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In Vivo *Comparison of Two Mixed Venous Saturation Catheters*

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The accuracy and stability of mixed venous saturation pulmonary arterial catheters under adverse physiologic conditions has not been assessed. Either a Shaw Opticath® catheter (three-wavelength) or a Swan-Ganz® oximetry TD catheter (two-wavelength) was calibrated *in vitro* and positioned in the pulmonary artery in each of ten mongrel dogs. The *in vivo* saturations were compared to measured saturations from anaerobically collected mixed venous blood analyzed with a reference cooximeter at each step in the protocol. Oxygen delivery was varied to obtain a broad range of mixed venous saturations ($S\bar{v}_{O_2}$) by altering inspired oxygen concentration, isovolemic hemodilution, reducing cardiac output, and increasing afterload. Calculated oxygen consumption varied from 128 to 311 ml/min. Pre-insertion calibration for both catheter types compared favorably with the cooximeter prior to physiologic manipulations, although the three-wavelength catheter more closely approximated the cooximeter. The three-wavelength catheter tracked measured $S\bar{v}_{O_2}$ accurately under adverse conditions for up to 10 h (R = .994; SEE = 2.2%). The two-wavelength catheter tended to drift under the same conditions (R = .808; SEE = 10.6%). At the conclusion of the experiment, the two-wavelength system was uniformly higher then the cooximeter by 5–31% with a mean of 21% ($P \leq .003$ as compared with the initial difference by paired Student's *t* test). Pending further analysis of the tendency of the two wavelength system to drift it would seem prudent to limit its clinical application. (Key words: Blood, hemoglobin: saturation. Equipment, monitors: mixed venous saturation catheter. Measurement technique: reflectance spectrophotometry. Monitoring: $S\bar{v}_{O_2}$; mixed venous saturation.)

SPECTROPHOTOMETRIC DETERMINATION of hemoglobin saturation replaced analytical chemical determinations in the 1940s, due to the pioneering efforts of Brinkman and Zijlstra.§ Many subsequent attempts to apply spectrophotometric techniques to *in vivo* monitoring *via* reflectance oximetry have met with limited success.[1–4] Specific obstacles have included fragility of glass optical fibers, vessel wall artifact, loss of light intensity, and the confounding effect of varying hematocrit. Some of the problems were overcome by the use of fiberoptics, light emitting diodes, and multiple reference light wavelengths. These features have been incorporated into the Shaw Opticath® pulmonary arterial catheter (Oximetrix Inc., Mountain View, CA) and the Swan-Ganz® flow-directed oximetry TD catheter (American Edwards Laboratories, Santa Ana, CA). Both catheters continuously monitor $S\bar{v}_{O_2}$ *via* fiberoptic reflectance spectrophotometry. The Edwards oximetry system permits the user to update hemoglobin or hematocrit values, but uses two-reference wavelengths. The Oximetrix system has no provision for incorporating changes in hemoglobin or hematocrit, but employs three-reference wavelengths. This study compares the ability of these two *in vivo* $S\bar{v}_{O_2}$ oximetry systems to track true $S\bar{v}_{O_2}$, as measured by a benchtop *in vitro* cooximeter, under widely varied physiologic conditions.

Methods

Ten fasted mongrel dogs were anesthetized with pentobarbital (30 mg/kg), ventilated with a volume ventilator to achieve normocarbia, and paralyzed with pancuronium (0.1 mg/kg). A 6-Fr catheter was placed percutaneously into a femoral artery using the Seldinger technique, and was used to withdraw blood and monitor arterial pressure. An 8.5-Fr introducer sheath was similarly placed in a femoral vein. In five each of the ten dogs, either a two-wavelength (Edwards) or a three-wavelength (Oximetrix) $S\bar{v}_{O_2}$ catheter was inserted following calibration *in vitro* according to the manufacturer's specifications. Each catheter was positioned in the pulmonary artery by observing the characteristic pressure waveforms displayed *via* a Hewlett-Packard monitoring system (Model 1280C transducers, Model 8805D amplifiers, and a Model 7754B recorder) (Waltham, MA).

