

Ambulatory Oximetry Monitoring in Patients With Severe COPD*

A Preliminary Study

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Background: The benefits of long-term oxygen supplementation in COPD patients with hypoxemia are well established. The standard approach to prescribing oxygen uses a static assessment of oxygen requirements in a hospital or clinic setting. The assumption behind this approach is that patients will maintain a “therapeutic” hemoglobin oxygen saturation (SpO₂) in the outpatient setting. We questioned the validity of this assumption, and hypothesized that many patients may demonstrate significant oxygen desaturation during normal activities of daily living.

Study design, methods, and measurements: We determined if oxygen supplementation maintained a therapeutic SpO₂ level in patients with COPD (n = 27), using the technique of ambulatory oximetry monitoring (AOM). AOM consisted of using a portable oximeter to monitor SpO₂, pulse rate, and patient activity while patients were engaged in normal activities of daily living over an extended time period (~18 h). The portable oximeter collected and stored these data every 15 s over the monitored time period. Each AOM recording was manually scored for desaturation events and other key variables, including average SpO₂ over the monitoring period, the average number of desaturation events per hour, and the percentage of monitored time deleted secondary to artifacts.

Setting: University-affiliated Veterans Affairs Medical Center.

Patients: All subjects were patients with stable COPD with no recent history of hospitalization or exacerbation of their lung disease.

Results: This cohort of patients demonstrated a surprising frequency of desaturation below the recommended target SpO₂ value (90%), which averaged approximately 25% of AOM recording time. There was wide variability among patients in the percentage of time SpO₂ was below the target value (range, 3 to 67% of AOM recording time). Motion artifact on the AOM recordings was not a major problem; an average of 8% of the recording time was deleted secondary to artifacts in this patient cohort.

Conclusions: The results demonstrate that AOM is feasible and accurate with an acceptable level of motion artifact. These results also suggest that the standard approach for prescribing oxygen may lead to subtherapeutic SpO₂ values in the outpatient setting. AOM holds promise as a tool to monitor the adequacy of oxygen prescriptions in the outpatient setting in patients with lung disease.

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Key words: ambulatory oximetry monitoring; COPD; long-term oxygen therapy

Abbreviations: ABG = arterial blood gas; AOM = ambulatory oximetry monitoring; LTOT = long-term oxygen therapy; SaO₂ = arterial oxygen saturation; SpO₂ = hemoglobin oxygen saturation

The current standards for prescribing oxygen to patients with lung disease recommend providing adequate flow of oxygen to correct hypoxemia at rest

and during usual exercise.^{1–3} This recommendation is based on the finding that supplemental oxygen administration is the only intervention that prolongs the life of patients with COPD.^{4,5} In addition to a reduction in mortality, other established benefits of oxygen supplementation include a reduction in hypoxemia-induced elevations in hemoglobin,^{5,6} decreased pulmonary artery pressure and vascular resistance, increased stroke volume index,^{5–9} improved exercise tolerance,^{4,10,11} increased functional status, and subjective improvement in quality of life.^{12,13}

The scientific basis for the use of long-term oxygen therapy (LTOT) was established two decades ago with prospective trials in patients with severe COPD.^{4,5} These trials demonstrated unequivocally that the use of LTOT in hypoxemic patients with COPD increased survival. Although the precise basis

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for the survival benefit is still not known, the assumption has been that patients develop an increased risk for hypoxemic organ dysfunction when these criteria are not met. The results of these trials led to the development of a set of clinical criteria for the initiation of LTOT, including a $\text{PaO}_2 < 55$ mm Hg or a hemoglobin oxygen saturation (SpO_2) $< 88\%$ at rest, during exercise, or sleep; higher values ($\text{PaO}_2 < 59$ mm Hg or $\text{SpO}_2 < 89\%$) are acceptable in the presence of right heart failure, cor pulmonale, or erythrocytosis.^{1-3,10}

The standard assessment before initiation of LTOT uses either an arterial blood gas (ABG) sample (for PaO_2) or pulse oximetry at rest and during exercise to determine whether LTOT should be initiated or modified. This evaluation is typically done in a clinic or hospital setting, and is based on an assessment of PaO_2 or SpO_2 at one time. The assumption is that patients will maintain a therapeutic level of SpO_2 as outpatients during normal activities of daily living. This standard approach for monitoring LTOT raises several questions. Does it lead to adequate SpO_2 in the outpatient setting? How often do patients develop clinically significant hypoxemia during normal activities of daily living? These questions highlight important gaps in knowledge regarding the temporal profile of SpO_2 in patients with COPD in the outpatient setting, and how to maintain optimal LTOT in these patients.

