Structured, Protocol-Based Pulse-Oximetry Measurement Improves the Evaluation of Hypoxemic Patients at Hospital Admission

Narin N. Carmel-Neiderman MD[1]*, Idan Goren MD[1]*, Yishay Wasserstrum MD[1], Tal Frenkel Rutenberg MD[1], Irina Barbarova MD[1], Avigal Rapoport MD[1], Dor Lotan MD[1], Erez Ramaty MD[1], Naama Peltz-Sinvani MD[1], Adi Brom MD[1], Michael Kogan MD[1], Yulia Panina MD[1], Maya Rosman MD[1], Carmel Friedrich MD[1], Irina Gringauz MD[1], Amir Dagan MD[1], Iris Kliers MD[1], Tomer Ziv-Baran PhD[2] and Gad Segal MD[1]

[1]Department of Medicine 'T', Sheba Medical Center, Tel Hashomer, Israel, affiliated with Sackler Faculty of Medicine, Tel Aviv University; Tel Aviv, Israel
[2]Department of Epidemiology and Preventive Medicine, School of Public Health, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel

ABSTRACT: **Background:** Accurate pulse oximetry reading at hospital admission is of utmost importance, mainly for patients presenting with hypoxemia. Nevertheless, there is no accepted or evidence-based protocol for such structured measuring.

Objectives: To devise and assess a structured protocol intended to increase the accuracy of pulse oximetry measurement at hospital admission.

Methods: The authors performed a prospective comparison of protocol-based pulse-oximetry measurement with non-protocol based readings in consecutive patients at hospital admission. They also calculated the relative percentage of improvement for each patient (before and after protocol implementation) as a fraction of the change in peripheral capillary oxygen saturation (SpO_2) from 100%.

Results: A total of 460 patients were recruited during a 6 month period. Implementation of a structured measurement protocol significantly changed saturation values. The SpO_2 values of 24.7% of all study participants increased after protocol implementation (ranging from 1% to 21% increase in SpO_2 values). Among hypoxemic patients (initial SpO_2 < 90%), protocol implementation had a greater impact on final SpO_2 measurements, increasing their median SpO_2 readings by 4% (3–8% interquartile range; $P < 0.05$). Among this study population, 50% of the cohort improved by 17% of their overall potential and 25% improved by 50% of their overall improvement potential. As for patients presenting with hypoxemia, the median improvement was 31% of their overall SpO_2 potential.

Conclusions: Structured, protocol based pulse-oximetry may improve measurement accuracy and reliability. The authors suggest that implementation of such protocols may improve the management of hypoxemic patients.

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*The first and second authors contributed equally to this study

Oxygen saturation measurement in the peripheral blood is one of the essential, widely-used vital signs for evaluating pulmonary and cardiovascular integrity of hospitalized patients. Low readings at hospital admission have profound implications on further investigation and management of such patients. Nevertheless, there are neither published recommendations nor protocols for proper measurement techniques, which may improve the accuracy of these measurements. Previous studies that addressed overnight pulse oximetry of chronic obstructive pulmonary disease (COPD) patients at home showed that sequential SpO_2 measurements show considerable variability [1]. Other studies [2], similar to our in-hospital clinical experience, showed that there could be substantial variability of oximetry results when different staff members measured the SpO_2 values of the same patient. Changes in posture, level of activity, length of measurement, and other temporal characteristics of patients at hospitalization may affect the reliability and reproducibility of SpO_2 measurements [2-7]. Decreased oximetry results from such postural and temporal factors might reflect ventilation-perfusion mismatch due to under recruitment of lung parenchyma, which may be irrelevant to the patient's condition and reason for hospital admission.

To improve the reliability and reproducibility of pulse-oximetry at hospital admission, we prospectively compared SpO_2 measurements taken without guidance with structured, protocol-guided pulse-oximetry measurements. Our aim was to propose a practical protocol for oximetry measurement, which could be applied not only by physicians but by all hospital personnel addressing this important vital sign.

PATIENTS AND METHODS

This study was approved by the ethics committee at the Sheba Medical Center. We conducted a prospective comparison of two approaches for SpO_2 measurement. Based on the relevant literature [4,5] and expert opinions, we devised a basic protocol

for saturation measurement. The protocol consisted of several actions by the patients prior to SpO_2 measuring. These actions were intended to assure that SpO_2 would indeed reflect pulmonary and cardiovascular integrity rather than deviate due to non-pathological confounders (such as temporary lung atelectasis giving rise to ventilation-perfusion mismatch or transient hypercapnia due to hypoventilation). Patient baseline characteristics are presented in Table 1. Consecutive protocol steps and the clinical rational behind each step are presented in Table 2.