All arterial and mixed venous blood samples were collected anaerobically into heparinized syringes and analyzed immediately with both an Intrumentation Laboratory Model 282 Cooximeter and Model 1306 pH/Blood Gas Analyzer (Lexington, MA). The cooximeter was adjusted for dog hemoglobin. It was calibrated and standardized daily to known reagents. The blood gas analyzer was calibrated prior to use and between each sample to reference gases and *p*H solutions. Two reference gases having the following compositions were used: gas 1–5% CO_2, 20% O_2, 75% N, and gas 2–10% CO_2 and 90% N. The fraction of inspired O_2 was adjusted according to a Ventronics Oxygen Monitor with Model 5584 EC Oxygen Sensor.

The following measurements were collected as a baseline and subsequent to each experimental manipulation after equilibration: mean arterial pressure; central venous pressure; thermal dilution cardiac output; arterial and mixed venous blood gases, hemoglobin saturation, and hemoglobin; and *in vivo* $S\bar{v}_{O_2}$. Oxygen consumption was

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§ Brinkman R, Zijlstra WG: Determination and the continuous registration of the percentage oxygen saturation in small amounts of blood. Archivum Chirurgicum Neerlendicum 1:177–182, 1949

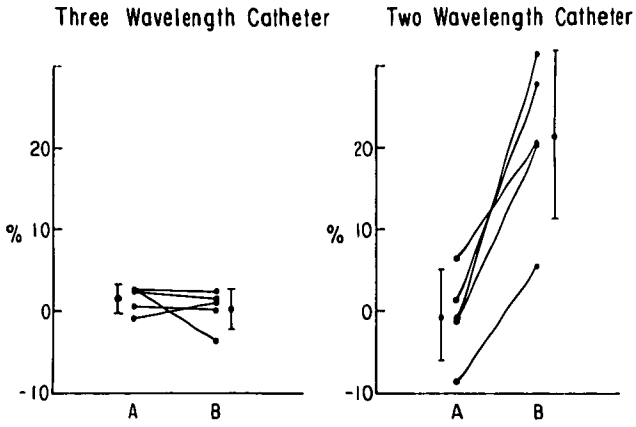

FIG. 1. Drift in $S\bar{v}_{O_2}$ catheters displayed as the difference between the catheter displayed value and the reference cooximeter at the beginning (A) and end (B) of each experiment. Means and standard deviation were not significantly different from A to B for the three-wavelength catheter. The two-wavelength catheter differed significantly from A to B ($P < 0.003$, paired Student's t test).

calculated as the difference between arterial and mixed-venous O_2 content times the cardiac output. Oxygen contents were derived from measured saturations, O_2 tensions, and hemoglobin. For the five experiments with the two-wavelength catheters, the current hemoglobin was updated prior to each measurement. The influence of hemoglobin variation upon the two-wavelength system was examined by also obtaining the $S\bar{v}_{O_2}$ with an erroneously updated hemoglobin 3 g higher and 3 g lower than the measured value for each $S\bar{v}_{O_2}$.

The experimental protocol consisted of sequentially manipulating those variables that contribute to $S\bar{v}_{O_2}$. Fi_{O_2} was varied from 1.0–0.12 initially and after each of the other manipulations. Isovolemic hemodilution to a hemoglobin level of less than 10 g/dl was then achieved by removing aliquots of blood (25 cc/kg) and replacing it with Ringers Lactate (75 cc/kg). Next, incremental doses of propranolol were administered until either cardiac output was reduced to 50% of baseline, or until a total propranolol dose of 1 mg/kg had been reached. Finally, phenylephrine was used to double the systemic vascular resistance. Temperature was maintained between 37–38° C during all experiments by warming the iv fluids and by using a warming blanket. All data was obtained during periods of relative hemodynamic stability (defined as a minimum of 10 min and an unchanging $S\bar{v}_{O_2}$ occurring after physiologic manipulation).