We hypothesized that patients with COPD would demonstrate a drop in SpO_2 below acceptable values while engaged in activities of daily living. The objectives of this study were to (1) determine the feasibility of monitoring SpO_2 in patients with severe COPD in the outpatient setting and (2) determine the temporal profile of SpO_2 in these patients during their normal activities of daily living. To accomplish these objectives, we developed a method called ambulatory oximetry monitoring (AOM) for the collection and analysis of SpO_2 data obtained from patients in the outpatient setting. This approach is based on earlier preliminary work.¹⁴⁻¹⁶

MATERIALS AND METHODS

Patient Selection

Twenty-nine patients with severe COPD were included in this study. Only patients with $\text{FEV}_1 < 50\%$ of the predicted value were included in this group. Patients were recruited from the Oxygen Clinic and the Pulmonary Outpatient Clinic at the Veterans Affairs Medical Center, Providence, RI. Within the last year, each patient underwent pulmonary function studies to verify the presence of severe COPD. All patients were regularly observed by a pulmonary staff member at our institution, and, while participating in this study, were clinically stable, oxygen-dependent patients at their baseline level of function.

All patients received continuous LTOT for 24 h each day during

the investigation. To be considered clinically stable, a patient must have had no recent episodes of COPD exacerbation that required hospitalization or the administration of antibiotics or increased doses of steroids during the preceding 2 months. To be included in the study, patients were required to be physically mobile (either ambulatory or in a wheelchair) and have sufficient cognitive function to follow the instructions for use of the AOM equipment. The major exclusion criteria included the presence of a significant medical problem precluding ambulatory activity as an outpatient and a recent COPD exacerbation. Written informed consent was obtained from all subjects as part of a protocol approved by the Investigational Review Board at our institution.

Equipment

We used a pulse oximeter (Cricket Recording Pulse Oximeter; Respironics Inc; Monroeville, PA) with computer software (Analysis Software, version 2.10; Respironics) to obtain AOM data. The unit is small ($5.3 \times 2.4 \times 1.0$ inches) and lightweight (6.3 oz), as well as economical to operate; a 9-V battery is adequate for a 24-h monitoring period. This portable oximeter can continuously record SpO_2 and a pulse rate waveform for ≤ 24 h. Each parameter (SpO_2 and pulse rate) is recorded or displayed as a weighted running average that is updated every 2 s. The finger probe of the unit is also equipped with a motion detector that registers patient movement. This allows correlation of patient activity with events occurring on the other two data channels during the recording period. In addition, the algorithm used to calculate SpO_2 values is designed to minimize the effects of movement and several other forms of oximetry artifact. For example, the unit performs a self-test each time it is turned on; this automatically adjusts the sensitivity of sensor light sources to compensate for skin pigmentation and thickness of the vascular bed. All data obtained during an AOM monitoring period are downloaded from the oximeter to a computer for final analysis.

Validation of Equipment

The portable oximeter has met FDA requirements for a biomedical device in use with human subjects, and has been validated by the manufacturer. The instrument has also recently been used for clinical investigation in humans.¹⁷ We validated the accuracy of this portable oximeter in several ways in preliminary work before beginning data collection in patients.

First, we compared the results of SpO_2 tracings obtained with the portable oximeter with similar tracings obtained from other oximetry units used to monitor SpO_2 in patients ($n = 20$) at our medical center. Patients were simultaneously connected to the portable monitor (model P20; Nellcor Puritan-Bennett; Pleasanton, CA) and a standard hospital oximeter (Biox 3700; Ohmeda; Louisville, CO) to obtain concurrent tracings from each recording device. Data were collected while patients were at rest and ambulatory in the hospital or clinic.

Second, we compared the at-rest SpO_2 values obtained with the portable oximeter with the at-rest arterial oxygen saturation (SaO_2) values obtained from samples collected simultaneously from nine hospitalized patients who underwent evaluation for LTOT. The data from the two techniques were tested for agreement using the method of Bland and Altman,¹⁸ which is more sensitive than the correlation coefficient.

