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Monitoring of central venous oxygen saturation versus mixed venous oxygen saturation in critically ill patients

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Abstract. Continuous monitoring of mixed venous (SvO_2) and central venous (ScO_2) oxygen saturation was compared in 7 critically-ill patients (Apache II score: 19 ± 2.1) to determine whether or not information derived from ScO_2 were reliable in clinical practice. Patients were catheterized with both a pulmonary artery (PA) and a central venous (CV) catheter, each of them mounted with fiberoptic sensors (Opticath PA Catheter P7110 and Opticath CV Catheter U440, Abbott). A total of 580 comparative measurements were obtained during periods without and with therapeutic interventions (drug-titration, bronchial suction, use of PEEP, changes in FiO_2...). The systematic error between the 2 measurement techniques was 0.6% and 0.3% in periods with and without therapeutic interventions, respectively. The variability between the 2 techniques was 10% for both periods. Differences between the values were $\geq 5\%$ in 49% of values during periods of stability and in 50% of values during periods with therapeutic interventions. There were poor correlations between the values during periods without ($r = 0.48$) and with therapeutic interventions ($r = 0.62$). Better, but still less than ideal, correlations were obtained with changes in SvO_2 and ScO_2 during periods without ($r = 0.70$) and with therapeutic interventions ($r = 0.77$). Although there is a need to develop a simple technique to monitor mixed venous oxygen saturation, the present study indicates that ScO_2 monitoring was not reliable in the study patients.

Key words: Central venous catheter – Central venous oxygen saturation – Mixed venous oxygen saturation – Pulmonary artery catheter

Continuous monitoring of mixed venous oxygen saturation SvO_2 has recently been made possible with the use of PA catheters mounted with fiberoptic sensors [1–5]. Modifications in SvO_2 are dependent on the effectiveness of air-blood gas exchange in the lung, cardiac output, tissue oxygen uptake and oxyhemoglobin dissociation. In critically ill patients there has been a considerable interest in the relationship of SvO_2 to cardiorespiratory function [6, 7]. However the risk/benefit ratio of PA catheters is still a matter for vigorous controversies [8, 9]. On the other hand CV catheters are routinely inserted in intensive care patients for monitoring of CV pressure and for administration of artificial parenteral nutrition. Monitoring of central venous oxygen saturation (ScO_2) would be an interesting alternative for SvO_2 monitoring as far as similar information is given by both methods.

The aim of this study was to compare simultaneous measurements of SvO_2 and ScO_2 obtained from PA and CV catheters inserted in critically ill patients. A special attention was paid to periods of instable clinical conditions (bronchial suctions, modifications in inspired oxygen fraction (FiO_2), treatment of septic shock...). A difference $\leq 5\%$ saturation was chosen to decide that the 2 methods of measurements were interchangeable.

Materials and methods

In a prospective study, 7 consecutive patients requiring monitoring of PA pressure and parenteral nutrition were catheterized with an Opticath® PA Catheter P7110, 7.5 F (Abbott) and an Opticath CV Catheter U440, 4 F (Abbott). The protocol was approved by the Human Investigation Committee of our institution. Prior to insertion, both catheters were calibrated in vitro following the manufacturer's instructions. The central venous catheters were inserted in the right internal jugular vein and the pulmonary artery catheters in the right axillary vein following standard aseptic technique. All these patients were receiving controlled mechanical ventilation, sedated with phenoperidine and paralyzed with vecuronium bromide and no local anesthesia was used. The PA catheter was positioned following standard procedures and advanced until a typical wedge pressure was obtained with the balloon inflated with 1.5 ml air. Obtaining a typical PA tracing with the balloon deflated was carefully checked in each patient. Central venous catheters were positioned in the lower part of the Superior Vena Cava. Correct positions of catheter tips were confirmed in each patient by a chest X-ray. Each catheter was connected to a venous oxygen saturation monitor (Oximetric 3® Abbott) that had the capacity to continuously and simultaneously display SvO_2 and ScO_2 values. Monitors were recalibrated every morning using a Co-oximeter (Instrumentation Laboratory).

