BASIC KNOWLEDGE OF THE CLINICAL APPLICATIONS OF PULSE OXIMETRY TECHNOLOGY AMONG HEALTH CARE PROFESSIONALS IN PEDIATRICS

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Aim Pulse oximetry monitors have become so commonplace in acute health care settings over the last decade that blood oxygen is now considered a "fifth" vital sign. This study assessed the knowledge base related to pulse oximetry technology and clinical interpretation of the data.

Method: A total of 50 participants, including nurses, respiratory therapists, and resident and fellow physicians at a large general pediatric unit of a children's hospital, completed a survey of open-ended questions.

Result: Preliminary analysis revealed that 89% of the clinicians felt they received adequate training; 82% correctly identified what a pulse oximeter measured; 38% correctly identified how a pulse oximeter worked, but only 15% had a correct understanding of the oxyhemoglobin dissociation curve. Clinicians identified a wide range of normal arterial oxygen saturation values. Although the majority of pediatric staff felt well trained and knowledgeable about pulse oximetry, there was a lack of knowledge of basic principles.

Conclusion: The results of this study suggest the need for basic professional education programs and the orientation and ongoing education of pediatric health care professionals.

PULSE OXIMETRY PROVIDES A NONINVASIVE, painless, and reliable method to measure arterial oxygen saturation. This technology adds valuable data for patient assessment for the pediatric practitioner. Ten years ago these devices were mainly found in operating rooms and some intensive care units. Since that time, they have entered into routine use for both continuous and episodic measurement of oxygen saturation of patients in clinics, physician offices, emergency departments, and ambulances. This measurement is now considered by many to be a component of routine vital signs. Like the other vital sign parameters, these data need to be interpreted so the significance of the reading in relation to patient condition may be assessed. This requires the practitioner to be familiar with the monitoring equipment to determine if accurate data were obtained as well as knowledge regarding what is being measured and the potential physiologic impact of the results obtained. These data points are integrated with other physical assessment to determine clinical patient stability. The knowledge of health care professionals may not always be sufficient. The lack of knowledge may affect patient care decisions, potentially adversely affecting patient outcomes. This research study was conducted to assess knowledge of pulse oximetry among pediatric health care professionals and test their clinical interpretation of selected patient scenarios.

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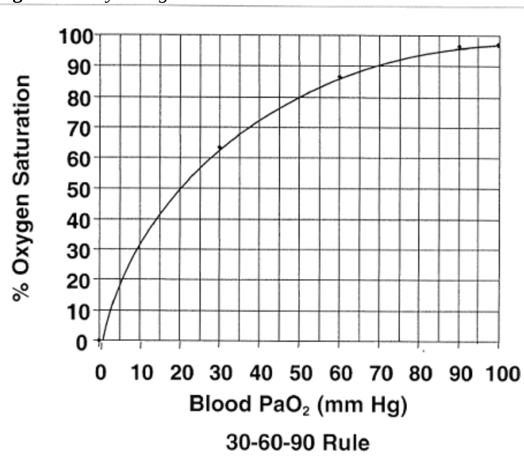
Pulse Oximetry Technology

Pulse oximetry measurement reflects the percentage of hemoglobin that is capable of transporting oxygen in the blood. Oxygen is carried in the blood in two ways, bound to hemoglobin or dissolved in plasma. Each molecule of hemoglobin is capable of combining with up to four molecules of oxygen, but not all hemoglobin molecules may be fully saturated with oxygen. The oximeter sensor is typically attached to a peripheral measurement site, such as a digit, the palm of the hand or foot in small children, and possibly the earlobe or bridge of the nose for older children. Intense wavelengths of red and infrared light are emitted by one surface of the oximeter sensor probe. The other surface of the probe has a light sensor detector and measures the amount and absorption of light as it passes through a pulsating vascular bed. Oxygenated blood absorbs more light in the infrared spectrum, and deoxygenated blood absorbs more light in the red spectrum. Using the measurements of light transmission, the pulse oximeter provides a value by calculating the proportion of infrared light to the total of infrared and red light detected.[1] The values are transformed to correspond to hemoglobin saturation. The estimate of hemoglobin saturation that is derived from these measurements is called "SpO_2 ". The SpO_2 is oxygenated hemoglobin expressed as a percentage of the hemoglobin that is capable of transporting oxygen.