Experimental Design

Recruited patients were individually instructed by one of the investigators (Dr. Pilling) in the proper use of the portable oximeter during a routine clinic visit. The finger probe of the

portable oximeter was positioned on the patient's nondominant hand to minimize interference during normal daily activities. The portable oximeter was worn on the patients' belt during the monitored period. The goal was to have patients complete AOM while engaged in their normal activities for 18 h. Patients were instructed to keep an activity log in which they recorded the time of their major daily activities (sleeping, walking, eating, resting, and other physical activities), any associated symptoms, and compliance with their supplemental oxygen prescription during the monitoring period. Patients were encouraged to perform all normal daily ambulatory activities, and to not alter their baseline level of function and daily physical activity.

Data Analysis

There are no established standards for analysis of AOM-derived data. All AOM recordings were manually scored for desaturation events using criteria developed during this study. Preliminary work indicated that one key issue with AOM is the ability to accurately detect artifacts in the SpO₂ channel of the AOM recordings, and to delete these sections from the data before final analysis.¹⁴ Artifacts in the SpO₂ tracing could potentially arise secondary to patient movement, leading to loss of contact at the finger probe site followed by loss of the oximetry signal. Therefore, we established a set of criteria that were applied to each AOM recording to insure consistency in data analysis. These criteria were developed from an analysis of a series of AOM recordings (n = 30) from normal persons without a history of lung disease, and patients with COPD who were monitored during rest, sleep, and a variety of ambulatory activities. These recordings were not included in the results of this study. The criteria were intentionally designed to minimize the possibility of introducing artifacts into the data, and to increase the sensitivity for detecting episodes of desaturation.

The AOM recordings were analyzed after they were downloaded to a computer, then printed out as a permanent record. Each recording was manually scored for motion artifact and SpO₂ desaturation events. A desaturation event occurred when SpO₂ decreased to < 90% for ≥ 30 s. There is controversy over what should be the "critical" target SpO₂ value during LTOT. The authors of one report¹ and Medicare recommend an SpO₂ value of ≥ 88% at rest or during exercise. This is the standard approach to assessing the adequacy of an oxygen prescription used at our medical center. Concern over the limitations of oximetry have led to recommendations that SpO₂ be maintained at > 90% at rest or during exercise in patients receiving LTOT.^{10,19–21} Therefore, our definition of a desaturation event during an AOM recording included a drop in SpO₂ to < 90% for ≥ 30 s during any segment of the recording. This definition of a desaturation event, using a critical target SpO₂ value of 90%, conforms to recent recommendations that suggest a minimal LTOT SpO₂ value of ≥ 90% at rest or during exercise.^{2,3,10,19,21} We defined an artifact as a change in SpO₂ > 10% from a stable baseline in < 30 s. This definition minimized the chance of including artifacts as real desaturation events in the final data analysis. The segments of each tracing containing artifacts were deleted from the final data before analysis of each AOM recording.

Each AOM recording was analyzed and manually scored for the following primary data parameters: average SpO₂ percentage during the entire recording period; average nadir SpO₂ percentage; percentage of total recording time in which SpO₂ < 90% (desaturation time); average number of desaturations < 90% hemoglobin saturation per hour per recording (desaturation index); and percentage of total AOM recording time deleted due to artifact (deletion). The software built into the portable unit permitted a semiautomated determination of the first two data parameters after all AOM recordings were first manually inspected for artifacts. The last three parameters required manual scoring of each record.

Finally, we determined the effect of using AOM-derived data to modify oxygen supplementation in our patients. We compared the use of AOM-derived data with the standard method of assessing the adequacy of an oxygen prescription to determine how often a change in a prescription would be made using either approach. We compared the number of patients qualifying for a change in their current oxygen prescription (on the basis of data demonstrating that they were not meeting the target SpO₂ value) with either a standard assessment or with use of AOM-derived data. In this analysis, a standard assessment was routinely performed as part of a normal clinic visit within 48 h of the time the AOM recording was obtained. All patients receiving LTOT at our medical center were followed by a clinician in the Oxygen Clinic. These clinicians were blinded to the AOM research protocol, and performed the standard assessment with no knowledge of AOM-derived data. Similarly, the investigators were unaware of the results of the standard assessment on a particular patient when AOM-derived data were analyzed.

