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PATIENT FACING SYSTEMS

# Wrist-Sensor Pulse Oximeter Enables Prolonged Patient Monitoring in Chronic Lung Diseases

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## Abstract

Pulse oximetry is an important diagnostic tool in monitoring and treating both in-patients and ambulatory patients. Modern pulse oximeters exploit different body sites (eg fingertip, forehead or earlobe). All those are bulky and uncomfortable, resulting in low patient compliance. Therefore, we evaluated the accuracy and precision of a wrist-sensor pulse oximeter (Oxitone-1000, Oxitone Medical) vs. the traditional fingertip device. Fifteen healthy volunteers and 23 patients were recruited. The patient group included chronic obstructive pulmonary disease (COPD) ($N = 8$), asthma ($N = 6$), sarcoidosis ($N = 5$) and others. Basic demographic data, skin tone type, smoking status and medical history were recorded. Blood oxygen level (SpO2) and pulse-rate values were determined by a non-invasive pulse oximeter (Reference, a conventional FDA-cleared fingertip pulse oximeter) and by Oxitone-1000. All tests were performed in singleton and in a blinded fashion. The measurements were done in sitting and standing positions, as well as after a 6-min walk test. The mean age was 60.4 ± 9.83 years, 55% were male. No significant differences were observed between the wrist-sensor and the traditional fingertip pulse oximeters in all tested parameters. Mean SpO2 was 96.45% vs. 97.18% and the mean pulse was 74.64 vs. 74.6 bpm (Oxitone-1000 vs. Reference, respectively, $p < 0.0001$). Precision rate was 2.28472% and the accuracy was met (Arms -Root mean-square-error < 3%). The Oxitone-1000 is both accurate and precise for SpO2 and pulse measurements during daily activities of pulmonary patients, and is not inferior to standard devices for spot checking or short period examinations. Its wrist-sensor design is comfortable and provides the advantage of extended use.

**Keywords** Pulse oximetry · 6-min walk test · Device assessment · COPD

## Introduction

Chronic obstructive pulmonary disease (COPD) represents a growing global public health problem. To date, COPD is the fourth leading cause of death, with over 3 million cases [1], and the number is expected to grow to exceed the third leading cause of death according the Global initiative for Chronic Obstructive Lung Disease (GOLD). Whether the perceived benefit of long term oxygen treatment (LTOT) is due to oxygen supplementation or to the placebo effect remains unclear [2–4], as those studies mainly included stable patients. Moreover, they had difficulties to obtain data on variability and prolongation of desaturations, especially for the period before, during and after exacerbations. The ability to predict exacerbation onset would be a significant step toward successful self-treatment and may prevent hospitalizations, health care expenses, as well as mortality [1].

Pulse oximetry is an important diagnostic tool in monitoring and treating both in-patients and ambulatory patients.

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Current, non-intensive care, pulse oximeters are exploiting different body sites, mostly the fingertip, forehead or earlobe. All those are bulky and uncomfortable, which results in a low patient compliance to wear the device continuously 24/7. Recent studies suggested the need for wearable pulse oximeter devices for continuous oxygen monitoring [5]. In practice, however, ambulatory COPD and other chronic lung disease patients are tested with the so called spot-check monitors for episodic measurements. Moreover, the clinical criteria for the initiation of long term oxygen therapy are sometimes based on a single measurement of resting oxygen levels [6, 7]. Studies on the influence of oxygen treatment on exercise or the daily life of patients also rely on these spot-check monitors, which fail to provide both patients and physicians the longitudinal data of the disease progress.

In order to address this issue, a bracelet-like device that enables the option of both continuous and spot-check monitoring of the $SpO_2$, pulse rate and movement was developed.

In this study we tested the precision and accuracy of this device for non-invasive oxygen saturation measurements in healthy volunteers and in COPD and other pulmonary patients.