When the PO_2 is low, as in peripheral tissues, oxygen is released from the hemoglobin; when the PO_2 is high, as in the pulmonary arterial beds, the oxygen binds with hemoglobin. This is the basis of normal oxygen transport. The pressure of oxygen in the arterial blood of a patient with normal levels of arterial oxygen is approximately 95 mm Hg (Figure 1). This corresponds to an oxygen saturation of hemoglobin of approximately 97%. A saturation of 99% or 100% could reflect a partial pressure of 100 mm Hg to 140 mm Hg, but a saturation of 90% corresponds to a partial pressure of approximately 60 mm Hg, and a saturation of 60% corresponds to a partial pressure of 30 mm Hg (Figure 1). The relationship between the partial pressure of oxygen in arterial blood (PaO_2) and oxygen saturation SaO_2 is not linear, but rather is represented by an S-shaped curve.

Figure: 1. *Oxyhemoglobin dissosciation curve*



This becomes a crucial concept for practitioners interpreting oximeters, as a fall in oximetry saturation readings corresponds to a more dramatic fall in the partial pressure of oxygen in arterial blood. If the relationship between PaO_2 and SaO_2 was viewed as linear, healthcare professionals would erroneously interpret an SaO_2 of 80% as corresponding with a PaO_2 of 80 mm Hg. The practitioner would not likely be concerned until the PaO_2 was dangerously low. If however, the practitioner understood the non-linear nature of the curve, the SaO_2 of 80% would be interpreted to correspond to a PaO_2 of 50 mm Hg, indicating significant hypoxemia.

Factors Influencing Accuracy of Data

Oximetry readings can be altered by a number of factors. The site of measurement must be clean and dry and have minimal movement to permit adequate signal transmission. Nail polish and other environmental factors such as bright overhead lighting or sunlight can also interfere with transmission.

Cold ambient temperature, leading to peripheral vasoconstriction, decreases skin blood flow and may make it difficult to measure the pulsatile flow needed for a reading. Patient conditions that likewise are associated with poor peripheral perfusion, such as decreased cardiac output, some dysrhythmias, shock, and certainly cardiac arrest, make it unlikely the oximeter will identify pulsatile flow and produce a valid reading[2]

Purpose

As vital as pulse oximetry data are becoming in patient care, the technology involved is relatively new. Practitioners have not uniformly had formal training in this area. The purpose of this study was to measure the knowledge of pediatric residents, nurses, and respiratory therapists and technicians regarding oximetry and the ability to apply it in a clinical scenario.

Method

This study took place in a large teaching hospital in the western region of Saudi Arabia. Based on clinical expertise, the researcher developed a 16-point survey that included both multiple choice and short-answer questions centering around three themes: (a) the parts and function of the oximeter, (b) interpretation of oximetry readings, and (c) application of pulse oximetry readings. The survey also included demographic elements (Table 1).

After receiving approval from the Department of Pediatrics, the surveys were distributed to pediatric residents and fellows, respiratory therapists and technicians, and nurses working on a general pediatric unit. All participants were asked to return the surveys whether or not they chose to participate. Respondents were assured of confidentiality and anonymity. The nurses were given the survey during a shift and asked to return it as soon as possible during that shift. The physicians were surveyed during one of their general meetings; surveys were completed and returned at the time of distribution. The respiratory therapists completed and returned their surveys at change of shift. These short time frames were chosen to minimize the possibility of respondents discussing answers or consulting sources that could help them complete the survey. The researchers did not review the surveys until all data collection periods were completed.

Table 1. *Demographic Data survey*

Please complete the following information

1) 1-Position
   a) RN
   b) Respiratory therapist
   c) First year pediatric house staff
   d) Third year pediatric house staff
2) Number of years of patient related experience in your profession
   a) < 6 months
   b) < than 1 year
   c) 6-10 years
   d) > 10 years
3) How many years of experience have you had you had using n
   a) No experience
   b) < 6 months
   c) < 1 year
   d) 2-5 years
   e) > 10 years
4) Do you feel you have received adequate training in the use of pulse oximeters
   a) Yes
   b) No
5) What kind of training have you had in the use of pulse oximeters : check all that applies
   a) Lecture
   b) Self study (handout, module, video..etc)
   c) Informed training during clinical practice
   d) Formal equipment inservice
   e) Other
6) What is the highest degree of training level in your specialty?
   a) Diploma in nursing
   b) Master degree in nursing
   c) MD
   d) other

The surveys (Table 2) were coded by a researcher. Questions 1 through 4, and 6, were coded as correct, incorrect, or incomplete. Question 5 asked respondents to provide the normal ranges of oxygen saturation for infants, children, and adults. This item was coded as the high and low values the respondents had provided. Questions 8 and 9, which required the respondents to describe the effects of certain factors on pulse oximetry readings, were coded as increased, decreased, no change, or no reading. The two clinical scenarios were initially coded as correct, incorrect, or incomplete.

