

Continuous Monitoring of Blood Oxygen Saturation During Extracorporeal Circulation

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Abstract

The Bentley* "oxysat" oxygen saturation meter is a small, digital, battery-operated, dual wave length, optical device. Two probes, arterial and venous, are mounted into the extracorporeal blood line during open-heart surgery.

Correlation tests between van Slyke, Lcx O₂ con, and calculated saturations, have shown accuracy and repeatability of oxygen saturation values during extracorporeal circulation on twenty cardiac patients.

The meter proved useful during extracorporeal circulation by providing access to immediate observation of blood saturation and valuable trend data in the course of perfusion, and allowing better control of gas and blood flow during bypass. It also helped prevent excessive pO₂s, gaseous microemboli, effort factor during blood sampling, and blood waste.

Introduction

The performance of an artificial lung during extracorporeal circulation, in terms of oxygen transfer, can only be measured by monitoring blood oxygen saturation levels. Recent advances in oxygenator technology have made it possible to use extracorporeal procedures for longer periods, and also to reach higher oxygen

saturation levels. Under these conditions, the blood saturation could be continuously monitored in order to observe the patient's condition as well as the performance of the machine.

The oxygen saturation levels are usually measured by taking samples of the circulated blood from both the inlet and outlet of the oxygenator. The pO₂, pCO₂, and pH, can be determined from these samples. Using this data, the oxygen saturation levels can be calculated.^{1,7} During bypass, many perfusionists do not have or take the time to perform the necessary calculations to compute the saturation levels.^{5,13} Instead, they estimate the blood saturation levels on the basis of the blood gases alone. This approximation does not always work, for it is possible to have 100% saturation within a wide range of pO₂, and other errors due to cumulative errors of the blood gas measurements can occur.

Optical in-line oximetry seems an ideal replacement for taking blood samples,^{2,3,4,9,10} since it provides immediate access to arterial, venous, and differential blood saturation levels. A saturation meter should be a necessary component for extracorporeal circuits because the blood saturation level is the major factor in regulating the oxygenator. The meter is imperative for studies involving the measurement of oxygen transfer rates of an oxygenator. Since the venous blood returning to the oxygenator from the animal or patient must be adjusted, the saturation meter obviates the need for first estimating the oxygen content by blood color, then drawing a venous blood sample to calculate

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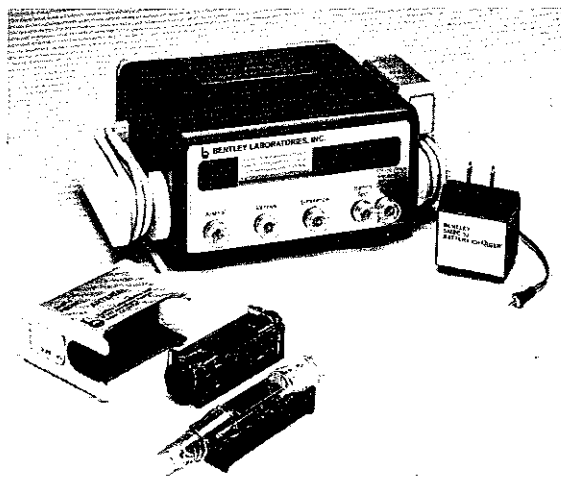


FIGURE 1. The oxygen saturation meter.

the saturation level. If the saturation level is not within the proper limits when the samples are drawn, the whole procedure must be repeated. An oximeter would reduce the time and problems involved in measuring oxygen saturation and improve the accuracy of experiments.

The Bentley oxygen saturation meter introduces optical oximetry to a clinical setting. In a 30-second response time, the perfusionist and anesthesiologist can have a continuous indication of blood oxygenation and adequacy of tissue perfusion, while simultaneously monitoring the arterial and venous oxygen saturation levels. The data is provided on demand, therefore no samples have to be withdrawn from the circulation. Blood loss and the hazards of infection are decreased, and the risk of oxygen toxicity and machine malfunction are reduced.

