$AccuO_2$ Oximetry-Driven Oxygen-Conserving Device Versus Fixed-Dose Oxygen Devices in Stable COPD Patients

Kathryn L Rice MD, Matthew F Schmidt PhD, John S Buan PhD, Francene Lebahn CCRC MT, and Ted K Schwarzock

BACKGROUND: Because standard home oxygen (O_2) systems deliver O_2 at fixed rates, these systems are not designed to ensure optimal oxygen delivery based on physiologic need. We tested the ability of the $AccuO_2$ (OptiSat Medical, Minneapolis, Minnesota), a portable, closed-loop, oximetry-driven, O_2-conserving device to maintain S_{pO_2} at ≥ 90%, compared to continuous-flow oxygen and a standard O_2-conserving device (CR-50, Puritan-Bennett, Pleasanton, California). METHODS: We randomly assigned 28 patients who were on continuous home O_2 for COPD to use each of 3 O_2 delivery systems (continuous-flow O_2, CR-50, and $AccuO_2$) for 8 hours a day, for 2 consecutive days, at home, at their current O_2 prescription. We recorded S_{pO_2} and calculated the conservation ratio (duration of a given O_2 supply with an O_2-conserving device compared to continuous-flow O_2). RESULTS: Twenty-two patients completed all 3 study arms; 2 additional patients completed the $AccuO_2$ arm and the continuous-flow O_2 arm. The mean ± SD S_{pO_2} was 92 ± 4% with continuous-flow O_2, 92 ± 4% with the CR-50, and 91 ± 2% with $AccuO_2$ ($P = .006$ for the $AccuO_2$ vs continuous-flow O_2, $P = .03$ for the $AccuO_2$ vs the CR-50). S_{pO_2} variability was less with the $AccuO_2$ ($P < .001$ vs continuous-flow O_2 and vs the CR-50). The conservation ratios were 9.9 ± 7.3 for the $AccuO_2$ and 2.6 ± 1.0 for the CR-50 ($P < .001$). CONCLUSIONS: Compared to continuous-flow O_2 or the CR-50, the $AccuO_2$ maintained S_{pO_2} closer to the target, and $AccuO_2$ had a higher conservation ratio than CR-50. *Key words: COPD; long-term oxygen therapy; oxygen-conserving device; pulse oximetry.* [Respir Care 2011;56(12):1901–1905]

Introduction

Chronic obstructive pulmonary disease (COPD) is estimated to afflict 24 million people in the United States and is the fourth leading cause of death.[1] In 2006 in the United States there were over 124,000 deaths attributable to COPD and allied conditions, 670,000 hospitalizations, and 16.3 million physician office visits.[1] The total economic cost of COPD for 2010 in the United States is projected to be $49.9 billion,[1] and long-term oxygen therapy (LTOT) accounts for a substantial portion of that cost. Medicare expenditures for LTOT exceed $2 billion annually.[2] Portable oxygen (O_2) accounts for a substantial portion of the provider cost of LTOT.[3]

SEE THE RELATED EDITORIAL ON PAGE 1975

Most LTOT systems provide a continuous fixed flow of O_2. The prescribed O_2 flow is typically based on a single measurement and aimed at keeping $S_{pO_2} \geq 90\%$.[4] O_2-conserving devices are added to portable LTOT systems for patient convenience and to reduce O_2 waste. The available continuous-flow and O_2-conserving systems are not designed to monitor and maintain $S_{pO_2} \geq 90\%$ on a minute-to-minute basis. We tested a prototype oximetry-driven O_2-conserving device, the $AccuO_2$ (OptiSat Medical, Minneapolis, Minnesota) (Fig. 1), against standard continuous-flow O_2 and a standard O_2-conserving device (CR-50, Puritan-Bennett, Pleasanton, California).

Dr Rice is affiliated with the Pulmonary Section, Minneapolis Veterans Affairs Medical Center, Minneapolis, Minnesota. Dr Schmidt, Dr Buan, and Mr Schwarzock are affiliated with OptiSat Medical, Minneapolis, Minnesota. Ms Lebahn is affiliated with the Academic Health Center, University of Minnesota, Minneapolis, Minnesota.

