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Original Contribution

Reliability of smartphone measurements of vital parameters: A prospective study using a reference method

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ABSTRACT

Objective: In this study, we aimed to evaluate the accuracy of HR and SaO_2 data obtained using a smartphone compared with the measurements of a vital signs monitor (VSM) and an arterial blood gas (ABG) device, respectively.

Material and methods: In this single-center prospective study, the HR and SaO_2 measurements were performed using the built-in sensor and light source of a Samsung Galaxy S8 smartphone and compared to the results of VSM and ABG device. The Bland-Altman analysis was used to evaluate and visualize the agreement between the methods.

Results: The data of 101 patients were analyzed. There was a high correlation between HR measured by smartphone and HR measured by VSM [$P < 0.0001$; 0.9918 (95% CI = 0.987–0.994)]. In addition, the SaO_2 values obtained by smartphone were highly correlated with those by ABG ($P < 0.0001$; 0.968 (95% CI = 0.952–0.978)).

Conclusion: The HR and SaO_2 values obtained by smartphone were found to be consistent with the measurements of the reference devices. With the growing use of smartphone technology in the health field, we foresee that patients will be able to make their own triage assessment before presenting to the hospital.

1. Introduction

Heart rate (HR) and oxygen saturation (SaO_2) are two basic parameters in the evaluation of patients admitted to the emergency department. In certain cases, having prior knowledge of these parameters may be helpful in referring patients to the hospital and making an accurate and timely diagnosis. Conventionally, HR is measured by manual or mechanical palpation of peripheral arterial pulses [1]. However, palpation of pulses or SaO_2 measurement may be difficult to undertake for patients or their relatives that do not have the necessary medical training or skills. As a result, some patients apply to health centers simply for the determination of their vital parameters [2].

Today, there are many free software applications utilizing the processing capabilities of smartphones. These applications are specifically designed for self-use and allow users to obtain HR in minutes (bpm) and SaO_2 levels in %. In recent years, with the addition of certain devices and software to smartphones, non-medically trained individuals can also measure parameters, such as HR and SaO_2 at any time and place. This allows patients with dyspnea, blood pressure disorder, and heart rhythm to obtain information about their own vital parameters through a smartphone that is widely available at any time, without requiring a specific device or incurring any additional cost.

The assessment and follow-up of vital signs undertaken by mobile devices not only allow emergency medical intervention to be undertaken at an early stage when there is a deterioration in his/her health status, but also reduces unnecessary hospital admissions, time spent on transport, and health-related costs [3]. Garde et al. argued that health data obtained from mobile devices could be useful in terms of identifying patients that need to be admitted to hospital [4].

Although smartphones are calibrated to perform the measurement of vital parameters, there is a lack of validation studies concerning applications that only use the built-in technology of these devices [5,6]. The measurement of arterial blood gas (ABG) analysis is the gold standard in SaO_2 measurement [7]. To the best of our knowledge, to date, no studies have been conducted to compare the ABG results to determine the accuracy of smartphone SaO_2 measurements in patients admitted to the emergency department. Therefore, in this study, we aimed to evaluate the accuracy of HR and SaO_2 data obtained using a smartphone compared with the measurements of a vital signs monitor (VSM) and an ABG device, respectively.

2. Material and methods

The study was approved by the University Review Board (dated 22.01.2018 and numbered 2017/KK/150).

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2.1. Study design and setting

