Continuous Mixed Venous Oxygen Saturation Monitoring during General Anesthesia

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Clinical evaluation of continuous $S\bar{v}_{O_2}$ monitoring during general anesthesia was made in 21 surgical patients utilizing a fiberoptic reflectometry system combined with a pulmonary artery flow-directed balloon catheter. On-line in vivo values for $S\bar{v}_{O_2}$ by the system were closely related to those obtained in vitro from a Radiometer ABL-300. There was a good correlation between changes of in vivo $S\bar{v}_{O_2}$ and corresponding changes in cardiac index. We also observed that there were significant correlations between $S\bar{v}_{O_2}$ and oxygen extraction ratio, and $S\bar{v}_{O_2}$ and oxygen delivery. These data indicate that continuous monitoring of $S\bar{v}_{O_2}$ during general anesthesia can provide on-line information not only about hemodynamic state but also on oxygen transport, which will be especially helpful in managing hemodynamicaly unstable patients during anesthesia. (Key words: $S\bar{v}_{O_2}$ monitoring, cardiac output, oxygen transport, general anesthesia)

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A pulmonary artery flow-directed balloon catheter combined with a fiberoptic reflectometry system can provide a cotinuous digital and trend display of mixed venous oxygen saturation ($S\bar{v}_{O_2}$) together with the usual intermittent blood sampling, and pressure and flow measurement capabilities of the thermodilution pulmonary catheter. These data, combined with an arterial blood gas analysis, provide detailed information regarding oxygen delivery to and extraction by the tissues. The system can thus be used both as a monitor and an alarm device for important changes in general anesthesia. Some reports have described a good correlation between on-line $S\bar{v}_{O_2}$ and hemodynamic changes[1–4], while some questioned this correlation[5–8]. This study therefore was designed to evaluate this system in patients during general anesthesia by comparing changes in on-line $S\bar{v}_{O_2}$ with those in cardiac index, together with comparison of in vivo $S\bar{v}_{O_2}$ measurements to those obtained in vitro using a Radiometer ABL-300. We hoped to be able to correlate on-line $S\bar{v}_{O_2}$ measurements with intermittent measured and derived oxygen transport variables.

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Methods

Twenty-one adult patients were studied, who were scheduled for elective major abdominal surgery and had indications for pulmonary catheter insertion. Their ages ranged from 33 to 74 years, average age of 53 years. Approval from the Hokkaido University Hospital Ethic Committee was granted

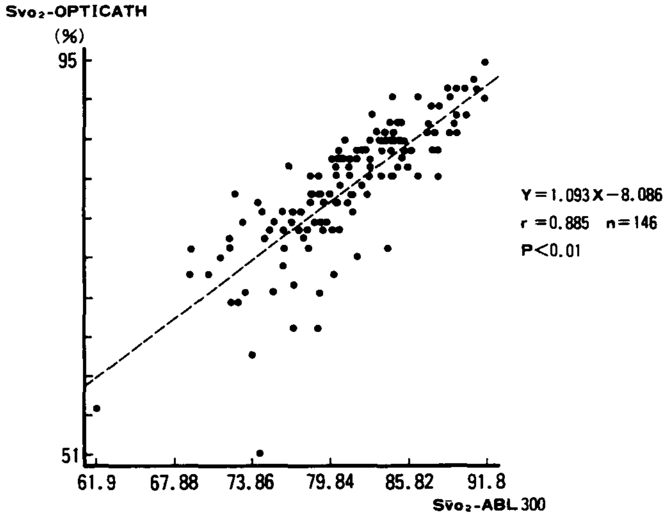

Fig. 1. Linear correlation between on-line in vivo $S\bar{v}_{O_2}$ and simultaneous in vitro $S\bar{v}_{O_2}$ measured by ABL-300.

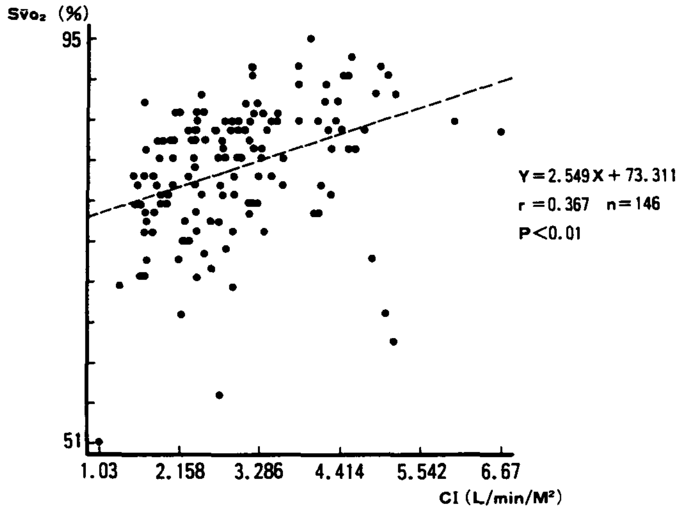

Fig. 2. Correlation of on-line $S\bar{v}_{O_2}$ and overall cardiac index (CI).

