Nocturnal Home Pulse Oximetry: Variability and Clinical Implications in Home Mechanical Ventilation

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Key Words

Pulse oximetry • Oxygen saturation • Mechanical ventilation

Abstract

Background: Nocturnal home pulse oximetry (NHPO) provides information by measuring a series of variables: time spent with $\text{SaO}_2 < 90\%$ expressed as percentage (T90) or in minutes (Tm90), mean SaO_2 (MnS), and lowest SaO_2 (LwS). The presence of significant nocturnal desaturation has been proposed as a parameter in decision making with regard to initiating home mechanical ventilation (HMV) or monitoring HMV effectiveness. However, there is limited information on the possible variability of the test, and this could influence the interpretation of results. **Objectives:** To explore the variability between 2 consecutive measurements of NHPO and to determine clinical applications in HMV. **Methods:** The patients presented diseases susceptible to HMV treatment and were enrolled in stable condition without respiratory failure. NHPO was conducted on 2 consecutive nights. The variables analyzed were: T90, Tm90, MnS, and LwS. The coefficient of variation (CV), a concordance coefficient (CC), and the Bland-Altman method were used in order to explore the variability. **Results:** We studied 40 cases. Two were excluded, and the

remaining 38 were aged 58 ± 16 years (19 males). Eighteen were receiving HMV. CV values exceeded 100% for T90 and Tm90 and were below 5% for MnS and LwS. The CC for T90, Tm90, and LwS showed confidence intervals with lower limits below 0.5, while for MnS the value was 0.88 (0.79–0.93).

Conclusions: There is a wide variability in NHPO recordings for T90, Tm90, and LwS, so a single determination to detect nocturnal desaturation may not be valid for decision making; the parameter with the least interindividual variability and intraindividual variability was MnS.

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Introduction

Nocturnal home pulse oximetry (NHPO) is a simple diagnostic procedure that provides information on patients' oxygenation in their usual environment. The variables obtained from NHPO and used in decision making are: the duration of time with oxygen saturation (SaO_2) $< 90\%$ expressed as percentage (T90) or as cumulative minutes (Tm90), the mean SaO_2 (MnS), and the minimum or lowest SaO_2 (LwS) [1–3]. The study of these parameters has led to the finding that, although the day-

time gas exchange is normal, there may be significant episodes of nocturnal desaturation in different situations [2, 4].

Although nocturnal pulse oximetry has been used in the management of various diseases such as chronic obstructive pulmonary disease (COPD) and obstructive sleep apnea syndrome (OSAS) and in patients on home mechanical ventilation (HMV), there is limited information on the possible interindividual variability (inter-V) and intraindividual variability (intra-V) of the test which may influence the interpretation of results as demonstrated in patients with COPD [2].

It has also been proposed that NHPO may provide useful information about the patient's ventilation in certain situations, with the intention of initiating treatment with HMV or monitoring the effectiveness of treatment [5–7], but there is no clear consensus on reference values or a threshold point for clinical decision making.

Our objective was to explore the variability between 2 consecutive measurements using NHPO performed on 2 successive nights in a population of patients with respiratory disease other than COPD as well as its subsequent clinical application, especially in the field of HMV.

Methods

Patients and Design

Patients attending our outpatient clinic were recruited consecutively; they were in stable condition without evidence of exacerbation in the 4 weeks prior to the study, presenting with diseases susceptible to treatment with HMV, i.e. neuromuscular diseases, obesity, or chest wall deformity. Patients were recruited regardless of whether they were receiving HMV treatment or were currently untreated. We only included patients with a pO_2 value greater than 60 mm Hg. All patients gave their written informed consent to be included in the study which was approved by the Hospital Ethics Committee. Patients with COPD or any other disease treated with home oxygen therapy were excluded.

