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Pulse Oximetry during One-lung Ventilation

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The variable intrapulmonary shunt that occurs during selective one-lung ventilation (OLV) may result in hypoxemia, even when inspired oxygen concentration is 100%. An accurate method of continuously monitoring oxygenation would increase the safety of OLV. We therefore compared directly measured arterial hemoglobin–oxygen saturation (Sa_{O_2}) with Sa_{O_2} obtained by continuous noninvasive pulse oximetry to determine if oximetry is useful during OLV.

METHODS

With the approval of our hospital Human Subjects Committee, 19 adult patients scheduled for surgical procedures in which we planned to use OLV consented to be studied. Operations included 10 pulmonary lobectomies, four pneumonectomies, two bilateral pulmonary wedge resections, two thoracoscopies, and one esophagogastrectomy.

In the operating room, a cannula was inserted into a radial artery for blood sampling and the sensor of a pulse oximeter (N-100, Nellcor®, Hayward, California) was placed on an index finger. Anesthesia was induced with thiopental and succinylcholine given to facilitate tracheal intubation with a double-lumen endobronchial tube. General anesthesia was maintained with isoflurane (1.0–2.0%) and O_2 (100%), supplemented with fentanyl, iv, as needed. Ventilation was controlled with a tidal volume of 12 ml/kg at a rate of 8–10/min. Seventeen patients were placed in the lateral position following anesthetic induction. Correct placement of the double-lumen tube was verified by auscultation immediately following tracheal intubation and again if the patient was transferred from the supine to lateral position.

The inspired oxygen concentration was maintained at 100% throughout the case. During surgery, the exposed lung was collapsed in order to improve surgical exposure. Ventilator settings were left unchanged during OLV. Arterial blood was sampled and Sa_{O_2} analyzed by CO-Oximeter® (IL 282, Instrument Laboratories, Menlo Park, California) immediately prior to the start and then every 5 min during OLV. These Sa_{O_2} values were compared with the Sa_{O_2} reading on the digital display of the pulse oximeter at the time the arterial samples were obtained.

RESULTS

A total of 120 matched measurements were made for the 19 patients studied. The average time of OLV was 50 min (range 10–95 min). During OLV, Sa_{O_2} ranged between 79–100%. Figure 1 shows the per cent error of the estimate of Sa_{O_2} for the 120 matched samples comparing noninvasive pulse oximetry with direct arterial blood analysis.

Data from the five patients who had at least one Sa_{O_2} measurement <90% are shown in figure 2. The 35 pooled data points from these patients were analyzed by analysis of linear regression. Correlation coefficient (R) was 0.93. In each case, hypoxemia was initially detected by pulse oximetry and later confirmed by the CO-Oximeter.®

Four patients were hypotensive (mean arterial pressure [MAP] <60 mmHg [range 47–120 mmHg]) during OLV. The matched Sa_{O_2} determinations were in very close agreement (<2.0% difference) during periods of hypotension.

Following reinflation of the collapsed lung, Sa_{O_2} returned to pre-OLV levels. The tracheas of all patients were extubated at the completion of surgery.

DISCUSSION

The hypoxemia that can occur during OLV makes rapid, accurate assessment of oxygenation extremely important. Direct arterial blood gas analysis for Sa_{O_2} is reliable, but the method is invasive and the intermittently obtained information is not immediately available. Frequent blood gas measurements are expensive.

Monitoring transcutaneous oxygen tension (Ptc_{O_2}) has been recommended for OLV.[1,2] Ptc_{O_2} monitors are noninvasive and provide continuous information. However, Ptc_{O_2} sensors need 10 min to warm-up before they can be used, and the skin beneath the sensor must be

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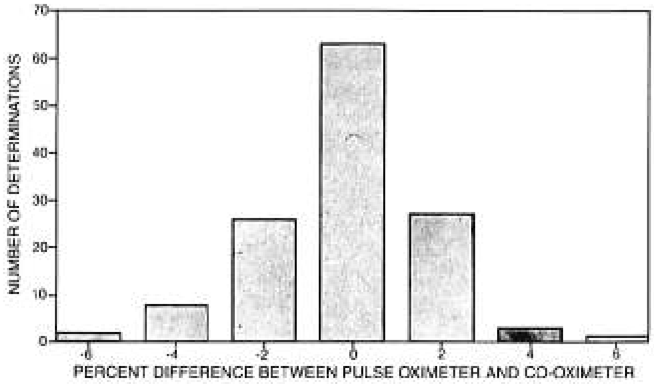


FIG. 1. The range of differences between arterial hemoglobin–oxygen saturation (Sa_{O_2}) obtained by CO-Oximeter® and pulse oximeter are shown.