for the study, and an informed consent was obtained from each patient at the time of the pre-anesthesia visit. Anesthesia was induced by intravenous administration of thiamylal and the trachea was intubated with the aid of succinylcholine. Anesthesia was maintained with enflurane/nitrous oxide in oxygen and respiration was adjusted to keep normocapnia. A fiberoptic oximetric catheter (Opticath 7.5-Fr and Shaw catheter oximetry system, Century Medical, Inc., Japan) was inserted through the right internal jugular vein and correct positioning of the catheter in the pulmonary artery was confirmed by continuous monitoring of the pressure waves. Fiberoptic catheters were calibrated before insertion and in vivo calibration was performed as needed according to the manufacturer's instructions. The right radial artery was cannulated for both arterial pressure monitoring and blood gas analyses. Continuous monitoring of arterial, central venous and pulmonary pressures was made with measurements of endtidal CO_2, $S\bar{v}_{O_2}$, arterial oxygen saturation (Sa_{O_2}) by pulse oximetry, ECG and intermittent cardiac output (CO), during the whole procedure. Serial measurements of hemodynamic variables, together with arterial and mixed venous gas analyses were made prior to and following

Table 1. Mean values of oxygen transport variables during perioperative periods

veriables	preanesthesia	postanesthesia	intraoperative	postoperative
$S\bar{v}_{O_2}$ (%)	79 ± 1.4	84 ± 1.2	82 ± 1.1	83 ± 1.7
Sa_{O_2} (%)	97 ± 0.4	99 ± 0.2	99 ± 0.1	99 ± 0.1
CaO_2 (%)	15.8 ± 0.5	15.9 ± 0.7	15.3 ± 0.4	16.2 ± 0.4
$C\bar{v}_{O_2}$ (%)	12.9 ± 0.5	12.9 ± 0.7	12.1 ± 0.4	12.7 ± 0.4
$\dot{D}_{O_2}$ (ml/min)	521 ± 29**	486 ± 31	466 ± 37	618 ± 44*
$\dot{V}_{O_2}$ (ml/min)	95 ± 6	90 ± 8	92 ± 8	130 ± 15*
O_2ER (%)	18 ± 1.2	19 ± 1.6	21 ± 1.3	22 ± 1.8
Hgb (g/dl)	11.5 ± 0.3	11.2 ± 0.4	10.9 ± 0.3	11.4 ± 0.3
CI (ℓ/min·m^2)	3.30 ± 0.14**	3.06 ± 0.17	3.02 ± 0.2	3.78 ± 0.2*

Mean ± SEM are shown.
$\dot{D}_{O_2}$ = oxygen delivery, $\dot{V}_{O_2}$ = oxygen comsumption, O_2ER = oxygen extraction ratio, CI = cardiac index
*significant difference vs values of other periods ($P < 0.01$)
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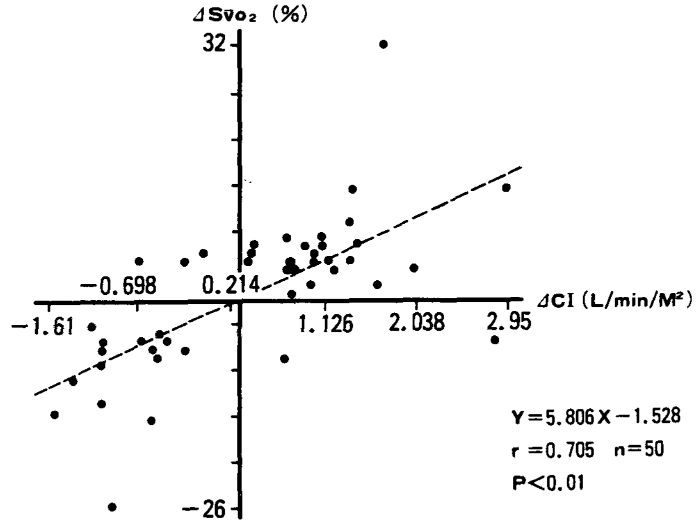

Fig. 3. Correlation of on-line $S\bar{v}_{O_2}$ changes with corresponding changes in CI.