There are no criteria for the use of AOM-derived data to assess the adequacy of an oxygen prescription. Therefore we devised specific criteria that we used to categorize each patient after analysis of their AOM recording. Patients were categorized in three groups: those experiencing a decrease in SpO₂ < 90% for > 10%, 20%, or 25%, respectively, of the total AOM recording time. The number of patients qualifying for a change in oxygen prescription using the standard approach (SpO₂ < 88% at rest or during exercise) was compared with the number of patients in each AOM category using a χ^2 analysis. A significant difference in the number of patients eligible for a modification of their oxygen prescription using the standard approach vs each AOM-derived category was defined as $p < 0.05$.

RESULTS

Validation of AOM Equipment

Although the portable unit used in this study is already in clinical use, we validated the accuracy of this unit in several ways. First, we compared resting and activity-related SpO₂ tracings obtained from patients with the portable unit with simultaneously obtained tracings of other oximeters in use at our medical center. There was an excellent correlation between SpO₂ tracings obtained with the portable oximeter and those from the different hospital oximeters; the data included tracings of desaturation events occurring in hospitalized patients engaged in physical activity (hallway walking). Visual inspection of the tracings revealed identical sensitivity among units in recording the fluctuations in SpO₂ occurring at rest or during exercise. The tracings obtained from the portable unit and the hospital units were superimposable (data not shown). This type of comparison was performed many times (n = 20) on different patients on separate days with the same results.

We also compared the SpO₂ values obtained with the portable oximeter with the SaO₂ values obtained simultaneously from patients undergoing in-hospital assessment for initiation of LTOT. The ABG samples were obtained on different patients on separate randomized days, and were analyzed on the blood gas analyzer

routinely used for patient samples at our institution. The regression analysis of resting SpO_2 vs SaO_2 demonstrated a significant correlation ($R = 0.86$ for $Y = 0.96x + 4.8$; $n = 9$ patients). Figure 1 illustrates the agreement between the saturation values obtained with the two methods, using a more sensitive approach¹⁸ for comparing results obtained with different techniques. This approach involved plotting the average from both techniques ($[\text{SpO}_2 + \text{SaO}_2]/2$) on the x-axis and the difference between both values ($\text{SpO}_2 - \text{SaO}_2$) on the y-axis for each pair of measurements. The difference between the upper and lower confidence intervals ($\delta + 1.96$ [SD] and $\delta - 1.96$ [SD], respectively) for the mean difference (δ) between values was reasonably small, and encompassed all the data points within the interval. These results suggest acceptable agreement between saturation values obtained with the portable oximeter vs the arterial samples.

AOM Recording Results

Twenty-nine patients were initially recruited for the study. Two were excluded from the final data analysis because adequate AOM recordings could not be obtained. Both patients discontinued AOM for nontechnical reasons. In the remaining patients, the portable oximeter scored high in subjective patient acceptance. The majority of patients found the portable unit easy to use and not burdensome to wear. They reported minimal interference with the performance of their normal daily activities in their patient logs. Technically adequate AOM recordings were obtained in all 27 patients.

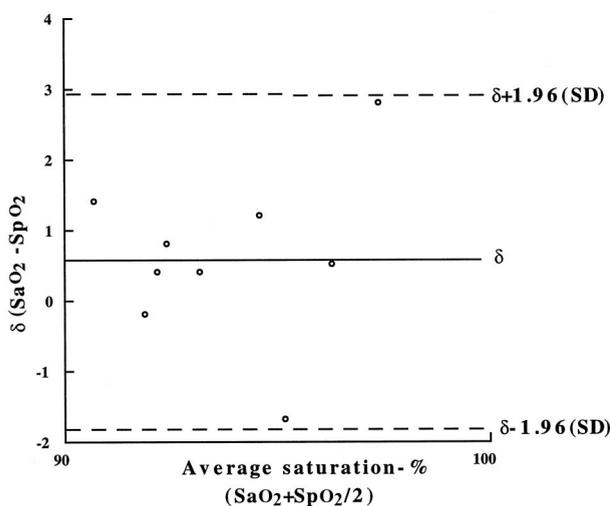


FIGURE 1. The average saturation vs the difference between SaO_2 and SpO_2 values for COPD patients. Mean SaO_2 , 94.1 ± 0.8 ; mean SpO_2 , 93.4 ± 0.7 ; $\delta = 0.62 \pm 1.2$; $n = 9$ patients. SD = standard deviation of the difference between ABG and oximeter values.

