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Normalization of blood oxygen levels and heart rate in adults using alternative measurement sites

Mohammed Abbood Al-Maliky, Maher Kamal Jasim, Hind H. Enad, Mustafa Wathiq Abdul Kareem

College of Dentistry, University of Al-Hadi, Baghdad, Iraq

ABSTRACT

This study addresses the need for reliable alternative measurement sites to the fingers, such as the lips and tongue, for measuring oxygen saturation (SpO_2) and pulse rate (PR). This is particularly important in cases of poor circulation, finger injury, or during surgery. The study included 20 healthy participants. SpO_2 and PR were measured using a pulse oximeter. Measurements were taken at the finger, lower and upper lips, and tongue. Descriptive and inferential statistics were done for site comparisons and for establishing reference ranges for these sites. SpO_2 readings were normally distributed ($p>0.05$), with the greatest readings coming from the finger site (98.23±1.83), followed by the lower lip (97.20±1.77), the upper lip (96.40±3.17), and finally the tongue (93.56±4.25). Pairwise comparisons indicated no significant differences between the suggested locations and the finger, except for the tongue ($p<0.05$). The PR data seemed normally distributed ($p>0.05$), with the greatest PR seen at the finger location (79.25±8.26), then the lower lip (75.30±7.69), the upper lip (74.55±8.37), and finally the tongue (71.5±9.05). Lower and upper lip sites showed no statistically significant changes, but a significant difference was found at the tongue site ($p<0.05$). Based on our findings, the lower and upper lips can serve as alternative sites for SpO_2 and PR measurements, as they closely align with values observed from the finger site. However, the tongue site showed significantly lower SpO_2 and PR values.

Key words: oximeter; lips; pulse rate; SpO_2; tongue; wavelength.

Corresponding author:
Mohammed Abbood Al-Maliky, College of Dentistry, Al-Hadi University, 10011 Baghdad, Iraq.
Tel.: +009647723676000
E-mail: m.a.almaliky@huc.edu.iq

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Introduction

The use of photoplethysmography (PPG) principles is employed by a pulse oximeter to get physiological measurements. Hertzman first developed the PPG method in 1937,[1] and the first commercially available pulse oximeter with practical functionality was launched in 1983. The process of obtaining oxygen saturation (SpO_2) measurements has been significantly simplified to the extent that it is sometimes referred to as the "fifth" vital sign.[2] The mechanism of action of this approach enables the quantification of the proportion of oxygen-saturated hemoglobin in arterial blood. The pulse oximetry system utilizes red and infrared light with a wavelength of 600-1000 nm.[3] The underlying premise of pulse oximetry is based on the fact that hemoglobin, in its oxygenated and deoxygenated forms, exhibits absorption of different wavelengths of light according to the Beer-Lambert law of absorption.[4] Two photodiodes, one generating light in the red spectrum and the other emitting light in the infrared spectrum,[5] are positioned on a specific side of the vascular region being examined. When light propagates through plasma, a portion of it gets absorbed by the hemoglobin. A photodetector situated opposite the diode is used to measure the quantity of light that successfully traverses a particular vascular network through photoelectric oximetry inspection technology.[4]
A SpO_2 measurement over 94% is often considered to fall within the normal range for most individuals. Values that fall below 94% are often associated with respiratory failure and indicate the existence of a significant respiratory disorder. However, individuals with stable chronic lung disease may have a tolerable range of 88-94%.[6]
While probing may be done at many locations on the body, some locations are more often used and dependable than others. The age, condition, and treatment setting of the patient may all influence the site selection for pulse oximetry. Although finger-clip pulse oximetry sensors are commonly used to obtain functional oxygen saturation readings (SpO_2), their performance may be compromised under certain conditions.[7] Factors include cold, poorly perfused digits, and excessive hand movements, like tremors, loss of fingers, fibrosis, and the presence of nail varnish and keratinization tissue.[8] Also, many conditions can reduce blood circulation to fingers, like shock, vasoconstriction, and the use of vasopressors.[9] Moreover, previous research on the utilization of earlobes as an alternative measurement site for pulse oximetry has shown less-than-ideal accuracy.[10] The face and oral area are close to the main arterial blood supply, which is provided by the external and internal carotid arteries, allowing for a faster response to changes in blood oxygen saturation, up to 7 seconds.[9] This emphasizes the importance of exploring alternative measurement sites, such as the lips and tongue, to measure oxygen saturation when facing the abovementioned limitations of finger-type measurement.
Recent literature studying alternatives to the finger site has shown that SpO_2 measurement during controlled hypoxemia studies (70-100% oxygen saturation range) at the ala of the nose is significantly more accurate than at the finger site. This supports the use of centrally perfused sites for SpO_2 monitoring.[11] In the intraoral area, Kashima *et al.* developed an intraoral oximeter sensor attached to a mouthpiece, which is placed on the gingiva. After testing their device on 12 adults, the results indicated that it provided practical and rapid measurements of desaturation events compared to the finger site. The palatal gingiva of the canine was observed to have the highest perfusion index in their experiment.[9] Reports on using the tongue to measure SpO include a study by Schober *et al.*, who measured SpO levels on the tongues of critically ill COVID-19 patients. The results showed that the SpO_2 measurement on the tongue is 2% lower than that of finger sites.[12]
This study aimed to use the lower and upper lips and tongue as alternative sites to record the oxygen saturation status when it is impossible to test blood oxygen percentage and heart rate with a finger using a clamp probe oximeter. Furthermore, it seeks to specify the normal standardized ranges of SpO_2 and pulse rate (PR) for these sites.