This research was partly supported by the University of Minnesota Technology Partnership Fund and the Minneapolis Veterans Affairs Research Service. Dr Rice has disclosed a relationship with Wyeth Pharmaceuticals. Dr Schmidt, Dr Buan, and Mr Schwarzock have disclosed relationships with OptiSat Medical. Ms Lebahn has disclosed no conflicts of interest.

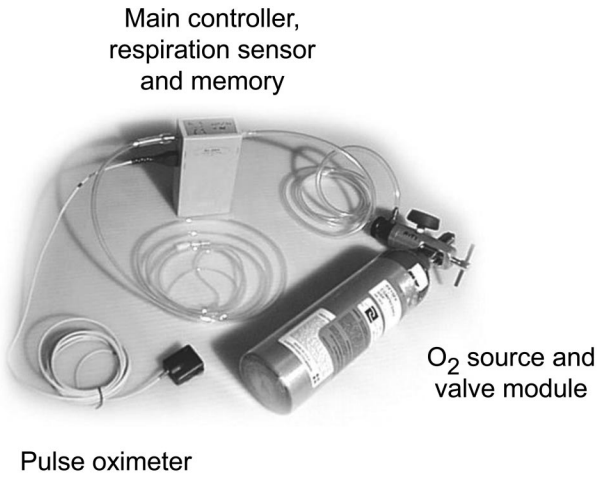

Fig. 1. The $AccuO_2$ closed-loop oximetry-driven portable O_2-conserving device.

Methods

This study was approved by the Minneapolis Veterans Affairs Medical Center Human Studies Committee. Written, informed consent was obtained from all subjects. The study was performed at the Minneapolis Veterans Affairs Medical Center between 1999 and 2000 and was therefore not subject to the requirement for clinic trial registration. Dr Rice had full access to all the study data and takes full responsibility for the integrity and accuracy of the data analysis.

Subjects

Via telephone, we recruited patients receiving LTOT for COPD from the Minneapolis Veterans Affairs Medical Center home O_2 roster. According to the policy of the medical center, all the patients were originally prescribed LTOT to achieve a target S_{pO_2} of 90–92%. The main inclusion criterion was a current LTOT prescription at a flow of 1–3 L/min for 18–24 hours per day. Exclusion criteria were current tobacco smoking, hospitalization for any reason within the last month, any respiratory drug prescription change in the previous 2 weeks, non-ambulatory status, active alcohol or drug addiction, any unstable disease state, and LTOT prescribed for conditions other than COPD.

Oxygen Delivery Systems

With the continuous-flow system or the CR-50, O_2 was delivered via nasal cannula at the flow previously prescribed for that patient to maintain $S_{pO_2} > 90\%$. The $AccuO_2$ (see Fig. 1) is designed to maintain S_{pO_2} at a selected target at all times. The outputs of the pulse oximeter and inhalation sensor are continuously monitored by the microcontroller. The volume of O_2 to be delivered is calculated by a modified proportional integral differential control algorithm, based on the difference between the observed and desired S_{pO_2} values and the trend in that difference. Oximeter data and O_2 pulse/bolus size are measured and updated every second. Starting from a steady-state situation (ie, the patient's S_{pO_2} is stable at the target), the $AccuO_2$ begins increasing the O_2 dose on the first inhalation after a valid S_{pO_2} reading below the target (ie, within 1–2 s). Signal averaging built into the oximeter gives an overall time constant of about 5–10 seconds. The oximeter's output includes error flags for a detached sensor, low-perfusion state, and heart rates of < 40 beats/min and > 180 beats/min. If an error condition occurs, the $AccuO_2$ continues to deliver O_2 during every inhalation at the same level administered prior to the error condition for 15 seconds. If the error condition persists for > 15 seconds the $AccuO_2$ defaults to a standard fixed-bolus, prescription-equivalent, pulse-delivery mode (33 mL/breath bolus). The maximum O_2 bolus was set at 66 mL/breath (equivalent to 4 L/min continuous flow). All the O_2 used in this study was in E-size cylinders.