Measurement parameters and patient characteristics potentially affecting SpO_2 results that were not addressed by our protocol were recorded to eliminate their potential confounding effects on SpO_2 value comparisons. Background diseases potentially affecting SpO_2 were not significantly different between hypoxemic and non-hypoxemic patients [Table 3].

This study was conducted in a single internal medicine department in a tertiary hospital. All participating physicians were trained for proper use of the structured protocol prior to the study initiation. All participating physicians were equipped with the same mobile SpO_2 digital probe (Check Mate®, Obelis S.A, Brussels, Belgium). The probe was designed for SpO_2 measurements in the range of 40% to 99%; accuracy range of ± 1%. Other personnel who actually or potentially measured patient SpO_2 values (e.g., emergency department medical personnel and department staff members not participating in this study) where blinded to the study.

Patients were recruited at their arrival to the department. The inclusion criteria included the following: age above 18 years, ability to cooperate with the study protocol [Table 2], and suitability for a digital upper limb SpO_2 measurement. Patients unable to cooperate with the study protocol or treated with mechanical ventilation (both invasive and non-invasive), or those with any background cognitive deficit or who refused to complete informed consent, were excluded from this study.

After completing informed consent documentation, SpO_2 readings were taken twice. The first measurement was a non-guided measurement by the physician. The second measurement was performed according to the structured protocol guidance. No therapeutic or other interventions were made between these two measurements. In order not to endanger patient oxygenation, oxygen supplementation was administered during SpO_2 measurements according to the attending physician's clinical assessment. Both measurements, regular and protocol-based, were conducted under the same conditions, namely with or without oxygen enrichment.

Table 1. Baseline patient characteristics

General	
Male, n (%)	258 (56.1%)
Age (years), mean ± standard deviation	66 ± 15
Co-morbidities potentially affecting SpO_2 measurement, n (%)	
Congestive heart failure	60 (13%)
Chronic obstructive pulmonary disease	51 (11.1%)
Obesity*	38 (8.3%)
Pneumonia	18 (3.9%)
Lung cancer	17 (3.7%)
Bronchial asthma	16 (3.5%)
Muscular disorder	9 (0.9%)
Obstructive sleep apnea	12 (2.6%)
Arterial hypertension	132 (28.7%)
Type 2 diabetes mellitus	148 (32.2%)
Ischemic heart disease	132 (28.7%)
Status/post stroke	76 (16.5%)
Chronic kidney disease	76 (16.5%)
Atrial fibrillation	74 (16.1%)
Anemia**	47 (10.2%)
Peripheral vascular disease	26 (5.7%)
Smoking Status	
Never smoked	298 (64.8%)
Current smoker	88 (19.1%)
Past smoker	73 (15.9%)

*Per diagnosis or documented body mass index › 35

**Per diagnosis or documented hemoglobin ‹ 7 g/dl

STATISTICAL ANALYSIS

Categorical variables are reported as frequency and percentages. Continuous variables are reported as mean ± standard deviation or median and interquartile range (IQR). Continuous variables were tested for normal distribution using histogram. Categorical

Table 2. Structured, protocol based steps prior to SpO_2 measurement

Step in Protocol	Action required prior to SpO_2 measurement	Rational
1	Place the patient in an upright position (standing if possible or sitting upright in bed)	• Minimize postural-dependent ventilation-perfusion mismatch • Decrease the impact of pleural fluid on functional lung capacity
2	Ask the patient to speak to you whenever possible for at least 2 minutes	• Assure adequate minute ventilation for hypercapnia reduction • Allows patient's proper alertness
3	Ask the patient to cough, at least three times	• Decrease lung tissue atelectasis • Remove transient, non-insignificant bronchial secretions
4	Untie any physical restrains from the patient's limbs	• Avoid false SpO_2 measurements when tested in restrained limbs