Subsequent coding was done to distinguish minimally correct responses from more in-depth correct responses. Statistical analysis was limited to descriptive analysis of the mean. A p value <0.05 was considered significant.

Table 2 : *Pulse Oximetery Knowledge Survey*

1) What does a pulse oximeter measure
2) How does pulse oximeter work
3) How often do you document the reading from the pulse oximeter?
4) What is the normal range of oxygen saturation for an adult? Child? Infant?
5) What is the unit of measure for
a) Oxygen saturation (SpO2)
b) Oxygen partial pressure (Pa O2)
6) What if any is the relationship between oxygen saturation and partial pressure of oxygen?>
7) What happens to the pulse oximeter of a patient
a) In cardiac arrest
b) In respiratory arrest
c) In shock
8) Identify what effect , if any ,the following factors have on pulse oximetery reading"
a) Nail polish
b) Dark skinned race
c) Jaundice
d) Anemia
e) Cardiac dysrhythmias
f) Cold environment
g) Peripheral vasoconstriction Clinical scenarios
9) A child is admitted with RSV. The oxygen saturation is 96% and HR 140. The oxygen saturation drops to 91%
   a) What are the implications of this pulse oximetery reading
10) A child with sickle cell disease is admitted with Hob of 5 from. The oxygen saturation drops from 98% to 95%. The heart rate is 140 on the saturation monitor and 142 on the ECG monitor.
   a) What are the implications of the oximetery reading?
   b) What is your immediate action you take?

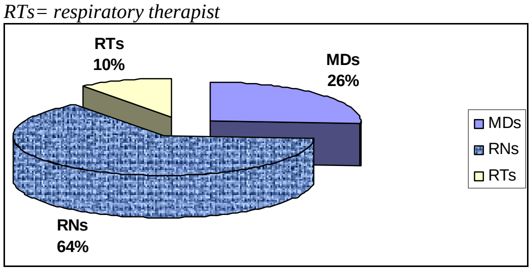
c) What changes in the plan of care?

Results

Demographic data

Researchers distributed a total of 66 surveys, of which 50 were returned, for a return rate of 75%. The 50 respondents included 13 (26%) physicians, 32 (64. 5%) registered nurses (RNs), and 5 (10%) respiratory therapists (Figure 2). Nurses had the most patient-related experience; of the 24% of all respondents that had greater than 10 years' clinical experience, 83% were nurses. More than half (55%) of the RNs had 5 or more years of clinical experience, while 96% of the MDs in the study had less than 6 years of patient-related experience. For the 5 respiratory therapists who completed the survey, the number of years of patient-related experience was evenly distributed from less than 6 months to greater than 5 years. Nurses had the most experience with the use of pulse oximetry equipment; of the 35% of all respondents who had more than 5 years' experience using pulse oximetry, 75% were nurses. All but one of the physicians had less than 6 years experience. Respiratory therapists' pulse oximetry experience corresponded with their patient-related experience and was evenly distributed from less than 6 months to greater than 5 years.

Figure 2: *Total number of pediatric health care professionals in this survey n=50, MDs=medical doctors,RNs= registered nurses, RTs= respiratory therapist*



Although the majority of respondents received only informal bedside training in the use of pulse oximeters (75% of physicians, 89% of nurses, and 73% of respiratory therapists), overall, 79% believed they had adequate training.

Knowledge questions

Knowledge questions. Knowledge related to pulse oximetry function and measurement was quite variable among respondents. Nurses (89%), physicians (62%), and respiratory technicians (75%) believed that they had received adequate training using pulse oximetry equipment. However, when asked to describe how pulse oximetry worked, only 22% of the nurses responded correctly, a significantly smaller number than for physicians or respiratory therapists (65% and 70.2%, respectively; $p < .001$). For an answer to be correct, the respondent must have mentioned a light sensor, red/infrared light absorption, and/or pulsatile blood flow in their response.

The fact that pulse oximetry measures the oxygen saturation of hemoglobin as well as the pulse rate was understood by 95% of physicians, 87% of respiratory therapists, and 72% of nurses. There was no difference between the practitioner groups ($p=.01$). Knowledge of the oxyhemoglobin dissociation curve as it relates to pulse oximetry was one of the least understood concepts by all respondents; only 7% of nurses, 10% of respiratory therapists, and 60% of physicians provided the correct answer to the question related to the curve, with physicians significantly more knowledgeable than nurses or respiratory therapists ($p < .00001$). While 33% of nurses and 76% of physicians correctly identified the unit of measure for pulse oximetry values as a percentage, fewer (12% of nurses, 57% of physicians) identified the unit of measure for the partial pressure of oxygen in blood as millimeters of mercury. The difference between nurses' and physicians' knowledge regarding unit of measure for each of these parameters was significant ($p =.001$ for $SpO_2$and $p < .00001$ for PaO_2). Respiratory therapists were not included in this portion of data analysis due to the small number responding to these two questions.

