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PHYSIOLOGICAL NOTE

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Pulse oximetry

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Introduction

Continuous monitoring of arterial blood saturation using pulse oximetry has become the standard of care in the ICU. With the proliferation of pulse oximeters, episodic hypoxemia is detected much more commonly than previously suspected. By alerting the clinician to the presence of hypoxemia, pulse oximeters can lead to a more rapid treatment of serious hypoxemia and possibly avoid serious complication. Moreover, pulse oximetry can reduce arterial blood gas analysis and potentially decrease health care costs [1].

Principles of pulse oximetry

Pulse oximeters determine oxygen (O_2) saturation by measuring light absorption of arterial blood at two specific wavelengths, 660 nm (red) and 940 nm (infrared) [2]. The ratio of absorbencies at the wavelengths is then calibrated empirically against direct measurements of arterial blood oxygen saturation (SaO_2), and the resulting calibration curve is used to generate the pulse oximeter's estimate of arterial saturation (SpO_2). In addition to the digital read-out of O_2 saturation, most pulse oximeters display a plethysmographic waveform, which can help clinicians distinguish an artifactual signal from the true signal (Fig. 1).

The accuracy of commercially available oximeters in critically ill patients has been validated in several studies [3]. Compared with the measurement standard (multiwavelength CO oximeter), pulse oximeters have a mean difference (bias) of less than 1% and a standard deviation (precision) of less than 2% when SaO_2 is 90% or above [4]. While pulse oximetry is accurate in reflecting one-point measurements of SaO_2, it does not reliably predict changes in SaO_2 [4]. Moreover, the accuracy of pulse oximeters deteriorates when SaO_2 falls to 80% or less. In critically ill patients, poor agreement between the oximeter and a CO oximeter has been observed, with bias the

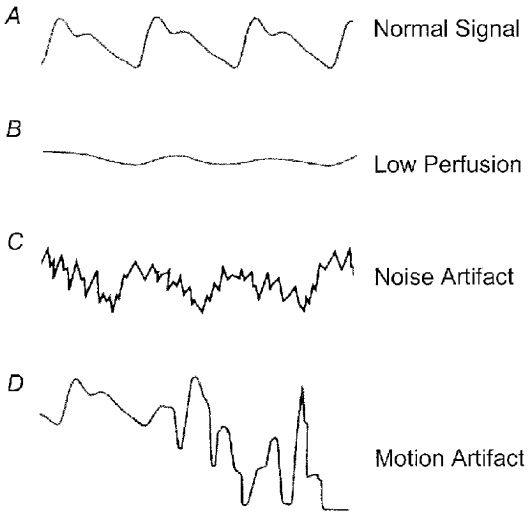

Fig. 1 Common pulsatile signals on a pulse oximeter. *Top panel* Normal signal showing the sharp waveform with a clear dicrotic notch. *Second panel* Pulsatile signal during low perfusion showing a typical sine wave. *Third panel* Pulsatile signal with superimposed noise artifact giving a jagged appearance. *Lowest panel* Pulsatile signal during motion artifact showing an erratic waveform. (From [1])

ranging from −12% to 18%, and oximetry tends systematically to underestimate SaO_2 when it is 80% or less.

Limitations of pulse oximetry

Oximeters have a number of limitations which may lead to inaccurate readings [1]; these are presented below.

Physiological limitations

Oxyhemoglobin dissociation curve

Pulse oximeters measure SaO_2, which is physiologically related to arterial oxygen tension (PaO_2) according to the oxyhemoglobin dissociation curve. Because the dissociation curve has a sigmoid shape, oximetry is relatively insensitive in detecting the development of hypoxemia in patients with high baseline levels of PaO_2.

Limitation in the signal processing

Ambient light

Although pulse oximeters correct for ambient light, falsely low SpO_2 readings have been reported with fluorescent and xenon arc surgical lamps. Wrapping the probe with an opaque shield can minimize this effect.

Low perfusion

Pulse oximetry depends on satisfactory arterial perfusion of the skin, and thus low cardiac output, vasoconstriction, or hypothermia can make it difficult for a sensor to distinguish the true signal from background noise. In cardiac surgery patients experiencing hypothermia and poor perfusion, only 2 of 20 oximeters (Criticare CSI 503, Datex Satlite) provide measurements within ±4% of the CO oximeter value.

Motion artifact

The occurrence of motion artifacts continues to be a significant source of error and false alarms. In 235 surgical patients managed in the ICU, 67% of pulse oximeter alarms were false [5]. An innovative technological approach, termed Masimo signal extraction technology, was introduced to extract the true signal from artifact due to noise and low perfusion. When tested in 50 postoperative patients, the pulse oximeter's alarm frequency was decreased twofold with the new system vs. a conventional oximeter. When tested under conditions of low perfusion and motion, the ability to track changes in SpO_2 and reduce nuisance alarms was improved with this technology [3].

Interference from substances

Dyshemoglobins

Pulse oximeters employ only two wavelengths of light and thus can distinguish only two substances, oxyhemoglobin and reduced hemoglobin. Accordingly, elevated carboxyhemoglobin and methemoglobin levels can cause inaccurate oximetry readings [1].

Intravenous dyes

Intravenous dyes such as methylene blue, indocyanine green, and indigo carmine can cause falsely low SpO_2 readings, an effect that persists for up to 20 min.