This single-center prospective study was carried out between January 2018 and June 2018 with eligible patients that applied to a tertiary care center and the emergency service of this center serves approximately 50,000 patients annually. Of the patients that presented to the emergency service of this center, those requiring an ABG evaluation due to indications of chronic obstructive pulmonary disease, congestive heart failure, acute dyspnea, pneumonia, and multiple trauma constituted the sample of the study. This study investigated the SaO_2 and HR measurement reliability and efficacy of a Samsung Galaxy S8 (SM-G950F) smartphone and the Samsung Health application (model code SM-G950F and version 6.1.0.047) preinstalled on the smartphone. The smartphone SaO_2 data were compared with the SaO_2 values obtained by a VSM (Welch Allyn, Connex Spot Monitor 71 WT) equipped with a Nellcor probe, and an ABG device (Radiometer ABL800, 754R0428N007), both available in the emergency service. The HR data measured by the smartphone were compared with the HR values obtained from the same VSM simultaneously. The triage nurse/paramedic measured the HR and SaO_2 values using VSM and noted them in the study form. The smartphone measurements were undertaken by a second emergency service nurse blinded to the HR and SaO_2 values determined by VSM and recorded in another form. The real-time ABG analysis was performed by doctors working in the emergency room on the same day and the results were noted in the ABG section of the study form.

For the determination of SaO_2 and HR using VSM, the right index finger was used. Blood was drawn from the radial artery using a blood gas injector and analyzed on the ABG device immediately to determine the amounts of arterial gases. The smartphone SaO_2 and HR measurements of the patients were obtained by gently pressing the right index finger on the related sensor located on the back of the phone and making sure that the tip of the finger completely covered the sensor (Fig. 1). In this process, continuous waveform formation and measurement took 15 s to complete. Each measurement was repeated three times. The room temperature was maintained at 20 °C (68 °F) to 25 °C (77 °F) in order to prevent any effect of the temperature changes on the results. The feature of the Samsung Galaxy S8 smartphone used in this study is that it performs SaO_2 and HR measurements using a dedicated sensor built in the device, rather than a camera and flash light.

The patients' age, gender, complaints at the time of presentation to the emergency service, blood pressure, HR measured by the smartphone and VSM, and SaO_2 measured by VSM and ABG were noted on the study form of each patient. The VSM and ABG devices were calibrated by a biomedical service provider prior to the study. Excluded from the study were patients aged under 18 years, those that did not agree or give consent to participate in the study, those requiring urgent intervention (blue code, unstable patients), those not able to adapt to the measurements with a device (unconscious, confused, etc.), those with a high degree of hypothermia that might adversely affect the measurement from the skin, and those wearing nail polish or false nails. Other demographic data that might negatively affect the measurement of saturation using a pulse oximeter, such as hypo/hyperthermia, obesity, and chronic diseases were noted.

We estimated the sample size required for this study to be 80 in light of the results from a previous simulation study. Similar to that simulation study, we targeted the highest estimable rate using the least possible resources [8]. As a result, the current study was completed with 114 patients who were selected using convenience sampling.

2.2. Statistical analysis

All data were processed by SPSS v. 22.0 for Windows (IBM, USA) and MedCalc software version 16.8.4 (MedCalc Software, Ostend, Belgium). Numerical variables were presented as median and categorical variables as numbers and percentages. The Shapiro-Wilk test was employed to evaluate the normality of the distribution of continuous variables. The Bland-Altman analysis was conducted to assess and visualize the agreement between the methods used in the study. The following paired comparisons were undertaken: VSM HR - smartphone HR, ABG SaO_2 - VSM SaO_2, and ABG SaO_2 - smartphone SaO_2. A P value of <0.05 was accepted as statistically significant. The 95% limits of agreement (LOA), defined as "the range within which most differences between measurements by the two methods will lie", were calculated for all paired comparisons.

3. Results

The results of 13 of 114 patients were excluded from the study for technical reasons (being unable to verify the ABG results due to drawing venous instead of arterial blood and clotted blood samples). The data of a total of 101 patients, 48 male (47.5%) and 53 female (52.5%), were analyzed. 48 male (47.5%) and 53 female (52.5%) patients were included in the study. The mean age of the male and female patients was 68.08 and 72 years, respectively. According to the age distribution of the patients, the highest number of patients were in the 60–69 years group (25.75%, n = 26). When the diagnosis of the patients was examined according to the category of diseases, it was determined that pulmonary diseases were the reason for the highest rate of referral to the emergency service (41.59%, n = 42) (Table 1).

