Original Article

DOI: 10.7860/JCDR/2020/45461.14378

Pulse Oximetry Understanding and Application: A Survey on Nursing Staff

Anaesthesia Section

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ABSTRACT

Introduction: Pulse Oximetry (PO) is widely used for the noninvasive detection of hypoxemia, particularly in the perioperative setting. Research regarding the perioperative assessment of nursing knowledge of PO continues to evolve. Prior evaluations have identified relative knowledge deficits among nurses regarding physiologic principles, data interpretation, and clinical application. Such deficits need identification and targeted education to prevent perioperative patient mismanagement.

Aim: To assess nursing knowledge of PO in perioperative and critical care settings of a single center in the United States and to analyse identified knowledge deficits.

Materials and Methods: A cross-sectional questionnaire study was conducted in Post Anaesthesia Care Unit (PACU) and Medical Respiratory ICU (MRICU) among 150 participants. The validated questionnaire on surveying PO principle consisted of 21 true/false and 3 open-ended questions. Univariate analysis of nursing Total Knowledge Score (TKS), years of clinical experience, and current practice settings was performed. Significance was set at $p<0.05$.

Results: A total of 51 questionnaires were completed, with a 34% response rate. The mean TKS for the true/false questionnaire was 16.4±2.0. There was no significant difference in TKS between PACU and MRICU nurses (16.5±1.7 vs. 16.2±2.5, respectively, $p=0.27$). Ninety-eight percent of all nurses scored >50% correct while 13.7% scored >90% ($p=0.19$ and $p=0.74$, respectively). The lowest percentages of correct responses (<50%) were seen in questions 3 and 16, which pertained to physiologic principles of PO. There was no significant difference in scoring percentiles between MRICU and PACU nurses, nor was there significant difference in TKS based on clinical experience.

Conclusion: The mean TKS of nurses in the study was higher than the mean TKS of nurses in reference studies. There was no significant difference in TKS between PACU and MRICU nurses. Furthermore, clinical experience did not correlate with TKS scores. The authors believe analysing these knowledge deficits may offer educational opportunities in initial and continuing nursing education as well as routine postgraduate assessments.

Keywords: Critical care nursing, Nursing education, Perioperative care

INTRODUCTION

The clinical PO serves as a critical tool in the peri-operative care of patients. Invented in the 1970s, PO quickly gained widespread acceptance around the world as a rapid tool and a noninvasive measure of oxygen bound to arterial hemoglobin. PO detects hypoxemia in a wide range of clinical settings, often more consistently than clinical physical assessment alone [1]. With tissue oxygenation essential in reducing postoperative complications and supporting recovery, a PO system is a standard monitor in both post-anaesthetic recovery areas and Intensive Care Units (ICUs) [2]. PO offers the greatest benefits to patients when clinicians understand its strengths and limitations.

To measure this understanding, many studies have evaluated PO knowledge in nursing staff on high-acuity wards. Giuliano KK and Liu LM evaluated 551 critical care nurses with a 7-item survey [3]. Kiekkas P et al., exchanged the earlier 7-question survey for an expanded 22-item version, which covered principles of PO function and various conditions affecting accuracy and reliability. This more in-depth questionnaire was administered to 207 Greek nurses across different healthcare settings [4]. The expanded survey suggested knowledge deficits existed regarding physiologic principles in the studied population. Similarly, a study of 307 participants, conducted by Seeley MC et al., suggested that the polled Australian nurses also had knowledge deficits that could result in patient mismanagement [5].

PO knowledge gaps have previously been studied in different countries and clinical settings. For example, a recent study found medical residents performed better than nursing staff in PO concept assessment [6]. A study from Serbia further challenged the assertion that "experience is everything" and found that PO knowledge scores were significantly different based on inpatient clinical settings [7]. Furthermore, a study in Greece offers insight into how adult and paediatric clinical staff compares in PO knowledge by finding that paediatric staff scored lower than Level 3 ICU staff [8]. Additional studies are necessary to ascertain how PO knowledge varies depending on geographical region, clinical setting and clinical experience.

