

Original Article

In Vitro Evaluation of Continuous Mixed Venous Oxygen Saturation and Hematocrit Monitors

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Keywords: cardiopulmonary bypass; equipment accuracy evaluation; venous saturation monitor; hematocrit monitor

ABSTRACT

Four venous hemoglobin oxygen saturation monitors, two of which provide hemoglobin monitoring, were evaluated and compared to a performance standard (control) during cardiopulmonary bypass (CPB). The CDI 100 Hematocrit/Saturation Monitor, CDI 400, Cobe Hematocrit/Saturation Monitor, and the Baxter Bentley OxySat values were compared to the Radiometer Copenhagen OSM3 Hemoximeter and the Damon International Equipment Company Microbore Centrifuge Hematocrit. The Bentley OxySat meter was found to be the most accurate venous oxygen saturation monitor, with the CDI 100 and the Cobe Hct/Sat monitors correlating closely with the control. Only the CDI 400 failed to correlate with the control. The hematocrit monitors, although useful as trending devices, demonstrated inaccuracies in measurements requiring further refinement.

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INTRODUCTION

The ability to evaluate oxygen consumption during cardiopulmonary bypass is critical to maintaining adequate gas exchange and optimizing oxygen supply/demand at the tissue level (1,2). Intermittent arterial blood gas analysis permits quantification of the amount of oxygen supplied to the tissues. The ability to continuously monitor the mixed venous oxygen saturation allows the perfusionist to approximate the patient's oxygen consumption when arterial saturation, cardiac output and hemoglobin remain relatively constant (3). The derivation of oxygen consumption is well described and is often referred to as the Fick equation (4):

$$O_2 \text{ consumption} = (1.34 * \text{Hgb} * \text{saO}_2) - (1.34 * \text{Hgb} * \text{svO}_2) * 10 * \text{CO}$$

Where Hgb = hemoglobin g/dl

saO₂ = arterial oxygen saturation %

svO₂ = venous oxygen saturation %

CO = cardiac output in liters per minute

Mixed venous oxygen saturation is dependent on oxygen consumption which in turn is related to a number of factors including hemoglobin level, oxygen delivery, anesthesia level, metabolic rate, cardiac output, pH status and temperature (5). Changes in temperature, hydrogen ion concentration, and 2,3 di-phospho-glycerate levels can alter the ability of hemoglobin to bind to oxygen. This is represented by the oxygen hemoglobin dissociation curve (6,7). At normal conditions, when 50% of the venous blood is saturated the PvO₂ equals 27 mmHg. This is termed the P₅₀ (8). An increase in the P₅₀ results in a shift of the curve to the right while a decrease in the P₅₀ results in a shift to the left. This provides more oxygen delivery at the tissue level at the same arterial saturation. The balance maintained between the amount of oxygen available versus the amount extracted is best determined by the mixed venous saturation (9). Thus, mixed venous oxygen saturation monitoring provides a simple continuous method to evaluate the adequacy of tissue perfusion during CPB when used in conjunction with intermittent blood gas analysis. The purpose of this evaluation was to determine the reliability and accuracy of four mixed venous oxygen saturation and hematocrit monitors in the clinical setting.

MATERIALS AND METHODS

A total of 18 clinical cases were evaluated for accuracy of continuous venous oxygen saturation/hematocrit monitoring devices. Patient selection was limited to coronary artery bypass or valve surgery. Modification of the CPB circuit required placement of a Bentley OxySat 1/2 inch Optical Transmission Cell^a, CDI 100 H/S cuvette, and a CDI 400 venous sensor/cell^b in the venous tubing proximal to the collapsible Cobe venous reservoir bag. The Cobe VRB^c maintains a saturation/hemoglobin port on the 1/2 inch venous inlet connector. Self calibration and quality controls were completed every two hours on the

Radiometer OSM3 Hemoximeter^d and every six hours on the IEC Hematocrit^e as recommended by the manufacturer. The CDI 400 monitor was calibrated before cardiopulmonary bypass in standard two point fashion. An in-line one point calibration with the venous blood gas values obtained from the Hemoximeter and IEC Hematocrit was completed following initiation of cardiopulmonary bypass as recommended by the manufacturer. Just prior to the initiation of cardiopulmonary bypass, internal calibrations of the CDI 100 and Cobe Hct/Sat monitor were completed according to the manufacturer's recommendations. The Bentley OxySat meter and probe were calibrated using calibration test cells, and maintained within two units of the value given on test cell. The CDI 100, CDI 400, and the Cobe Hct/Sat monitors were stored simultaneously with the initial blood gas sample on cardiopulmonary bypass and calibrated according to the manufacturers recommendations (Hct, pO₂, svO₂). Subsequent blood gas samples were taken during hypothermia, during systemic rewarming, and prior to termination of cardiopulmonary bypass. The devices were recalibrated for each subsequent blood gas analysis. Regression analysis was performed on data produced from all four monitors for both venous oxygen saturation and hematocrit values.

