Pulse Oximeter: A Boon Or A Bane

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Abstract

Pulse oximetry is one of the most commonly employed monitoring modalities in the critical care setting and as a basic monitor during anaesthesia. Despite the reliance placed on the information received from this essential monitor, the underlying principles and limitations of pulse oximetry are poorly understood. Hence, the technical errors in the functioning of the pulse oximeter, be it in calibration of the equipment or in the time over which the pulse signals are averaged, can cause mayhem during a critical incident. In the background of a critical incident where pulse oximeter failed to notify the desaturation, the need for the anaesthesiologist to be aware of the specifications of the equipment at his disposal is highlighted.

INTRODUCTION

There is no doubt that pulse oximetry represents the greatest advance in patient monitoring in many years. It has the unique advantage of continuously monitoring the saturation of hemoglobin with oxygen, easily and noninvasively, providing a measure of cardio-respiratory function. By virtue of its ability to quickly detect hypoxaemia, it has become the standard of care during anaesthesia as well as in the recovery room and intensive care unit. A closed claim analysis concluded that the incidence of critical incidents due to airway accidents declined in the 1980s since the introduction of pulse oximetry.[1] This led the ASA Standards for Basic Monitoring during anaesthesia to adopt pulse oximetry as of January1,1990.[2]

Pulse oximeter performs substantial signal processing of optically transduced physiological data. Although the principle governing pulse oximetry is straight forward, application of this principle to produce a clinically useful device include significant engineering problems. The following case report focuses on one such technical bug in the pulse oximeter design which had substantial impact in the intraoperative management.

CASE REPORT

A one-and-half year old male child was posted for cleft-palate repair. On the day before surgery, the child was found to be asymptomatic but for the defect in the palate which was present from the time of birth. The child was accepted for the procedure under general endotracheal anaesthesia. On the day of surgery, the baby was shifted to the operating room and intravenous access was secured with 24G cannula. Preinduction monitors used were pulse oximeter, ECG and precordial stethoscope. After induction of anaesthesia using inhalational agents – halothane and oxygen, endotracheal intubation was done with 4.0mm internal diameter oral RAE tube and the tube secured after confirming bilateral equal air entry. Anaesthesia was maintained with N_2O:O_2 (67:33) and intermittent halothane titrated to autonomic response. Atracurium was used as the muscle relaxant. The baby was hemodynamically stable and oxygenation was shown to be well maintained while applying the Dingman retractor and during the initial part of the procedure. At a particular point of time, the ECG monitor showed a decrease in the heart rate and auscultation over the chest revealed bilateral diminished air entry while pulse oximeter showed a steady heart rate and good oxygen saturation. Subsequently when the heart rate dropped to around 50 beats per minute on the ECG monitor, the surgical procedure was stopped, Dingman retractor released and cardiac resuscitation instituted. Bilateral good air entry was achieved and ventilation was continued with 100% oxygen. Even during the initial period of resuscitation, the pulse oximeter was showing a good plethysmographic tracing and oxygen saturation. Later on, the pulse oximeter also showed dropping heart rate and oxygen saturation. The baby was successfully resuscitated; procedure resumed and completed uneventfully thereafter. If the ECG monitor was not there, the pulse oximeter would have delayed the detection of cardiac arrest by a finite duration of time, which would have cost dearly considering the diminished oxygen reserve and increased oxygen consumption in paediatric age group.[3]

Hence, we decided to investigate further regarding the possible technical error in that particular pulse oximeter (MODEL 900 – MEDIAID). We applied the pulse oximeter probe on the finger of a healthy volunteer. The pulse in that arm was obliterated by inflating a BP cuff well over the systolic pressure. But the pulse oximeter displayed continuous plethysmograph and 100% saturation for another 30 seconds before it showed "NO PULSE" visual indicator in the LCD display. In the user's manual of this particular product, it was stated that when the oximeter searches for approximately 45 seconds and no valid pulse signal is detected, dashes "-----" in the %SpO_2 and pulse rate displays are indicated. It is also mentioned in the users' manual that the last detected readings are displayed while the oximeter searches for a valid pulse.

Thus we concluded that it was the software bug in the pulse oximeter which delayed notification of the compromised oxygenation in the baby intraoperatively which subsequently led to cardiac arrest. We advocate use of pulse oximeter which can indicate changes in the oxygenation more promptly and taking into account the physical and physiological problems of pulse oximeter, ECG monitoring and in paediatric patients, precordial stethoscope should be included in the monitoring. Moreover, the most important monitor is the standard I monitor mentioned in the Standards for Basic Anaesthetic Monitoring (which shall be present in the OR throughout the conduct of all general anesthetics, regional anesthetics and monitored anaesthesia care) and it is none other than qualified anaesthesia personnel.