The results of the Bland–Altman analysis showed that the mean difference was −0.20 between VSM HR and smartphone HR (Fig. 2) (95% CI = −0.524 to 0.124), −1.04% between VSM SaO_2 and ABG SaO_2 (Fig. 3) (95% CI = −1.299 to −0.780), and −0.67% between SP SaO_2 and ABG SaO_2 (Fig. 4) (95% CI = −0.845 to −0.494). The correlation coefficient were 0.9918 for VSM HR - smartphone HR (95% CI = 0.987 to 0.994; $P < 0.0001$), 0.936 for VSM SaO_2 - ABG SaO_2 (95% CI = 0.907 to 0.957; $P < 0.0001$), and 0.968 for smartphone SaO_2 – ABG SaO_2 (95% CI = 0.952 to 0.978) (Tables 2–3).

4. Discussion

Mobile applications are software programs that run on smartphones or other mobile communication devices. These programs may be either accessories added to these devices or a combination of accessories and software. For the appropriate follow-up and diagnosis of patients, it is crucial to determine their vital parameters, such as HR and SaO_2.

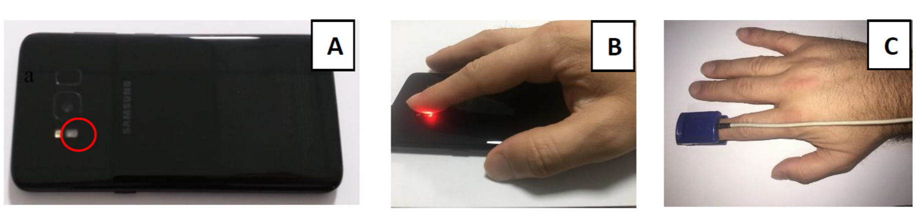

Fig. 1. A. The built-in oxygen saturation and heartbeat sensor of a Samsung Galaxy S8 smartphone. B. Demonstration of the measurement of heart rate and oxygen saturation using the built-in sensor on the Samsung Galaxy S8 smartphone based on the contact photoplethysmography method. When the tip of the right index finger is directly placed on the sensor, a dedicated light source (not camera flash light) is activated (red) to visualize blood cells. C. Demonstration of the measurement of arterial oxygen saturation using a vital parameter monitor.

Table 1
Distribution of the patients according to disease groups.

Disease group	n	%
Pulmonary	42	41.59
Cardiac	15	14.85
Urinary	11	10.89
Surgical	10	9.90
Other	10	9.90
Endocrine	7	6.93
Neurological	6	5.94
Total	101	100

Recently, smartphones have been increasingly used for many purposes in the health field, particularly for the measurement of HR and SaO_2.

Smartphone applications use different methods to measure HR. One example is phonocardiogram, which utilizes the microphone of the mobile phone to measure the heartbeat by listening. This method requires an online server analysis or training the application to recognize the heart sounds of the user [9]. Another method to measure HR is photoplethysmography (PPG) based on the same principle a pulse oximeter uses for SaO_2 measurement. PPG analyzes rhythmic color changes in the skin caused by the beating of the heart [10].

There are two methods for the PPG measurement of HR: First is non-contact PPG, in which the camera is held in front of the user's face and the measurement is undertaken without the need for skin contact. Second is contact PPG, in which the user places his/her finger on the camera and the flash light provides the light source required for the blood cells to become visible [11]. Tomlinson et al. compared the HR and SaO_2 levels of healthy children and the triage values of pediatric patients using a camera-based application (CBA) and probe-based application (PBA) using Apple iPhone 5 and iPhone 6 applications [12]. The authors reported the mean differences as −3.0 bpm between PBA HR and triage HR, −12.0 bpm between CBA HR and triage HR, −0.17% between PBA SaO_2 and triage SaO_2, and −0.33% between CBA SaO_2 and triage SaO_2. In the current study, the mean differences between VSM HR and smartphone HR and VPM SaO_2 and smartphone SaO_2 were in favor of smartphone measurements, similar to those of PBA and better compared to CBA. The reason for the more favorable results obtained from smartphone use in the current study may be because the Samsung Galaxy S8 is equipped with a light source and sensor specifically designed for SaO_2 and HR measurements, rather than relying on the phone camera and flash light as was the case for CBA in the study by Tomlinson et al. Another reason may be that in pediatric patients, the size of fingertips may not be sufficient for an accurate CBA measurement of HR or children may have lower adaptability to the device or measurement process compared to the adult sample in our study.