Table 1 illustrates the demographic and functional characteristics of the patient cohort, and a summary of the temporal profile of SpO_2 during AOM. The average age and FEV_1 of our population demonstrate the presence of advanced COPD in this patient cohort. Patients were monitored for an average of $1,143 \pm 48$ min, or approximately 19 h. Because of variation in AOM recording time among patients, the number of desaturation events was normalized by expressing results as then desaturation index, which was defined as the number of desaturation events per hour ($0.9 \pm 0.1/\text{h}$ for the entire patient cohort). A decrease in SpO_2 values below the critical level ($< 90\%$) was found on average to be approximately 25% of the total AOM recording time in this patient cohort, but there was significant variability among patients in the percentage of total recording time in which the SpO_2 target value was not reached (3 to 67% of recording time). These data demonstrate the unpredictable variability in the overall temporal pattern of SpO_2 in COPD patients considered to be oxygen-dependent on the basis of standard clinical criteria.

The amount of data deleted secondary to motion artifact was variable from patient to patient, but comprised a small percentage (8.0%) of total AOM recording time for this patient cohort (recording time range, 11 to 253 min). Collectively, these results suggest that acceptable AOM recordings can be obtained in the majority of patients.

Sample Tracings From Individual Patients

It is instructive to look at illustrative individual AOM recordings in addition to the averaged AOM results (Table 1). In each AOM recording, there were many segments in which a stable pulse rate and a well-defined SpO_2 waveform that remained $> 90\%$ were observed (data not shown). Figure 2 illustrates the short segment of a recording for one patient in

Table 1—AOM Results in Patients With COPD*

Measurement	Average Values
FEV_1 , L	0.93 ± 0.10
Age, yr	68 ± 2
SpO_2 avg	92.0 ± 0.5
SpO_2 min	73.9 ± 1.2
Desaturation time, %	24.6 ± 3.8
Desaturation index	0.9 ± 0.1
Deletion, %	8.0 ± 1.4

*Values given as mean \pm SE. SpO_2 avg = average % hemoglobin saturation during the entire recording period; SpO_2 min = average nadir % hemoglobin saturation; desaturation time = percent of total AOM recording time that SpO_2 values were $< 90\%$; desaturation index = average number of desaturations of $< 90\%$ hemoglobin saturation per hour per recording; deletion = % of total AOM recording time deleted due to artifact.

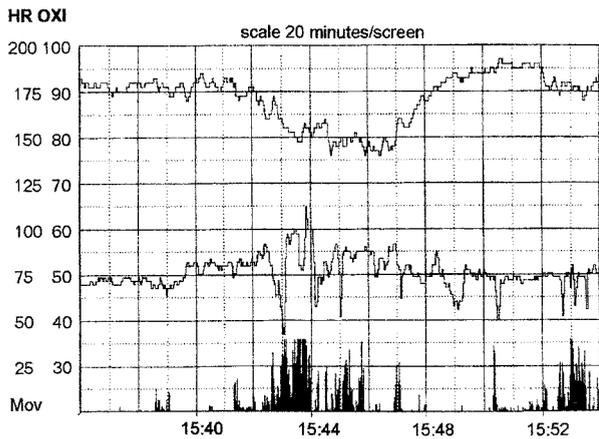


FIGURE 2. SpO₂ desaturation with activity. This record demonstrates a desaturation event lasting 6 min during physical activity. During this event, the pulse rate signal (middle tracing) was obscured by a motion artifact (bottom tracing). HR = heart rate; OXI = % hemoglobin saturation; Mov = motion detection.

which a clearly discernible drop in SpO₂ to < 90% (top tracing) occurred during patient activity, with a return to the baseline value of > 90% when the patient completed this activity (walking). Figure 3 shows a severe oxygen desaturation at rest (top tracing) in another patient for whom there was no visible activity on the motion detection channel, suggesting that this patient was not engaged in any physical activity during this episode. This oxygen-desaturation episode, lasting > 12 min, was associated with no noticeable symptoms according to the patient's log. In some patients, a complex pattern of changes in SpO₂ with recurring episodes of desaturation (some lasting several hours) were observed (data not shown). The other basic features illustrated in these AOM recordings are the pulse rate and the motion detection component of each tracing. We consistently observed that the pulse-rate waveform was more sensitive to disruption during activity than the SpO₂ tracing.