## Methods

**Study group** This was a prospective, single-arm, single-center, open-label clinical study, performed on patients as well as on healthy subjects. Subjects over the age of 18 were enrolled at the Pulmonary Department, Meir Medical Center. The subjects were represented by male and female adults who optimally covered a range of ethnic backgrounds (skin pigmentation). Healthy volunteers were recruited from hospital personnel or medical students. Patients were either outpatients in the pulmonary clinic, or ambulatory patients undergoing pulmonary rehabilitation program.

**Inclusion criteria** Participants over the age of 18 with Normal values of methemoglobin (MetHb<2%) and carboxyhemoglobin (COHb <3%).

**Exclusion criteria** Significant deformity, degenerative changes or edema of the hand wrist, localized infection, ulceration or skin breaks involving the wrist. Low peripheral body temperature (tissue hypoperfusion) <36.0 °C or anemia (Hb < 10.0 g/dl). Vascular disease or Raynaud's phenomenon affecting the hand, elevated levels of methemoglobin (MetHb ≥2%) or carboxyhemoglobin (COHb ≥3%). Individuals exposed to high levels of carbon monoxide that result in elevated carboxyhemoglobin levels. Basic clinical and demographic information, including skin type (Fitzpatrick scale), and past medical history were recorded.

**Measurements** Peripherial oxygen saturation levels (SpO2) and Pulse Rate (PR) values were determined by a non-invasive traditional fingertip pulse oximeter (Nonin 3230, Nonin Medical Inc., US), used as the 'Reference' device, and by a novel wrist-sensor pulse oximeter (Oxitone-1000, Oxitone Medical, Israel), the device under test (DUT), Fig. 1. Both the DUT and the reference devices are based on the Photoplesthysmography (PPG) technology, using similar red and infra-red wavelengths (290 Hz and infrared PPG, respectively). The data from both devices was digitally collected simultaneously on a single dedicated mobile application, using Bluetooth Low Energy (BLE) technology, and therefore synchronized according to the mobile clock. The DUT transmitted both raw signals (red and infrared signals) and the measured vital signs (SpO2 and PR) every 1 s, while the Reference device transmitted only the measured vital signs at the same data transmission rate. The SpO2 and PR values, generated by all involved devices, were collected passively from the beginning until the end of the trial and served as the database for the statistical analysis. For accurate statistical comparison, The DUT was set with the same averaging mode of 12 s, as used in the Reference device (not configurable).

All testing was performed in singleton and in a blinded fashion. Blood pressure before and after exercise was measured for all subjects. The patient group also underwent pulmonary function tests before the 6-Minute walk test (see below).

**6-minute walk test (6MWT)** All subjects were simultaneously tested using the Oxitone-1000 oximeter and the Reference


**Fig. 1** The Oxitone-1000 device

device (i.e. the standard fingertip pulse oximeter) in accordance with the American Thoracic Society (ATS) Guidelines [8]. Measurements were taken and recorded prior to and after the 6 MWT t. The distance of the 6MWT was recorded.

**Procedure set-up** Two sensors were placed simultaneously on the subjects: a standard fingertip pulse oximeter (i.e. the Reference, see above) was placed on the subject's index finger and the tested wrist-sensor pulse oximeter (i.e. the DUT, see above) was placed on the subject's wrist of the same hand.

**Spot-check measurements** All subjects were simultaneously tested by using the wrist-sensor pulse oximeter and the standard fingertip pulse oximeter in a stationary state. The SpO2 and PR values were measured and digitally collected within 1 min at 12 s intervals (5 paired data points per minute) in 4 different conditions: sitting resting, standing resting, sitting recovering (after 6MWT) and standing recovering (after 6MWT). Data collected during motion as well as missing or non-reliable data were excluded from the analysis.

**Level of comfort and data clarity assessment** The subjects were asked to grade the level of comfort and whether the device display was readable and clear in the scales of 1–5 (1 = Not at all, 2 = Poor, 3 = Neutral, 4 = Good, 5 = Very good).