During the study period, SvO_2 and ScO_2 values were simultaneously noted every hour. A special attention was paid to abrupt changes in O_2 saturation ($\geq 10\%$ in order to determine whether or not changes in ScO_2 paralleled changes in SvO_2 in critical clinical conditions. Venous oxygen saturations were also carefully noted during periods where acute changes in SvO_2 and ScO_2 could be expected because of therapeutic interventions (drug titration during treatment of shock, bronchial suction with disconnection from the ventilator, use of PEEP, changes in FiO_2...). During these periods, SvO_2 and ScO_2 values were obtained every 10–60 s. Patients were studied as long as PA catheters were needed. In one patient with septic shock, ScO_2 values were impossible to obtain after 40 h because of a technical problem with the fiberoptic sensor of the CV catheter.

The statistical significance of differences between oxygen venous saturations was analyzed by a paired Studtent's *t*-test. The systematic error (bias), and the random error, or variability (standard deviation of the bias) between the two techniques were calculated following the recommendations of Bland and Altman [10]. Bias was mathematically expressed as ($SvO_2 - ScO_2$). Linear regression analysis using the least squares method and calculation of correlation coefficients (r) were also performed. The difference in correlation coefficients were analyzed using the Fisher's *Z*-test. All values are given as mean ± standard deviation and a level of significance of $p < 0.05$ was chosen to reject the null hypothesis.

Results

The 7 patients were 5 men and 2 women (mean age: 61 ± 8 years, Apache II Score: 19 ± 2.1). They presented with severe sepsis of pulmonary origin (2 patients) and septic shock due to pneumonia (3 patients) and peritonitis (2 patients). The catheters were used for 54 ± 22 h (range: 24–86 h). During the study period, 580 comparative measurements of SvO_2 and ScO_2 were obtained. In Table 1 SvO_2 and ScO_2 mean values are given. No difference between the mean values was observed for periods with and without therapeutic interventions.

The bias between the two measurement techniques was 0.6 ± 10% and 0.3 ± 10% in periods with and without therapeutic interventions, respectively. The relative frequency of the differences between SvO_2 and ScO_2 are given in Table 1. The difference between the two was

Table 1. Mixed venous (SvO_2) and central venous (ScO_2) oxygen saturations in critically ill septic patients during periods with and without therapeutic interventions*. ($|ScO_2 - SvO_2|$, absolute value of difference between central venous and mixed O_2 saturation; *n*, number of comparisons within given range; %, relative frequency)

	No therapeutic interventions ($n = 420$)		Therapeutic interventions[a] ($n = 160$)	
	SvO_2	ScO_2	SvO_2	ScO_2
Mean ± SD (range)	67 ± 10 (41–91)	68 ± 9 (44–93)	70 ± 11 (49–90)	68 ± 10 (47–88)
	$\lvert ScO_2 - SvO_2 \rvert$		$\lvert ScO_2 - SvO_2 \rvert$	
diff. < 3%	$n = 155$ (37%)		$n = 56$ (35%)	
3% ≤ diff. < 5%	$n = 63$ (15%)		$n = 24$ (15%)	
5% ≤ diff. ≤ 10%	$n = 82$ (20%)		$n = 32$ (20%)	
10% < diff.	$n = 120$ (29%)		$n = 48$ (30%)	

[a] Therapeutic interventions: drug titration during treatment of shock, bronchial suctions, use of PEEP, changes in FiO_2, etc....

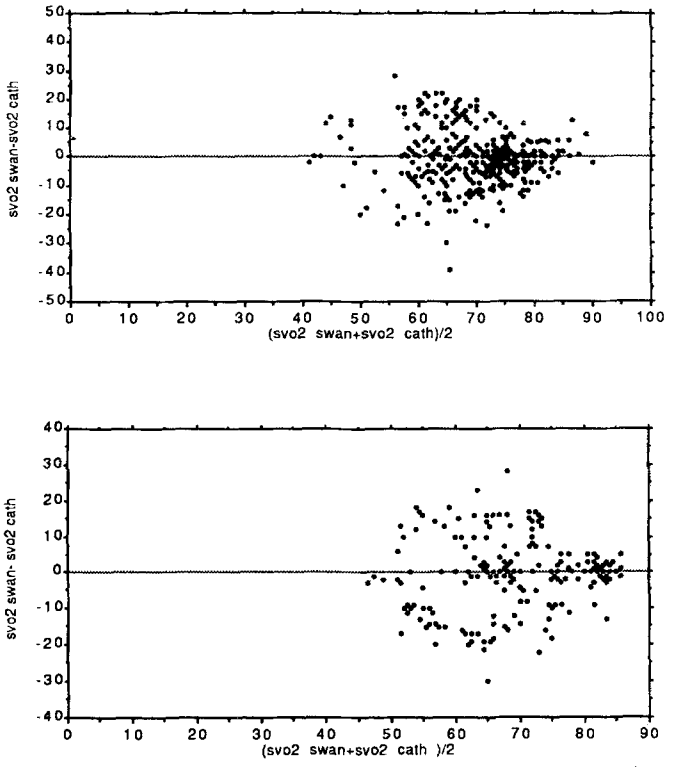

Fig. 1. Distribution of individual differences between central (SvO_2 cath) and mixed venous (SvO_2 Swan) O_2 saturations in situations without (*top*) and with therapeutic interventions (*bottom*). (*Dashed line*: bias or mean (SvO_2 Swan − SvO_2 cath)

