Comparison between Portable Pulse Oximeter and Conventional ICU Pulse Oximeter Measurements in Healthy Adults: A Cross Sectional Study

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Abstract

Objective: To assess the agreement between oxygen saturation reading between portable pulse oximeter and conventional ICU monitor pulse oximeter.

Methods: This cross-sectional study was conducted at Department of Medicine, Fatima Hospital Baqai Medical University, Karachi, from 1st March 2023 to 31st March 2023. Participants in the study included healthy health care workers and medical students who were over the age of 18 and did not have any known co-morbid conditions like hypertension or diabetes that may affect peripheral perfusion. None of the participants had hypotension, clinical evidence of anemia, fingernail paint or poor peripheral perfusion as these are the factors that may influence pulse oximetry readings. Both the portable pulse oximeter and the traditional intensive care unit (ICU) monitors were utilized to take and record the oxygen saturation levels of each of the ten fingers in a sequential manner while the patient was seated. Data was analyzed using SPSS version 22. Readings of both instruments were compared employing Regression analysis. Bland-Altman analysis was applied to measure the level of agreement between readings of portable pulse oximeter and conventional ICU monitors.

Results: Total 200 participants were enrolled for this study and most of them were from younger age group. (Mean age of participants = 33.05 ± 10.31). There was no significant difference between oxygen saturation readings of respective finger from portable pulse oximeter and conventional ICU monitors on regression analysis ($p > 0.05$). Highest mean oxygen saturation was recorded in right middle finger using portable pulse oximeter (98.71 ± 1.21). On the ICU monitor pulse oximeter, it was 2nd highest in right middle finger (98.33 ± 2.49). Therefore, Bold-Altman analysis applied between oxygen saturation reading for two devices in right middle finger and was found to be comparable. (Mean difference (bias) = 0.375 with 95% confidence interval).

Conclusion: Modern portable pulse oximeters can reliably be used to rule out hypoxemia.

Key Words: Pulse oximetry, Portable pulse oximeter, ICU monitors, Oxygen saturation, Hypoxemia

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Introduction

In recent times, portable pulse oximetry has become an essential instrument in the realm of contemporary patient care, especially during the post-COVID era. This technique offers a cost-effective means of assessing the oxygenation status of patients. It is non-invasive, safe, and user-friendly. pulse oximeters function on the principle that oxygenated and deoxygenated blood absorb different spectra of light[1]. Noninvasive measurement of oxygen saturation was started by Glenn Allen Millikan during World War II for measuring oxygen saturation of pilots flying at high altitude. He named his instrument “oximeter” which was based on Beer-Lambert’s Law and was being attached to ear lobe. Even this “oximeter” and the one developed by Hewlett Packard in 1970 for clinical purpose involved heating of ear lobe. Credit goes to Takuo Aoyagi who developed a device for noninvasive measurement of oxygen saturation for clinical purposes which can truly be named as pulse oximeter. It was based on difference in absorption spectra of light, the principle for current modern pulse oximeters[2].

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It is observed that a decline in oxygen saturation happens even before the onset of the typical clinical signs of respiratory distress. Monitoring the oxygen saturation of patients admitted to the critical care unit is a routine practice or procedure. It timely detects episodic hypoxemia. However, in order to get accurate readings from a pulse oximeter, the correct procedure needs to be followed. The pulse oximetry readings can be influenced by various factors, including the patient's movement, the pigmentation of their skin, and their peripheral perfusion status[3]. Oxygen saturation measurements are also the part of pre and post operative protocols of surgical patients. This leads to improved clinical outcomes as well as patient safety. The World Health Organization (WHO) surgical safety checklist includes pulse oximeters as an essential piece of equipment[4]. In 2021, the National Health program (NHS) of England launched the COVID oximetry @home (CO@h) program. Every COVID positive patient was provided with a portable pulse oximeter to enable them to monitor their oxygen saturation levels from their own homes comfortably. The goal of this initiative was to reduce unnecessary visits to the hospital and ensure prompt admission of critically ill patients. The implementation of this service resulted in a 4% decrease in death rates[5].