Table 3. Medical background of both hypoxic and non-hypoxic patients

Medical background	SpO_2 ‹ 90% N (%)	SpO_2 ≥ 90% N (%)	*P*
Hypertension	6 (28.6%)	126 (28.7%)	0.99
Type 2 diabetes mellitus	8 (38.1%)	140 (31.9%)	0.55
Peripheral vascular disease	2 (9.5%)	24 (5.5%)	0.43
Atrial fibrillation	4 (19%)	70 (15.9%)	0.70
Chronic kidney disease	3 (14.3%)	73 (16.6%)	0.78
Cerebral vascular disease	5 (23.8%)	71 (16.2%)	0.36
Lung cancer	1 (4.8%)	16 (3.6%)	0.79
Congestive heart failure	2 (9.5%)	58 (13.2%)	0.62

variables were compared using chi-square or Fisher's exact test, and continuous variables by independent samples *t*-test or Mann–Whitney test. Friedman test was used to detect differences in repeated measures. Wilcoxon signed ranks test was used for post hoc comparison. A two-tailed $P < 0.05$ was considered statistically significant. Statistical analyses were performed using IBM Statistical Package for the Social Sciences statistics software, version 21 (SPSS, IBM Corp, Armonk, NY, USA).

RESULTS

A total of 460 patients were recruited for the study during a 6 month period. Main patient characteristics (both general demographics and medical background) are presented in Table 1.

All patients participating in this study accomplished both SpO_2 non-guided measurements: regular measurement at admission and per-protocol readings. The majority of measurements were obtained from the right limb (61.3%). Only 4.6% (n=21) of patients were evaluated using the protocol while treated with oxygen supplementation via nasal cannula or a mask with an oxygen reservoir. A minority of patients were treated in the emergency department or prior to their arrival at the hospital with medications potentially affecting their SpO_2 readings (mainly diuretics, 6.3%). As for other potential confounders, very low percentage of our cohort had skeletal abnormalities, deformations, and restrictions of the chest wall (2.4%) or paraplegia (1.18%). One patient had acrylic artificial nails (0.2%), which could affect accurate measurements [3].

SpO_2 READINGS

Use of a structured protocol-guided measurement significantly changed SpO_2 readings: in re-measurement, after protocol implementation, 24.7% of SpO_2 values of all study participants increased (increase ranging from 1–21% increase in SpO_2 values). Among hypoxemic patients ($SpO_2 < 90\%$ on initial measurement, n = 21 [4.5%]), protocol implementation had a statistically significant impact. Their median increase in SpO_2 readings was 4% (3–8% IQR; $P < 0.05$).

The values and increments were calculated as if all patients were supposed to achieve maximal (100%) saturation values. Nevertheless, this is not the case for many patients whose maximal or best saturation values are lower than 100%. Therefore, we calculated the actual SpO_2 improvement potential for each patient. This potential was defined as the relative percentage of improvement for each patient (before and after protocol implementation) as a fraction of the change in peripheral capillary oxygen saturation (ΔSpO_2) from 100%. For example, if a patient's SpO_2 reading prior to protocol application was 88%, and after per-protocol measurement the SpO_2 reading increased to 92%, the improvement potential by protocol application was 33% (4% improvement as a fraction of 12% below 100% on initial measurement). In our study population, 50% of the cohort improved by 17% of their overall potential and 25% improved by 50% of their overall improvement potential. As for patients presenting with hypoxemia, the median improvement was 31% of their overall SpO_2 potential.

Since both hypoxemia and the potential improvement of SpO_2 values could be influenced by the patient's background diagnoses, we analyzed our study population with regard to the following background medical conditions: ischemic heart disease, congestive heart failure, type 2 diabetes mellitus, peripheral vascular disease, persistent or paroxysmal atrial fibrillation, chronic kidney disease, history of cerebral-vascular accident, and the presence of lung cancer. We did not find significant differences between hypoxemic and non-hypoxemic patients with regard to background diagnoses [Table 3]. While most background medical conditions did not affect the results of implementing the study's protocol on SpO_2 values, an association between improvement of SpO_2 values and certain medical diagnoses was detected in patients presenting with pneumonia ($P = 0.01$) and in patients presenting with type 2 diabetes mellitus ($P = 0.01$) and ischemic heart disease ($P < 0.001$).