In another study conducted with children, the accuracy of HR values measured on the finger and ear using a probe inserted into the smartphone were compared and found to be better for the earlobe method [13]. Although the authors noted a significant correlation between these two methods, their coefficients were not as high as those achieved in the current study. This can also result from problems due to the children's lack of cooperation in the measurement process and the sensor not being able to detect smaller fingertips. In addition, the previous study was carried out with a device and software technology available in 2014, compared to our study, in which we used a more advanced smartphone released in 2017 with an application updated in 2018. We believe that the technological progress that has taken place since 2014 has had a positive effect on our measurement results.

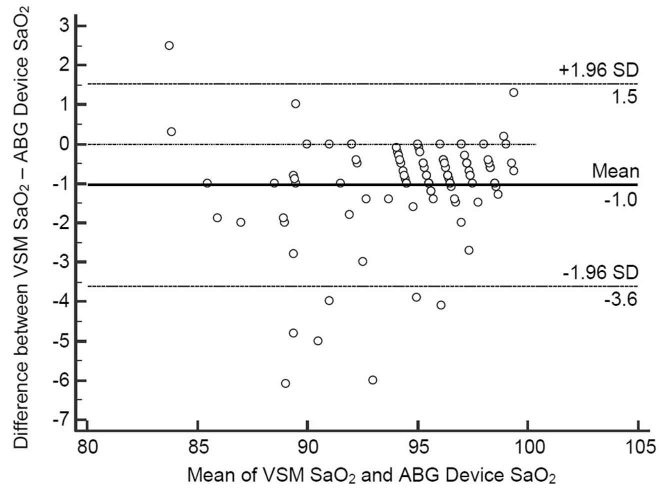

Fig. 3. The Bland-Altman plots for the differences in the SaO_2 measurements between VSM and ABG device. The solid line represents the mean bias. The two dotted lines represent the lower and upper limits of agreement. Ninety-five percent of the differences are expected to be within these limits of agreement (SaO_2: oxygen saturation, VSM: vital signs monitor, ABG: arterial blood gas).

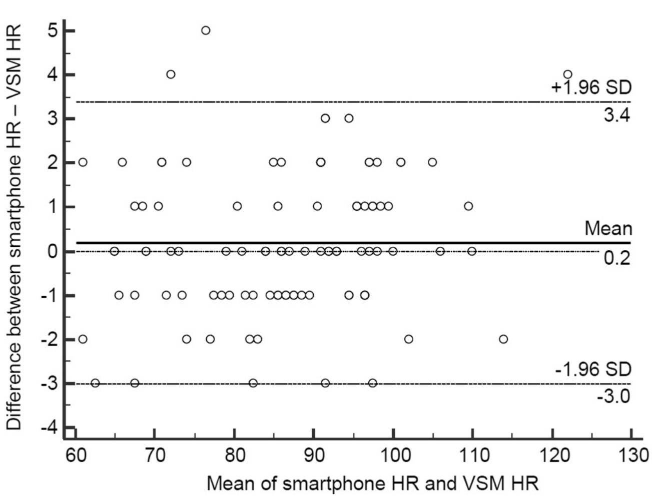

Fig. 2. The Bland-Altman plots for the differences in the HR measurements between the smartphone and VSM. The solid line represents the mean bias. The two dotted lines represent the lower and upper limits of agreement. Ninety-five percent of the differences are expected to be within these limits of agreement (HR: heart rate, VSM: vital signs monitor).