Skin pigmentation and other pigments

Inaccurate oximetry readings have been observed in pigmented patients. In critically ill patients, a bias of more than 4% has been observed to occur more frequently in black (27%) than in white patients (11%). Nail polish, if blue, green, or black, causes inaccurate SpO_2 readings; however, mounting the oximeter probe sideways alleviates the problem with nail polish. Acrylic nails do not interfere with readings.

Limited knowledge of technique

Many users have only a limited understanding of pulse oximetry. One survey revealed that 30% of physicians and 93% of nurses thought that the oximeter measured PaO_2. A more recent audit demonstrated that less than 50% of nurses and physicians were able to identify that motion artifact, arrhythmias, and nail polish can affect the accuracy of pulse oximeter [6].

Clinical applications

Detection of hypoxemia

With the introduction of pulse oximetry hypoxemia (defined as an SpO_2 value less than 90%) is detected more often in critically ill patients. Moreover, myocardial ischemia (defined as angina or ST segment depression) in postoperative patients is less common in patients monitored with pulse oximetry than those without oximetry [7].

Assessing pulmonary gas exchange

Pulse oximeters measure SaO_2, which is physiologically related to PaO_2. In critically ill patients receiving mechanical ventilation, changes in SpO_2 may not accurately reflect changes in PaO_2 and may in fact be in an opposite direction to the change in PO_2. Decisions in therapy made on the basis of SpO_2 alone can also differ from those based on PO_2. Accordingly, caution is required when making decisions in critically ill patients based solely on pulse oximetry. While pulse oximetry is a suitable way of measuring arterial oxygenation, it does not assess ventilation. Indeed, measurements of SpO_2 have been shown to be inaccurate in assessing abnormal pulmonary gas exchange, defined as an elevated alveolar-arterial O_2 difference [1].

Titration of fractional inspired oxygen concentration

Pulse oximetry can assist with titration of fractional inspired oxygen concentration (FIO_2) in ventilator-dependent patients, although the appropriate SpO_2 target depends on a patient's pigmentation. In white patients, an SpO_2 target value of 92% predicts a satisfactory level of oxygenation, whereas black patients required an SpO_2 target of 95%. In patients with severe acute respiratory distress syndrome, an SpO_2 target of 88–90% is acceptable in order to minimize oxygen toxicity.

Blood pressure measurements

In pulse oximeters that display a pulsatile waveform, systolic blood pressure can be measured by noting the reappearance of the pulsatile waveform during cuff deflation or the waveform disappearance during slow cuff inflation (Fig. 1). In healthy volunteers, good agreement (i.e., bias <1.0 mmHg) was obtained when the average of oximetry based-systolic pressure estimates at the disappearance and reappearance of the waveform were compared with Korotokoff sound pressures and noninvasive equipment blood pressures.

Cardiopulmonary arrest

The usefulness of pulse oximetry as part of the first-line resuscitation equipment at the site of a cardiopulmonary arrest was assessed in 20 patients [8]. A signal in which the pulse rate on the oximeter was correlated with the electrocardiogram or chest compression rate was observed in the three patients who suffered only a respiratory arrest and in only 4 of 17 patients who suffered a cardiac arrest. The physicians judged the pulse oximeter was to be of definite benefit in the management of 7 of 20 patients, 5 of whom survived.

Screening test for cardiopulmonary disease

The potential usefulness of pulse oximetry as a screening tool for cardiopulmonary disease that could supplement or supplant respiratory rate as a "pulmonary vital sign" was investigated in patients managed in the emergency department [9]. An inverse but weak relationship (correlation coefficient –0.16) was observed between SpO_2 and respiratory rate. Overall only one-third of patients with an SpO_2 value below 90% would exhibit an increase in respiratory rate. While pulse oximetry could be used as a screening tool for cardiopulmonary disease, there are no data to suggest that decisions based on SpO_2 improve outcome over decisions based on respiratory rate.

Screening for respiratory failure in asthma

Pulse oximetry has been evaluated as a means of screening for respiratory failure in patients with severe asthma [10]. Respiratory failure occurred in only 4% of the patients with an SaO_2 value higher than 92%. The investigators concluded that an SpO_2 higher than 92% in this setting suggests that respiratory failure is unlikely and therefore arterial blood gas measurements are unnecessary. Interestingly, this threshold value of 92% is the same target value that predicted reliably a satisfactory level of oxygenation during titration of FIO_2 in ventilator-dependent patients.

Pulmonary embolus

In patients with documented pulmonary embolism the room air SpO_2 level may be an important predictor of death; mortality was found in one study to be 2% in patients with pulse oximetry of 95% or higher vs. 20% with pulse oximetry less than 95% [11]. When the threshold value was prospectively evaluated in 119 patients, 10 of whom developed hospital complications, SpO_2 less than 95% had a sensitivity of 90%, specificity of 64%, and overall diagnostic accuracy of 67%. Although the number of patients with complications were low, these data suggest that pulse oximetry may be useful in predicting outcome in patients with pulmonary embolus.

In summary, pulse oximetry is probably one of the most important advances in respiratory monitoring. The major challenge facing pulse oximetry is whether this technology can be incorporated effectively into diagnostic and management algorithms that improve the efficiency of clinical management in the ICU.

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