Materials and Methods

The study was conducted on 20 subjects aged 18 to 33 years (average 23±4.5) who were healthy, had no mustaches, and did not receive lidocaine injections at the time of the experiment. The study took place from April 2023 to June 2023. Informed consent was obtained from the subjects before the commencement of the study. The study protocol was approved by the College of Dentistry, University of Al-Hadi Ethical Committee (2/2023).
The SpO_2 and PR were recorded using a pulse oximeter (CONTEC CMS-60D-VET, Contec Medical Systems, Hebei Province, China) that contains a clamp probe

made of soft biocompatible silicone material (Figure 1). For the SpO_2 and PR measurements, the device has a resolution of 1% and an accuracy of ±2%. For the PR measurement, the device has a resolution of 1 bpm and an accuracy of ±2 bpm. The device emits two wavelengths in the red and infrared regions of the electromagnetic spectrum. The red wavelength is 660 nm with an output power of 6.65 mW, and the infrared wavelength is 905 nm with an output power of 6.75 mW.

The measurements were conducted on the index finger, lower and upper lips, and tongue. The recordings were made with the patients seated in the dental chair in a semi-supine position between 9 a.m. and 12 p.m. For standardization, the sensor was placed by clamping either the lower or upper lip on the right side near the angle of the mouth, depending on the test group. The subjects were instructed to close their mouths around the sensor and remain motionless during the measurement (Figure 2). During the oximeter measurement on the tongue, the sensor clamp held the tip of the tongue, and the subject was instructed to remain still while the measurement was taken. The device operated in continuous monitoring mode, and the maximum value recorded during each test was used for further analysis. It was essential to ensure that the tongue was not too dry, as this could affect the accuracy of the measurement. The optimum working temperature for the device is 10-40°C; the experiment was conducted at a room temperature of 25°C. No nearby equipment generating a strong electric field that could affect the measurement was present.

Figure 1. Handheld pulse oximeter device. The sensor clamp is convenient for grasping the test sites: finger, lower and upper lips, and tongue.

Figure 2. Measurement procedure of SpO_2 and PR. a) Testing at the fingertip site; b) testing at the upper lip.

The oximeter measurement of the index finger was also taken to serve as a reference for measuring the lips and tongue. The data history was transferred from the oximeter device to a computer *via* a USB cable using the CMS60D software version 2.0 and tabulated in an Excel sheet for further statistical analysis.

The normal distribution of the data was tested using the normal distribution function one-sample Kolmogorov-Smirnov test. The statistical analysis included descriptive statistics and pairwise comparisons of repeated measures using within-subjects effects tests for SpO_2 and PR across the studied sites: upper lip, lower lip, tongue, and index finger. Additionally, the analysis aimed to establish normalized reference values for SpO_2 and PR at the proposed measurement sites. A significance threshold of 0.05 was applied.

Results

Normal distribution function (goodness-of-fit test)

The results showed that the distribution of studied readings concerning SpO_2 and PR has normal distribution functions relative to different sites (lower lip, upper lip, and tongue), as evidenced by p-values greater than 0.05 in all cases.

Test results of SpO_2 and PR

Tables 1 and 2 represent descriptive statistics of SpO_2 and PR in different sites (finger, lower lip, upper lip, and tongue).

Results showed that both SpO_2 and PR markers accounted for the highest level at the finger site, followed by the lower lip site, the upper lip site, and finally the tongue site, which recorded the lowest mean value compared with the other sites (Figures 3 and 4).