Employing pulse oximetry decreases the need for arterial blood gas analysis, hence leading to a decrease in the overall cost of medical care. Several investigations have been undertaken to validate the concordance between the findings of arterial blood gas analysis and pulse oximetry. Monitoring of oxygen saturation at home is needed in certain conditions, especially chronic respiratory disorders. During COVID epidemic, the significance of domiciliary pulse oximetry has grown significantly. This can be achieved by utilizing a simple and portable pulse oximeter[6]. These pulse oximeters are not only cost-effective, but they are also portable, user-friendly, and lightweight, rendering them suitable for transportation and usage. These portable pulse oximeters can be quite helpful in low resources settings and makeshift arrangements made during a catastrophe, where apart from financial constraints, clinicians face shortage of trained support staff. These pulse oximeters are manufactured and marketed by different companies. Studies found that there is no significant difference in pulse oximetry readings of different pulse oximeters[7].

Clinicians are usually concerned about authenticity of portable devices. Although these devices undergo a standardization process before to being marketed, it has been observed that there is frequently a level of discrepancy in the results or readings in real clinical scenarios[8]. With this background, we conducted this study to compare the oxygen saturation values obtained from conventional and portable fingertip pulse oximeters. This will not only add further data to existing studies but may give confidence to healthcare professionals to take clinical decisions on basis of readings of these portable devices.

Methodology

This cross-sectional study was conducted in the Department of Medicine, Fatima hospital, Baqai Medical University, Karachi. The data was collected between the periods of March 1st and March 31st, 2023. The study participants were healthy health care professionals and medical students who were over the age of 18-years and volunteered to participate in study. The study excluded individuals who engaged in tobacco smoking, were pregnant or experiencing active menstrual bleeding, had radial or ulnar failure, hypotension, bradycardia, clinical anemia, fingernail paint (nail polish) on their nails, a history of hypertension, or diabetes. The ethics committee, in a letter with the reference number EC/01-2023, granted approval to the proposed study.

The open-source statistical tool G*Power 3.1.9.7[9] was utilized to determine the minimum sample size required for acceptability. Based on a statistical power of 80% and a significance level of 5%, it was decided that a total sample size of 200 is adequate.

All the volunteer participants gave written consent before inclusion in study. All information was gathered in a single sitting from all patients. Data on general characteristics (variables), such as age, gender, and underlying medical conditions, was collected using a self-reporting questionnaire. An experienced staff member measured blood pressure using conventional blood pressure apparatus. Blood pressure was measured after confirming that the patient had been resting for ten minutes and had not taken caffeine during the last thirty minutes. The same staff member recorded the subject's measurements for height, weight, and temperature. A postgraduate trainee in the Medicine Department assessed the participants' pulses and examined for general indicators such as anemia, cyanosis, and nail conditions to exclude persons who did not meet the qualifications for the study. The same postgraduate trainee was tasked with documenting the oxygen saturation levels of the subjects. We used a portable pulse oximeter produced by Certiza Germany, model No: PO-907, due to its easy availability in Pakistan, even online platforms, and the manufacturer's claim of its reliability in meeting certification standards. The authors bought the instrument at their own source. Medex, USA Smartview ECO 12B ICU monitor, already installed at Emergency Department, Fatima Hospital, Baqai Medical University, was used for the measurement of oxygen saturation and was compared with readings of portable pulse oximeter. The postgraduate trainees tested the participant's oxygen saturation while they were seated and had rested for atleast five minutes. Portable pulse oximeter and ICU monitor were separately connected to each finger, one by one, for a duration of one minute, so that we could have stable reading.