**Statistical analysis** Statistical analyses were performed using SAS® v9.4 (SAS®, SAS Institute Cary, NC USA) software. The required significance levels of findings are equal to or lower than 5%. All statistical tests were two-sided, if not defined otherwise. SpO2 accuracy was evaluated for root-mean-square (rms) difference between the DUT and the reference for the overall range and by decade. The average of the measurements was calculated to show the bias of the device under test as compared to the reference. Bland-Altman graphical plots, error (SpO2 – SaO2) vs, average SaO2 + SpO2 were generated with linear regression fit, mean, and upper 95% and lower 95% limits of agreement, according to [9].

The precision of a measurement expresses the closeness of agreement (degree of scatter) between a series of measurements obtained from multiple sampling of the same homogeneous sample under the prescribed conditions. Precision may be considered at two levels: repeatability and reproducibility. Repeatability expresses the precision under the same operating conditions over a short interval of time. Reproducibility expresses the precision between different operating conditions. Accuracy calculations were based on healthy subjects, as well as on patients. Precision was measured on healthy subjects only.

**Table 1** Spectrum diseases in the patient study population

| Patient Diagnosis | % (n/N) |
|---|---|
| Asthma | 26.1% (6/23) |
| Bronchiectasis | 4.3% (1/23) |
| Bronchitis (RADS) | 4.3% (1/23) |
| COPD | 34.8% (8/23) |
| Dyspnea | 8.7% (2/23) |
| Obstructive Sleep Apnea (OSA) | 8.7% (2/23) |
| Post-inflammatory Pulmonary Fibrosis | 4.3% (1/23) |
| Pulmonary Fibrosis | 4.3% (1/23) |
| Pulmonary Nodules, Cough | 4.3% (1/23) |
| Respiratory abnormality | 4.3% (1/23) |
| Sarcoidosis | 21.7% (5/23) |

**Ethical approval** This study was approved by the Institutional Ethics Committee at the Meir Medical Center (MMM-0172-15). Only those who gave a written informed consent were included in the study. NIH study number NCT02658045.

## Results

27 subjects were screened, of whom 4 were screen failure, and thus 23 were included in the full analysis (FA) set. Two subjects had invalid data for the analysis of the primary endpoint because of instability of the reference measurement and a low perfusion index. In total, 8 COPD patients were included, of which two were classified as 'Mild' form of disease, four were 'Moderate' form of COPD and two with 'Severe' COPD. The diagnoses of the patients are listed in Table 1.

Among the healthy subjects, 16 subjects were screened, of whom 1 was a screen failure, and thus 15 were included in the FA set. All subjects had valid data for the analysis of the primary endpoint. Basic patient and healthy subject characteristics are listed in Table 2. There were no (0) adverse events or serious adverse events reported throughout the study, among 38 subjects (healthy and patients) in the FA set.

### Oxygen saturation of patients and healthy subjects

SpO2 was measured by both devices simultaneously in a sitting and standing position, and also before and after the 6MWT. No significant desaturations were observed during the test. The mean SpO2 as measured by Oxitone-1000 was 96.45% (range 83.8–99.0) and for the Reference 97.18% (range 91.3–100.0). The main claim of accuracy is based on the root-mean-square difference

**Table 2** Clinical Characteristics of the Study Populations

| | Patients ($N = 23$) | Healthy Subjects ($N = 15$) |
|---|---|---|
| Age, years (mean (SD)) | 60.4 (9.83) | 51.5 (15.52) |
| Gender (% male) | 47.8% | 66.7% |
| Weight, kg (mean (SD)) | 76.1 (17.48) | 79.6 (10.76) |
| Height, cm (mean (SD)) | 164.9 (10.74) | 175.3 (10.81) |
| Smoking history | | |
| Never smoked | 39.1% (9/23) | 66.7% (10/15) |
| Past smoker | 34.8% (8/23) | 33.3% (5/15) |
| Active smoker | 26.1% (6/23) | 0 |
| Skin Type | | |
| Type II (scores 7–13) Fair | 21.7% (5/23) | 46.7% (7/15) |
| Type III (scores 14–20) Medium | 26.1% (6/23) | 46.7% (7/15) |
| Type IV (scores 21–27) Olive | 34.8% (8/23) | 6.7% (1/15) |
| Type V (scores 28–34) Brown | 13.0% (3/23) | 0 |
| Type VI (scores 35–36) Black | 4.3% (1/23) | 0 |
| Pre-test vital signs (mean (SD)) | | |
| Systolic blood pressure | 131.1 (19.18) | 128.1 (19.43) |
| Diastolic blood pressure | 71.7 (12.89) | 75.2 (7.87) |
| Heart Rate | 70.5 (10.44) | 72.5 (9.65) |
| Oxygen Saturation (%) | 97.5 (1.59) | 98.2 (1.15) |
| Perfusion Index | | |
| <3 | 26.1% (6/23) | 20.0% (3/15) |
| 3–5 | 8.7% (2/23) | 40.0% (6/15) |
| >5 | 65.2% (15/23) | 40.0% (6/15) |