NHPO was measured continuously during sleep, with the patient supine, using a finger tip infrared pulse oximeter (Pulsox-3iA; Konica Minolta Sensing, Osaka, Japan), provided with the finger clip and a multisite probe (SR-5C, 0.3 m; Konica Minolta Sensing). Digital readings of nocturnal arterial oxyhemoglobin saturation (SpO_2) and pulse rate were displayed on a computer screen with an interface unit (IF-3; Konica Minolta Sensing), an interface cable (I/F cable; Konica Minolta Sensing), and Pulsox DS-3 software for Windows XP (Konica Minolta Sensing). The quality of readings was checked and the results were printed out.

Patients were instructed to connect the pulse oximeter at the beginning of sleep and disconnect it at the time of waking. Patients handed in the pulse oximeter after 2 nights of recording and were asked about incidents that may have affected the recording quality. Recordings with a minimum of 5 h without significant incidents were considered valid for analysis. We analyzed the

variability between the 2 recordings using the following parameters: T90, Tm90, MnS, and LwS.

Statistical Analysis

Results are expressed as arithmetic means, ranges, and standard deviations (SD) for continuous variables and as frequencies and percentages for qualitative variables. We calculated the variation coefficient (VC) (SD/mean) in order to explore inter-V. Confidence intervals were limited to 95%. In order to explore intra-V, first and second measurements of T90, Tm90, MnS, and LwS were compared using a concordance correlation coefficient (CC) [8]. T90 and Tm90 were also plotted graphically following the Bland-Altman method for each pair of nocturnal recordings and using the difference between the 2 recordings versus the arithmetic mean of each pair of measures. The mean difference and 95% limits of agreement for each comparison were calculated. Statistical analysis was carried out with SPSS version 17.0 (Chicago, Ill., USA) and MedCalc version 10.1.3.0. (Mariakerke, Belgium).

Results

General Characteristics

A total of 40 patients were studied; 2 were excluded because of poor data quality, while the remaining 38 patients (aged 58 ± 16 years; 19 men and 19 women) were included in the study. Subjects suffered from: chest wall disorders ($n = 6$; 16%), obesity with BMI >30 ($n = 17$; 45%) ($n = 11$ with obesity hypoventilation syndrome), and neuromuscular disease ($n = 15$; 39%). Eighteen patients (44%) were receiving HMV. The mean values of PaO_2 , $PaCO_2$, and pH were 72 ± 11 mm Hg, 44 ± 6.8 mm Hg and 7.40 ± 0.31 , respectively. No relevant incidences during the recording time were reported by any of the participants.

Variability of Nocturnal Desaturation

The duration of the recordings on the first night was 390 min (SD 40), and the duration on the second night was 410 min (SD 55) ($p > 0.05$). The values of the variables under study (T90, Tm90, MnS, and LwS) showed no significant differences between the 2 recordings (table 1). The VC for T90 and Tm90 were above 100%, while MnS and LwS showed a VC of less than 5% (table 1). The CC for T90, Tm90, and LwS were around 0.70 with the lower limits of the confidence intervals near or below 0.5. The CC for MnS was 0.88 (0.79–0.93) (table 2).

The intra-V could differ depending on the value of the variable. Figures 1 and 2 illustrate how T90 and Tm90 values showed greater dispersion with respect to the mean when the variable had intermediate values (20–40% for T90 and 150–200 min for Tm90). In contrast, more extreme values of both T90 and Tm90 showed greater stability.

Fig. 1. Plotted values (T90). T90 = Percentage of the recording with an SpO₂ below 90%.

Fig. 2. Plotted values (Tm90). Tm90 = Number of minutes with an SpO₂ below 90%.

Table 1. Pulse oximetry values

	n	Minimum	Maximum	Mean	SD	p value	Coefficient of variation (%)
T90 (first measurement)	38	0.00	100.00	15.5242	25.29	NS ^a	162
T90 (second measurement)	38	0.00	99.93	18.08	26.66		147
Tm90 (first measurement)	38	0.00	519.0	69.97	117.64	NS ^a	168
Tm90 (second measurement)	38	0.00	455.00	77.5803	123.64		152
MnS (first measurement)	38	74.63	96.99	92.0953	4.15	NS ^b	4.9
MnS (second measurement)	38	76.3	97.2	91.936	4.53		4.9
LwS (first measurement)	36	44	91	76.92	13.08	NS ^b	1.7
LwS (second measurement)	38	45	93	78.00	12.04		1.5

Tm90 = Number of minutes with an SpO₂ below 90%; T90 = percentage of the recording with an SpO₂ below 90%.