SPSS version 22 was used to analyze the data. Proportions and frequencies were employed to describe categorical variables, such as sex. The normality of continuous variables was assessed using the Shapiro-Wilk test. The data, which exhibited a normal distribution, was presented as mean± standard deviation. Regression analysis was conducted to assess the presence of a statistically significant difference in the oxygen saturation readings of all the fingers recorded by two different instruments. In order to measure the level of agreement between the findings acquired from portable and standard ICU pulse oximeters, Bland-Altman analysis was employed. Bold and Altman have defined bias and precision estimates as the standard reported statistic for evaluating the agreement between a novel or lesser-known measurement technique and an existing one. Both measurement methods can be used interchangeably when the predetermined boundaries of agreement are small (the 95% limits of agreement are set as bias plus or minus 1.96 standard deviations) and when the clinical importance of the data is not significant. For this study, we decided that an oxygen saturation level difference below 2% had minimal or no clinical significance.

Results

The oxygen saturation values of a group of two hundred participants were recorded. Table 1 displays the overall traits of the individuals who took part in the study. All participants were from younger age groups. The mean age of all participants was 33.05 ± 10.31 years. 145 participants were male and 55 were female (male to female ratio 2.63:1). The study population had a relatively higher mean body mass index (BMI) of 26.36±4.22 kg/m^2, despite the absence of any known comorbidities among the participants. This alarms us about our new endemic.

Table1. Demographic and Clinical Characteristic of Study Population

Parameter(variable)	Mean ± SD
Age (years)	33.05 ± 10.31
Height (m)	1.59 ± 0.09
Weight (Kg)	67.19 ± 11.25
BMI (kg/m^2)	26.36 ± 4.22
Systolic blood pressure (mmHg)	117.83 ± 11.24
Diastolic blood pressure (mmHg)	76.91 ± 7.99
Heart rate (beats/minute)	80.07 ± 10.58
Body temperature (OF)	97.98 ± 0.29

Mean oxygen saturation in all the ten fingers is shown in table 2. Highest mean oxygen saturation (%) was shown in right middle finger while using portable pulse oximeter (98.71 ± 1.21). A plausible rationale for this is that all individuals who took part in our study were right-handed. On the other hand, while using conventional ICU pulse oximeter, the highest level of oxygen saturation (%) was observed in the left thumb (98.59 ± 0.94), with the right middle finger following closely after (98.33 ± 2.49). It is important to note that the difference of mean oxygen saturation in all the ten fingers was minimal (table 2). No significant statistical difference ($p<0.05$) was identified between mean oxygen saturation values recorded by portable and conventional pulse oximeter on regression analysis. Readings of left thumb showed some degree of statistical difference ($p= 0.052$). Left little finger readings also showed comparatively higher difference between portable and conventional pulse oximeter readings (1.45 vs < 1 in all other fingers). This suggests that hand dominance and the specific finger used for pulse oximetry may have an impact on the procedure.

Table 2. Comparison of oxygen saturation readings between portable and conventional ICU pulse oximeters

Finger	Oxygen Saturation (%) in Portable Pulse Oximeter	Oxygen Saturation (%) in Conventional ICU Pulse Oximeter	Mean Difference between oxygen saturation (%) by two instruments	P value
Right Thumb	98.28 ± 1.07	98.36 ± 2.75	-0.08	0.359
Right Index Finger	98.46 ± 1.18	98.43 ± 2.93	0.03	0.222
Right Middle Finger	98.71 ± 1.21	98.52 ± 2.40	0.18	0.394
Right Ring Finger	98.26 ± 1.19	98.33 ± 2.49	-0.07	0.108
Right Little Finger	98.03 ± 1.28	98.25 ± 1.12	-0.22	0.080
Left Thumb	98.53 ± 1.19	98.59 ± 0.94	-0.06	0.052
Left Index Finger	98.14 ± 1.08	98.19 ± 2.95	-0.05	0.670
Left Middle Finger	98.25 ± 1.31	98.09 ± 2.64	0.16	0.359
Left Ring Finger	98.36 ± 1.10	98.12 ± 2.61	0.24	0.518
Left Little Finger	96.89 ± 1.15	98.34 ± 2.57	-1.45	0.917

Researchers have found that the right middle finger is the most effective finger for pulse oximetry analysis(10). Our research shows that the oxygen saturation measurement obtained from the right middle finger was the highest when using a portable pulse oximeter, and the second highest when using conventional ICU pulse oximeters. Therefore, we used readings from the right middle finger to create the Bold-Altman plot. The mean difference (bias) between the conventional pulse oximeter and the portable pulse oximeter for the right middle finger was 0.375, with a 95% confidence interval ranging from 0.0279 to 0.7221. Figure 1 illustrates this difference. The upper and lower limits of agreement were 3.2758 and 2.5258 respectively, as shown in figure 1. These results demonstrate that the readings from portable and traditional pulse oximeters are comparable.