between the measured and reference values, Arms. The study success criterion, per the guidance document (ISO 80601-2-61 (2011): Particular Requirements for Pulse Oximeter Equipment) [10], was Arms <3.0% in the range of SpO2 between 70 and 100%. Arms = 2.12762% (<3.0%). Thus, the success criterion was met for patients and healthy subjects. In total, there were 1138 pairs of oxygen saturation measurements. Figure 2 presents the Bland-Altman plot that shows the level of agreement between the devices. The repeatability of the DTU was 1.367% (95% CI: [1.303, 1.438] %) and the reproducibility was 1.355% (95% CI: [1.287, 1.426] %).

### Pulse rate measurements

In addition to SpO2, pulse was measured by both devices simultaneously. The mean pulse as measured by Oxitone-1000 was 74.64 bpm (range 50.9–119.6) and 74.60 bpm for the Reference (range 51.8–118.6). There were 1182 pairs of pulse measurements. Figure 3a presents the Bland-Altman plot that shows the level of agreement between the devices, limits of the 95% agreement [−3.41, 3.38] bpm. Arms = 1.72946 bpm for patients and healthy subjects (<3.0%). We found a statistically significant correlation (Pearson's correlation coefficient) between Oxitone-1000 and the Reference, r = 0.98908 (95% CI: [0.987762, 0.990248], $p < 0.0001$) Fig. 3b. The repeatability of the DTU was 4.606 bpm (95% CI: [4.393, 4.841] bpm) and the reproducibility was 4.564 bpm (95% CI: [4.235, 4.896] bpm).

### Device usability

As a secondary endpoint, we assessed the level of comfort using the two devices and the level of data display clarity. Among all subjects in the FA set, 83.8% (31/37) reported that the level of comfort using Oxitone-1000 device was good or very good in comparison to only 38.9% (14/36) for the reference device. In addition, 97.3% (36/37) said good or very good regarding whether the device display was readable and clear for the Oxitone device and 100% (36/36) said so about the reference device.

## Discussion

In this study, we evaluated a newly developed wrist-sensor pulse oximeter device and compared its accuracy and precision to a standard FDA cleared fingertip device. The measurements were done in a resting position, as well