The oxygen saturation meter (Fig. 1) is a small, digital, battery-operated, electronic, dual wave length, optical device, which mounts on an IV pole. Two probes, arterial and venous, are attached to cuvettes mounted in the oxygenator blood line during open-heart surgery. The cuvette is a plastic straight-through connector with a window in it, through which the optical coupling is made. This electronic probe clips onto the connector, which is the only part of the device to come into contact with the blood. Specifically, the meter is a device for high-speed, on-line, full-flow, oxygen saturation measurement in an extracorporeal circuit.

All the circuits in the oximeter are designed to provide a fail-safe circuit, so that if a switch fails, a probe

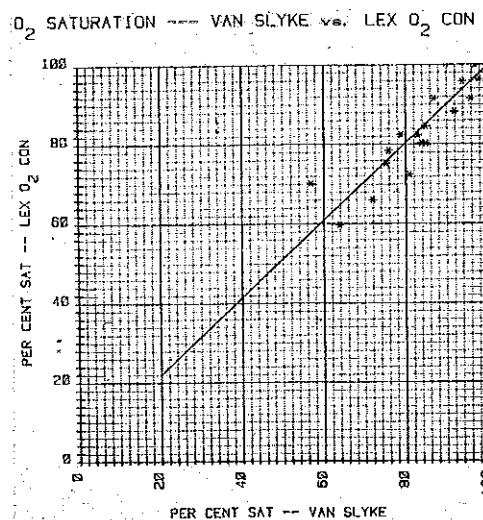
breaks, or a cuvette is improperly chosen or assembled, the meter will read a nonsense number clearly defined as an error on the face of the instrument.

Methods and Materials

The efficacy and usefulness of the oximeter was tested by correlating the results between the van Slyke,** Lex O₂ con, Radiometer*** blood gas machine, and the oxysat. In vitro testing of the machine was conducted using 21-day old human blood, standardized to the following values: HCT = 35 ± 2 , HGB = 11 ± 2 , pH based in normal physiologic range, pO₂ equivalent to saturation of 30%, temperature 37 C. The calibrations were set on the same scale for each different method of testing. See Graphs I, II, and III.

The calibration references for the oximeter were determined by color chips, blank cuvettes filled with color to indicate an optical reflection equal to the desired value (approximately either 30 or 60% ± 2) of blood oxygen saturation. These color chips are prepared for the operator's calibrations by the Manufacturer.

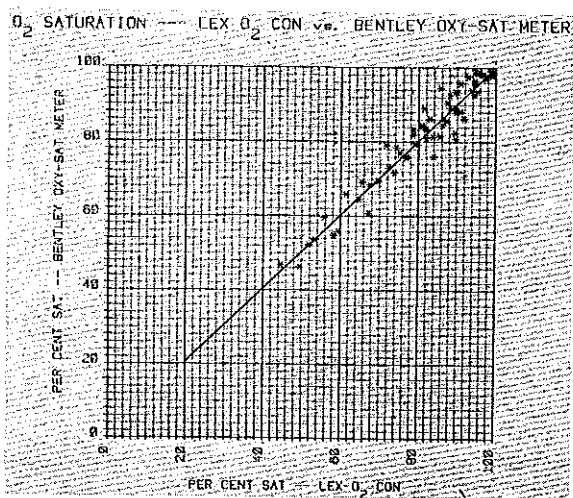
The Lex O₂ con, van Slyke, and Radiometer blood values were calculated according to the method described in the operator's manual for the oxysat. The results are expressed in volumes per cent and then converted to blood oxygen saturation levels. A calcu-



GRAPH I. Oxygen saturation correlation between van Slykes and Lex O₂ con. Where the mean of X = 85.24, with a standard deviation of 13.57476651, and the mean of Y = 87.802, with a standard deviation of 12.89295789. $Y = 0.9110516267 \times X + 10.1439534$. Standard error of slope: 0.3874469054, T-value: 23.5142316. Standard error of estimate: 3.681650893. Correlation Coefficient R: 0.9592300858, R squared: 0.9201223576.