Hypoxemia is a common occurrence in the postoperative period and this study aimed to replicate parts of the aforementioned previous studies in acute care nurses in the United States [9]. The primary goal of the project was to determine if nurses in this study's institution, a tertiary referral center in the United States, have similar knowledge concerning PO relative to their international counterparts. The secondary goal was to determine if either the setting of current nursing practice (postanaesthesia vs. medical respiratory ICU) or years of nursing experience had an effect on PO knowledge.

MATERIALS AND METHODS

This was a cross-sectional questionnaire survey assessing nursing staff knowledge of clinical PO device application. The survey was conducted on paper, remained anonymous and did not require the nursing participant's personal identification, including name, date of birth, license number or any other personal health identifiers protected by Health Insurance Portability and Accountability Act (HIPAA). A copy of the survey was submitted for review to the institution's IRB along with the study's educational aim and for which exemption was granted.

Furthermore, consent for research was obtained via a study statement on each questionnaire which indicated that completion implied consent for participation.

The study was conducted at an American academic tertiary referral hospital with Nursing Magnet status in September 2019. A total of 150 clinical nurses from the PACU and MRICU were surveyed, based on willingness to complete the survey. Both groups were given a brief verbal introduction to the study. Questionnaires were placed in an accessible area for nurses to take and complete at their discretion. A total of 51 questionnaires (32 MRICU and 19 PACU) were completed and submitted for data analysis within a time period of one week. The completed questionnaires were returned to a centralised location with the unit's charge nurse and collected at the end of the week by members of the research team.

Questionnaire design: Numerous tools to assess nursing knowledge regarding PO have been previously described [10-12]. After this review, the questionnaire developed by Kiekkas P et al., was selected as the most comprehensive in its assessment of gas exchange, oxygen transport, ventilation, and practical limitations of PO [4]. In order to improve completion rates of questionnaires and suitability for data analysis, a true or false design was used for the 21-item questionnaire adapted from Kiekkas P et al., [4].

Three optional free-response questions were added at the end of the questionnaire. The first two assessed PO troubleshooting and the third offered opportunity for feedback. The three free-response questions were:

22: What are the things that you check or patient do when a PO alarm goes off?

23: Do you have any frustrations with working with and relying on PO?

24: Any other questions or comments?"

STATISTICAL ANALYSIS

Statistical analysis was performed using R Core Team (2020) [13]. Categorical variables were analysed using Pearson Chi-square test and continuous variables underwent Student t-test. Post-hoc analysis was not required to be performed. Significance was set at $p<0.05$.

RESULTS

Fifty one questionnaires were completed (32 MRICU, 19 PACU) with a 34% response rate from 150 questionnaires distributed. Of the entire set of responses, the largest fraction (31.3%) was from nurses with 3-5 years of clinical experience. Among the MRICU cohort, the largest group (46.9%) had 2 years or less of clinical experience, while the largest group in the PACU nurses (47.4%) had greater than 10 years of clinical experience. Subgroup analysis by years of clinical experience for both cohorts has reported in [Table/Fig-1].

Years of clinical experience	MRICU (%) N=32	PACU (%) N=19	Total (%) N=51
0-2	15 (46.9)	0 (0)	15 (29.4)
3-5	10 (31.3)	6 (31.6)	16 (31.4)
6-10	4 (12.5)	4 (21)	8 (15.7)
>10	3 (9.3)	9 (47.4)	12 (23.5)

[Table/Fig-1]: Years of clinical experience by nursing staff location.

The mean TKS of the 21-item survey assessing clinical knowledge of PO application was 16.4±2.0 correct responses. The mean TKS for the MRICU and PACU cohorts has reported in [Table/Fig-2]. Of the 51 total participants, 50 (98.0%) had a score ≥11, and 37 (72.5%) had a score ≥16. A breakdown of how participants performed on each question is recorded in [Table/Fig-3]. TKS was comparable regardless of nursing staff location or practice, with 100% of MRICU and 94.7% of PACU nurses answering >50% of questions correctly. Fewer nurses achieved ≥90% correct scores (13.7%), with a breakdown of 15.7% in PACU nurses and 12.5% in MRICU nurses [Table/Fig-3].

	Mean	Standard deviation	Standard error	p-value (Student t-test)
MRICU (n=32)	16.5	1.74	0.31	0.27
PACU (n=19)	16.2	2.50	0.57	0.27
Total (n=52)	16.4	2.04	0.29	0.27

[Table/Fig-2]: Total Knowledge Score (TKS) for true/false questions (number correct/21 questions).

