procedures. The use of continuous in-line venous oxygen saturation allows for the recognition of oxygen delivery or consumption abnormalities and, therefore, the possibility of early intervention and management (1-3). Children present an added challenge due to the extreme metabolic variations, temperatures, and flow ranges experienced during a typical pediatric CPB case. The recent introduction of continuous in-line saturation and hematocrit measurements could provide important information in assessing pediatric patient status if found to be both accurate and reliable. The purpose of this investigation was to look at venous oxygen saturations and hematocrits over the range of blood flow rates, temperatures, and hematocrits typically used during a pediatric CPB case.

MATERIALS AND METHODS

The Baxter Bentley OxySat[a] and the Medtronic MX2 Oxygen Saturation and Hematocrit System[b] were evaluated at our institution during pediatric CPB procedures. The continuous hematocrit readings from the MX2 system were compared to spun hematocrits from the Hematastat C-70 centrifuge[c]. The saturation values obtained from these two analyzers were compared to those from the ABL500[d] blood gas analyzer. The ABL500 is the standard used for operating room patient management at our institution. A full range of quality control samples as well as one and two-point calibrations were performed on the ABL500 daily.

The OxySat is a noninvasive, electronic, digital, dual wavelength optical device with a 20 second response time. The MX2 is a noninvasive, electronic, digital, tri-optic device with a 12 second response time. Probes are attached to either 1/4" or 3/8" cuvettes placed into the extracorporeal circuit. Twenty-nine pediatric patients ranging from 2.3 kg - 43.3 kg were randomly selected. All patients had surgical repair of congenital heart defects.

Both the OxySat and the MX2 cuvettes were placed into the venous line of the extracorporeal circuit. Cuvettes used were 1/4" for patients with blood flow requirements of 1.5 L/min or less and 3/8" for patients requiring blood flow rates above 1.5 L/min. Blood sampling was initiated soon after the placement of the cross clamp and performed every 15 minutes. A total of 163 venous blood samples were obtained. Simultaneous readings from the OxySat and the MX2 were recorded as well as venous blood temperature and CPB blood flow rate as each venous blood sample was drawn. Each sample was analyzed by the ABL500 and a spun hematocrit performed.

The data points were then compared within different blood flow rate, temperature, and hematocrit ranges (Tables 1 and 2). Regression analysis and paired t-test were performed. Reliability of the instruments was shown by regression analysis and the resulting correlation coefficients. Paired t-tests indicated the accuracy of the OxySat and the MX2 to the ABL500 and spun hematocrit.

a Baxter Bentley Laboratories Inc., Irvine, CA 92704
b Medtronic HemoTec, Inc., Englewood, CO 80112
c Separation Technology, Inc., Salt Lake City, Utah 84119
d Radiometer America Inc., Westlake, OH 44145

Table 1
ANALYSIS OF SVO_2 MEASUREMENTS

	OXYSAT VS. ABL500		MX2 VS. ABL500		SAMPLE SIZE
	R-VALUE	p-VALUE~	R-VALUE	p-VALUE~	
FLOWS (l/min)					
(1/4" ID)					
<0.75	0.96	0.4E-2	0.97	0.01	71
0.75-1.5	0.93	0.7E-3	0.92	0.82*	30
(3/8" ID)					
0.75-.5	0.98	0.82*	0.98	0.24E-4	24
>1.5	0.99	0.07*	0.98	0.21E-4	34
TEMPS (°C)					
<26	0.97	0.3E-3	0.97	0.45E-5	74
26-32	0.89	0.04	0.90	0.92*	27
>32	0.94	0.58*	0.93	0.2E-2	62
HCTS (%)					
<22	0.99	0.27*	0.98	0.52*	28
22 - 30	0.97	0.02	0.97	0.24E-7	77
>30	0.93	0.02	0.93	0.06*	58

~p-value refers to t-test
*Paired t-test indicates the mean difference between the two instruments is not significantly different.