> 5% saturation in 49% and 50% of measurements in periods with and without therapeutic interventions, respectively. In Fig. 1 are shown the distributions of individual differences between the two parameters ($ScO_2 - SvO_2$) during the two periods studied. Differences up to 40% were observed in some patients.

Figure 2 presents the individual correlations between the two sites for each of the series of measurements. No difference between these correlations was observed ($p > 0.05$). Correlations of changes of SvO_2 with changes of ScO_2 are shown in Fig. 3. These correlations were significantly higher ($p < 0.01$) when compared with individual correlations shown in Fig. 2. Even when actual values of SvO_2 and ScO_2 were quantitatively different, qualitatively, changes in ScO_2 often paralleled changes in SvO_2. When considering abrupt changes in O_2 saturation ($\geq 10\%$), they were determined in 186 of 227 cases (82%) by both catheters.

Discussion

In this study, conducted in critically ill patients, changes of oxygen saturation values of mixed venous and central venous blood were often discordant during different clinical situations. This was true either during periods of clinical stability or during various pathological or therapeutic events.

The between-technique variability of two different measurements methods can be evaluated by correlation,

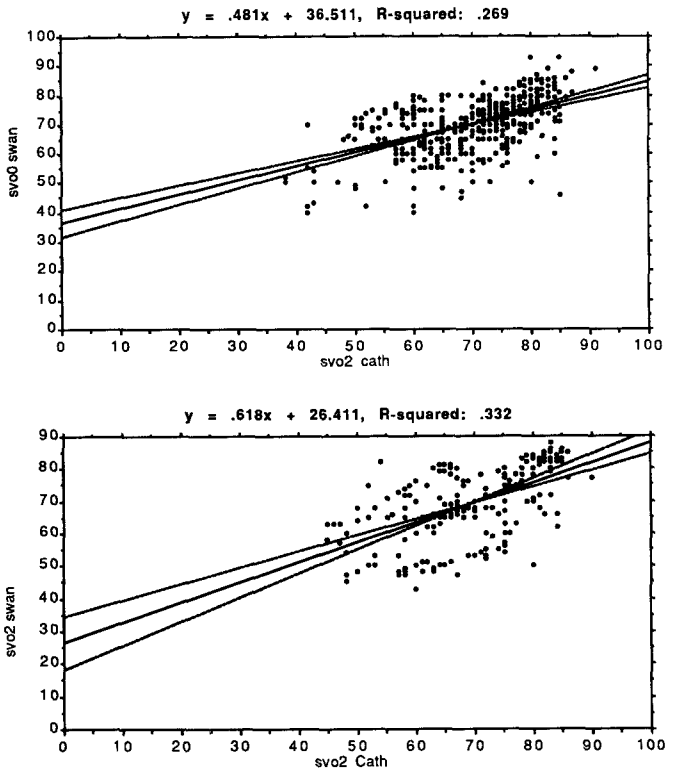

Fig. 2. Correlations between mixed venous (SvO_2 Swan) and central venous oxygen saturation (SvO_2 cath) in situations without (*top*) and with therapeutic interventions (*bottom*). A significant correlation was found for both regression lines ($p < 0.0001$). Regression lines and 95% confidence limits for slope of regression lines are presented