Percent correct scores	MRICU (%) N=32	PACU (%) N=19	Total (%) N=51	p-value (Student t-test)
≥50% (11/21)	32 (100)	18 (94.7)	50 (98.0)	0.19
≥75% (16/21)	24 (75)	13 (68.4)	37 (72.5)	0.61
≥90% (19/21)	4 (12.5)	3 (15.7)	7 (13.7)	0.74

[Table/Fig-3]: Percent correct scores by nursing staff location.

Overall, nurses with 6-10 years of experience showed trends toward very high scores, with 37.5% answering at least 90% of the questions correctly [Table/Fig-4].

Percent correct scores	3-5 years (%) N=16	6-10 years (%) N=8	10+ years (%) N=12	p-value (Student t-test)
≥50% (11/21)	15 (93.7)	8 (100)	12 (100)	0.53
≥75% (16/21)	13 (81.2)	4 (50)	9 (75)	0.26
≥90% (19/21)	1 (6.3)	3 (37.5)	1 (8.3)	0.09

[Table/Fig-4]: Percent correct scores by years of clinical experience. <3 years of clinical experience excluded

Years of clinical experience correlated with higher TKS in PACU nurses (72.1%, 77.3%, 79.8%; 3-5 years, 6-10 years, ≥10 years, respectively). Length of MRICU experience did not correlate with rising TKS, as most respondents scored 75-80% from 0-2 years of experience to ≥10 years [Table/Fig-5].

Years of clinical experience	MRICU mean TKS±SD (% correct) N=32	PACU mean TKS±SD (% correct) N=19	p-value (Student t-test)
0-2	16.6±1.63 (79.0)	N/A	N/A
3-5	16.8±2.40 (80.0)	15.1±10.10 (72.1)	0.19
6-10	15.7±6.25 (75.0)	16.2±11.58 (77.3)	0.82
≥10	16.3±6.33 (77.7)	16.7±2.19 (79.8)	0.71

[Table/Fig-5]: Combined mean TKS by years of clinical experience.

Of the 21 true/false questions that addressed knowledge of PO, three questions had an overall correct response rate of lower than 50% with no difference in performance based on nursing staff location or experience [Table/Fig-6]. Two questions with <50% correct scores addressed physiologic principles, while the remaining question addressed PO technique. Of the 51 participants, only 18 provided answers to the open-ended questions. In response to the question concerning what one should do when a PO alarm goes-off, the majority of participants (n=15) commented on checking to make sure the PO monitor is correctly placed, checking connections, and checking the monitor to look for appropriate waveforms. Nine respondents commented on making sure that the patient is not moving and that the PO sensor is not on the same arm as the blood pressure cuff. Eight respondents recommended a physical assessment of the patient. Regarding the question about "any frustrations with PO," the majority of respondents (n=8) expressed the frustration that they believe most alarms are false [Table/Fig-7].