In-Clinic Testing

In baseline testing with each patient we confirmed the ability of the continuous-flow O_2 system and the CR-50 to achieve $S_{pO_2} \geq 90\%$, and the ability of each patient to trigger the CR-50. We tested several prototypes of the $AccuO_2$ in the clinic to determine the appropriate proportional integral differential control parameters and to verify and refine the respiration-sensing algorithm. To determine O_2 savings and verify that the prototype $AccuO_2$ maintained the target S_{pO_2}, we tested the phase-1 prototype and proportional integral differential control parameters under supervision in the clinic, with patients at rest and while walking at their own pace for 15-min periods, if possible, to mimic home activities. The final version of the $AccuO_2$, built by a contract manufacturer, was tested in the clinic with a finger oximetry sensor (8000AA-3, Nonin Medical, Plymouth, Minnesota) for up to 6 hours, during which time the patients were encouraged to mimic their usual activity levels by walking at their own pace within the Minneapolis Veterans Affairs Medical Center. After reviewing the preliminary results, our institutional review board gave further approval for the in-home testing protocol.

Dr Rice presented a version of this paper at the 103rd International Conference of the American Thoracic Society, held May 18–23, 2007, in San Francisco, California.

Correspondence: Kathryn L Rice MD, Pulmonary Section, Minneapolis Veterans Affairs Medical Center, 1 Veterans Drive, Minneapolis MN 55417. E-mail: kathryn.rice@va.gov.

DOI: 10.4187/respcare.01059

In-Home Testing

Patients were studied on their standing O_2 prescriptions, all of which were ≤ 3 L/min. We asked the patients to use each O_2 system, in random order, at home, for 8 hours a day, during daytime hours only, on 2 consecutive days. We encouraged the patients to go about their normal daily activities during every study period. The target S_{pO_2} for the $AccuO_2$ was set at 90%. In all 3 treatment arms the patients wore a logging pulse oximeter (8500M, Nonin Medical, Plymouth, Minnesota). The average duration of home use for each O_2 delivery device was based on the amount of time recorded by the oximeter.

We continuously recorded the patients' activity levels with an actigraph (Actiwatch, Philips Respironics, Murrysville, Pennsylvania) during daytime hours only. Readings above zero during any 15-second period were counted as activity.

To determine the amount of O_2 used during each 2-day period, we weighed the specially marked O_2 cylinders before and after each 2-day period. A full E-cylinder nominally contains 680 L of O_2. The molecular weight of O_2 is 31.9988 g/mole, and molar volume is 24.465 L/mole at 25°C, so 680 L of O_2 weighs 889.4 g. We calculated the conservation ratio as the duration a given amount of O_2 lasted with an O_2-conserving device, compared to during continuous-flow O_2 therapy.

Statistical Analysis

We analyzed the S_{pO_2} values and conservation ratios with the Mann-Whitney test. Differences in standard deviations were analyzed with the 2-tailed Kolmogorov-Smirnov test. We report mean ± SD values.

Results

Twenty-eight patients (all male, mean age 72.3 y, age range 60–81 y) consented to participate in the in-home study (Fig. 2), but 3 of the 28 withdrew consent before testing any device. Twenty-two patients completed all 3 study arms; 2 additional patients used only the $AccuO_2$ and the continuous-flow system. One patient used only the CR-50 and continuous O_2.

The mean S_{pO_2} during the in-home study periods was significantly lower with the $AccuO_2$ (91 ± 2%) than with the CR-50 (92 ± 4%, $P = .03$) or continuous-flow O_2 (92 ± 4, $P = .006$) (Fig. 3). $AccuO_2$ appeared to reduce the amount of time spent at low S_{pO_2}, although this difference was not statistically significant (Fig. 4). The S_{pO_2} was ≤ 88% for more than 50% of the study period in 0, 2, and 4 patients, respectively, with the $AccuO_2$, CR-50, and continuous-flow O_2. The amount of time spent with S_{pO_2} > 90% was significantly less with the $AccuO_2$ (see Fig. 4). S_{pO_2} was > 95% more than 50% of the time in 0, 9, and 6 patients, respectively, with the $AccuO_2$, CR-50, and continuous-flow O_2. S_{pO_2} variability was significantly lower with the $AccuO_2$. The S_{pO_2} standard deviation was significantly smaller with the $AccuO_2$: the means of the individual patients for the $AccuO_2$, CR-50, and continuous-flow O_2 were 2.4%, 3.2%, and 3.5%, respectively ($P < .001$ for $AccuO_2$ versus CR-50 or continuous-flow O_2).