DISCUSSION

The critical incidents due to pulse oximeter errors are rare. The study published by S Fasting et al [4] came across only 7 out of 157 equipment problems being attributed to pulse oximeter errors, and that too the severity of the event was of grade 1 only. Despite the reliance placed on the information received from this essential monitor, the underlying principles and limitations of pulse oximetry are poorly understood.

The pulse oximeter combines the two technologies of spectrophotometry (which measures hemoglobin oxygen saturation) and optical plethysmography (which measures pulsatile changes in arterial blood volume at the sensor site). Modern pulse oximeters consist of a peripheral probe together with a microprocessor unit displaying a waveform, the oxygen saturation and the pulse rate. The probe is placed on the digit, earlobe or nose. Within the probe are two LEDs, one in the visible red spectrum (660nm) and the other in the infrared spectrum (940nm). The beams of light pass through the tissues to the photo detector. During passage through the tissues some light is absorbed by blood and soft tissues depending on the concentration of hemoglobin. The amount of light absorption at each frequency depends upon the degree of oxygenation of hemoglobin within the tissues.[5]

Oximeters are calibrated during manufacture and automatically check their internal circuits when they are turned on. They are accurate in the range of oxygen saturations of 80 to 100% (+/-2%), but less accurate under 80%. The pitch of the audible pulse signal falls with reducing values of saturation.[6]

The size of the pulse wave (related to flow) is displayed graphically. Some models automatically increase the gain of the display when the flow decreases and in these the display may prove misleading. The alarms usually respond to slow or fast pulse rate or oxygen saturation below 90%. At this level there is a marked fall in PaO_2 representing serious hypoxia.

The paradox of conventional pulse oximetry has been that in those patients where continuous monitoring of oxygenation status would be most beneficial, their condition (physiology and environmental) can foil the measurement.[7] As it is mandatory to have a good pulse waveform (this is essential for the oximeter to calculate the ratio of pulsatile to non-pulsatile absorbance and derive the oxygen saturation), the pulse oximeter fails to give accurate readings whenever the peripheral pulsations are poor. Under these conditions, some pulse oximeters blank the display or give a message such as Low Quality Signal or Inadequate Signal.[8] Others freeze the display at the previous reading when they are unable to detect a consistent pulse wave. The presence of a functioning pulse oximeter should not be construed as evidence of adequate tissue oxygenation or oxygen delivery to vital organs.

Pulse oximeters are most unreliable in the newborn, as minor changes in skin temperature, as well as minor adjustments in contact can cause motion artifacts and a poor signal. The response of the devices to an acute loss of pulsation revealed differences in design and performance with some oximeters indicating zero saturation and others continuing to display a value while indicating a "low quality signal." [9]

While the response time of the pulse oximeter is generally fast, there may be a significant delay between a change in

alveolar oxygen tension and a change in the oximeter reading. It is possible for arterial oxygen to reach dangerous levels before the pulse oximeter alarm is activated. Delay in response is related to sensor location. Desaturation is detected earlier when the sensor is placed more centrally. Lag time will be increased with poor perfusion and a decrease in blood flow to the site monitored. Performance of a neural block may cause the lag time to decrease while venous obstruction, peripheral vasoconstriction, hypothermia and motion artifacts delay detection of hypoxaemia. Increasing the time over which the pulse signals are averaged also increases the delay time.[4]

A discrepancy in readings between difference brands of oximeters on the same patient at the same time is not uncommon.[10] One reason for this is differences in methods of calibration and the variation in the time it takes various monitors to detect desaturation. Reynolds et al [11] studied response of 10 pulse oximeters to an in vitro test system. They have developed an in vitro system to test the accuracy of pulse oximeter calibration. The oximeters tested varied widely in their accuracy and linearity. They concluded that their system can test the accuracy, reproducibility and linearity of response of pulse oximeter readings at low oxyhaemoglobin saturations.

Since pulse oximeter is accepted an important monitor for detecting critical incidents, the technical errors in the functioning of the pulse oximeter, be it in calibration of the equipment or in the time over which the pulse signals are averaged, can cause mayhem during a critical incident. Hence it is important to optimize the technical parameters to make the best use of this essential and basic monitor. It is also important that the anaesthesiologist need to be aware of the specifications of the equipment at his disposal.

To quote an editorial in Anesthesiology "…as the blindfolded anesthetist walks unknowingly toward the cliff of hypoxia - whether due to problems of inspired gas, equipment failure, underventilation, or abnormal pulmonary shunting - the protective hand of the pulse oximetry sentry stops him from falling over the edge".[12]

Intelligent use of pulse oximetry can truly help save lives and prevent disasters due to hypoxic events.

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