Question (C= correctly stated; I= incorrectly stated)	Correct responses (%)			
	MRICU (%) N=32	PACU (%) N=19	Total N=51	p-value (student t-test)
1. Pulse oximetry (PO) is a noninvasive method for measuring arterial oxygenation (C)	24 (75.0)	11 (57.9)	35 (68.6)	0.20
2. Pulse oximetry has been found to be accurate for oxygen saturation between 70-100% (C)	30 (93.8)	19 (100)	49 (96.1)	0.27
3. Pulse oximetry is used for the rapid detection of tissue hypoxia (I)	16 (50.0)	8 (42.1)	24 (47.1)	0.58
4. Clinical assessment alone has been shown to be as effective as PO monitoring in the detection of hypoxemia (I)	18 (56.3)	13 (68.4)	31 (60.8)	0.39
5. Anemic patients may be hypoxic in the setting of normal SpO2 (C)	30 (93.8)	15 (79.0)	45 (88.2)	0.11
6. During vasoconstriction, sensor placement on the fingernail provides more accurate readings than its placement on central sites (I)	30 (93.8)	16 (84.2)	46 (90.2)	0.27
7. Colored nail polish and synthetic nails do not affect the accuracy of PO readings (I)	31 (96. 9)	19 (100.0)	50 (98.0)	0.44
8. Pulse oximetry readings are less accurate when the patient is moving (C)	31 (96.9)	16 (84.2)	47 (92.2)	0.10
9. An oxygen saturation value of 90% provided by PO corresponds to a partial oxygen pressure in arterial blood of 90 mmHg (I)	27 (84.4)	13 (68.4)	40 (78.4)	0.18
10. Oxygen saturation values provided by PO are equally accurate to those provided by the analysis of arterial blood gases (I)	24 (75.0)	16 (84.2)	40 (78.4)	0.44
11. Accurate PO readings are more difficult to obtain when peripheral perfusion is poor (C)	32 (100)	19 (100)	51 (100)	1.00
12. Pulse oximetry readings are usually not affected by body position or ambient light (I)	22 (68.8)	14 (73.7)	36 (70.6)	0.71
13. Patients are at increased risk for desaturation during invasive procedures (C)	30 (93.8)	17 (89.5)	47 (92.2)	0.58
14. Pulse oximetry is not an indicator of adequacy of ventilation (C)	19 (59.4)	16 (84.2)	35 (68.6)	0.06
15. Pulse oximetry provides real-time readings when the sensor is placed on the fingernail (I)	9 (28.1)	3 (15.8)	12 (23.5)	0.32
16. Use of PO is strongly recommended during cardiopulmonary resuscitation (I)	15 (46.9)	8 (42.1)	23 (45.1)	0.74
17. Use of PO is strongly recommended when the patient is on supplemental oxygen (C)	32 (100.0)	18 (94.7)	50 (98.0)	0.19
18. The majority of PO alarms are correct (I)	20 (63.0)	15 (79.0)	35 (68.6)	0.22
19. Conventional PO is based on the absorption of red and infrared light by blood (C)	31 (96.9)	18 (94.7)	49 (96.1)	0.70
20. Pulse oximetry sensor is highly sensitive to mechanical damage (C)	31 (96.9)	17 (89.5)	48 (94.1)	0.28
21. Pulse oximetry readings are not affected by smoke inhalation (I)	27 (84.4)	16 (50.0)	43 (84.3)	0.99

[Table/Fig-6]: Correct responses to true/false questions: differences among cohorts.

N=8	N=15	N=9	N=8	N=6
Respondents identified that when a PO alarm goes off, they should assess the patient via physical and mental exam.	Respondents identified that when a PO alarm goes off, they should check PO connections, placement of monitor, and analyse waveforms on the monitor.	Respondents identified that when a PO alarm goes off, they should make sure the PO monitor is not on the same arm as the blood pressure cuff and that patient is not moving.	Respondents identified having frustrations with PO	Respondents identified as not having frustrations with PO
Selected sample response	Selected sample response	Selected sample response	Selected sample response	Selected sample response
"Check the sensor, look at the waveform, ask the patient to cough or deep breath but FIRST LOOK AT THE PATIENT!"	"Check the patient, look at connections, look at waveform, check placement of pulse ox" "I check if I'd have a perfect waveform on screen to see if it's real alarm vs artifact"	"Make sure the fingers are straight or if the blood pressure cuff is on the same arm"	"Yes-80-99% of alarms are false. Movement, waveform, and constant alarms lead to unsafe desensitisation"	"Not always able to get a great reading"

[Table/Fig-7]: Content analysis with example responses from respondents.

DISCUSSION

This study assessed the knowledge base of PACU and MRICU nurses from a single United States center and revealed several areas of significant strength along with opportunities for focused education and review.

Total knowledge scores: The study reported questionnaire results as TKS. The mean TKS of the population was higher than the mean TKS of those evaluated by Kiekkas P et al., and Seeley MC et al., (12.8 and 11.7, respectively). Given the differences in TKS among United States, Greek, and Australian nurses, a brief overview of nursing curricula in these countries was undertaken [4,5].