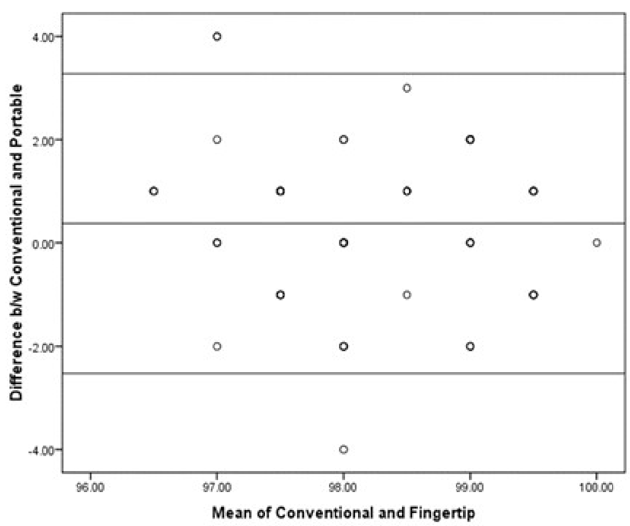

Fig 1. Bold Altman Plot for peripheral oxygen saturation readings
(Central line is at mean and upper and lower lines at +1.96 SD and -1.96 SD respectively)

Discussion

Our study found that there is no significant difference in the clinical use of oxygen saturation measurements obtained from portable pulse oximeters and conventional intensive care unit monitors in healthy individuals. These findings could be valuable in terms of aiding patient care. This relationship needs to be assessed in critically ill patients.

Portable pulse oximeters have been shown to be accurate in preoperative patients who do not have any cardiovascular compromise. Tekin K et al concluded that portable pulse have significant impact on patient care in modern medicine and can reliably be used to detect hypoxemia[11]. Smith RN compared oxygen saturation levels obtained from portable and conventional intensive care unit monitors for patients who were scheduled to undergo elective and emergency procedures. Patients who had cardiovascular impairment were not included in the study. Based on oxygen saturation, they divided the study population into two groups: those with an oxygen saturation greater than 93% and those with an oxygen saturation below 93%. In the group with an oxygen saturation level greater than 93%, they discovered that there was a level of agreement between two pulse oximeter readings. On the other hand, in the group with an oxygen saturation level less than 93%, there was little agreement on readings of two instruments[12]. Harksamp RE et al compared ten portable pulse oximeters of various brands with arterial blood gas analysis in a study that involved thirty-five patients. They came to the conclusion that all of these portable pulse oximeters are capable of reliably ruling out hypoxemia; nevertheless, these portable pulse oximeters did not meet the standards set by the International Organization for Standardization (ISO), which are necessary for clearance from the Food and Drug Administration (FDA). Most of the studies conclude that these oximeters may be used to rule out hypoxemia but cannot be an alternative to arterial blood gas analysis. However, these portable pulse oximeters can be very helpful in making prompt decisions on the transfer of patients from a low-resource facility to a tertiary care setting[7]. Pilcher J et al also found that pulse oximeters can reliably rule out hypoxemia. These oximeters also reliable to continuously monitor oxygen saturation[13]. In our investigation, we used conventional ICU monitor and portable pulse oximeters to measure oxygen saturation levels in normal, healthy persons. The results revealed that there was no significant difference ($p > 0.05$) between readings of two devices. A new area of research is now open to compare smart phone applications with these conventional devices. Data gathered in this field has shown conflicting results till date.