At the conclusion of the protocol, each catheter was recalibrated *in vivo* according to the manufacturer's instructions. Validity of the recalibration was confirmed by checking a subsequent sample for saturation, which was required to be within 1% of the displayed catheter value. At the conclusion of the series of experiments, both $S\bar{v}_{O_2}$ monitors were returned to their respective manufacturers who confirmed their proper functioning.

Paired data points (*in vivo* and *in vitro* saturations) were analyzed by the method of least squares, which yielded a regression line and correlation coefficient for each catheter. Fisher's Z test was used to compare the differences in correlation between catheters overall and in selected ranges. Fisher's Z test was also used to test the effect of varying hemoglobin in the two-wavelength catheters. The difference between the initial *in vivo* $S\bar{v}_{O_2}$ and the measured $S\bar{v}_{O_2}$ and the same difference at the conclusion of each experiment was analyzed with paired Student's t test to assess each catheter's tendency to drift.

Results

Each experiment lasted from 6–10 h due to the variability in reaching the physiological endpoints defined by the protocol. The two groups were similar in this regard. Catheter performance was examined over a wide range of $S\bar{v}_{O_2}$ from 9.4–89.6%. The derived O_2 consumption varied from 128–311 ml/min.

The *in vitro* calibration of both $S\bar{v}_{O_2}$ catheters initially approximated the cooximeter $S\bar{v}_{O_2}$ with the five three-wavelength catheters differing by $1.54 \pm 1.63\%$ (SD) and the five two-wavelength catheters differing by $-0.64 \pm 5.48\%$. At the conclusion of the experiment, the three-wavelength catheters differed from the cooximeter by $0.26 \pm 2.43\%$ and the two-wavelength catheters had drifted by a mean of $21.02 \pm 9.99\%$ ($P < 0.003$ by paired t test for the two-wavelength catheters) (fig. 1). All of the two-wavelength catheters displayed a higher $S\bar{v}_{O_2}$ than the measured $S\bar{v}_{O_2}$ at the end of the protocol.

The individual regression lines, correlation coefficients, standard errors of the estimate, and 95 percentile confidence intervals are shown for three-wavelength and two-wavelength catheters *versus* the cooximeter in figures 2 and 3, respectively. The correlation coefficients between catheter $S\bar{v}_{O_2}$ and measured $S\bar{v}_{O_2}$ are presented in three ranges in table 1. Fisher's Z test was used to compare differences in correlation between catheters. The effect of varying the hemoglobin either 3 g higher or 3 g lower than the measured value did not change the correlation coefficients for the two-wavelength catheters significantly (Fisher's Z test).

Discussion

The value of a continuous determination of mixed venous saturation depends on how accurately the *in vivo* $S\bar{v}_{O_2}$ approximates measured saturations under adverse physiologic conditions. Clinical comparisons have been limited to measurements predominantly made at greater than 60% range of $S\bar{v}_{O_2}$.[5–10] In the present study, the experimental model allowed for the manipulation of physiologic variables that reduced cardiopulmonary reserve sufficiently to produce the broad range of observed $S\bar{v}_{O_2}$. Four variables contributing to O_2 delivery (concentration of inspired O_2, hemoglobin level, cardiac output, and afterload) were manipulated. Calculated O_2 con-

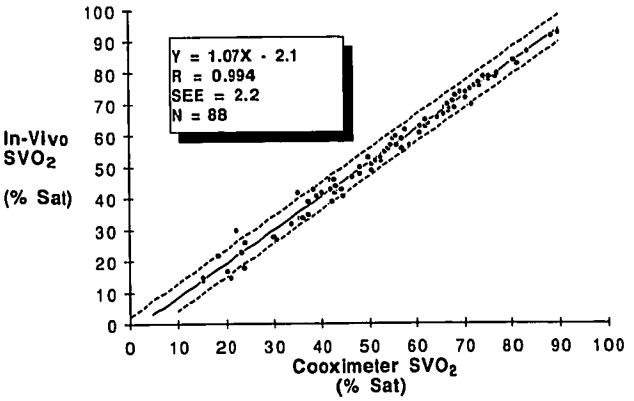

FIG. 2. Regression line for *in vivo* determination of $S\bar{v}_{O_2}$ by the three-wavelength system *versus* the *in vitro* reference cooximeter. Dashed lines represent the 95 percentile confidence interval. Inset: Regression slope and intercept, correlation coefficient (R), standard error of the estimate (SEE), and number of data points represented (N).