RESULTS

Figure 3 demonstrates that the Bentley OxySat meter achieved the most statistically significant correlation with the control (R² = 0.79; p<0.001). Of the remaining devices the Cobe Hct/Sat monitor (Figure 4) also produced acceptable results (R² = 0.74; p<0.001). The CDI 100 (Figure 2) did not meet statistical correlation (R² = 0.68; p<0.001), while the CDI 400 (Figure 1) was found to be the most unreliable (R² = 0.18; p<0.308). Temperature and hematocrit did not correlate with the error of any of the devices. Regression curves for the hematocrit monitors are shown in Figures 5 and 6 and reveal that both monitors did not achieve statistical significance, (CDI 100, R² = 0.53; p<0.000, Cobe Hct/Sat, R² = 0.31; p<0.002).

DISCUSSION

During the evaluation of all the devices, a number of issues regarding the design, feasibility, and cost effectiveness were raised. While the Cobe Hct/Sat and CDI 400 utilized AC power for operation, the CDI 100 and Bentley OxySat did not have AC power capability. Following this study the CDI 100 has since been converted to AC power. Repeated use of the Bentley OxySat and CDI 100 significantly reduced the battery life span,

- a Baxter Bentley Laboratories Inc., Irvine, CA 92704
- b CDI, 3M Health Care, Tustin, CA 92680
- c COBE Laboratories Inc., Lakewood CO 80215
- d Radiometer, Copenhagen, Denmark
- e International Equipment Company, Needam Heights MA 02194

Figure 1

Regression analysis for venous oxygen saturation: CDI 400 vs. control.

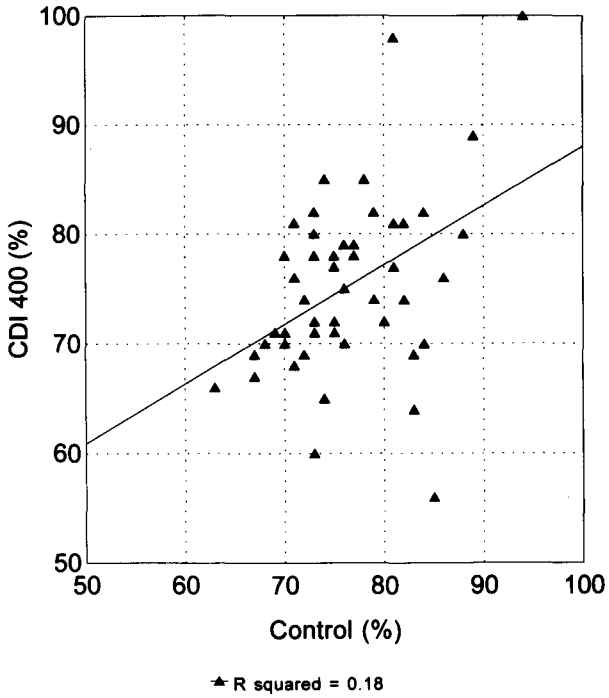


Figure 3

Regression analysis for venous oxygen saturation: Bentley OxySat vs. control.