The average percentage of invalid/error oximeter data across all arms and patients was 3.3 ± 2.7%, and there were no statistically significant differences between the arms. The $AccuO_2$ applies more stringent requirements on the oximeter data to be in closed-loop mode: the average percentage of time in the fixed-dose default mode (ie, not in closed-loop) was 14.4 ± 12.1%. Twenty-one of 24 patients were in closed-loop mode more than 75% of the time with the $AccuO_2$.

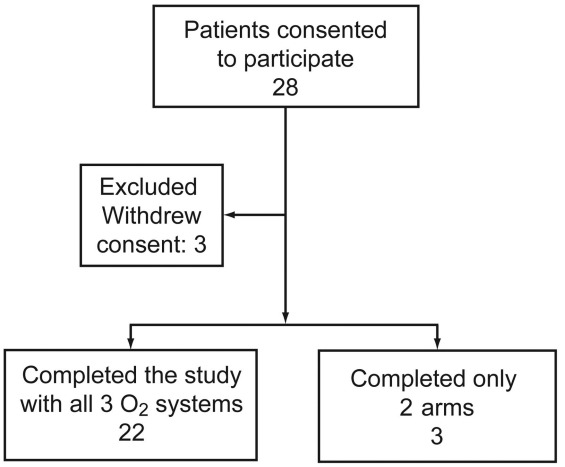

Fig. 2. Flow chart.

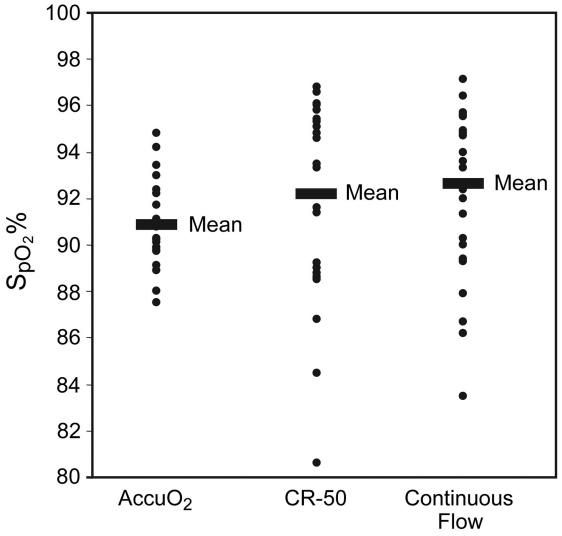

Fig. 3. Individual and mean S_{pO_2} values during 48-hour periods at home. $P = .006$ for $AccuO_2$ versus continuous-flow O_2, $P = .03$ for $AccuO_2$ versus CR-50.

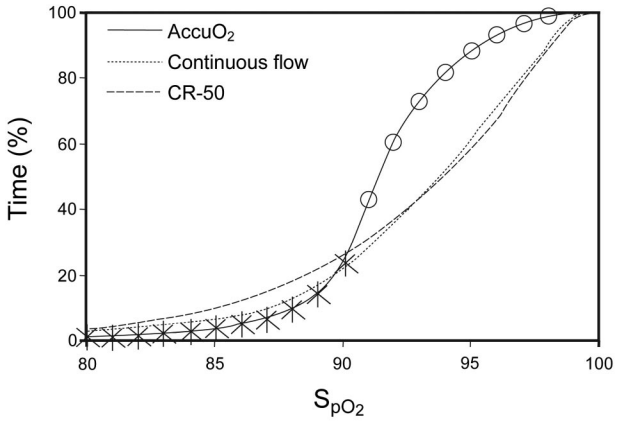

Fig. 4. Cumulative percent of time under various S_{pO_2} levels during two 8-hour periods on 2 consecutive days at home. *P* values compared to continuous-flow O_2 for each 1% increment increase in S_{pO_2} are represented by open circles for *P* values $< .05$, and by Xs for *P* values $> .05$.