heated to 44–45° C with a potentially harmful local heat source in order to "arterialize" the blood. Normally, Ptc_{O_2} is approximately 80% of actual arterial oxygen tension (Pa_{O_2}). Ptc_{O_2} is accurate only while the patient is hemodynamically stable with a cardiac index greater than 2.2 $l \cdot min^{-1} \cdot m^{2^{-1}}$.[1] During periods of hypotension, Ptc_{O_2} does not accurately follow Pa_{O_2} but drops because of decreased cardiac output and inadequate tissue oxygen delivery.[1] Therefore, a low Ptc_{O_2} reading may be misleading if Pa_{O_2} is adequate but tissue perfusion is not. Even for normotensive patients, Ptc_{O_2} determinations may be inaccurate. The simultaneously obtained readings from two identical Ptc_{O_2} sensors placed next to each other on the skin of 21 surgical patients were compared.[3] There was an enormous variability between these

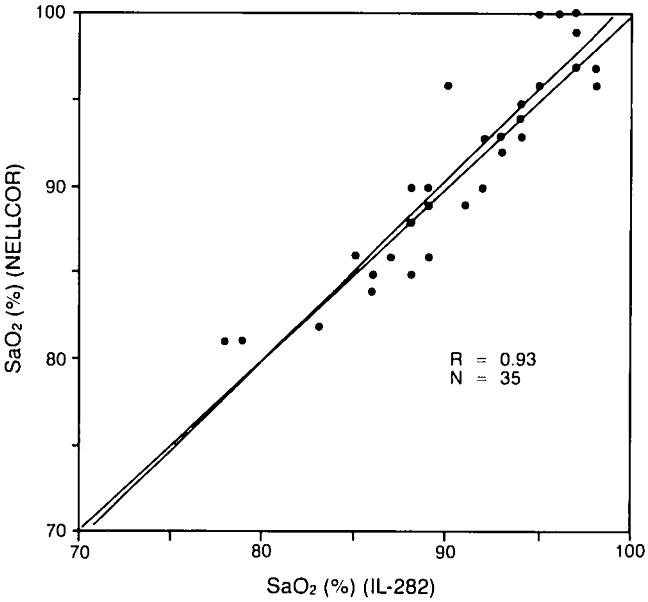
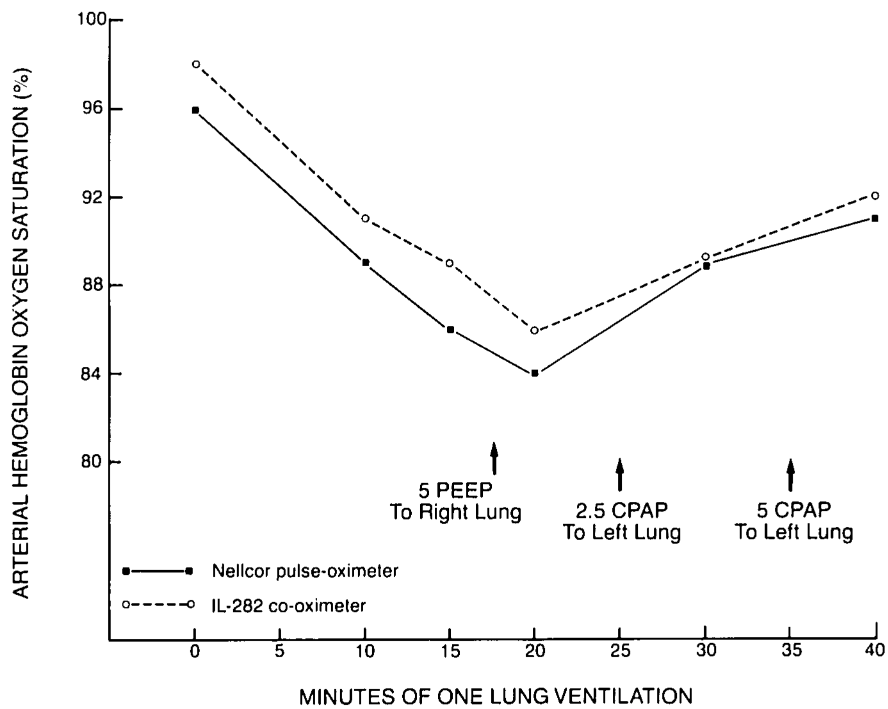


FIG. 2. The pooled data from five patients with Sa_{O_2} <90% during one-lung ventilation are shown. The pulse oximeter accurately measured Sa_{O_2} during periods of hypoxemia.

matched Ptc_{O_2} measurements, prompting the investigators to question the reliability of Ptc_{O_2} monitoring in estimating the value of, or changes in, Pa_{O_2} during surgery.