induction of anesthesia, 5 min before and after incision of the skin, anytime during the procedure when on-line $S\bar{v}_{O_2}$ values increased or decreased by 5% or more, and 15 min following the operative procedure. Cardiac output measurements were performed in at least duplicate using the thermodilution techinique. The following variables of oxygen transport were calculated by derivation from arterial and mixed venous contents (Ca_{O_2} and $C\bar{v}_{O_2}$) measured with a Radiometer ABL-300: Oxygen delivery ($\dot{D}_{O_2}$) = CO × Ca_{O_2}, Oxygen consumption ($\dot{V}_{O_2}$) = CO × (Ca_{O_2} − $C\bar{v}_{O_2}$), and Oxygen extraction ratio (O_2ER) = (Ca_{O_2} − $C\bar{v}_{O_2}$)/Ca_{O_2}.

Results

Regression analysis of the 146 paired in vivo and in vitro $S\bar{v}_{O_2}$ measurements showed a good correlation (r = 0.885, $P < 0.01$) (fig. 1). Mean values of oxygen transport variables during anesthesia were summarized in table. Although there was a positive correlation between on-line $S\bar{v}_{O_2}$ and Cl as shown in figure 2, a higher correlation existed between increases or decreases in on-line $S\bar{v}_{O_2}$

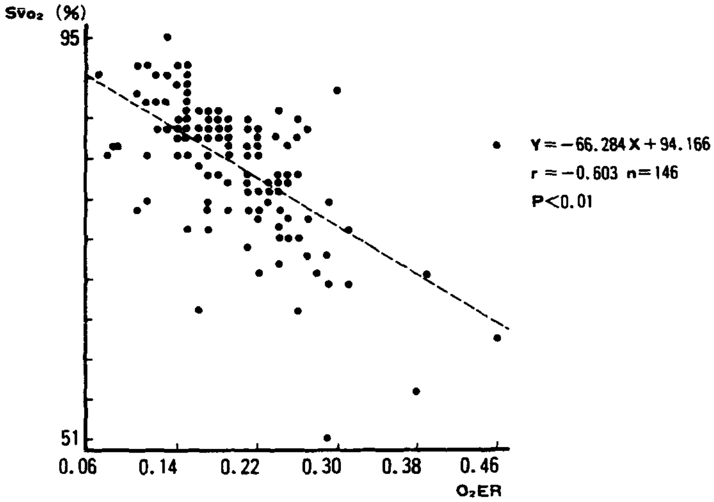

Fig. 4. Correlation of on-line $S\bar{v}_{O_2}$ and oxygen extraction ratio (O_2ER).

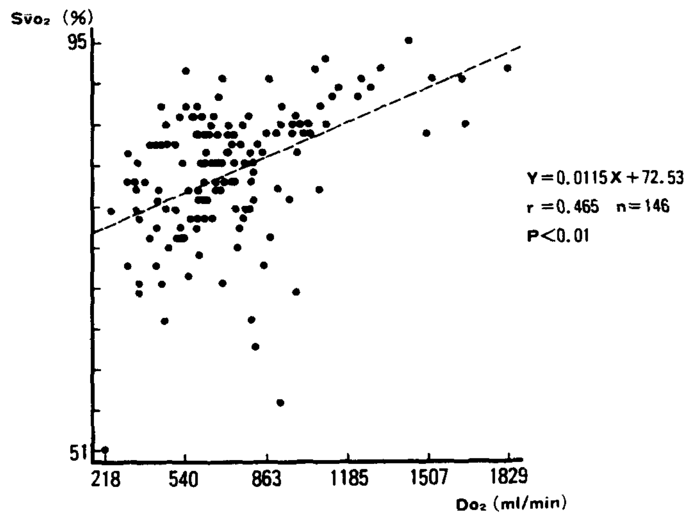

Fig. 5. Correlation of on-line $S\bar{v}_{O_2}$ and oxygen delivery ($\dot{D}_{O_2}$).

values of more than 5% and corresponding changes in CI (r = 0.706, $P < 0.01$) (fig. 3). There were 50 instances during the study when $S\bar{v}_{O_2}$ values changed by 5% or more, decreasing 20 times and increasing 30 times. There was a significant negative correlation between on-line $S\bar{v}_{O_2}$ values and O_2ER (r = −0.603, $P < 0.01$) as depicted in figure 4, whereàs there was a positive correlation between on-line $S\bar{v}_{O_2}$ and $\dot{D}_{O_2}$ (fig. 5). However, there was a poor correlation between $S\bar{v}_{O_2}$ and $\dot{V}_{O_2}$ (r = −0.065).