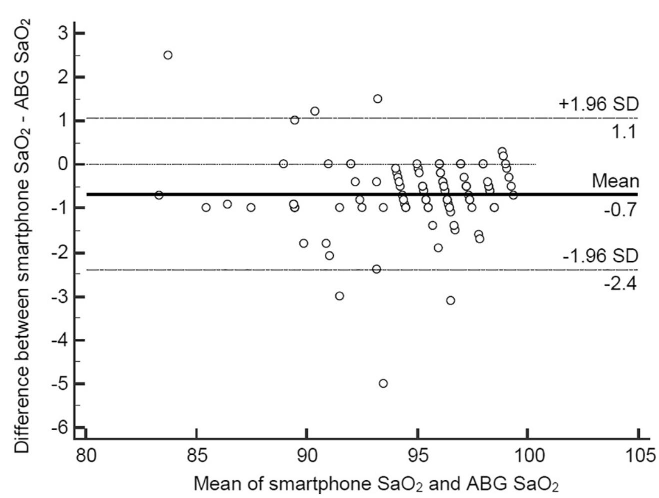

Fig. 4. The Bland-Altman plots for the differences in the SaO_2 measurements between the smartphone and ABG device. The solid line represents the mean bias. The two dotted lines represent the lower and upper limits of agreement. Ninety-five percent of the differences are expected to be within these limits of agreement (SaO_2: oxygen saturation, ABG: arterial blood gas).

Table 2
Comparison of the HR values measured by the smartphone and VSM, and the results of the Bland-Altman analysis, correlation coefficient, and significance level of correlation (HR: heart rate, VSM: vital signs monitor).

	HR calculated by VSM	HR calculated by smartphone
Mean	86.4	86.6
Median	88.0	87.0
Standard deviation	12.484	12.741
Standard error of the mean	1.248	1.274
Regression equation		y = 0.000000 + 1.000000x
Intercept (95% CI)		0.0000 (−4.3000 to 0.0000)
Slope (95% CI)		1.0000 (1.0000 to 1.0500)
Correlation coefficient (95% CI)		0.990 (0.985 to 0.993)
Significance level of correlation coefficient		P < 0.0001

In a study with 100 healthy volunteers, Alexander et al. compared the accuracy of SaO_2 measurement of VSM and a smartphone, and despite concluding that the results of the two methods were not correlated, the authors did acknowledge that their results could not be generalized to other applications used for the measurement of vital signs [14]. In the same study, Alexander et al. noted that the sample only consisting of healthy volunteers might be considered a limitation and future studies should be undertaken with those who are unwell. Accordingly, we performed the measurements on patients who presented to the emergency department, rather than healthy volunteers.

The single-center design is the major limitation of the current study. In addition, the smartphone measurements were undertaken by health professionals with experience in this area. There may be differences in the speed and quality of measurements performed by patients and their relatives who lack sufficient knowledge of or experience with smartphone measurements.

In conclusion, the use of smartphones for the measurement vital parameters in daily life is becoming widespread. In this study, we compared our results to those of earlier studies and found that parallel to the development of technology and software updates for these devices, the accuracy of smartphone measurements is increasing day by day. However, studies on this subject are still limited in number, and therefore, we recommend further research to be undertaken with different patient populations and larger samples.

Table 3
Comparison of the SaO_2 values measured by the smartphone with those obtained from VSM and ABG device. The results of Bland-Altman analysis, correlation coefficient and significance level of correlation coefficient (SaO_2: oxygen saturation, VSM: vital signs monitor, ABG: arterial blood gas, SP: smartphone).

