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RELIABLE MONITORING OF OXYGEN SATURATION VIA PULSE OXIMETRY: WHICH SITE TO CHOOSE?

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ABSTRACT

This study focuses on identifying the best site for placement of pulse oximeter probe for accurate measuring of oxygen saturation. Twenty-three healthy male volunteers aged 20 to 40 years old were recruited in this study. Cold pressor test was done to stimulate vasoactivity and 460 measurements of SpO_2 level were obtained throughout the study. The results were analyzed using ANOVA with $p < 0.05$ was considered to be significant. Bias between sites are determined using Bland-Altman plot whilst the internal consistency of each measurement sites are identified via Cronbach-Alpha (α). Results showed that the best site for cutaneous oxygen saturation measurement is at the earlobe using the ear sensor. Portable finger pulse oximeter oxygen saturation estimation is accurate and reliable at specific fingers (thumb, right middle and right ring fingers) regardless of stimulation on peripheral vasoactivity.

Keywords: SpO_2; oxygen saturation; cold pressor test; vasoactivity; pulse oxymetry.

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1. INTRODUCTION

Gold standard measurement of oxygen saturation percentage is measured using arterial blood gas (ABG) analyses [1].The method has been proven to be very accurate and useful for diagnostic purposes [2]. In current practice, the test is not a routine investigation because the method is invasive, requires skillful personnel, time consuming and provide only intermittent measurement [3]. Alternatively, measurement of oxygen saturation using pulse oximeter offers many advantages in the continuous assessment of oxygen saturation either in hospital or out of hospital settings [4]. The method is non-invasive and allows instant monitoring on all types of patients and in any situations. Recent development of medical instruments provide various choices of hospital based pulse oximeter and portable pulse oximeter that is readily available in the market [5-6]. However, there is limited evidence-based recommendation as to the best site for pulse oximeter probe placement in order to gain reliable measurement of SpO_2 level.

The first phase of this study aimed to identify the reliable sites for placement of pulse oximeter probe to measure SpO_2 level. Hence, the second phase was to compare simultaneous measurements of SpO_2 level using non-invasive hospital based pulse oximeter against portable finger pulse oximeters in healthy male subjects during cold-pressor test

2. EXPERIMENTAL

2.1. Study Design

This study was done at clinical skill laboratory of Universiti Sains Islam Malaysia from August 2016 until February 2017. Based on PS software, the minimum sample size for this study was 15 [7-8]. The sampling frame for this study included male volunteers aged 20 to 40 years who were never diagnosed with any non-communicable or communicable diseases prior to their participation. Those selected had normal body mass index (BMI), blood pressure and random blood glucose. The exclusion criteria were clearly spelled out during the promotion of this study which include any physical disability, congenital or acquired abnormality and those using nail polish.

2.2. Study Protocol of Cold Pressor Test

Subjects were instructed to abstain from caffeine and other known vasoconstrictive compounds for at least 24 hours before reporting for the one-session test. The test was done with subjects lying recumbent in a temperature-regulated room (25°C + 0.5°C). Electrodes were applied for electrocardiography and respiratory monitoring, and a noninvasive blood pressure reading was taken before and after ice water immersion. Oxygen saturation was monitored through finger and ear probe of fixed-gain hospital based pulse oximeter (Nellcor N-560) and portable finger pulse oximeter (OLED SPO_2). After 10 minutes of baseline monitoring, the contralateral hand was immersed in ice-water for 30 seconds while the recordings continued. The results were analyzed with ANOVA, where $p < 0.05$ was considered to be significant. Bland-Altman plot was used to determine the bias and the internal consistency was identified via Cronbach-Alpha (α).

3. RESULTS AND DISCUSSION

This study received ethical approval from the institution review board (USIM/REC/FPSK-2016-19). The SpO_2 measurements were obtained from 23 healthy male volunteers. Their age ranged from 20 to 40 years (mean age: 24.1 + 6.3), mean BMI was 22.9 + 2.8 kg/m^2 and mean body temperature was 36.2 + 0.41^{o}C during the test. There were no episodes of hypotension, hypothermia, tachycardia or bradycardia observed amongst the subjects throughout the test.