Apart from the type of pulse oximeter used, some other factors also have an effect on oxygen saturation readings. Louie A et al found that pulse oximetry readings are affected by patient movement, particularly in states of low perfusion[14]. In order to exclude this factor, we took pulse oximetry readings of the participants while they were seated in a stable position. Silverston P et al concluded that the inaccuracy of pulse oximetry devices increased with the degree of desaturation. In addition to this, they suggested that the oxygen saturation level should be monitored over a period of time and the trend of readings should be followed when making clinical judgments. Research is required in order to determine that what trend, the lowest reading, or the greatest reading should be followed[15]. In our study, oxygen saturation was measured for a period of sixty seconds in all the fingers, and the highest measurement was taken into consideration. Giuliano KK et al also investigated the impact of patient movements and perfusion status had on the results of pulse oximetry. They used controls for similar brands of pulse oximeters. However number of participants in their study was rather low (n=28)[16]. There are some manufacturers of novel pulse oximeters that assert that their pulse oximeters are reliable even when the person's perfusion level is low. They are capable of detecting aberrant venous signals and extracting arterial signals from those signals[17]. Cabanas AM et al found that skin pigmentation may potentially have an effect on pulse oximetry values.

In state of poor peripheral perfusion, this effect becomes an even more significant factor[18]. Gudelunas M et al also studied the impact of skin pigmentation on pulse oximetry values in healthy adults. They concluded that having dark skin and a poor perfusion index could result in low pulse oximetry readings. Feiner JR et al also had similar observation. They concluded that type of sensor used and gender also contribute to an error attributed due to skin colour[19]. Ochoa-Gutierrez V et al similarly discovered that skin pigmentation may have an effect on pulse oximetry results[20]. Such bias may also be observed with nail polish. Aggarwal AN found that certain dark colour nail polish paints result in low oxygen saturation readings[21]. None of our study participant had nail paint, however, our research did not take into account the pigmentation of their skin. Importantly, all of the people who participated in the study were healthy and none of the participants exhibited any substantial hypoxia or bradycardia, according to the data that we collected. Nevertheless, a new technology is required to take into consideration skin pigmentation when measuring oxygen saturation because our region has a wide variety of skin tones, ranging from very light (mainly in the north) to very dark (in the center and south).

Basaranoglu G et al determined that the right middle finger and right thumb show the highest oxygen saturation level. They gave a concept of preferred finger for pulse oximetry[10].Sur A et al also concluded that significant inter-finger variation exists in oxygen saturation readings. They found highest oxygen saturation is recorded in middle finger followed by thumb. They found lowest oxygen saturation reading is recorded in little finger[22]. Which finger is preferentially used by health care professional becomes important. Mitzukoshi et al found that health care professionals prefer index finger for oxygen saturation recording. On the other hand they also concluded that highest oxygen saturation values are recorded in middle finger[23]. In our study we compared oxygen saturation reading of each finger from portable pulse oximeter and conventional ICU monitor. However, data of right middle finger was used for Bland-Altman analysis to quantify degree of agreement between readings of two instruments.

One of the limitations of our study was that we did not perform arterial blood gas analysis in order to compare the results with the oxygen saturation findings of the pulse oximeter. However, studies have demonstrated that pulse oximeters are reliable and accurate in measuring oxygen saturation. Louie A et al documented long time ago that pulse oximeter findings were accurate enough to predict oxygenation status of body[14]. Pulse oximeter findings, on the other hand, may be affected by and become less reliable in some conditions that are associated with low peripheral perfusion like vasculitis, anemia or low blood pressure. It was made sure before inclusion in our study that our study participants did not have poor peripheral perfusion.