Regarding the testing, pairwise comparisons of repeated measures using the test of within-subjects effects (Tables 3 and 4) revealed the inferential statistics between the means. The results showed that the differences between the finger site and both the lower and upper lips were not statistically significant ($p>0.05$). In contrast, a highly significant difference was observed between the finger and tongue sites ($p<0.01$). In addition, the normalization of normal blood oxygen level is presented under the assumption that the normal range (94-99) is correct for measuring the rate of oxygen SpO_2 by measuring at the finger site.

Normalization of the normal PR range was based on the assumption that adult values typically fall between 60 and 100 bpm, which is considered accurate when measured at the finger site. Accordingly, the normalization value was calculated using the following formula: standard value Lb (lower bound)/Ub (upper bound) – width of the 95% CI (confidence interval).

Table 1. Descriptive statistics regarding the SpO_2 test distributed across various sites.

Factor	Sites	Patients (n)	Mean	Standard deviation	Standard error	Min	Max
SpO_2	Finger	20	98.25	1.83	0.41	95	100
	Lower Lip	20	97.20	1.77	0.39	94	100
	Upper Lip	20	96.40	3.17	0.71	90	100
	Tongue	20	93.65	4.25	0.95	86	100

SpO_2, oxygen saturation.

Table 2. Descriptive statistics regarding the PR test distributed in different sites.

Factor	Sites	Patients (n)	Mean	Standard deviation	Standard error	Min	Max
PR	Finger	20	79.25	8.26	1.85	60	93
	Lower Lip	20	75.30	7.69	1.72	63	88
	Upper Lip	20	74.55	8.37	1.87	60	93
	Tongue	20	71.50	9.05	2.02	60	96

PR, pulse rate.

Table 3. Pairwise comparisons of repeated SpO_2 measures using a within-subjects effects test to evaluate differences across the studied sites and to support the normalization of blood oxygen levels at the proposed measurement locations.

Pairwise comparisons		Mean	Standard	p-value*	95% CI for difference		Normalization of blood oxygen level		
SpO_2(I)	SpO_2 (J)	difference (I-J)	error		Lb	Ub	Width	Lb	Ub
Finger	Lower Lip	1.050	0.535	0.388	-0.526	2.626	3.152	91	96
	Upper Lip	1.850	0.737	0.128	-0.320	4.020	4.340	90	95
	Tongue	4.600	1.125	0.004	1.289	7.911	6.622	87	92

*SpO_2, oxygen saturation; I, finger; J, other sites; Lb, lower bound; Ub, upper bound; *p>0.05, statistically significant.*

Table 4. Pairwise comparisons of repeated PR measures using a within-subjects effects test to evaluate differences across the studied sites and to support the normalization of blood oxygen levels at the proposed measurement locations.

Pairwise comparisons		Mean	Standard	p-value*	95% CI for difference		Normalization of blood oxygen level		
SpO_2(I)	SpO_2 (J)	difference (I-J)	error		Lb	Ub	Width	Lb	Ub
Finger	Lower Lip	3.95	1.727	0.203	-1.133	9.033	10.166	50	90
	Upper Lip	4.40	1.577	0.070	-0.242	9.042	9.284	51	91
	Tongue	7.75	2.230	0.015	1.185	14.315	13.130	47	87

*SpO_2, oxygen saturation; I, finger; J, other sites; Lb, lower bound; Ub, upper bound; *p>0.05, statistically significant.*

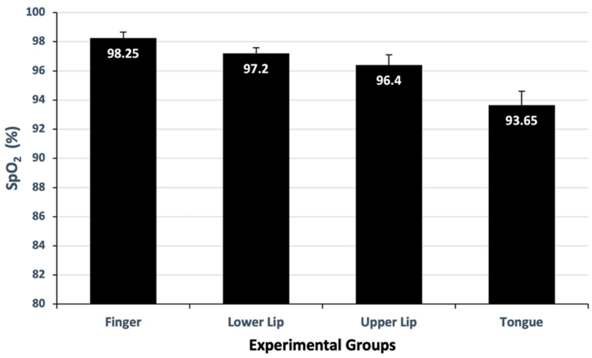

Figure 3. Graphical representation of a bar chart showing mean values of SpO_2 test readings across different sites (n=20).