Figure 4 illustrates the results of the comparison of the use of AOM-derived data with the standard approach for optimizing oxygen prescriptions in this patient cohort. Because there are no standards for the use of AOM data for this purpose, we placed patients with SpO₂ values < 90% into three groups of percentages of total AOM recording time ("Materials and Methods" section). These groups were used for a hypothetical comparison between the standard approach and the use of AOM-derived data for optimizing oxygen prescriptions.

Using standard clinical criteria for assessing the adequacy of oxygen supplementation during a routine clinic visit (< 88% SpO₂ during rest or exercise), 7 of 27 patients (26%) were deemed eligible for a

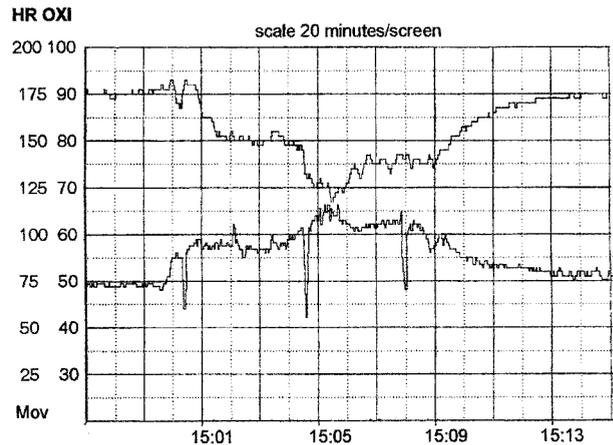


FIGURE 3. Severe SpO₂ desaturation with a nadir of < 70% saturation and an associated increase in pulse rate. The spikes in the pulse signal (middle tracing) are artifacts. No spikes are present in the motion detection channel (bottom tracing), suggesting that this event occurred at rest or with light physical activity. See Figure 2 for abbreviations.

modification of their current oxygen prescription. Analysis of the AOM-derived data revealed that the numbers of patients with SpO₂ values < 90% for > 10%, 20%, or 25% of total AOM recording time were 20 patients (74%), 13 patients (48%), and 9 patients (33%), respectively, of the total patient cohort (n = 27). A χ^2 analysis of the data showed that the number of patients eligible for a modification of their oxygen prescription using AOM-derived data with an SpO₂ < 90% for > 10%, 20% of total AOM recording time was significantly greater than the number of patients qualifying for a modification of their prescription using the standard approach (Fig 4). Although 9 of 27 patients (33%) had SpO₂ values < 90% for > 25% of their total recording time, this result was not significantly different from

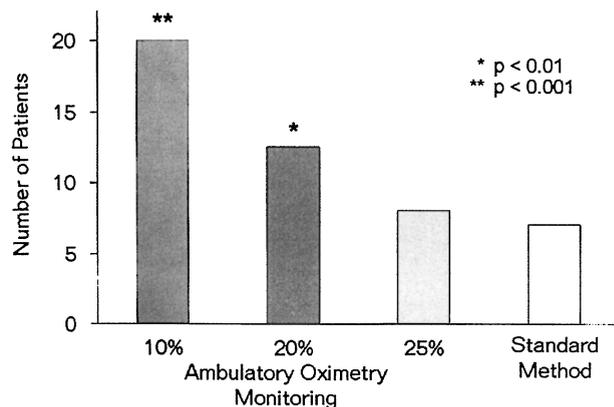


FIGURE 4. Comparison of the number of patients eligible for a change in their oxygen prescription using the standard approach vs AOM-derived data.

the number of patients (7/27) eligible for prescription modification using standard criteria.