Table 2
ANALYSIS OF HEMATOCRIT MEASUREMENTS

	MX2 HCT VS. SPUN HCT		SAMPLE SIZE
	R-VALUE	p-VALUE~	
FLOWS (l/min)			
(1/4" ID)			
<0.75	0.91	0.9E-2	71
0.75-1.5	0.93	0.34*	30
(3/8" ID)			
0.75-1.5	0.87	0.64E-6	24
>1.5	0.87	0.58E-7	34
TEMPS (°C)			
<26	0.66	0.21E-7	74
26-32	0.86	0.13*	27
>32	0.88	0.09*	62

~p-value refers to t-test
*Paired t-test indicates the mean difference between the two instruments is not significantly different.

Figure 1
Oxysat SVO_2 Values - Blood FLow Rate ≤0.75 L/min

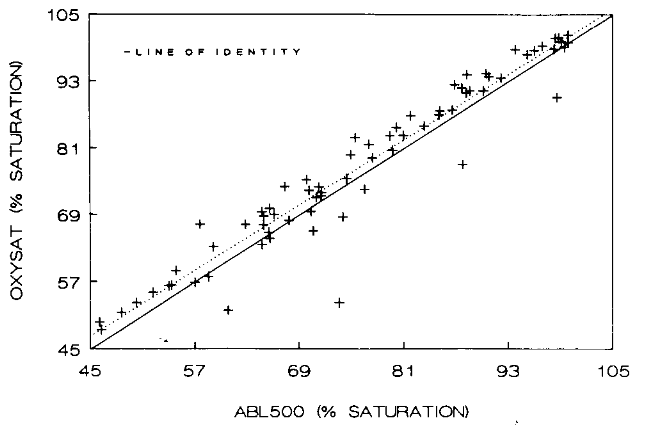


Figure 2
MX2 SVO_2 Values - Blood Flow Rate ≤0.75 L/min

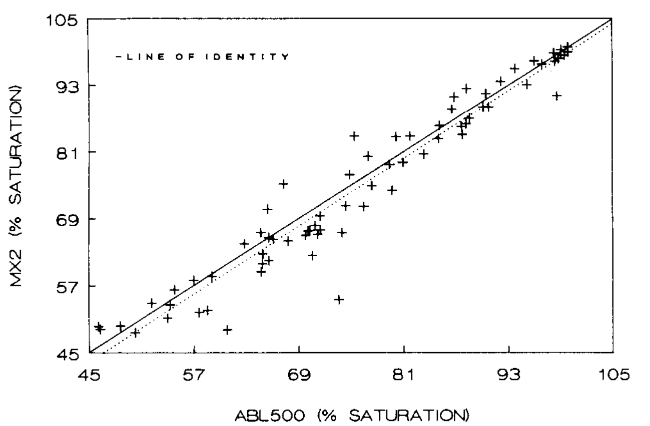


Figure 3
SVO_2 Values - Temperature >32°C

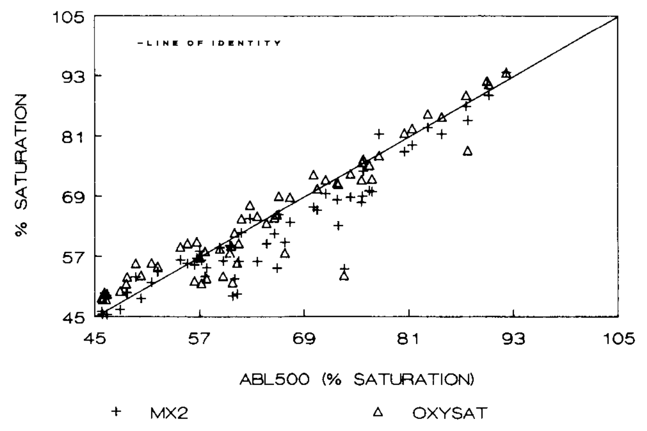
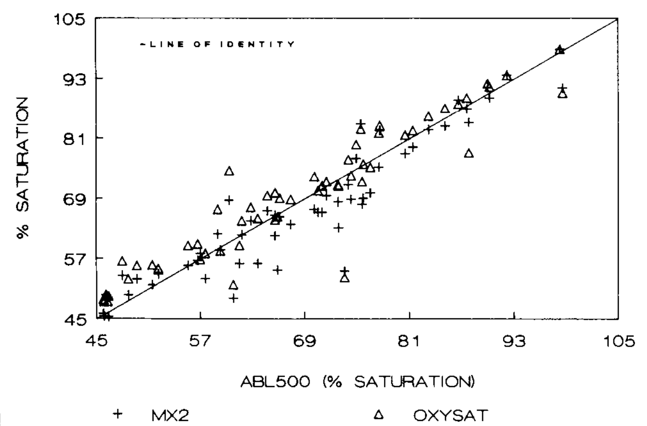