	SaO_2 calculated by VSM	SaO_2 calculated by ABG device	SaO_2 calculated by smartphone
Mean	95.06	94.02	94.39
Median	96.0	95.0	95.00
Standard deviation	3.508	3.738	3.487
Standard error of the mean	0.350	0.373	0.348

	VSM SaO_2-ABG SaO_2	SP SaO_2-ABG SaO_2
Regression equation	y = −4.103448 + 1.034483x	y = 0.0542 + −0.006171x
Intercept (95% CI)	−7.2533 (−14.1041 to −0.4024)	−0.08542 (−4.9254 to 4.7545)
Slope (95% CI)	0.0657 (−0.0006 to 0.1381)	−0.00617 (−0.0572 to 0.04489)
Correlation coefficient (95% CI)	0.936 (95% CI = 0.907 to 0.957)	0.968 (95% CI = 0.952 to 0.978)
Significance level of correlation coefficient	P < 0.0001	P < 0.0001

Abbreviations

SPSS	Statistical Package for the Social Science
SaO_2	oxygen saturation
HR	heart rate
VSM	vital signs monitor
ABG	arterial blood gas
PPG	photoplethysmography
CBA	camera based application
PBA	probe based application

Conflicts of interest

The authors declare that they have no conflicts of interest.

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References

[1] Meyer-Sabellek W, Schulte KL, Gotzen R. Non-invasive ambulatory blood pressure monitoring: technical possibilities and problems. J Hypertens Suppl 1990;8:3–10.
[2] Yıldız S, Bilgili N. Evaluating individual characteristics and applications of elderly patients presented to emergency service. Gazi Sağlık Bilimleri Dergisi 2016;1:15–31.
[3] Wootton R. Twenty years of telemedicine in chronic disease management - an evidence synthesis. J Telemed Telecare 2012;18:211–20.
[4] Garde A, Zhou G, Raihana S, Dunsmiur D, Karlen W, Dekhordi P, et al. Respiratory rate and pulse oximetry derived information as predictors of hospital admission in young children in Bangladesh: a prospective observational study. BMJ Open 2016; 6:e011094.
[5] Cortez NG, Cohen IG, Kesselheim JS. FDA regulation of mobile health technologies. N Engl J Med 2014;371:372–9.
[6] Bruining N, Caiani E, Chronaki C, Guzik P, van der Velde E. Task force of the e-cardiology working. Acquisition and analysis of cardiovascular signals on smartphones: potential, pitfalls and perspectives: by the task force of the e-cardiology working group of European Society of Cardiology. Eur J Prev Cardiol 2014;21:4–13.
[7] Zeserson E, Goodgame B, Hess JD, Schultz K, Hoon C, Lamb K, et al. Correlation of venous blood gas and pulse oximetry with arterial blood gas in the undifferentiated critically ill patient. J Intensive Care Med 2018;33:176–81.
[8] Teare MD, Dimairo M, Shephard N, Hayman A, Whitehead A, Walters SJ. Sample size requirements to estimate key design parameters from external pilot randomised controlled trials: a simulation study. Trials 2014;15:264.
[9] Chen YH, Chen HH, Chen TC, Chen LG. Robust heart rate measurement with phonocardiogram by on-line template extraction and matching. Conf Proc IEEE Eng Med Biol Soc 2011:1957–60.
[10] Kim JM, Arakawa K, Benson KT, Fox DK. Pulse oximetry and circulatory kinetics associated with pulse volume amplitude measured by photoelectric plethysmography. Anesth Analg 1986;65:1333–9.
[11] Coppetti T, Brauchlin A, Muggler S, Attinger TA, Templin C, Schonrath F, et al. Accuracy of smartphone apps for heart rate measurement. Eur J Prev Cardiol 2017;24: 1287–93.
[12] Tomlinson S, Behrmann S, Cranford J, Louie M, Hashikawa A. Accuracy of smartphone-based pulse oximetry compared with hospital-grade pulse oximetry in healthy children. Telemed J E Health 2018;24:1–7.
[13] Ho CL, Fu YC, Lin MC, Chan SC, Hwang B, Jan SL. Smartphone applications for heart rate measurement in children: comparison with electrocardiography monitor. Pediatr Cardiol 2014;35:726–31.
[14] Alexander JC, Minhajuddin A, Joshi GP. Comparison of smartphone application-based vital sign monitors without external hardware versus those used in clinical practice: a prospective trial. J Clin Monit Comput 2017;31:825–31.