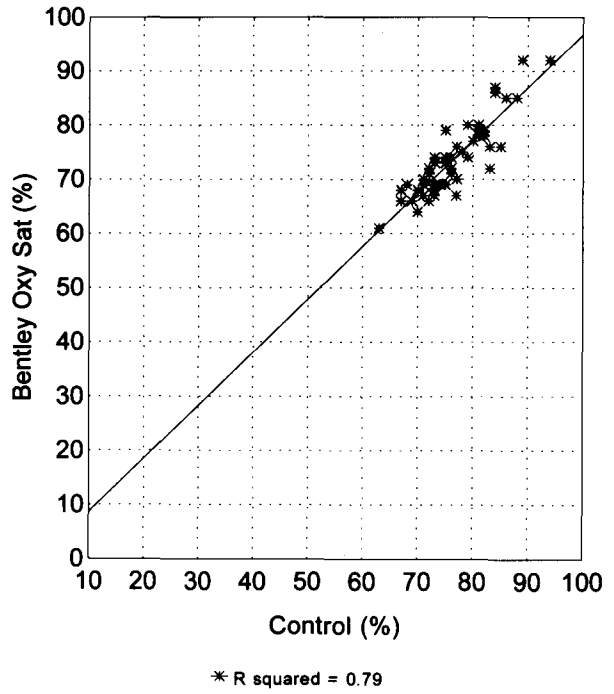


Figure 2

Regression analysis for venous oxygen saturation: CDI 100 vs. control.

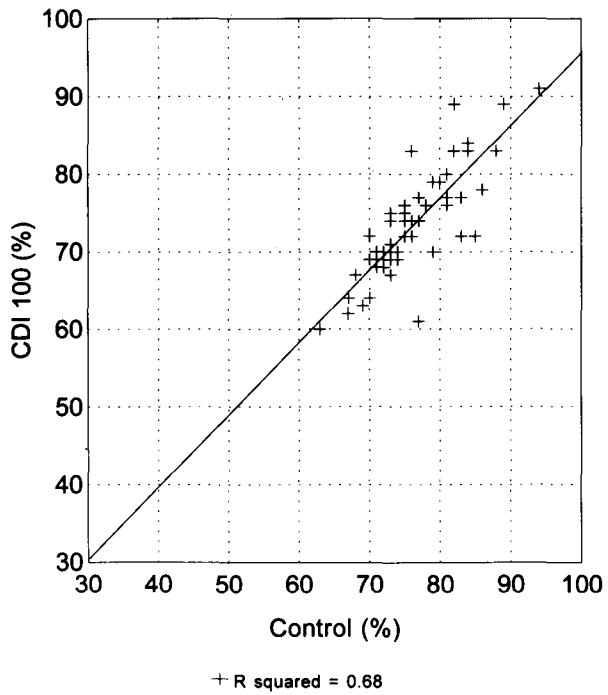


Figure 4

Regression analysis for venous oxygen saturation: Cobe VRB vs. control.

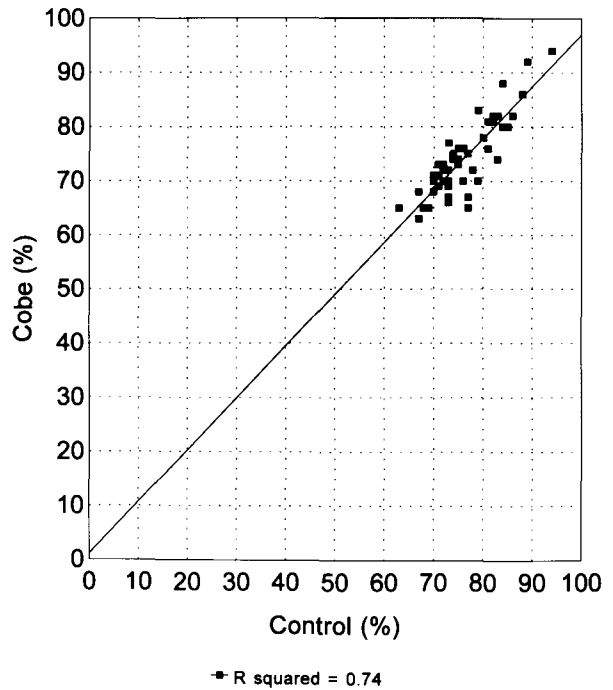
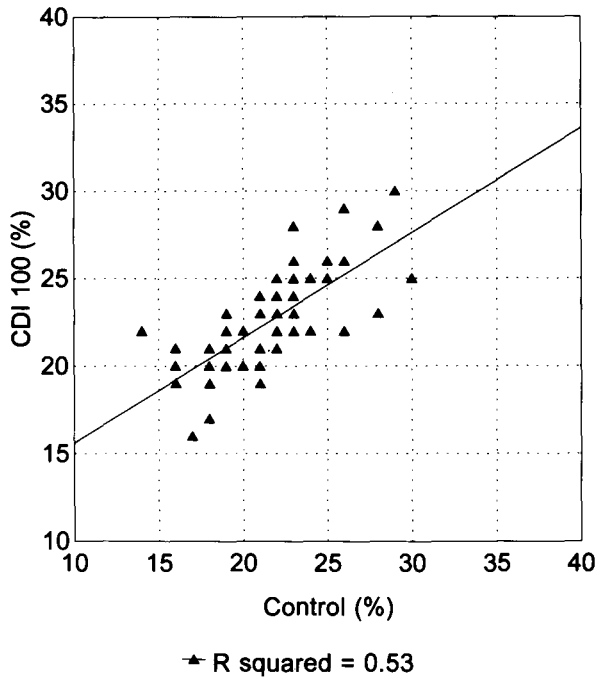
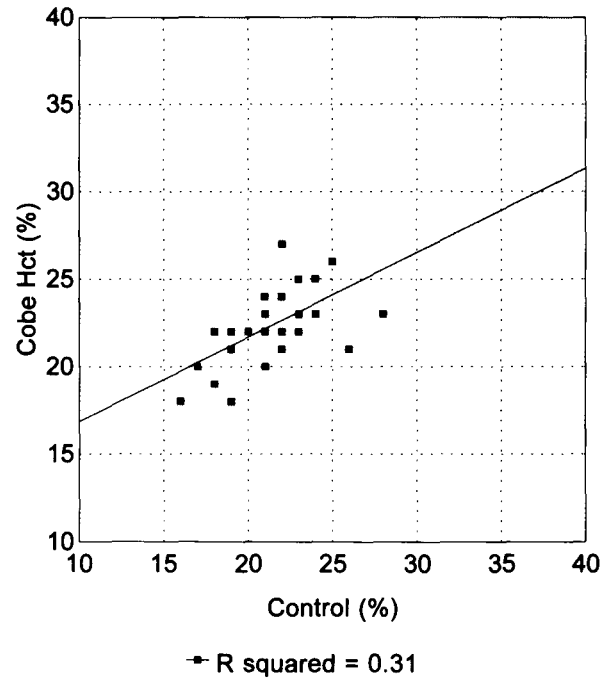