Like the Ptc_{O_2} monitor, the pulse oximeter is noninvasive and gives continuous information. However, pulse oximetry requires no heat source and is ready to use immediately. The pulse oximeter works by placing a

FIG. 3. The changes in Sa_{O_2} during one-lung ventilation in a 55-year-old man undergoing left upper lobectomy for carcinoma are shown. Early recognition of hypoxemia by pulse oximetry allowed us to treat the patient immediately with PEEP to the ventilated right lung. When no improvement was evident, incremental amounts of CPAP were added to the nonventilated left lung until Sa_{O_2} returned to a satisfactory level.



pulsating arterial vascular bed between a light source and a detector. The optical transducer used in the Nellcor® instrument consists of two light-emitting diodes and a photocell mounted in adhesive tape. The pulsating vascular bed, by expanding and contracting, creates a change in the light path that modifies the amount of light detected. Nonpulsatile substances such as skin, bone, and venous blood are not detected. In order to determine the percentage of arterial hemoglobin saturated with oxygen, the oximeter measures the ratio of the pulse amplitude of a pulse of red light (660 nm) and compares it with the pulse amplitude of the same pulse in infrared light (940 nm). The ratio varies, depending upon the relative fraction of saturated to unsaturated hemoglobin in the arterial blood. This ratio is used to calculate the Sa_{O_2}.

Pulse oximetry is accurate for a wide range of hemodynamic conditions as long as a pulse is present beneath the sensor.[4] The oximeter we used accurately measures Sa_{O_2} to 70%.[4] Early recognition of hypoxemia (Sa_{O_2} <90%) by oximetry enabled us to institute steps to improve oxygenation, as illustrated in figure 3. Oxygenation can be optimized during OLV by a variety of means including CPAP to the nonventilated lung, PEEP to the ventilated lung, or discontinuation of OLV.[5]

We found no clinically significant differences between directly and transcutaneously measured Sa_{O_2}. With the pulse oximeter the information was available sooner, hence, there was no delay waiting for the results of blood gas analysis before beginning appropriate therapy. Although we still place an indwelling arterial line for blood pressure and arterial blood gas monitoring during thoracic operations, we now also monitor all our patients by pulse oximetry. We no longer are dependent on frequent arterial blood gas samples to follow arterial oxygenation during OLV.

REFERENCES

1. Tremper KK, Konchigeri HN, Cullen BF, Kapur PA, Thangathurai D, Percival C: Transcutaneous monitoring of oxygen tension during one-lung anesthesia. J Thorac Cardiovasc Surg 88:22–25, 1984
2. Salmenpera M, Heinonen J: Transcutaneous oxygen measurement during one-lung anaesthesia. Acta Anaesthiol Scand 28:241–244, 1984
3. Adriano KP, Pace NL, Wilbrink J, Zwanikken P, Stanley TH: Intraoperative transcutaneous PO_2 ($TcPO_2$) monitoring quantitates PaO_2. Fact or fiction? Anesth Analg 63:178, 1984
4. Yelderman M, New W Jr: Evaluation of pulse oximetry ANESTHESIOLOGY 59:349–352, 1983
5. Capan LM, Turndorf H, Patel C, Ramanathan S, Acinapura A, Chalon J: Optimization of arterial oxygenation during endobronchial anesthesia. Anesth Analg 59:847–851, 1980

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Epidural Block Using Large Volumes of Local Anesthetic Solution for Intercostal Nerve Block

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Repeated intercostal nerve blocks for analgesia have been used in postoperative patients, *e.g.*, cholecystectomy[1] and in certain trauma patients, *e.g.*, rib fractures.†† Adequate analgesia improves pulmonary compliance with coughing and deep breathing, thereby decreasing the risk of pulmonary atelectasis and ventilation/perfusion abnormalities.[2]

Continuous intercostal nerve blockade over five dermatomes has been achieved by inserting a catheter in one intercostal space.[3] Murphy has used this technique successfully in patients with rib fractures†† and following cholecystectomy.[4] How can a single injection of anesthetic into one intercostal space produce analgesia over several dermatomes? In cadaver studies, Nunn and Slavin[5] and Moore[6] identified the spread of an agent using small volumes of dye solutions. The use of radionuclides provides a method wherein the spread of an anesthetic

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†† Murphy DF: Intercostal nerve blockade for fractured ribs and postoperative analgesia. Regional Anesthesia 8:151–153, 1983.