Figure 4
SVO_2 Values - Hematocrit > 30%



RESULTS

Tables 1 and 2 present the results of the regression analysis and the paired t -test. At all blood flow rates, temperatures, and hematocrits the venous saturation results from the OxySat and the MX2 correlated well with the ABL500 values (Figures 1-4). The paired t-test indicated no significant difference between the mean values obtained from the OxySat and the ABL500 at blood flows greater than 0.75 L/min (3/8"ID tubing); at temperatures greater than 32°C; and at hematocrits less than or equal to 22%. The mean values obtained from the MX2 and the ABL500 showed no significant difference at blood flows between 0.75 L/min and 1.5 L/min (1/4"ID tubing); at temperatures between 26°C and 32°C; and at hematocrits less than or equal to 22%.

The correlation between the MX2 and the spun hematocrit varied with temperature ranges (Figures 6-7). The correlation coefficient tended to decrease with decreasing temperature. Using the paired t-test the mean values obtained from the MX2 and the spun hematocrit showed no significant difference at blood flows between 0.75 L/min and 1.5 L/min (1/4"ID tubing); and at temperatures greater than 26°C.

DISCUSSION

The relationship between oxygen consumption (VO_2), cardiac output (CO), and arterial and venous oxygen content difference is described by the following equation (2,6):