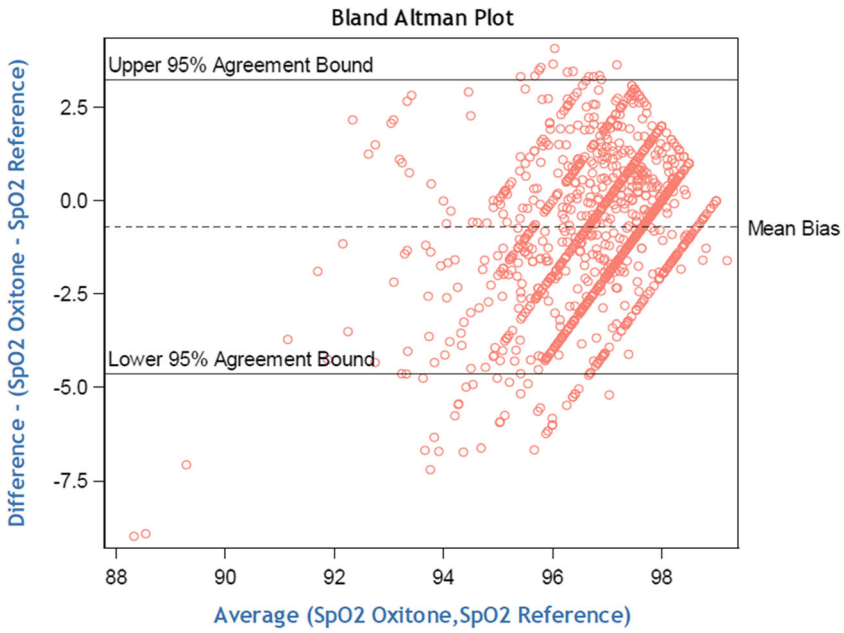


**Fig. 2** The level of agreement between the devices using the Bland-Altman plot for Oxygen saturation levels. Most differences between the two measurements will lie between the 95% agreement limits of [−4.64, 3.24]%

as before and after exercise. We found the device to be accurate and precise, in addition to a potential increase in patient compliance since it's more comfortable to wear.

The aim of this study was to test device accuracy and precision. Therefore, the measurements were done in a range of SpO2 between 70 and 100%, since it was previously shown that at lower oxygen saturation ranges, most pulse oximeters do not enable precise absolute measurements [11]. Our device, as well as the reference device are both FDA approved. This is an important point, since many pulse oximeters sold to consumers demonstrate highly inaccurate readings. In fact, a recent study performed by Lipnick et al. that tested the accuracy of low-cost finger pulse oximeters in healthy subjects found that the majority of the oximeters tested did not meet US FDA standards for accuracy (FDA and ISO, an Arms <3%). Moreover, the inexpensive units that did pass these requirements, failed to meet current World Health Organization or World Federation of Societies of anesthesiologists standards for use in clinical practice and showed highly inaccurate saturation readings during hypoxia [12].

In this study, we tested healthy individuals, as well as COPD and other ILD patients. Spirometry is essential in