In the United States, students may start nursing coursework in a three to four-year undergraduate program. Alternatively, nursing coursework may be completed within a focused two-year program covering the basics of nursing for students who have already completed other undergraduate degrees. Upon the successful completion of nursing school, a US nursing candidate must pass the national National Council Licensure Exam (NCLEX) to become eligible to work as a Registered Nurse (RN). Upon starting a clinical position, the typical orientation for recent graduate nurses is variable and individualised to each healthcare system. This orientation typically consists of several weeks of sessions teaching basic skills such as BLS, ACLS, and CPR [14]. Most hospitals in the United States have a collegial environment where learning is ongoing and discussion between nurses, physicians, pharmacists, nutritionists and other healthcare members is encouraged to facilitate learning [14].

In Greece, nursing undergraduate degrees consist of eight semesters over four years, with the eighth semester being clinical practice [15]. There is no nationwide board exam upon completion of the nursing program. Similarly, Australian nursing students may start work following completion of a three-year program with no requirement of a nationwide board exam [16]. In contrast, nursing students in the United States are required to take a national board exam in order to practice as registered nurses. This may support the claim that nursing students trained in the United States undergo a more comprehensive education which is reflected in the relatively higher TKS of United States nurses. A national board exam such as the National Council Licensure Examination -Registered Nurse (NCLEX-RN) aims to cover a broad range of basic physiology, including respiratory information such as PO [17]. To prepare, nurses taking this exam are encouraged to have adequate knowledge about PO.

This difference in TKS between nursing staff in this study and those in Greece may be attributed to differences in nursing curriculum. Other study done by Nimbalkar S et al., which compared knowledge of medical residents and nursing staff also suggest that a difference in curricula affects PO application [6]. Briefly, medical residents undergo a longer schooling period than nurses with more frequent standardised examination. This supports the authors claim that improvement in PO application knowledge will require some type of formal education and that experience alone is inadequate.

Role of clinical experience: The correlation between years of clinical experience and TKS was further analysed. The importance of "practical knowledge" was previously shown in the career development of healthcare professionals [18]. This study defined total years of clinical experience by time spent caring for patients both in the inpatient and outpatient setting. This study found a small but not statistically significant difference in TKS based on years of clinical experience. In PACU nursing staff, TKS incrementally increased from 72.1% correct in those with 3-5 years of experience to 79.8% among those with 10 years or more clinical experience.

Role of healthcare setting: Across the literature, there exist conflicting views on how healthcare setting affects PO knowledge [6-8]. The current study found no significant difference between PO knowledge in ICU staff compared to non-ICU staff. On the other hand, a study has shown that clinical setting does make a difference with paediatricians scoring lower on a PO assessment compared to Level 3 ICU staff [8].

This study found that MRICU nurses had slightly higher but not statistically significant TKSs than PACU nurses (16.5 vs. 16.2, p=0.27). Kiekkas P et al., have similarly shown that nurses working in critical care environments such as the ICU had higher TKS scores than their counterparts in the Emergency or Anaesthesia Departments [4]. Curiously, a study done in Greece found that ICU nurses performed better on PO assessment relative to non-ICU nurses suggesting that perhaps the clinical experience in this region might be superior to other regions [8]. Further such studies should be conducted in various regions of the United States to get a more representative sample of healthcare setting on PO application.

ICU nurses may have a stronger grasp on cardiovascular and respiratory parameters by nature of caring for critically ill patients daily. Nurses in other clinical environments such as ward medicine, emergency departments may not frequently deal with the same types of patients [19]. This was the case in the aforementioned study where paediatricians scored lower on a PO assessment compared to Level 3 ICU staff. It seems healthcare setting might have also accounted for these differences as the training a general paediatrician receives does not revolve around critical care.

Graduates' knowledge of gas exchange and PO: Regarding knowledge of gas exchange and cardiopulmonary physiology, this study's results differed from the results of Kiekkas P et al., and Seeley MC et al., [4,5] Whereas these previous studies found significant gaps in fundamental principles required for the proper use and interpretation of PO, this study's results did not demonstrate a significant knowledge gap.

For example, Seeley MC et al., found that 57% of their participants incorrectly thought that the relationship between SpO_2 and PaO_2 was linear (Questionnaire item # 9) [5]. This study found that only 21.6% of nurses incorrectly believed this statement. Kiekkas P et al., state that in their study the lowest percentages of correct responses (<50%) were found in five of eleven questions pertaining to physiologic principle required to understand PO [4]. This study demonstrates that the lowest percentages of correct responses (<50%) were found only in two of eleven questions pertaining to physiologic principles of PO (Question 3 and 16). Nurses in the United States undergo extensive education which has advantages in learning the basic physiologic principles and application of PO. Recent study have explored this concept, termed a "theory-practice gap," and have consistently found that practical education is a critical supplement to theoretical classroom education [20].