Figure 5
Hematocrit Values - Blood FLow Rate ≤1.5 L/min

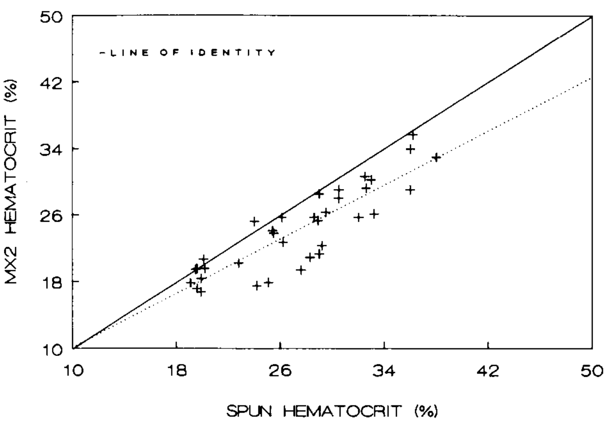


Figure 7
Hematocrit Values - Temperature > 26°C

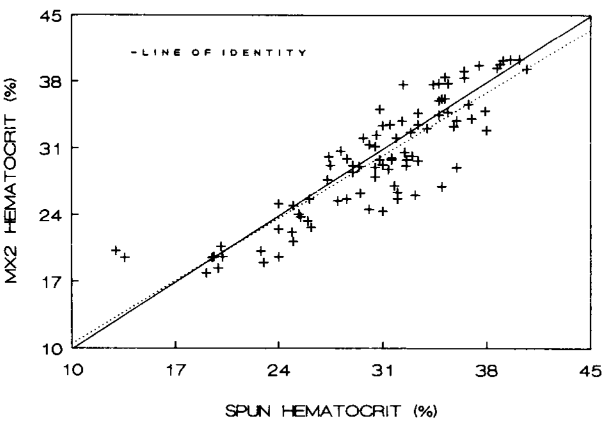
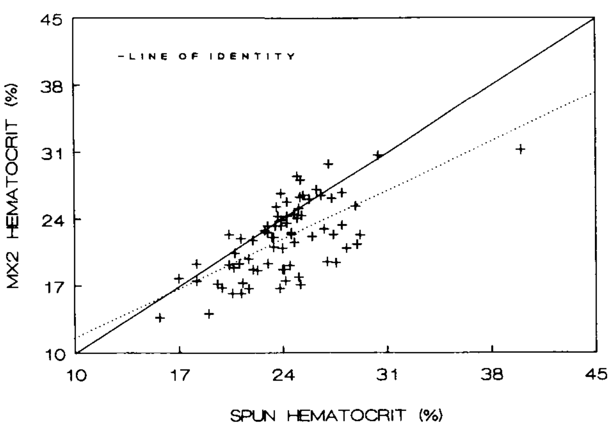


Figure 6
Hematocrit Values - Temperature < 26°C



$$VO_2 = \frac{(SAO_2 - SVO_2) \times HB \times 1.34 \times CO}{100}$$

where
VO_2 = oxygen transfer in ml oxygen/minute
$SAO_2 - SVO_2$ = arterial - venous O_2 saturation difference
HB = hemoglobin concentration in gm/100ml blood
1.34 = O_2 capacity of hemoglobin in ml oxygen/gm hemoglobin

While on CPB, the SAO_2 is usually maintained at 100% saturation, therefore the variation in SVO_2 can be attributed to the variation in oxygen consumption. Monitoring SVO_2 can aid in selecting an appropriate blood flow rate (CO) while on CPB. Many pediatric CPB procedures involve extreme temperature and blood flow variations. Consequently, during extended periods of rewarming radical changes in oxygen delivery and consumption can occur (4,5). Continuous SVO_2 monitoring affords protection from inadequate tissue oxygenation during these critical periods. Our results indicate that the MX2 and the OxySat are reliable instruments for SVO_2 measurement according to the high correlation values. Table 1 and Figures 1-4 show that while consistent at all blood flow rates, temperatures, and hematocrits, the instruments were not always accurate. The paired t-test gives an indication of accuracy between the ABL500 and the SVO_2 monitors. If the distribution of data points around the line of identity is skewed positive or negative, the paired t-test will suggest inaccuracy between the two instruments as Table 1 and Figures 1 and 2 demonstrate. The OxySat (1/4"ID tubing) consistently gave higher SVO_2 values than the ABL500, while the MX2 for both tubing sizes generally gave lower SVO_2 values.

The correlation coefficients between the MX2 hematocrits and the spun hematocrits were significant at the blood flow rates studied (Table 2), but, the degree of scatter of the data points was unacceptable (Figure 5). The results from the MX2 needed to be within ±2 of the spun hematocrit to be clinically useful at our pediatric institution. Approximately half (80 out of 163 samples) proved to be outside of our accepted range. Our results indicate that at temperatures less than 26°C, the MX2 device is not reliable or accurate for the measurement of hematocrit, as Table 2 and Figure 6 exhibit. At temperatures greater than 26°C, the correlation coefficients appear acceptable but, as Table 2 and Figure 7 display, the distribution is fairly even while the scatter is too extreme. Data points displaying excessive scatter can result in a paired t-test suggesting accuracy if the data points are equally distributed above and below the line of identity.

Clinically we found the MX2 hematocrit measurement not to be a valuable tool for patient management during cardiopulmonary bypass. As long as their performance limitations are understood, the OxySat and the MX2 were found to be reliable and useful tools for following SVO_2 trends during the pediatric cardiopulmonary bypass procedure.

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