Factors influencing accuracy of pulse oximetry readings

The pulse oximeter requires a pulsatile signal and will make an alarm when it cannot detect the peripheral pulse. One question tested whether respondents knew that immediately after a cardiac arrest or in the event of shock, the signal would be lost and there would be no reading. When this question regarding cardiac arrest was posed in the 1994 Stoneham study,[3] two nurses (7%) and five physicians (17%) answered it correctly. The current study revealed similar results with 12% of nurses, 30% of physicians, and 21% of respiratory therapists answering correctly. Differences among practitioner groups were not statistically significant. Yet, in the event of a respiratory arrest, 90% of physicians, 67% of nurses, and 42% of respiratory therapists correctly identified that the saturation would decrease, perhaps with the understanding that saturations during respiratory arrest fall until hypoxia results in cardiac arrest.

Respondents were asked to identify how common factors might affect the accuracy of pulse oximetry readings. The factors were divided into life threatening, physiologic, and environmental situations. Overall, there was a surprising lack of knowledge related to the impact of these factors by physicians, nurses, and respiratory therapists; however, no significant differences were demonstrated between these groups. Cardiac arrest, by definition, would result in no pulsatile flow needed for this technology to function; however, only 30% of physicians, 12% of nurses, and 21% of respiratory therapists recognized this fact. Of the three groups of factors, all respondents were more likely to recognize that physiologic factors such as dark skin and jaundice did not alter the readings. Of the physiologic factors, anemia was the least correctly recognized factor by all groups (15% physicians, 10% nurses, and 10% respiratory therapists). Environmental factors as a whole yielded fewer correct responses. Only 18% of physicians, 16% of nurses, and 11% of respiratory therapists recognized that bright light or sunshine on the sensor probe would potentially falsely increase the saturation reading. Additionally, there was a lack of appreciation that nail polish or cold environment could result in the probe failing to detect an adequate signal.

Practitioners were asked to identify the normal range of oxygen saturation in arterial blood for adults, children, and infants. Pediatric nurses identified a lower mean "low normal" for adults than they did for children or infants (adult = 92.4%, children = 94.3%, infant = 93.6%; NS). Physicians identified similar means as nurses (adult = 94%, child = 94.2%, and infant = 93.5%; NS). Respiratory therapists consistently identified the lowest mean "low normal" of all the practitioners (adult = 91.1 %, child = 91.3%, infant = 91.7%; NS).

Clinical Scenarios

Four clinical scenarios were presented in the survey, and respondents were asked to identify appropriate responses or courses of action. The scenarios were designed to assess the clinical judgment and decision-making ability of pediatric practitioners. None of the respiratory therapists chose to complete this portion of the survey.

Scenario number 1. This scenario involved a child with RSV. Respondents were asked what the implications of the oximetry reading were. Components of a correct response: The heart rate readings on the two monitors correlate indicating a true desaturation. The PaO_2 has decreased from approximately 90 mm Hg to 60 mm Hg. The practitioner should first check the airway, breathing, and circulation; increase the oxygen flow rate; and notify the physician if appropriate.
Results: Significantly fewer of the nurses (21%) than of the physcians (47%) responded correctly that the desaturation was clinically important and identified an appropriate course of action (p = .0015).

Scenario number 2. This scenario involved a child with sickle cell anemia with a Hgb of 5 gm/dL. Respondents were asked what the implications of the oximetry reading were and what would be their immediate response. Components of a correct response: The PaO_2 has decreased from approximately 94 mm Hg to 90 mm Hg. The pulse oximeter does not reflect decreased oxygen carrying capacity secondary to a low Hgb. Anemic patients may not have adequate oxygen to meet metabolic demands even though their Hgb is saturated with oxygen and they have an acceptable SaO_2. This patient is becoming hypoxic. Appropriate courses of action include checking the airway, breathing, and circulation; increasing the oxygen flow rate; and notifying the physician.
Results. Only 12% of physicians and 14% of nurses identified the implication of the decreasing saturation with no statistically significant difference between the groups (p = .0191). Significantly more physicians were able to identify an appropriate course of action 47%), than nurses (14%; p < .0001).