Figure 5

Regression analysis for hematocrit determination: CDI 100 vs. control.

**Figure 6**

Regression analysis for hematocrit determination: Cobe VRB vs. control.



requiring replacement of their 6.0 volt batteries during CPB. Unfortunately, replacement of the CDI 100 battery results in loss of DC power and requires recalibration of the device. Loss of DC power with the Bentley OxySat monitor merely requires replacement of the battery. The CDI 400 provides an additional 12 volt battery backup in case AC power failure occurs. The CDI 100, Cobe Hct/Sat, and the Bentley OxySat monitors utilize infrared spectroscopy to derive oxygen saturation. The CDI 400 measures the pvO_2 utilizing optical fluorescence. Once the pvO_2 is known, venous saturation can be derived by plotting the pvO_2 on the oxygen dissociation curve. Thus the CDI 400 reports venous oxygen saturation as a calculated value based on the pvO_2 . The only technical difficulty encountered during our evaluation was the failure of the fiber optic probe of the Cobe monitor, which required replacement on two different occasions. We believe the location of the Hct/Sat port on the venous inlet of the Cobe VRB, positioned in close proximity to the cardiomy reservoir return line, results in a continued variance in the svO_2 and hematocrit during procedures when the addition of crystalloid or blood to the cardiomy reservoir is excessive. This monitor further limits itself as the Hct/Sat port is only available as an integration with the Cobe hard shell or collapsible venous reservoirs. Knowledge of the venous oxygen saturation is an effective method of evaluating oxygen supply/demand at the tissue level when interpreted along with other clinical parameters (i.e., cardiac output, arterial saturation, hemoglobin, lactate). Equally important is the reliability and

accuracy of the device being employed. The ability to monitor continuously provides the perfusionist tremendous flexibility with minimal intervention. Of the two Hct/Sat monitors, we found both to be reliable in measurement of svO_2 , although we believe that continuous measurement of hematocrit requires further refinement. We found that the Bentley OxySat provided accurate venous oxygen saturation monitoring with minimal preparation and intervention at a nominal cost.

ACKNOWLEDGEMENTS

We would like to thank the following for their material and technical support: Baxter Healthcare Corporation, CDI 3M Health Care and Cobe Cardiovascular Inc. We also wish to thank Jan Carney of the Presbyterian University Hospital Stat Lab for technical support, and Patricia Sawzik, PhD for editorial review.

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