Due to the COVID pandemic, patient management standards and strategies have been altered. Unconventional settings were used to provide patient care. Such devices, if accurate enough or in other words do not show significant difference from standard devices, can be valuable. Such devices were of value at that time and even now. Such devices may be given to patients at risk to monitor oxygen saturation at home and seek higher level of care when oxygen saturation crosses certain cutoff. Furthermore, they can be utilized in makeshift facilities developed during natural disasters and wars. However, one important aspect that needs to be addressed is proficiency of nursing staff in using pulse oximeters. Hasanien AA et al found that nurses have inadequate knowledge about pulse oximeter use and interpretation[24].Most of such studies are from 3rd world countries[25]. Considering this, we deputed a senior postgraduate trainee from Department of Medicine for pulse oximetry who thoroughly explained protocols and purpose of study.

Conclusion

Use of portable pulse oximeters is valuable in modern medicine in terms of cost, easy accessibility, and patient care. Portable pulse oximeter readings are comparable to conventional ICU monitor readings. Patients with respiratory disorders can detect hypoxemia timely at home and may seek hospital care at the right time. However, users, both patients and nurses, must be trained in using portable pulse oximeters. They need information about factors that may affect pulse oximetry readings.

Conflict of Interest

Authors have no conflict of interest and no grant funding from any organization.

References

1. Kuen LS, Kaur A, Amalnerkar T. Abstracts of the Third Biennial International Scientific Conference of the Faculty of Medicine and Health Sciences, Universiti Tunku Abdul Rahman, Sungai Long, Malaysia held on 22–26 November 2021. Malays J Pathol 2022;44(1):133-62. Available from: http://www.mjpath.org.my/2022/v44n1/abstracts-3rd-biennial-ISC.pdf. Accessed on 24th February 2024.
2. Tremper KK. Pulse oximetry. Chest 1989;95(4):713-5. [DOI: 10.1378/chest.95.4.713.]. Available from: https://journal.chestnet.org/article/S0012-3692(16)30698-5/fulltext. Accessed on 24th February 2024.
3. Friedman J, Calderón-Villarreal A, Bojorquez I, Hernández CV, Schriger DL, Hirashima ET. Excess out-of-hospital mortality and declining oxygen saturation: the sentinel role of emergency medical services data in the COVID-19 crisis in Tijuana, Mexico. Ann Emerg Med 2020;76(4):413–26. [DOI: 10.1016/j.annemergmed.2020.07.035]. Available from: https://www.sciencedirect.com/science/article/pii/S0196064420306016. Accessed on 24th February 2024.
4. Igbodike EP, Eleje GU, Igbodike NT, Ikechebelu JI. World Health Organization Surgical Safety checklist: Proposed new Safety Checklist addressing and repositioning the key stems. Trop J Med Res 2022;21(1):229-34. [[DOI: 10.5281/zenodo.7109158]. Available from: https://tjmr.org.ng/index.php/tjmr/article/view/32. Accessed on 24th February 2024.
5. Sherlaw-Johnson C, Georghiou T, Morris S, Crellin NE, Litchfield I, Massou E, et al. The impact of remote home monitoring of people with COVID-19 using pulse oximetry: a national population and observational study. EClinicalMedicine. 2022;45:1-12. [DOI: 10.1016/j.eclinm.2022.101318]. Available from: https://www.thelancet.com/journals/eclinm/article/PIIS2589-5370(22)00048-7/fulltext. Accessed on 24th February 2024.
6. Joshi LR. Principles, utility and limitations of pulse oximetry in management of COVID-19. J Lumbini Med Coll 2020;8(1):105-10. [DOI: 10.22502/jlmc.v8i1.356]. Available from: https://jlmc.edu.np/index.php/JLMC/article/view/356. Accessed on 24th February 2024.
7. Harskamp RE, Bekker L, Himmelreich JC, De Clercq L, Karregat EP, Sleeswijk ME, et al. Performance of popular pulse oximeters compared with simultaneous arterial oxygen saturation or clinical-grade pulse oximetry: a cross-sectional validation study in intensive care patients. BMJ Open Respir Res 2021;8(1):1-7. Available from: https://bmjopenrespres.bmj.com/content/bmjresp/8/1/e000939.full.pdf. Accessed on 24th February 2024.
8. Leppänen T, Kainulainen S, Korkalainen H, Sillanmäki S, Kulkas A, Töyräs J, et al. Pulse Oximetry: The Working Principle, Signal Formation, and Applications. In: Advances in the Diagnosis and Treatment of Sleep Apnea: Filling the Gap Between Physicians and Engineers. Springer; 2022:205–18. Available from: https://link.springer.com/book/10.1007/978-3-031-06413-5. Accessed on 24th February 2024.
9. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. Behav Res Methods 2009;41(4):1149-60. [DOI: 10.3758/BRM.41.4.1149]. Available from: https://link.springer.com/article/10.3758/BRM.41.4.1149. Accessed on 24th February 2024.
10. Basaranoglu G, Bakan M, Umutoglu T, Zengin SU, Idin K, Salihoglu Z. Comparison of SpO2 values from different fingers of the hands. Springerplus. 2015;4(1):1-3. [DOI: 10.1186/s40064-015-1360-5]. Available from: https://springer plus. springeropen.com/articles/10.1186/s40064-015-1360-5#:~:text=SpO2%20measurement%20from%20 the,in%20 right%2 Dhand %20 dominant %20volunteers. Accessed on 24th February 2024.
11. Tekin K, Karadogan M, Gunaydin S, Kismet K. Everything About Pulse Oximetry-Part 1: History, Principles, Advantages, Limitations, Inaccuracies, Cost Analysis, the Level of Knowledge About Pulse Oximeter Among Clinicians, and Pulse Oximetry Versus Tissue Oximetry. J Intensive Care Med. 2023;38(9):775–84. [DOI: 10.1177/08850666231185752]. Available from: https://journals.sagepub.com/doi/10.1177/088506 66231185752?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%20%200pubmed. Accessed on 24th February 2024.
12. Smith RN, Hofmeyr R. Perioperative comparison of the agreement between a portable fingertip pulse oximeter v. a conventional bedside pulse oximeter in adult patients (COMFORT trial). S Afr Med J 2019;109(3):154-8. [DOI: 10.7196/SAMJ.2019.v109i3.13633]. Available from: http://www.samj.org.za/index.php/samj/index. Accessed on 24th February 2024.