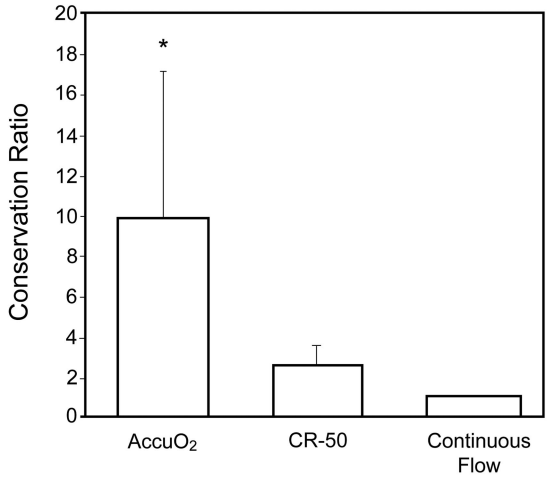

Fig. 5. Mean conservation ratios during 48-hour periods at home. $*P < .001$ for $AccuO_2$ versus CR-50 and for $AccuO_2$ versus continuous-flow O_2.

The average duration of home use was 15.5 ± 2.0 hours with the $AccuO_2$, 14.3 ± 2.5 hours with the CR-50, and 15.8 ± 1.3 hours with the continuous-flow O_2 system. Less supplemental O_2 was required to maintain the target S_{pO_2} with the $AccuO_2$. With continuous-flow O_2 as the reference, the mean conservation ratios for the $AccuO_2$ and CR-50 were 9.9 ± 7.3 and 2.6 ± 1.0, respectively ($P < .001$) (Fig. 5).

The patients' daytime home activity levels were not significantly different with the different O_2 systems. The average actigraphy output counts were: $AccuO_2$ 20.5 ± 59.8, CR-50 22.0 ± 65.3, and continuous-flow O_2 26.3 ± 77.5. The mean percentages of time spent in activity during the 8-hour study periods were: $AccuO_2$ 31.6%, CR-50 32.0%, and continuous-flow O_2 32.0%.

We asked the patients to rank the O_2 systems according to their preference (1 = most preferred, 3 = least preferred), and the mean scores were: $AccuO_2$ 2.1 ± 0.9, CR-50 1.7 ± 0.7, and continuous-flow O_2 2.2 ± 0.8.

Discussion

The $AccuO_2$ maintained a clinically acceptable S_{pO_2} with less S_{pO_2} variation and lower O_2 consumption than CR-50 or continuous-flow oxygen. Mean S_{pO_2} was lowest with $AccuO_2$, because the $AccuO_2$ is designed to maintain the S_{pO_2} as close as possible to 90%, consistent with the therapeutic goal of the Nocturnal Oxygen Therapy Trial,[5] in which patients with a baseline $P_{O_2} < 55$ mm Hg were given supplemental O_2 to achieve a P_{O_2} range of 60 mm Hg (which approximately corresponds to an S_{pO_2} of 90%) to 80 mm Hg. Based on the results of that trial, there is general consensus that the S_{pO_2} goal of LTOT should be ≥ 90%. The current COPD treatment guidelines[4] recommend titrating LTOT to $S_{pO_2} \geq 90\%$. Available evidence does not support a higher target S_{pO_2}, as shown in a study by Gorecka and colleagues, in which a target P_{O_2} of > 65 mm Hg in patients with less severe hypoxemia did not confer a survival benefit.[6] Patients treated with continuous LTOT have been reported to spend 10–30% of their time in a hypoxic state, including both sleep and waking hours.[7-10] The primary advantage of oximetry-driven O_2 delivery is maintaining the S_{pO_2} at or near 90% while reducing O_2 waste.