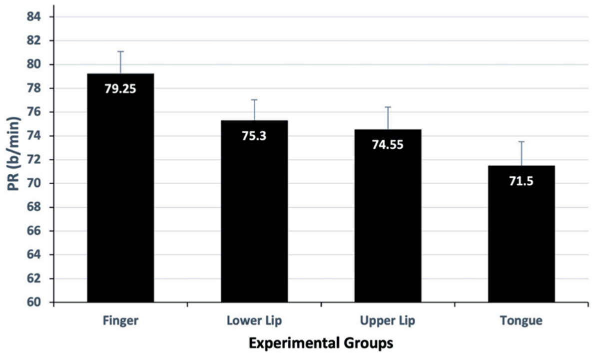

Figure 4. Graphical representation of a bar chart showing mean values related to the PR test readings across different sites (n=20).

Discussion

This study aimed to evaluate the potential of the lower lip, upper lip, and tongue as alternative sites for measuring oxygen saturation and heart rate when the use of a finger clamp probe oximeter is not feasible. The findings indicated that SpO_2 and PR results for the lower and upper lips are comparable to those obtained from the finger ($p>0.05$); in contrast, the results for the tongue showed significant differences from those of the finger ($p<0.05$).

Statistical normalization of SpO_2 and PR measurements from the lower and upper lips was performed, using the established normal finger-site SpO_2 range of 94-99% as a reference. The normalized SpO_2 values were 91-96% for the lower lip and 90-95% for the upper lip. To the best of our knowledge, no previous studies have reported SpO_2 and PR measurements obtained from the lower and upper lip sites. However, Richard *et al.*[13] tested the buccal pulse oximeter as an alternative site for SpO_2 compared to the finger measurement ($p=1.65$). The authors recommended this site as an alternative in cases of burns to fingers and toes. Regarding tongue SpO_2 measurement, Charles *et al.*[14] recommended that this site is a reasonable assistant but not an alternative to finger measurement. Other related studies have suggested earlobe[15-17] and forehead sites.[18]

SpO_2 values of the lower and upper lip were close to finger site readings with non-significant differences ($p>0.05$). In particular, lower lip readings showed proximity to the finger, which could be attributed to the vascularity of these regions. Although the tongue has good circulation, there were difficulties in obtaining oximeter readings, and the results of SpO_2 and PR were not close to the finger measurement ($p>0.05$). The high thickness of the tongue could explain this, as a high percentage of the emitted light is absorbed and cannot reach the sensor at the ventral side of the tongue.

This is based on the different absorption peaks of oxygenated hemoglobin at 940 nm (infrared) and reduced hemoglobin at 660 nm (red).[19] Nonetheless, determining the hemoglobin saturation in living tissue can be challenging due to its light-absorbing nature. To address this, an oximeter probe is used, emitting alternating pulses of red and infrared light. On the other side of the tissue, a detector is placed opposite the light sources. These light-emitting diodes switch on and off rapidly, and the detector measures the variations. These measurements are then processed by an algorithm in a microprocessor to calculate and eventually display the oxyhemoglobin saturation to the user.[20]

This study requires validation through larger-scale investigations involving diverse patient populations across different age groups and health statuses, conducted at national or international levels, to ensure the results are robust, generalizable, and widely accepted.

Limitations of the current study include the inability to test patients allergic to the silicone material of the probe. Additionally, SpO_2 and PR measurements cannot be obtained from damaged skin, during cardiopulmonary resuscitation, or while the patient is receiving ventilatory support. Moreover, measurements should be taken from the contralateral side in patients with local lidocaine anesthesia to avoid vasoconstricted tissues. In summary, the lower and upper lips could serve as an alternative to finger measurement in cases of difficult or impossible finger measurement situations. This includes burns or loss of fingers. Besides, the lips are less subject to decreased circulation compared to other peripheral sites of the body.

Conclusions

In conclusion, the study findings support the use of lower and upper lip pulse oximetry as a reliable monitoring method for SpO_2 and PR when conventional measuring sites are dysfunctional.
Conversely, tongue pulse oximetry does not demonstrate the same level of accuracy, highlighting the need for further investigation when this approach is used in clinical settings.

Contributions

MAA, conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing – original draft, visualization, project administration, supervision; MKJ, conceptualization, methodology, validation, data curation, writing – review and editing, visualization, supervision; HHE, conceptualization, methodology, validation, formal analysis; MWA, investigation, resources, data curation, writing – review and editing, visualization. All the authors have read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Conflict of interest

The authors declare that they have no financial or commercial interests related to this study.

Ethics approval and consent to participate

This study was approved by the College of Dentistry, University of Al-Hadi Ethical Committee (2/2023). Informed consent was obtained from the patients included in this study.

Consent for publication

Written informed consent has been obtained from all study participants for the publication of this article.

Availability of data and materials

Data are available upon request from the corresponding author, under the regulations of the Al-Hadi University Ethics Committee and with the consent of the study participants.

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