DISCUSSION

To our knowledge, these results represent the most detailed report of the feasibility of using AOM to determine the temporal profile of SpO₂ in oxygen-dependent patients engaged in activities of daily living in the ambulatory setting. AOM is feasible, demonstrates a high degree of patient acceptance, and produces acceptable data > 90% of the total recording time. These results are an improvement over earlier attempts to implement this technique in human subjects.^{14–16} These findings also highlight an important potential limitation of the current approach to prescribing and modifying LTOT in this patient population. An unexpectedly large fraction of our patients demonstrated oxygen desaturation for a significant portion of AOM recording time, despite maintaining an optimal SpO₂ at rest. The results demonstrate that 74% (20/27 patients) of this patient cohort did not meet the target SpO₂ value for > 10% of AOM recording time. In addition, 33% of this patient cohort showed subtherapeutic SpO₂ levels for > 25% of AOM recording time in the outpatient setting. Intuitively, these results are not surprising, considering that the standard assessment typically involves measuring SpO₂ at one time point, while the patient is not engaged in normal daily activities. These data support the previous suggestion that determining the temporal pattern of SpO₂ may be a better method for prescribing LTOT than using measurements made at one time point.²² The results of this study suggest that AOM may be a valuable tool for defining the temporal pattern of SpO₂, which may then be used for fine-tuning LTOT prescriptions and maximizing patient benefit.

Knowledge of the profile of SpO₂ in COPD patients in the outpatient setting during the performance of activities of daily living is limited.^{15–17,23–26} Oxygen desaturation during exercise and other daily activities has been noted,^{24,27,28} but the temporal profile of SpO₂ in these patients remains poorly defined. Several earlier reports have made similar observations as noted in this study. Sliwinski et al²⁹ monitored a group of oxygen-dependent COPD patients for 24 h at home in a similar fashion as in this study, and noted an SaO₂ < 90% for approximately 30% of this time period. Schenkel et al¹⁷ monitored a group of COPD patients with more moderate hypoxemia and not receiving LTOT as in this study, and noted decreases in SpO₂ during activities of daily living, but did not include an analysis of the amount of time spent below the recommended SpO₂ values. Morrison et al²³ documented a more severe

degree of oxygen desaturation in oxygen-dependent COPD patients over a 24-h measurement period than in this study, but this report did not include any specific details of the recording technique or the data analysis. Our findings extend these earlier reports, and suggest that significant hypoxemia in COPD patients during activities of daily living in the outpatient setting is more common than previously appreciated.

Decker et al^{14–16} performed preliminary studies of AOM, and found the procedure potentially feasible, but the cumbersome portable oximetry units available at that time were a major drawback. Significant technical improvements in this equipment have been made over the past decade. The latest generation of oximeters are capable of recording, storing, and then downloading data to a computer for further analysis. Further technical improvements in these instruments will undoubtedly improve the quality of the data obtained. The major technical concern with AOM at present is motion artifact, which did not lead to a significant loss of data in this study as indicated by the small amount of total recording time discarded secondary to artifacts in the SpO₂ channel. Analysis of AOM recordings is a labor-intensive procedure that cannot be automated with available equipment. This is a second technical limitation of AOM.

Several possible limitations of our study deserve comment. First, there has been some controversy over the reliability of oximetry measurements, especially in hypoxemic patients during exercise.^{20–22,30–32} We did not document significant discrepancy between results obtained with the portable oximeter vs ABG samples, as did earlier reports.²⁶ Our findings are similar to those of earlier reports that investigated the accuracy of oximetry during exercise in elite athletes and patients with lung disease.^{26,31,32} Despite some recognized drawbacks, we used oximetry to conform to current practice patterns. In our experience, the majority of clinicians do not measure PaO₂ values when adjusting LTOT in a busy clinic setting because it is an invasive, time-consuming, and less practical procedure. Related in part to the potential limitations of oximetry, a recent study suggested that the critical SpO₂ target value should be raised from 90 to 93% to ensure that patients are not undertreated during LTOT.²¹ This highlights an important question regarding the use of oximetry to monitor LTOT: what SpO₂ target value is associated with maximal clinical benefit? This question is beyond the scope of this investigation, and awaits further study.

A second limitation is that we did not directly monitor compliance with the oxygen prescription in each patient, as in the classic LTOT trials.^{4,5} Instead, we based our estimate of compliance on subjective

patient response by requesting that patients note any deviations from their prescriptions in their log. Therefore, we may have overestimated patient compliance with their oxygen prescriptions. Thus, we cannot exclude the possibility that a part of the decrease below the SpO₂ target value during AOM involves lack of compliance rather than a suboptimal oxygen prescription.