^a Wilcoxon signed-rank test. ^b Paired sample Student's t test.

Table 2. Concordance CC

Variable	Tm90 (first and second measurements)	T90 (first and second measurements)	MnS (first and second measurements)	LwS (first and second measurements)
Concordance CC	0.6808	0.7214	0.8836	0.7210
95% confidence interval	0.4663–0.8197	0.5273–0.8440	0.7931–0.9359	0.5267–0.8437
Sample size	38	38	38	38

Tm90 = Number of minutes with an SpO₂ below 90%; T90 = percentage of the recording with an SpO₂ below 90%.

Discussion

This study found that in patients with respiratory diseases other than COPD and without daytime respiratory failure it was possible to detect nocturnal periods where the SaO_2 fell below 90%, and the parameter most widely used for quantification (T90) may present a wide variability that affects our ability to properly discriminate between these patients.

A reliable diagnostic test would have to yield very similar results if performed under similar conditions, i.e. the variability should be as little as possible. We studied this variability from 2 angles: firstly the inter-V, which was elevated for T90 and Tm90 while MnS and LwS remained more stable, and secondly the intra-V, which also varied widely for T90, Tm90, and LwS, with MnS showing greater stability. It should be emphasized that most authors use T90 as the reference measurement to identify significant desaturation [2, 7, 9].

Respiratory failure characteristically manifests as increased blood pCO_2 levels, and the gold standard technique to monitor these levels is therefore arterial blood gasometry. Nevertheless, noninvasive transcutaneous capnography has been shown to provide sufficient and reliable information, and it obviates the need for repeated extractions of blood samples [10, 11]. However, the limitations of this technique include the complexity of the devices and scarce availability, so their use in home monitoring is not widespread. Nocturnal pulse oximetry allows the direct measurement of arterial SaO_2 and, indirectly, respiratory status. In this regard, a significant relationship has been shown between a decreased MnS measured by nocturnal pulse oximetry and the presence of daytime hypercapnia [12, 13]. Currently, various authors [3, 6, 9, 12, 13] and consensus documents [6, 14, 15] support the use of nocturnal pulse oximetry that provides reliable information for the assessment and monitoring of respiratory disorders.

Among the possible explanations for the variability of results found in this study, pretest factors can be ruled out since all patients were in stable condition and subsequent questioning revealed no detectable relevant changes in patient state between the 2 tests. Test-specific factors also fail to explain the results because there were no changes in the pulse oximeter model, there was no significant difference between the duration of the records, and no patients reported relevant events during the recordings. The reading of the recordings was performed with the same software in all cases.

Our findings with regard to T90 are similar to those obtained by Lewis et al. [2] who used NHPO in 26 patients diagnosed with COPD in stable condition on 2 occasions. The authors concluded that a single recording when using T90 as a basic parameter may not be sufficient to establish the diagnosis of nocturnal desaturation. In addition, both this study and ours found a greater variability in intermediate values. This phenomenon may be influenced by 2 factors: firstly, nocturnal pulse oximetry was conducted in private homes where each patient's personal circumstances may alter the quality of recordings, and secondly, an unknown part of the recording could have been taken in periods of wakefulness, undetected due to the absence of EEC monitoring. These 2 possible causes of distortion may represent unknown factors of variability and explain, at least in part, the more dispersed values found in our study.