Discussion

These date indicate that during general anesthesia this fiberoptic refractometry system provides accurate, on-line and in vivo $S\bar{v}_{O_2}$ values in the range of 60% or more. These findings are in accordance with those of previous reports[1–6]. Our data also show that changes of $S\bar{v}_{O_2}$ values closely reflect changes of cardiac index as reported by Waller, et al.[1] and Kan, et al.[4] Therefore, changes in cardiac index will immediately apparent via a corresponding change in $S\bar{v}_{O_2}$ unlike the measurement of cardiac index by thermodilution. This is of particular benefit in patients during anesthesia when immediate assessment of response to therapeutic interventions become important[4]. However, some reported that the value of continuous $S\bar{v}_{O_2}$ monitoring as an early predictor of cardiac output change remains questionable by studying critically ill patients[7,8]. When respiratory function, hemoglobin concentration and oxygen consumption are relatively stable as in our study, $S\bar{v}_{O_2}$ can reflect accurately parallel changes in cardiac output. However, in critically ill patients, stable variables are not usually present, and then the $S\bar{v}_{O_2}$ reflect the body's compensatory mechanism to maintain homeostasis such as right shifted oxyhemoglobin curve.

According to Fick's principle, $S\bar{v}_{O_2} = Sa_{O_2} - \dot{V}_{O_2}/CO$ when hemoglobin values are relatively constant. In clinical anesthesia $\dot{V}_{O_2}$ is decreased and relatively stable during the anesthetized state. Therefore, it is reasonable to conclude that $S\bar{v}_{O_2}$ reflects cardiac output during anesthesia. However, this is not always true in cases where $\dot{V}_{O_2}$ is increased by shivering or excitement during recovery from anesthesia. If cardiac output is increased along with enhanced $\dot{V}_{O_2}$, $\dot{V}_{O_2}/CO$ may be relatively constant and then $S\bar{v}_{O_2}$ does not change too much. In our study, we showed that $S\bar{v}_{O_2}$ correlates well with O_2ER. O_2ER can be simplified to $1 - S\bar{v}_{O_2}/Sa_{O_2}$ by removing cardiac output and this equation can be expressed as $1 - S\bar{v}_{O_2}$ since arterial saturation is usually close to 100% during anesthesia. Then $S\bar{v}_{O_2}$ can be expected to correlate well with O_2ER as reported by Schmidt, et al.[6] Cardiac output enhances to increase $\dot{D}_{O_2}$ when additional oxygen is required by tissues. The residual level of oxygen in mixed venous blood indicates adequacy of $\dot{D}_{O_2}$ in clinical anesthesia. Therefore, it is understandable that we found a positive correlation between $S\bar{v}_{O_2}$ and $\dot{D}_{O_2}$. Thus, $S\bar{v}_{O_2}$ is an indication of adequacy of compensation for changes in tissue oxygen requirements. However, there is a poor correlation between $S\bar{v}_{O_2}$ and $\dot{V}_{O_2}$ in our study. this is because our data show both $\dot{V}_{O_2}$ and CI increasing as the patient awakens in the postoperative period, and then, $S\bar{v}_{O_2}$ is relatively stable and does not reflect changes of cardiac output during this period. It seems to be that $\dot{D}_{O_2}$ is more dependent on cardiac output than $\dot{V}_{O_2}$. It is, of course, necessary to evaluate $S\bar{v}_{O_2}$ values in relation to many factors including hemoglobin concentration, arterial oxygen saturation, cardiac output and oxygen consumption. Therefore, it is very important to monitor and evaluate $S\bar{v}_{O_2}$ along with other hemodynamic variables.

Our data indicate that continuous $S\bar{v}_{O_2}$ monitoring can provide on-line information not only about hemodyanamic state but also an oxygen transport during general anesthesia. It would be reasonable to use a catheter combined a fiberoptic reflectometry system rather than a simple Swan-Ganz catheter if insertion of a pulmonary catheter is indicated during anesthesia, since this system can provide more useful information in managing patients, especially poor risked patients.

In conclusion, continuous monitoring of $S\bar{v}_{O_2}$ during anesthesia is clinically valuable, since 1) on-line values for $S\bar{v}_{O_2}$ were closely related to those obtained in vitro from a Radiometer ABL-300, 2) there was a significant correlation between increases or decreases in $S\bar{v}_{O_2}$ values and corresponding changes in cardiac output, 3) there was a significant correlation between $S\bar{v}_{O_2}$ and percentage oxygen extraction from blood and oxygen delivery to tissues, and 4) continuous monitoring of $S\bar{v}_{O_2}$ can provide an indication of deterioration of cardiopulmonary function during anesthesia.

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