The first phase of this study aimed to identify the best site to place the sensor for measurement of SpO_2 using hospital based pulse oximeter. Average SpO_2 values measured via hospital based pulse oximeter at different sites were ranked from the highest to lowest SpO_2 value: Ear > R4 > R3 > L4 > L1 >R1 > L3 > R2 > L2 > R5 > L5. The mean values of SpO_2 level and the abbreviations used to represent each fingers are listed in Table 1. The highest average SpO_2 mean value was measured from the earlobe using ear sensor. Thus, differences of the mean SpO_2 level measured from different sites were statistically significant ($F_{(10,253)}$ = 2.077, $p < 0.05$). Based on post-hoc test, the significant differences were between the level estimated at the ear with both right and left index and little fingers (R2, R5, L2, and L5). Cold pressor test also revealed good internal consistency with no significant difference of means for SpO_2 level at different time point using the ear sensor ($F_{(3,92)} = 0.829$, $p > 0.05$; $\alpha = 0.89$), R1 ($F_{(3,92)} = 0.42$, $p > 0.05$; $\alpha = 0.86$), R3 ($F_{(3,92)} = 0.137$, $p > 0.05$; $\alpha = 0.96$) and R4 ($F_{(3,92)} = 0.016$, $p > 0.05$; $\alpha = 0.97$).

Table 1. Mean SpO_2 at different sites measured via hospital based pulse oximeter

Sites of Measurements	Mean SpO_2 (%)
Ear	98.6 + 1.3
Right thumb (R1)	96.9 + 2.1
Right index finger (R2)	96.8 + 2.0
Right middle finger (R3)	97.3 + 2.0
Right ring finger (R4)	97.3 + 1.9
Right little finger (R5)	96.7 + 2.2
Left thumb (L1)	97.0 + 1.9
Left index finger (L2)	96.8 + 1.7
Left middle finger (L3)	96.9 + 1.6
Left ring finger (L4)	97.1 + 1.6
Left little finger (L5)	96.6 + 1.5

Results are presented in mean (standard deviation)

The second phase of this study involved comparison of the SpO_2 measurements between the hospital based pulse oximeter as standard and the measurements via portable finger pulse oximeter during cold pressor test. Standard measurement was taken using ear sensor whilst the fingers selected for measurements using portable finger pulse oximeter were chosen based on results from phase 1 that include R1, R3 and R4. The mean value of SpO_2 from standard was 98.6 + 1.3% and results from portable finger pulse oximeters are listed in Table 2. There were no significant differences of mean between each finger studied against the standard ($p > 0.05$).

Bland-Altman analyses indicated a bias of 0.85% for R1 (95% CI: 0.18 to 1.52), 1.01% for R3 (95% CI: 0.43 to 1.59) and 1.07% for R4 (95% CI: 0.50 to 1.65) (Fig. 1-3). All results indicate low bias between SpO_2 level measurement via portable finger pulse oximeter and the standard.

Table 2. Mean SpO_2 at different sites measured via portable finger pulse oximeter

Sites of Measurements	Mean SpO_2 (%)
R1	97.5 + 1.5
R3	97.0 + 1.8
R4	96.9 + 1.5

Results are presented in mean (standard deviation)

Measurement of arterial oxygen saturation using pulse oximeter is a low cost non-invasive technique that is widely accepted as a standard practice [9-10]. There is an increased demand of continuous and instantaneous monitoring of arterial oxygenation at out of hospital settings such as pre-hospital care, sport related studies and also altitude related activities[10-11].