For diagnosis and decision making, there is a need to establish threshold values which serve as diagnostic reference values. In an in-hospital study by Perez Llano et al. [7] in 24 patients with obesity hypoventilation syndrome, the patients underwent NHPO and a daytime test. The parameter selected to detect nocturnal desaturation was T90, and the cutoff point was arbitrarily set at 15%; other authors have used a 30% cutoff [4], which also seems arbitrary. In 19 patients with Duchenne muscular dystrophy, Craig et al. [5] choose a T90 value greater than 2% as the threshold to detect hypoventilation. None of these studies report the number of tests needed to confirm the diagnosis. If in our study we had applied a T90 value of 30% as a threshold value to detect nocturnal desaturation [2], we would have detected 10 cases (26%) and in 5 of these cases (50%) the 2 measurements would have been discordant. If we had set the threshold at 15% [7], 15 patients (39%) would have been diagnosed with nocturnal desaturation and in 9 of these (60%) there would have been diagnostic disagreement between the 2 recordings. In other words, up to 60% of nocturnal desaturations could remain undiagnosed if a single recording is used. For this reason we recommend at least 2 NHPO tests.

In our analysis of Tm90 we found a variability similar to that of T90. In this regard, Velasco et al. [16] used a 1-min threshold of Tm90 to detect hypoventilation in patients with amyotrophic lateral sclerosis (ALS), which appeared in a recently published consensus document as a reference value in these patients for the diagnosis of hypoventilation and for considering the initiation of HMV [6]. If we had applied this proposed value of 1 min as a diagnostic threshold value in our series, 14 of our 38 patients would have been diagnosed with hypoventilation

and 13 of these 14 cases (92%) would have shown concordant measurements of Tm90.

Our results agree with those of Lewis et al. [2] in that the parameter MnS showed great stability with slight inter-V and intra-V. Although MnS has not been widely adopted as a reference measure to detect nocturnal desaturation, it is worth remarking that some studies [16] have demonstrated a relationship between an Msn <93% and a worse prognosis in patients with ALS, which could be related to a greater involvement of the ventilator muscles.

Finally, the LwS in our study showed little inter-V and an increased intra-V. There are few references in the literature on this parameter which has been used to detect hypoventilation in patients with ALS [13]. We found no studies that explore its variability, and its clinical usefulness seems limited.

Despite the advantages of nocturnal pulse oximetry and its utility in the hospital and in the patient's home, a recent study by Ramsey et al. [17], which surveyed a group of physicians on their interpretation and indications, detected a surprising lack of uniformity in the use of the technique; this suggests the need for more standardization. In this regard, Gries et al. [1] performed in-hospital nocturnal pulse oximetry in 350 normal subjects; they obtained normal values for MnS and LwS, but there were no values established as normal for the other parameters, whether in a hospital or home environment. One of the strengths of our study is that it provides information from key parameters that can be obtained by NHPO to improve interpretation, and we propose home monitoring as a valid working model.

The major limitation is that our study was not complemented by the determination of sleep parameters, which would have allowed us to exclude those parts of the re-

cordings corresponding to periods of wakefulness. With regard to this point, polysomnography is the gold standard technique since it distinguishes between periods of wakefulness and sleep at various stages. Its performance would have improved the interpretation of NHPO results in relation to excluding with certainty the parts of the recording in which patients were awake. In our study we used a subjective post-NHPO survey to exclude parts of the recording where patients experienced wakefulness or had poor quality and quantity of sleep, so our T90 results may be slightly lower than the real values.

Finally, our inclusion criteria meant that the study population was heterogeneous, with some patients on HMV and others untreated. In the former, NHPO was performed to monitor HMV treatment and in the latter to diagnose the presence of nocturnal hypoventilation. However, we believe that this limitation did not substantially influence our interpretation of the results.

In conclusion, our NHPO results showed wide inter-V and intra-V in Tm90 and T90 values and therefore cast doubt on the utility of the cutoff points suggested by some authors. We believe that a single determination may not be valid for establishing the presence or absence of desaturation. In addition, the possibility of using MnS as a benchmark should be considered since it proved to be the most stable parameter in NHPO. Finally, we believe long-term studies are required to establish the clinical importance of significant nocturnal desaturation.

Financial Disclosure and Conflicts of Interest

The authors declare no conflict of interest.