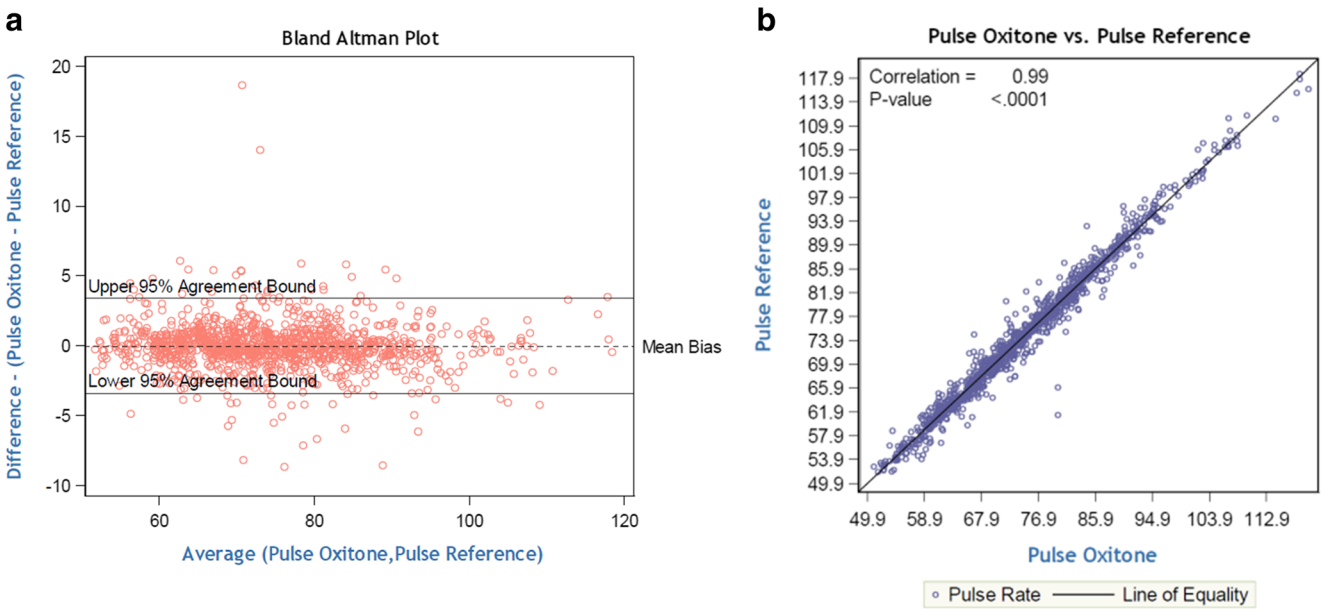


**Fig. 3** **a** The level of agreement between the devices using the Bland-Altman plot for pulse rate measuring. **b** Correlation Between Pulse Oxitone and Pulse Reference ($n = 1182$, $p < 0.0001$)

determining whether the probable cause of respiratory symptoms is COPD, though clinical criteria, such as the intensity of breathlessness in relation to specific tasks and frequency of exacerbations should also be used when evaluating disease severity [13]. Annual spirometry is advised, particularly in patients with a severe disease, since they were shown to benefit from long-term oxygen therapy [4]. For milder resting hypoxemia patients however, there was no apparent survival benefit [14, 15]. The Long-Term Oxygen Treatment Trial (LOTT) randomly assigned 738 participants with COPD and mild to moderate hypoxemia at rest to receive or not receive long term supplemental oxygen. The authors concluded that there was no significant value to the addition of LTOT. However, they also suggested that a lack of evidence of effect is not an evidence of lack of effectiveness. Indeed, the INOX trial [16] is now underway in order to further clarify this issue. We suggest the use of this device in future COPD - LTOT studies in order to further establish recommendations regarding LTOT use for moderate- mild COPD patients.

Chronic severe hypoxemia as measured by pulse oximetry ($SpO_2$) is of below 88% and moderate hypoxemia is $SpO_2$ of 88–90%. These characteristics have thus been the clinical eligibility criteria for a long term oxygen therapy [17]. These measurements are performed as a single measurement at rest. Since the oxygenation status of patients fluctuates throughout a 24 h period, a single measurement of resting oxygen level may not reflect the oxygen patient needs. Therefore, continuous oxygen monitoring for a better adjustment of oxygen treatment was suggested. Indeed, a study performed by Zhu et al. that used the OxyHolter device for only 24 h twice a week, found that the adjustment of oxygen prescriptions resulted in an increase in the percentage of time that the $SpO_2$ level was between 88 and 92% by almost two fold (from 24.8 ± 21.7% to 52.8 ± 25%, $p = 0.001$). Moreover, any reduction in the $O_2$ prescription did not lead to a significant increase in the percentage of time that the $SpO_2$ was below 88% [7].

The present study has several limitations. Firstly, study subjects were recruited on a volunteer basis, with a limited number of subjects with dark skin (Type V and VI). Although pigment is known to cause inaccurate readings in pulse oximeters [18], the most bias is due to dark skin [19]. Our study included a low percentage of such patients (10%) and therefore we believe it didn't significantly influence data accuracy. Another limitation of the study was the difference in frequency measurements that were due to the Reference device. Since we wished to synchronize the measurements between devices, only 5 readings per minute were analyzed (instead of a possible 60).

In conclusion, the Oxitone measurement of oxygen saturation and pulse fulfills the success criterion for Arms (accuracy), shows high repeatability and reproducibility (i.e. small standard deviation) (precision), has a high level of comfort (usability) and is safe. Larger and more long term studies are suggested.

**Acknowledgements** The statistical analyses was performed by BioStat statistical consulting company, using SAS® v9.4 (SAS®, SAS Institute Cary, NC USA) software.