DISCUSSION

Non-invasive pulse oximetry is a simple and reliable method to estimate hemoglobin oxygenation, assessing the extent of pathology of both the cardiovascular and respiratory systems in a myriad of diseases. Therefore, pulse oximetry is defined as an essential vital sign at hospital admission [8]. Unlike continuous SpO_2 measurements commonly used in intensive care units, during a patient's stay in medicine departments, SpO_2 is measured only intermittently, several times during each hospitalization day. The device commonly used for this purpose is a mobile pulse oximeter. This device calculates hemoglobin oxygen saturation by measuring the ratio of absorbance between two light wavelengths passed by an external probe through peripheral tissues, mainly digits or ear lobes. The device is designed to measure only pulsating (arterial) light absorbance, which is translated to percentage of oxyhemoglobin saturation. Following proper calibration, pulse oximetry carries an inherent measurement error no larger than 4% [9].

Much of each patient's medical investigations and treatments during a hospital stay are influenced by the initial oxyhemoglobin saturation values. Fluctuations of even 1% in SpO_2 values could have a significant impact, especially when close to 90%, which is commonly the threshold between normoxemia and hypoxemia. Falsely measured, lower than normal SpO_2 values due to technical or situational circumstances, such as patient's posture and position or existence of upper airway secretions, might lead physicians to conduct unnecessary diagnostic procedures and prolong hospital stays [2]. Moreover, differences in oximetry values, as measured in sequential hospitalization days, have an important role in the clinical appreciation of patient

improvement or deterioration. Therefore, it is essential that pulse oximetry is conducted in a manner that assures not only reliability and punctuality but also reproducibility, as much as possible.

Reliability and reproducibility of SpO_2 measurements can be affected by various, non-pathologic variables. Some mechanical obstacles that impact accuracy of measurement include acrylic artificial nails [3]. Oximetry results might also be influenced by physical restraining of patients. Restrained limbs demonstrate lower SpO_2 values [4]. Data suggest that oximetry readings from patients affected by severe scoliosis or cerebral palsy are also impacted by position at the time of measurement [5]. These results are irrespective of the fact that patients having pleural effusions will have lower SpO_2 values while lying supine [10], pointing out an acute pathology.

Similar to other vital signs, such as blood pressure and pulse, a single, non-continuous SpO_2 measurement may yield a range of results and may be operator dependent. Among patients admitted to intensive care units with de-saturation, even vigorous measurements of SpO_2 in short intervals have been shown to be significantly inferior when compared to continuous monitoring [11,12]. Unlike the broad data about continuous monitoring of SpO_2, evidence regarding the quality of an intermittent measurement is scarce.

In this study, we aimed to establish a structured protocol for SpO_2 measurements using a pulse oximeter at hospital admission. Our main goal was to assess the effect of a protocol-based measurement on SpO_2 values and to identify possible sub-groups of patients who would benefit the most from the implementation of this protocol. Our study results show significant improvement of SpO_2 values while using a structured, simple protocol. In most cases, application of this protocol resulted in higher oximetry values, which were found to be especially significant in patients presenting with hypoxemia ($SpO_2 < 90\%$).

One plausible explanation for our results is the fact that our protocol increased available lung parenchyma recruitment, decreasing areas of ventilation-perfusion mismatch. As a result, our protocol potentially eliminates hypoxemia, which is temporary, easily reversible, and independent of a patient's main reason for hospitalization.

LIMITATIONS

Our study has several limitations. First, the number of hypoxemic patients within the study population was relatively small. This effect is explained by the fact that significant hypoxemia in most cases gave rise to an exclusion criteria to this study (lowered alertness and need for non-invasive and invasive ventilation). Moreover, our study did not include patients who were unable to fully cooperate. For such patients, the yield of our protocol may be limited.

CONCLUSIONS

Our protocol includes a basic set of actions aimed toward better alertness and proper ventilation. It was found to have a significant beneficial effect on many hypoxemic patients. Widespread use of the protocol may lead to more structured SpO_2 measurement methods, thus potentially preventing unnecessary oxygen enrichment, non-invasive and invasive ventilation, and further imaging studies. The protocol's simplicity makes it suitable for application, not only by physicians, but also by non-medical personnel. Adopting the protocol guidelines into the regular nursing protocols may decrease false alerts. Combined with proper guidance to the patient's families and primary physicians, it may eventually decrease excessive patient referrals to the emergency departments.

Correspondence
Dr. G. Segal
Dept. of Medicine 'T', Sheba Medical Center, Tel Hashomer 5265601, Israel
email: gad.segal@sheba.health.gov.il

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"If you're not failing every now and again, it's a sign you're not doing anything very innovative"

Heywood "Woody" Allen, (born 1931), American filmmaker, writer, actor, comedian, and musician whose career spans more than six decades