Prescribing criteria for LTOT originated from two multicentered, prospective trials of the effect of oxygen supplementation on survival in COPD patients.^{4,5} In these studies, which included a total of 290 patients, oxygenation was monitored by measuring PO₂ in ABG samples obtained intermittently in the hospital or clinic setting. In the Nocturnal Oxygen Therapy Trial, measurements of a resting ABG sample obtained once per month were used to adjust oxygen liter flow “to maintain a PaO₂ of 60 to 80 mm Hg” with an “automatic increase of 1 L/min during exercise and sleep.”⁴ In the British Medical Research Council study, oxygen prescriptions were reassessed bimonthly using arterial samples, with a target resting value of PO₂ > 60 mm Hg.⁵ Neither study determined SpO₂ while patients were engaged in normal activities of daily living. The current approach to prescribing LTOT, using a static assessment of SpO₂ at one point in time, is derived from these studies.

These studies provided the scientific foundation for the use of LTOT in patients with lung disease, but left several important questions unanswered. The optimal duration of oxygen supplementation per day and the optimal SpO₂ target value to be reached to maximize survival are still not precisely defined.^{10,19,21,33} The conclusion from these studies was that patients with hypoxemia (resting PaO₂ < 55 mm Hg or SpO₂ < 88%) should receive oxygen supplementation “continuously,” because the benefits were proportional to the duration of treatment. Compliance data from the Nocturnal Oxygen Therapy Trial revealed that patients receiving “continuous” oxygen averaged only 17.7 h/d (SD, 4.8 h/d) of oxygen supplementation, similar to the AOM recording time in this study. Oxygen supplementation in this fashion decreased mortality ~50% when compared to patients receiving only 12 h of oxygen therapy.⁴

A key unanswered question is whether longer oxygen supplementation would have reduced mortality even further. Nevertheless, on the basis of these results, the current recommendation is that LTOT be given 18 h/d as a minimum, and maintained at the SpO₂ target value for the entire period.^{3,19} Extended to this study, this would mean achieving SpO₂ target values for 100% of AOM recording time. The majority of patients in this study did not meet this goal. Does 18 h of oxygen supple-

mentation result in maximum benefit? Selinger et al⁶ demonstrated that pulmonary artery pressure, pulmonary vascular resistance, and residual volume work index, and, in some patients, oxygen consumption increased significantly within 2.5 h after the removal of oxygen supplementation in COPD patients. Studies in animal models have shown that right ventricular hypertrophy can develop with as little as 2 h of hypoxemia per day.³⁴ These data suggest that even short periods of hypoxemia lead to adverse effects that might be minimized with adequate LTOT.

The results of this study are clinically relevant from several perspectives. First, they suggest that a percentage of patients receiving LTOT develop significant hypoxemia during activities of daily living, suggesting that they may be receiving inadequate therapy. Earlier observations on the adequacy of LTOT supplementation made this point.²⁵ Unexplained erythrocytosis or worsening right heart failure are late manifestations of end-organ dysfunction that suggest the presence of occult hypoxemia, but these changes are not good indicators of the need for early intervention. Our results suggest that asymptomatic hypoxemia in “stable” patients, the forerunner of end-organ changes, is more common than previously appreciated. Thus, the current method for prescribing LTOT may result in undertreatment of some patients by underestimating their oxygen requirements as outpatients. The clinical significance of these “silent” episodes of hypoxemia in the outpatient setting is unknown. An unanswered question is whether detection and treatment of these episodes, especially exercise-induced hypoxemia, would have a major impact on morbidity or mortality in COPD patients as suggested.²⁴ Longitudinal studies correlating the temporal profile of SpO₂ with outcome measures will provide the answer. Second, the findings of this study have economic implications in that LTOT is an expensive treatment modality.^{35,36} Our results suggest that defining the temporal profile of SpO₂ may be a cost-effective method for monitoring LTOT treatment.

In conclusion, AOM is a feasible method for monitoring SpO₂ in the outpatient setting, and this warrants its development as a tool for optimizing LTOT. The latest recommendations on LTOT conclude with the statement that “prescribing practices may need to be modified as scientific data become available to support or refute them.”² Our data suggest that AOM provides a more realistic, physiologic assessment of oxygen requirements in the outpatient setting than the current approach. Nevertheless, we must emphasize that AOM is an experimental procedure, and continued work is required before it can be recommended for routine use.

These results, involving a small cohort of COPD patients, need to be replicated on a larger scale to document the potential benefits of this approach before AOM can be used in routine clinical practice.

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