13. Pilcher J, Ploen L, McKinstry S, Bardsley G, Chien J, Howard L, et al. A multicentre prospective observational study comparing arterial blood gas values to those obtained by pulse oximeters used in adult patients attending Australian and New Zealand hospitals. BMC Pulm Med. 2020;20(1):1–9. [DOI: 10.1186/s12890-019-1007-3.]. Available from: https://bmcpulmmed.biomedcentral.com/articles/10.1186/s12890-019-1007-3. Accessed on 24th February 2024.

14. Louie A, Feiner JR, Bickler PE, Rhodes L, Bernstein M, Lucero J. Four types of pulse oximeters accurately detect hypoxia during low perfusion and motion. Anesthesiology 2018;128(3):520–30. [DOI: 10.1097/ALN.000000 0000002002]. Available from: https://pubs. asahq. org/anesthesiology/article/128/3/520/18780/Four-Types-of-Pulse-Oximeters-Accurately-Detect. Accessed on 24th February 2024.

15. Silverston P, Ferrari M, Quaresima V. Pulse oximetry in primary care: factors affecting accuracy and interpretation. Br J Gen Pract 2022;72(716):132-3. [DOI: 10.3399/bjgp22X718769]. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8884444/pdf/bjgpmar-2022-72-716-132.pdf. Accessed on 24th February 2024.

16. Shi C, Goodall M, Dumville J, Hill J, Norman G, Hamer O, et al. The effects of skin pigmentation on the accuracy of pulse oximetry in measuring oxygen saturation: a systematic review and meta-analysis. medRxiv 2022;1-10. [DOI: 10.1101/2023.10.18.23297133]. Available from: https://www.medrxiv.org/content/10.1101/2023.10.18.23297133v1.full. Accessed on 24th February 2024.