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## Compliance with ethical standards

**Conflict of interest** Sarah Kohn is an employee at Oxitone Medical. All other authors have nothing to disclose.

**Ethics approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee at MMC and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

## References

1. Riis, H. C., Jensen, M. H., Cichosz, S. L. et al., Prediction of exacerbation onset in chronic obstructive pulmonary disease patients. *J. Med. Eng. Technol.* 40:1–7, 2016.
2. Bradley, J. M., and O'Neill, B., Short term ambulatory oxygen for chronic obstructive pulmonary disease. *Cochrane Database Syst. Rev.* 2:CD004356, 2005.
3. Nonoyama, M. L., Brooks, D., Guyatt, G. H. et al., Effect of oxygen on health quality of life in patients with chronic obstructive pulmonary disease with transient exertional hypoxemia. *Am. J. Respir. Crit. Care Med.* 176:343–349, 2007.
4. Long-Term Oxygen Treatment Trial Research, G, Albert, R. K., Au, D. H. et al., A randomized Trial of long-term oxygen for COPD with moderate desaturation. *N. Engl. J. Med.* 375:1617–1627, 2016.
5. Kramer, M., Lobbestael, A., Barten, E. et al., Wearable pulse oximetry measurements on the torso, arms, and legs: A proof of concept. *Mil. Med.* 182:92–98, 2017.
6. National Collaborating Centre for Chronic, C, Chronic obstructive pulmonary disease. National clinical guideline on management of chronic obstructive pulmonary disease in adults in primary and secondary care. Thorax 59(Suppl 1):1–232, 2004.
7. Zhu, Z., Barnette, R. K., Fussell, K. M. et al., Continuous oxygen monitoring–a better way to prescribe long-term oxygen therapy. *Respir. Med.* 99:1386–1392, 2005.
8. Laboratories, A.T.S.C.o.P.S.f.C.P.F, ATS statement: Guidelines for the six-minute walk test. *Am. J. Respir. Crit. Care Med.* 166:111–117, 2002.
9. Altman, D. G., and Bland, J. M., Assessing agreement between methods of measurement. *Clin. Chem.* 63:1653–1654, 2017.
10. Medical electrical equipment—Part 2–61: Particular requirements for basic safety and essential performance of pulse oximeter equipment. 2017
11. Wurtemberger, G., Muller, S., Matthys, H. et al., Accuracy of nine commercially available pulse oximeters in monitoring patients with

chronic respiratory insufficiency. *Monaldi Arch. Chest Dis.* 49:348–353, 1994.
12. Lipnick, M. S., Feiner, J. R., Au, P. et al., The accuracy of 6 inexpensive pulse oximeters not cleared by the Food and Drug Administration: The possible global public health implications. *Anesth. Analg.* 123:338–345, 2016.
13. Niewoehner, D. E., Lokhnygina, Y., Rice, K. et al., Risk indexes for exacerbations and hospitalizations due to COPD. *Chest* 131:20–28, 2007.
14. Gorecka, D., Gorzelak, K., Sliwinski, P. et al., Effect of long-term oxygen therapy on survival in patients with chronic obstructive pulmonary disease with moderate hypoxaemia. *Thorax* 52:674–679, 1997.
15. Anthonisen, N. R., Long-term oxygen therapy in moderate hypoxaemia. *Thorax* 52:667–668, 1997.
16. Lacasse, Y., Bernard, S., Series, F. et al., Multi-center, randomized, placebo-controlled trial of nocturnal oxygen therapy in chronic obstructive pulmonary disease: A study protocol for the INOX trial. *BMC Pulm. Med.* 17:8, 2017.
17. Hardinge, M., Annandale, J., Bourne, S. et al., British Thoracic Society guidelines for home oxygen use in adults. *Thorax* 70(Suppl 1):i1–43, 2015.
18. Bickler, P. E., Feiner, J. R., and Severinghaus, J. W., Effects of skin pigmentation on pulse oximeter accuracy at low saturation. *Anesthesiology* 102:715–719, 2005.
19. Feiner, J. R., Severinghaus, J. W., and Bickler, P. E., Dark skin decreases the accuracy of pulse oximeters at low oxygen saturation: The effects of oximeter probe type and gender. *Anesth. Analg.* 105: S18–S23, 2007 tables of contents.