Next, Seeley MC et., found that 71% of their total participants (and 83% of those with at least one postgraduate year) incorrectly thought PO was used for the rapid detection of tissue hypoxia (Questionnaire item # 3) [5]. Similarly, Kiekkas P et al., found that 71.5% of their participants incorrectly believed this. This study showed that 52.9% of participants incorrectly believed this statement [4]. While better than the other two studies, it is concerning that over half of this study's cohort did not understand this concept. A pulse oximeter can indicate hypoxemia by estimating the SaO_2. Hypoxia, however, refers to decreased oxygen at the cellular level, which is not measured by PO. A nurse who is unaware of this limitation may fail to perform various physical assessments of inadequate tissue oxygenation status under conditions of normal SpO_2 [5].

Important deficits in the use of PO to assess perfusion in extremities were noted. Decreased arterial perfusion compromises the ability of PO to determine hypoxemia. This concept was well understood by participants in this study as well as participants in the Seeley MC et al., and Kiekkas P et al., studies [4,5]. A 100% of this study's participants, 92.5% of Seeley MC et al., and 84.5% from Kiekkas P et al., understood that poor peripheral perfusion causes difficulty in obtaining accurate PO readings (Questionnaire item #11) [4,5]. A 90.2% of this study's participants, 71% of Seeley MC et al., participants, and 69.1% of Kiekkas P et al., participants were able to expand on this concept by answering that vasoconstricted states create errors in peripheral PO sensors, encouraging centrally applied pulse oximeters probes to increase accuracy (Questions 6) [4,5]. However, participants from all studies, this current study included, failed to extrapolate this concept to the setting of cardiopulmonary resuscitation, a state where impaired cardiac functioning causes diminished perfusion, both centrally and peripherally. This error was committed by 45.1% of this study's participants, 38% of Seeley MC et al., study, and 41% of Kiekkas P et al., correctly identified that PO is not recommended during cardiopulmonary resuscitation (Questionnaire item # 16) [4,5]. This again suggests a specific theoretical knowledge deficit that might be corrected at a pre-graduate level.

Limitation(s)

One of the main limitations to this study was the small sample size. Participation of nursing staff in this study was voluntary which increases the likelihood of a selection bias. Furthermore, responder fatigue may have skewed some results. To limit the risk of fatigue, the questionnaire was limited to a reasonable 21 items with a binary true/false format rather than multiple choice. Adding this additional choice may have prevented bias from a participant guessing the correct response.

Lastly, there existed no way of knowing if participants accessed any resources while taking the survey. This "open book" risk may have been a limitation of the reference study populations as well.

CONCLUSION(S)

The effective use of PO in perioperative and critical care settings requires a strong grasp of physiologic and clinical knowledge. This study, conducted in the United States, indicates a higher fund of knowledge of nursing staff relative to other reference studies. In this study's surveyed population, there was no significant difference in PO knowledge scores with regard to clinical setting or years of clinical experience. Some areas of opportunity were identified related to deficits in physiologic principles of PO. To address these areas, this study recommends frequent standardised assessments of clinical staff to ensure competency in physiologic and principles of clinical application. Improvement in postgraduate education curriculum and implementation of regular assessments will ensure up-to-date understanding of these clinical principles and ultimately lead to safer patient care.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]

- Plagiarism X-checker: Jul 11, 2020
- Manual Googling: Nov 05, 2020
- iThenticate Software: Dec 14, 2020 (11%)

ETYMOLOGY: Author Origin

AUTHOR DECLARATION:

- Financial or Other Competing Interests: As declared above
- Was Ethics Committee Approval obtained for this study? Yes
- Was informed consent obtained from the subjects involved in the study? Yes
- For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: **Jul 10, 2020**
Date of Peer Review: **Sep 28, 2020**
Date of Acceptance: **Nov 18, 2020**
Date of Publishing: **Dec 15, 2020**