Discussion

Pediatric practitioners included in this survey expressed relatively high confidence in their knowledge related to pulse oximetry. However, the level of understanding by these practitioners was unacceptably low as reflected in their responses to survey questions. In 1997 Kruger and Longden[4] conducted a similar survey-based study of physicians, nurses, and anesthesia technicians in an Australian hospital. These researchers avoided multiple choice questions as they felt the prompts of the options provided would lead to inaccurate assessment of the subjects' knowledge; thus seven of the study's knowledge elements were formatted as open-ended, short-answer questions. Researchers coded answers as correct, partially correct, or incorrect. In this study, 39% of the participants felt they had adequate training in pulse oximetry and 69% correctly reported that pulse oximeters measured oxygen saturation. However, 88% were not aware of the basic relationship between oxygen saturation and the partial pressure of oxygen in arterial blood (oxygen dissociation curve). Kruger and Longden[4] concluded that there was a general lack of knowledge of pulse oximetry in the study sample. They also recommended that appropriate education regarding pulse oximetry needed to be initiated so that hospital staff would be able to reliably interpret pulse oximetry data.

Previous studies[1-14] demonstrated marked lack of understanding of the oxyhemoglobin dissociation curve (OHDC), lack of knowledge of other technology, and inadequate interpretation of data leading to delayed interventions and changes in plans of care. The current study results support the previous studies' findings in understanding of the technology, its limitations, and application in the clinical setting. This is somewhat surprising considering the increased use of oximetry equipment in all health care settings since the time those earlier studies were conducted.

The results of this study indicate that overall pediatric staff surveyed were not consistently able to recognize the significance of low oximetry readings and did not consistently indicate an appropriate action. Physicians responded correctly more frequently than nurses or respiratory therapists to "theoretical questions," such as the units of measure for SaO_2 and PaO_2, and the relationship between these (OHDC). Respiratory therapists were more comfortable with the technology of the equipment. Nurses, however, were more likely to take action in the clinical scenarios and problem-solve to correct or prevent recurrence than physicians. This may be due to the direct care-giving role of bedside nurses and the fact that all but one of the physicians had less than 6 years experience. Neither nurses nor physicians appreciated that small changes in saturations could result in significant sequelae. The clinical scenario of the child with sickle cell anemia would require integration of theoretical knowledge. Although anemia does not interfere with oximeter readings per se, it yields readings that are prone to misinterpretation by practitioners. Marked anemia would shift the OHDC to the left, resulting in smaller decreases in saturation corresponding to increasingly significant drops in PaO_2.

In 1991 Cote et al.[5] pointed out that appreciable clinical signs and symptoms do not become evident until there is a significant hypoxic event. Clinical evidence of hypoxia is seen at a mean $SpO_2$of 70 +/- 8%. Further, Cote and colleagues define a major hypoxic event to have occurred when the SpO_2 is < 85% for more than 30 seconds. Identification of major hypoxic episodes would require oximetry equipment and the strong clinical judgment of practitioners to correctly interpret the data.

Our study has some limitations. The survey distribution methodology may have influenced the results. No one method of distribution was feasible for all practitioner groups. The methodologies used meant that all three groups were faced with time constraints for completion of the survey. Nurses were trying to complete the surveys during the course of a busy shift and were frequently interrupted during survey completion to attend to patient care priorities. The respiratory therapists were asked to complete the surveys at their change of shift, giving them quite a limited time frame for survey completion. The physicians completed the survey during an educational meeting; consequently their attention may have been diverted. Thus, the time needed to complete the surveys was underestimated and may have contributed to incomplete responses and increased anxiety on the part of the participants.

Our sample size was not large enough (total of 50 participants) to draw definitive conclusions about the knowledge base related to pulse oximetry technology and clinical interpretation of the data given knowledge among pediatric health care professionals.

This study showed that although there is wide exposure to the equipment, practitioners of all disciplines did not consistently have the knowledge needed to interpret data and make appropriate alterations in plans of care. The danger in this situation lies in the consequence of significant hypoxic episodes being under-recognized and under-treated despite sophisticated monitoring. As these findings and those of previous studies indicate, there is a definite need for increased and improved education about the proper use of pulse oximetry technology and interpretation of oximetry readings.

The full value of the addition of oximetry to monitor pediatric patients will not be realized until the knowledge level of all pediatric health care professionals is improved. Formal and informal education programs need to be developed for all disciplines to specifically address oxygen saturation as a physiologic parameter in routine patient assessment. Educators in health care settings should validate practitioner knowledge during orientation. Mentors should confirm that practitioners are correctly interpreting oximetry data from actual patient situations. Additionally, an annual review of critical decision-making could include oximetry as a high-risk, problem prone skill using a clinical scenario-based approach. Continued education and future research will help facilitate the appropriate integration of this technology into patient care.

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