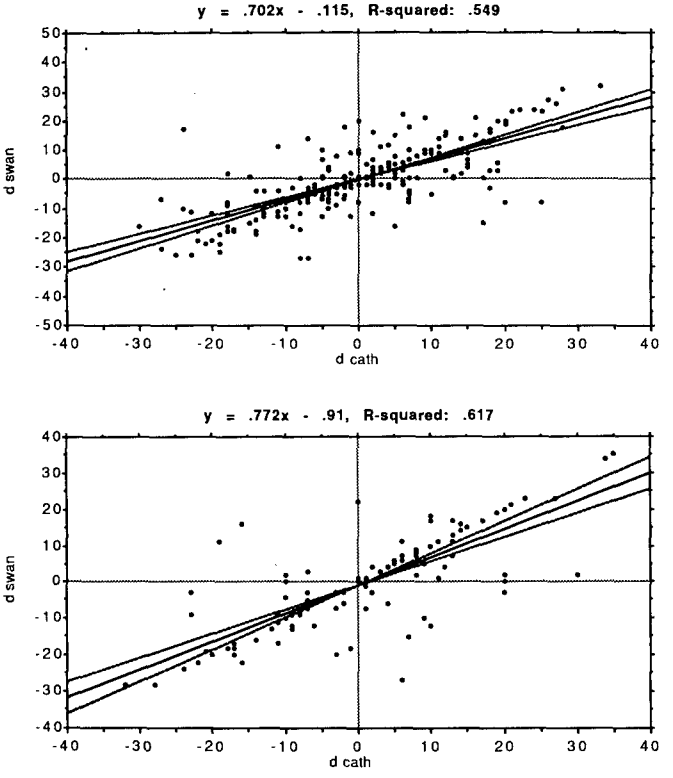

Fig. 3. Correlations of changes in mixed venous (*d. Swan*) and central venous (*d. cath*) oxygen saturation in situations without (*top*) and with therapeutic interventions (*bottom*). A significant correlation was found for both regression lines ($p < 0.0001$). Regression lines and 95% confidence limits for slope of regression lines are presented

regression and bias and precision statistics [10]. Correlation coefficient is a poor parameter to establish equivalence between two methods. It measures association (whether two parameters increase or decrease proportionally), not agreement. Regression analysis gives information concerning proportional and constant errors between the measurement techniques. It is a calibration of one technique in terms of another [10]. Correlation coefficient and regression analysis were statistically significant in the present study, probably because of the large number of measurements performed, but this does not give information on the agreement between the two techniques. To determine if two techniques are in agreement and therefore interchangeable, calculation of bias (mean error) and standard error of bias (magnitude of error) is preferable. In this study, the bias was very low and close to zero: 1.1% for both periods of clinical stability and instability. However, if the errors are evenly distributed above and below zero, the mean error is close to zero leading to the erroneous conclusion that both techniques are in agreement. Unfortunately, the magnitude of error (SD of bias) was high: 10%, in periods with and without therapeutic interventions, respectively. The limits of agreement between the two techniques are ± 2 SD [10]. In this study the 2 SD limits were 20%, for the periods with and without therapeutic interventions, which exceeded that permissible (5%) to conclude that the two methods were in agreement.

These results are at variance with those of a study conducted in dogs during changes in oxygen-supply demand [11]. The design of the present study does not allow us to determine the exact reasons of such a discrepancy. At least, part of the difference could be explained by modifications of blood flow distribution between the lower and the upper part of the body. The study patients had severe sepsis and/or septic shock, all situations known to affect the distribution of cardiac output [12, 13]. When monitoring central-venous oxygen saturation, relative oxygen consumption of the superior vena cava system may remain stable, at a time when oxidative metabolism of vital organs, such as the splanchnic region, may reach a level where a flow-limited oxygen consumption is achieved, together with a marked decrease in oxygen saturation. In this situation, ScO_2 provides a false favourable impression of an adequate body perfusion, because of the inability to detect organ ischemia in the lower part of the body [14].

In patients without sepsis, the use of central venous blood has been advocated to estimate mixed venous blood saturation [15–18]. The data showed significant positive correlations between mixed and central venous blood. However, a correct statistical analysis, according to the recommendations of Bland and Altman [10] was not performed, and the use of correlation tests is often misleading. It should also be noted that despite good correlations, the confidence limits presented in the studies

on cardiac patients allow remarkable errors [15, 16]. Furthermore, results obtained in non-septic patients show that the best correlation was obtained in patients with low SvO_2 and ScO_2 values; in patients with higher values – such as those found in septic patients – correlation was far less good [16]. Consequently, even in non septic patients, the value of central venous blood to replace mixed venous blood should be considered with caution [19].

In conclusion, differences between ScO_2 and SvO_2 were found to be greater than 5% saturation in 50% of the measurements and abrupt changes in SvO_2 were not detected by ScO_2 monitoring in 18% of the measurements. In the conditions of this study, monitoring of ScO_2 and SvO_2 was not interchangeable.

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