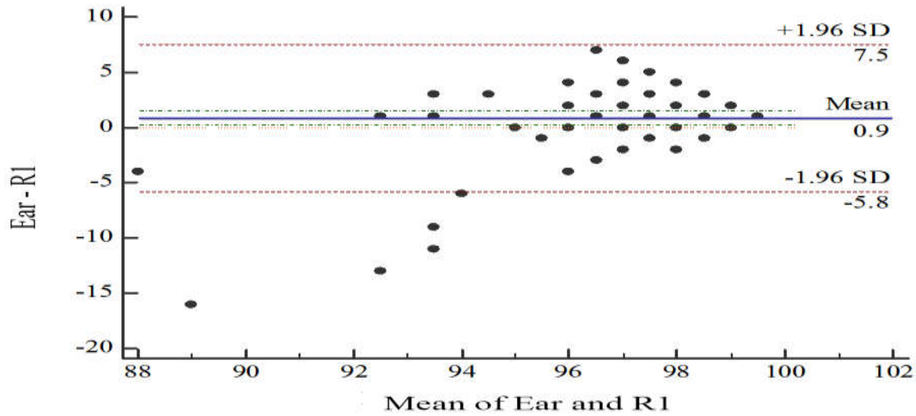

Fig.1. Bland-Altman plot of standard and R1

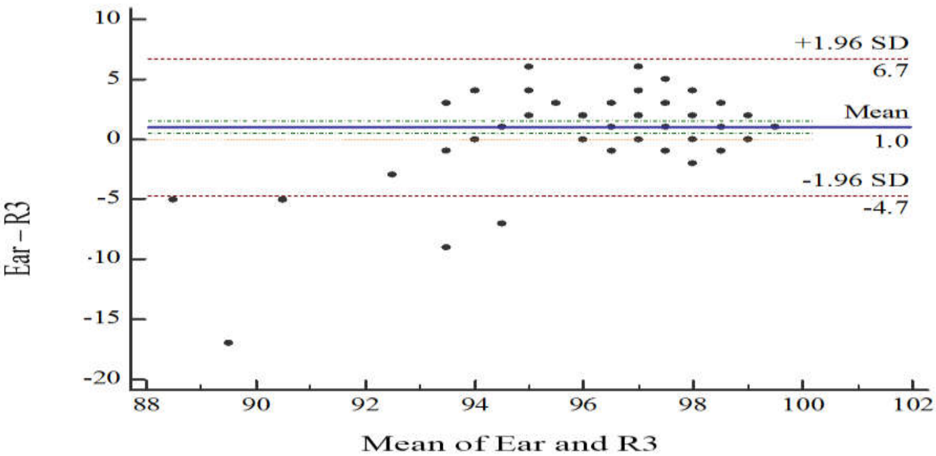

Fig.2. Bland-Altman plot of standard and R3

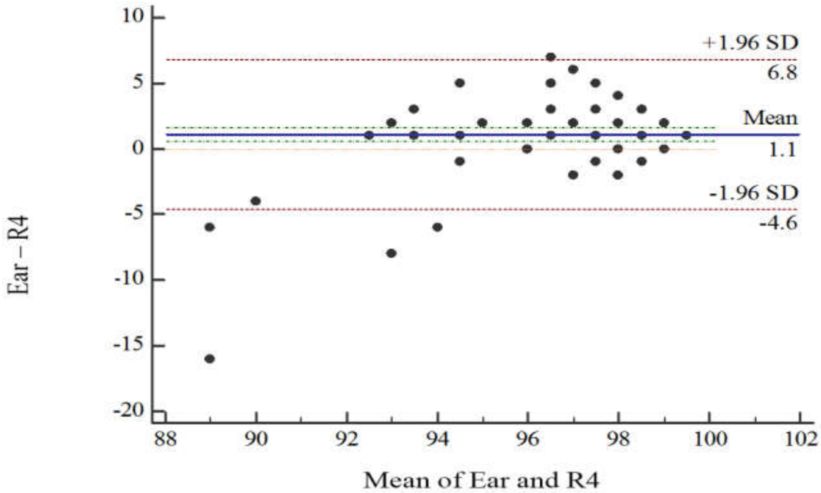

Fig.3. Bland-Altman plot of standard and R4

The principle of pulse oximeter SpO_2 measurement is an in vivo determination of colour difference between oxygenated and deoxygenated blood by a light source and a photodetector [12]. As all pulse oximeters utilize the same basic function, certain physiological conditions or limitations may have impact on the estimation. Previous studies reported that the reliability of the pulse oximeter measurements were highly affected by hypothermia and motion artifacts [13]. Other conditions that reduce peripheral blood flow may also perturb the measurement of SpO_2 via pulse oximeter.

There were a few studies reporting conflicting results on the superiority of oxygen saturation measurement taken at sites nearer to the trunk (earlobe, forehead) in comparison to the finger tips [14-15]. It was clearly highlighted from the previous studies that the discrepancies were due to the use of probes not indicated for the allocated sites. Therefore, it is particularly essential to place the right probe at the right site as recommended in the manual [16]. Results from this study indicated that a higher mean of saturation of SpO_2 was achieved with the earlobe probes, providing reliable results regardless the stimulation of vasoactivity.

We used the cold pressor test in this study to identify the effect of extreme low temperature on the measurement of SpO_2, specifically the fingers due to peripheral vasoconstriction [17]. Our results indicated that the right thumb, middle and ring fingers were not affected by the cold pressor test and gave consistent measurements prior, during and 30 seconds after the test. However, the mean readings from finger sites were still lower than the mean readings from the earlobe. The persistently lower readings are influenced by the greater vasoactivity of peripheral blood vessels in the fingers as compared to those supplying the forehead and ear [18]. This is in agreement with previous studies which highlighted the earlobe to be the most reliable site for SpO_2 measurement regardless the change of temperature [19-20].

The differences or bias between measurements at different sites in this study are not clinically significant. However, the result from this study provides the evidence for further recommendation of standard operating procedure for reliable monitoring of SpO_2 level via pulse oximeter.

4. CONCLUSION

The best site for cutaneous oxygen saturation measurement is by using pulse oximeter ear sensor at the earlobe. Portable finger pulse oximeter that is readily available in the market is also a reliable tool for SpO_2 estimation. However, accuracy of the measurement as compared to the standard (hospital based pulse oximeter) is highly dependent on the site of measurement. The right thumb, middle and ring fingers are the recommended sites. These sites are less affected by low temperature. Therefore, it is strongly suggested that placement of finger sensors should be standardized whether in or out of hospital settings.

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