sumption varied, as well, over the course of the individual experiments, presumably reflecting changes in depth of anesthesia and metabolic rate.

The possibility of sampling error in the measured $S\bar{v}_{O_2}$ was reduced by the immediate availability of the reference cooximeter, deliberate anaerobic sampling technique, and confirmed reproducibility of $S\bar{v}_{O_2}$ measurements prior to initiating the protocol. The displayed *in vivo* $S\bar{v}_{O_2}$ was recorded as the sample was being drawn, prior to measuring the $S\bar{v}_{O_2}$ with the cooximeter.

The results demonstrate that both systems are able to be calibrated *in vitro* prior to insertion. The three-wavelength calibration more closely approximates the reference cooximeter (fig. 1, point A). The three-wavelength system is able to accurately track measured $S\bar{v}_{O_2}$, both over a wide range of abnormal saturations caused by different physiological manipulations, and over the time course of this study (up to 10 h).

The two-wavelength system, however, repeatedly

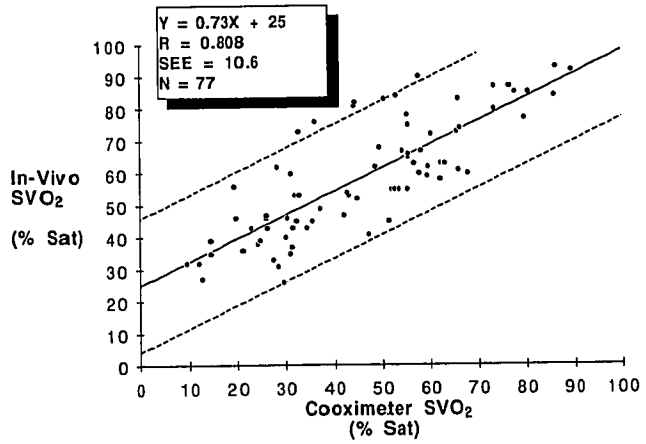

FIG. 3. As in figure 2, data collected using the two-wavelength catheter system.

TABLE 1. Correlation Between In Vivo and In Vitro Saturations

$S\bar{v}_{O_2}$ Range	Three-wavelength, R (N)	Two-wavelength, R (N)	Significance*
All	0.994 (88)	0.808 (77)	$P < 0.001$
IL < 46%	0.949 (30)	0.603 (38)	$P < 0.001$
IL 46–60%	0.909 (20)	0.268 (21)	$P < 0.001$
IL > 60%	0.987 (38)	0.789 (18)	$P < 0.001$

* Fisher's Z test used to compare differences in correlations between catheters.

N = number of observations per group; IL = reference cooximeter.

drifted during the course of the experiments, resulting in deviations from the measured $S\bar{v}_{O_2}$ from 5–31% at the conclusion of the experiments. Importantly, all five of the two-wavelength catheters showed a higher $S\bar{v}_{O_2}$ than the actual measurement. The protocol does not allow one to conclude whether the drift observed in the two-wavelength system occurred due to the adverse physiologic conditions, or time, or both.

The magnitude of the error measured in the two-wavelength system is sufficiently large to be clinically important. Until further explanation of this discrepancy is available, it would seem prudent to reserve its clinical applications to rigorously controlled experimental observations. The three-wavelength system accurately reflects measured $S\bar{v}_{O_2}$ during a wide variety of simulated clinical conditions.

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