** Lexington Instrument Corp., Waltham, MA.

*** Radiometer-Copenhagen, Copenhagen, Denmark.



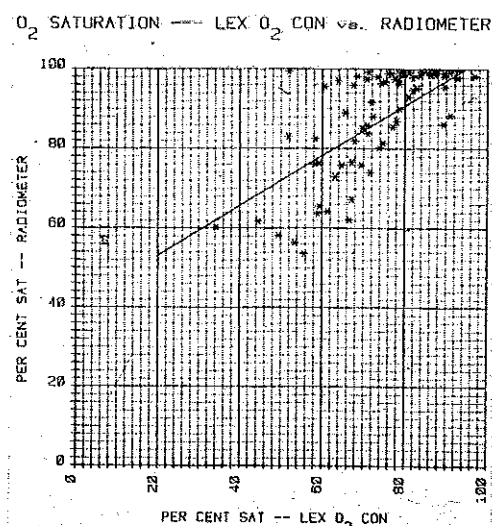
GRAPH II. Oxygen saturation correlation between Lex O₂ con and the Bentley oxygen saturation meter. Where the mean of X = 86.53571429 with a standard deviation of 14.2395431, and the mean of Y = 86.54897959, with a standard deviation of 14.55197046. $Y = 0.9936076078 \times X + 0.5664346689$. Standard error of slope: 0.02438983684. T-value: 40.73859224. Standard error of estimate: 3.42050923. Correlation coefficient R: 0.9722750972. R squared: 0.9453188647.

lation volume, which is a blood sample fully oxygenated to 100% saturation (or as close as possible), is called the capacity sample. A set of arterial, venous, and capacity samples is taken simultaneously during the testing. A total of 36cc's of blood was drawn for each sample: 12cc's each for an arterial, venous, and capacity volume. This procedure was repeated approximately every 15–20 minutes, or about three times per test.

The device was also tested routinely in both arterial and venous blood lines for 23 ex vivo calf perfusions. When the saturation meter was tested clinically, twenty consenting patients were randomly selected from patients undergoing cardiopulmonary bypass. Techniques used for the extracorporeal circulation did not vary from standard procedures at Pacific Medical Center. The same methods for calibrations used in in vitro testing were applied to ex vivo and clinical cases.

Results

Correlations between van Slyke, Lex O₂ con, and the Bentley oximeter during in vitro, ex vivo, and clinical testing proved to be excellent. The correlation between the oxysat and the pO₂ saturation, however, was rather poor, when derived from calculations using the Lutz method.⁷ Like many other authors,^{12,8} we believe that the pO₂ method of calculation is technique dependent.



GRAPH III. Oxygen saturation correlation between Lex O₂ con and the radiometer. Where the mean of X = 80.09814815 with a standard deviation of 15.27105246, and the mean of Y = 90.8287037, with a standard deviation of 12.48202484. $Y = 0.6294018249 \times X + 40.41478308$. Standard error of slope: 0.02438983684. T-value: 12.42639585. Standard error of estimate: 8.000988969. Correlation coefficient R: 0.770037587. R squared: 0.5929578853.

Discussion

It should be noted that some errors in the calculations can be caused by the technique used in taking van Slyke and Lex O₂ con samples which result in major discrepancies in the saturation readings. The system, monitored by the saturation meter, is constantly changing, so variations are always possible. Errors can also occur in the calculated saturation (PaO₂), as studies on the relative values of oxygen saturation and oxygen tension show⁷ when there is a marked shift in the oxygen dissociation curve. The results on the blood gases measured by the Radiometer were inaccurate because of variations in the calculations.⁶

The saturation meter gives insight into dealing with problems of variations in the pO₂ between the arterial and venous lines, which have been linked to temperature changes and blood saturation levels. Fluctuations in the oxygen tension in the extracorporeal circuit between the arterial and venous lines tend to increase at a lower temperature.¹¹ When the blood in the extracorporeal circuit is fully saturated, however, a temperature decrease of 10% along the arterial line will not change the total oxygen content, and the temperature will no longer significantly effect the oxygen tension.¹¹ With the oxysat, the saturation levels can be monitored in order to control this type of situation.

The oxygen saturation meter could be an important addition to the extracorporeal circuit, because it is an advanced piece of technology which compliments the sophistication of the other equipment used during open-heart surgery. A constant monitoring of blood saturation levels gives the perfusionist the opportunity to maintain a fuller understanding of his patient's condition and his machine's operation. The main attribute of the oxysat is that it provides a continuous, immediate access to blood oxygen saturation levels. It is an efficient replacement for standard methods of determining saturation levels. Therefore, the performance of the artificial lung can be easily monitored during extracorporeal circulation.

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