17. Giuliano KK, Bilkovski RN, Beard J, Lamminmäki S. Comparative analysis of signal accuracy of three SpO2 monitors during motion and low perfusion conditions. J Clin Monit Comput. 2023;1–11. [DOI: 10.1007/s10877-023-01029-x]. Available from: https://link.springer.com/article/10.1007/s10877-023-01029-x. Accessed on 24th February 2024.

18. Cabanas AM, Fuentes-Guajardo M, Latorre K, León D, Martín-Escudero P. Skin pigmentation influence on pulse oximetry accuracy: a systematic review and bibliometric analysis. Sensors. 2022;22(9):1-20. [DOI: 10.3390/s22093402]. Available from: https://www.mdpi.com/1424-8220/22/9/3402. Accessed on 24th February 2024.

19. Feiner JR, Severinghaus JW, Bickler PE. Dark skin decreases the accuracy of pulse oximeters at low oxygen saturation: the effects of oximeter probe type and gender. Anesth Analg 2007;105(6):S18–23. [DOI: 10.1213/01.ane.000 0285988.35174.d9]. Available from: https://journals.lww.com/anesthesia-analgesia/fulltext/2007/12001/dark_s kin_ decreases_ the_ accur acy_of_pulse.4.aspx. Accessed on 24th February 2024.

20. Ochoa-Gutierrez V, Guerrero-Zuñiga S, Reboud J, Pazmino-Betancourth M, Harvey AR, Cooper JM. Changes in Oxygenation Levels during Moderate Altitude Simulation (Hypoxia-Induced): A Pilot Study Investigating the Impact of Skin Pigmentation in Pulse Oximetry. In: Oxygen Transport to Tissue XLIII. Springer; 2022. p. 391–6. [DOI: 10.1007/978-3-031-14190-4_64]. Available from: https://link.springer.com/chapter/10.1007/978-3-031-14190-4_64. Accessed on 24th February 2024.

21. Aggarwal AN, Agarwal R, Dhooria S, Prasad KT, Sehgal IS, Muthu V. Impact of Fingernail Polish on Pulse Oximetry Measurements: A Systematic Review. Respir Care. 2023;68(9):1271-80. [DO: 10.4187/respcare.10399]. Available from: https://rc.rcjournal.com/content/68/9/1271.short. Accessed on 24th February 2024.

22. Sur A, Kundu SB. A study on inter-finger variation and hand dominance in peripheral capillary oxygen saturation values recorded from the different fingers of the hands by pulse oximetry. Natl J Physiol Pharm Pharmacol. 2021;11(12):1411-15. Available from: https://www.bibliomed.org/mnsfulltext/28/28-1635420983.pdf?1708761196. Accessed on 24th February 2024.

23. Mizukoshi K, Shibasaki M, Amaya F, Mizobe T, Tanaka Y. Which finger do you attach pulse oximetry to? Index finger or not. Eur J Anesth. 2009;26(suppl 45):3AP1–5. Avalable form: https://www.masimo.co.jp/pdf/clinical/set/mizukoshi-which-finger-do-you-attach-pulse-oximetry-to-may-2009.pdf. Accessed on 24th February 2024.

24. Hasanien AA, Albusoul RM. Knowledge of pulse oximetry among emergency and critical care nurses. Nurs Crit Care. 2023; [DO: 10.1111/nicc.12971]. Available from: https://onlinelibrary.wiley.com/doi/10.1111/nicc.12971. Accessed on 24th February 2024.

25. Peterson ME, Mattingly AS, Merrell SB, Asnake BM, Ahmed I, Weiser TG. Pulse oximeter provision and training of non-physician anesthetists in Zambia: a qualitative study exploring perioperative care after training. BMC Health Serv Res 2022;22(1):1–10. [DO: 10.1186/s12913-022-086 98-5]. Available from: https://bmchealth servres .biomedcentral.com/articles/10.1186/s12913-022-08698-5#:~:text=Among%20a%20 cohort %20 of%20non,especially%20during%20transfers %20of%20care. Accessed on 24th February 2024.