References

- 1 Gries RE, Brooks LJ: Normal oxyhemoglobin saturation during sleep. *Chest* 1996;110:1489-1492.
- 2 Lewis CA, Eaton TE, Fergusson W, Whyte KF, Garrett JE, Kolbe J: Home overnight pulse oximetry in patients with COPD: more than one recording may be needed. *Chest* 2003;123:1127-1133.
- 3 Jackson CE, Rosenfeld J, Moore DH, Bryan WW, Barohn RJ, Wrench M, Myers D, Heberlin L, King R, Smith J, Gelinas D, Miller RG: A preliminary evaluation of a prospective study of pulmonary function studies and symptoms of hypoventilation in ALS/MND patients. *J Neurol Sci* 2001;191:75-78.
- 4 Lewis CA, Fergusson W, Eaton T, Zeng I, Kolbe J: Isolated nocturnal desaturation in COPD: prevalence and impact on quality of life and sleep. *Thorax* 2009;64:133-138.
- 5 Hukins CA, Hillman DR: Daytime predictors of sleep hypoventilation in Duchenne muscular dystrophy. *Am J Respir Care Med* 2000;161:166-170.
- 6 Miller RG, Jackson CE, Kasarskis EJ, England JD, Forshe D, Johnston W, Karla S, Katz JS, Mitsumoto H, Rosendfeld J, Shoemaker C, Strong MJ, Woolley SD: Practice parameter update: the care of the patient with amyotrophic lateral sclerosis: drug, nutritional, and respiratory therapies (an evidence-based review). *Neurology* 2009;73:1218-1226.

- 7 Perez de Llano LA, Golpe R, Piquer MO, Racamonde AV, Caruncho MV, López MJ, Fariñas MC: Clinical heterogeneity among patients with obesity hypoventilation syndrome: therapeutic implications. *Respiration* 2008;75:34–39.
- 8 Li L: A concordance correlation coefficient to evaluate reproducibility. *Biometrics* 1989; 45:255–268.
- 9 Banerjee D, Yee BJ, Piper AJ, Zwillich CW, Grunstein RR: Obesity hypoventilation syndrome: hypoxemia during continuous positive airway pressure. *Chest* 2007;131:1678–1684.
- 10 Stege G, van den Elshout FJ, Heijdra YF, van den Ven MJ, Dekhuijzen PN, Vos PJ: Accuracy of transcutaneous carbon dioxide tension measurements during cardiopulmonary exercise testing. *Respiration* 2009;78: 147–153.
- 11 Randerath WS, Stieglitz S, Galetke W, Anduleit N, Termil M, Schafer T: Evaluation of a system for transcutaneous long-term capnometry. *Respiration* 2010;80:139–145.
- 12 de Carvalho M, Costa J, Pinto S, Pinto A: Percutaneous nocturnal oximetry in amyotrophic lateral sclerosis: periodic desaturation. *Amyotroph Lateral Scler* 2009;10:154–161.
- 13 Elman LB, Siderowf AD, McCluskey LF: Nocturnal oximetry: utility in the respiratory management of amyotrophic lateral sclerosis. *Am J Phys Med Rehabil* 2003;82: 866–870.
- 14 Kaw R, Hernandez AV, Walker E, Abousouan L, Mokhlesi B: Determinants of hypercapnia in obese patients with obstructive sleep apnea: a systematic review and meta-analysis of cohort studies. *Chest* 2009;136: 787–796.
- 15 Tintignac A, Gonzalez-Bermejo J: Follow-up and management of non-invasive home mechanical ventilation (in French). *Rev Pneumol Clin* 2009;65:237–247.
- 16 Velasco R, Salachas F, Munerati E, Le Forrester N, Pradat PF, Lecomber L, et al: Nocturnal oximetry in patients with amyotrophic lateral sclerosis: role in predicting survival. *Rev Neurol* 2002;158:575–578.
- 17 Ramsey R, Mehra R, Strohl KP: Variations in physician interpretation of overnight pulse oximetry monitoring. *Chest* 2007;132:852–859.