The mean conservation ratio with the $AccuO_2$ was more than 3 times that with the CR-50 and 9 times that with continuous-flow O_2. Although we used E cylinders in this study, by extending the duration with any cylinder size, the $AccuO_2$ would provide a similar duration benefit for patients using smaller, less cumbersome tanks, and might substantially reduce the cost of LTOT with all cylinder sizes, because portable equipment accounts for a substantial portion of LTOT costs.

Although we observed a non-significant reduction in desaturations, this observation should be considered hypothesis-generating only: further studies with sufficient power to determine this effect are needed. Because we chose a single target S_{pO_2} of 90% for the $AccuO_2$, we did not determine its effectiveness or O_2 savings at other target S_{pO_2} levels. The difference in O_2 savings between the $AccuO_2$ and standard O_2 delivery devices might be smaller if standard O_2-conserving devices were more tightly set to achieve S_{pO_2} of 90%, although the practicality of that approach is questionable. We believe testing patients on their standing LTOT prescriptions is applicable to clinical practice, as all patients were originally prescribed LTOT to achieve a target S_{pO_2} of 90–92%.

Limitations

Because the in-home study period was limited to 2 consecutive days, the performance of the $AccuO_2$ over longer

periods and under more varied clinical circumstances is not known. The actigraphy data did not allow us to distinguish between sleep and inactivity, because readings above zero were counted as activity. We doubt that a reading of zero indicated that the patient was asleep, however, because the actigraph readings were zero more than 60% of the time during the day. The patients' activity levels were similar across all 3 arms, so the activity differences could not account for the substantial O_2 savings we observed with the AccuO$_2$.

Although the patient survey results suggest that the AccuO$_2$ was as well tolerated as the CR-50, more detailed information on specific aspects of patient preference, such as comfort or convenience, is needed to better determine the feasibility of the AccuO$_2$. Options for potentially less burdensome oximeter sensors, such as a reflectance sensor on the forehead or behind the ear, an ear-lobe sensor, or wireless oximeters, should be considered for future testing.

Closed-loop, oximetry-driven O_2 delivery has potential application beyond ambulatory LTOT. Almost 50% of patients on LTOT for COPD are reported to experience substantial nocturnal desaturation with standard O_2 delivery systems.[10] Although we did not study our patients during sleep, the AccuO$_2$ has potential application for maintaining a therapeutic nocturnal S_{pO_2}. Oximetry-driven O_2 delivery systems may also have applications in settings other than the treatment of patients with stable COPD. In patients who are hospitalized for COPD exacerbation, pulse oximetry-driven O_2 delivery could be used to avoid the high S_{pO_2} values that have been associated with acute CO_2 retention. Systems driven by continuous oximetry and blood-gas data have been used to automate O_2 delivery in neonates and pre-term infants.[11-13]

Conclusions

This study provides preliminary evidence that O_2 delivery with the AccuO$_2$ is as or more effective than standard O_2 delivery systems in maintaining a target S_{pO_2} via continuous adjustment of O_2 delivery based on physiologic need. By improving O_2 conservation, AccuO$_2$ may improve patient convenience, potentially at a lower cost. Further studies should be done to confirm the observation that patients appear to spend less time at low S_{pO_2} with AccuO$_2$. Long-term studies, particularly in the ambulatory setting in patients with various levels of disease stability and other clinical conditions, are also needed to determine the impact of this novel O_2 delivery system.

REFERENCES

1. National Institutes of Health, National Heart, Lung, and Blood Institute. Morbidity & mortality: 2009 chart book on cardiovascular, lung, and blood diseases. http://www.nhlbi.nih.gov/resources/docs/2009_ChartBook.pdf. *Accessed October 11, 2011.*
2. National Institutes of Health, National Heart, Lung, and Blood Institute. Long-term Oxygen Treatment in COPD Working Group executive summary. May 10–11, 2004. http://www.nhlbi.nih.gov/meetings/workshops/oxygen-rx.htm. *Accessed October 11, 2011.*
3. Morrison Informatics. A comprehensive cost analysis of Medicare home oxygen therapy: a study for the American Association for Homecare. June 27, 2006. http://www.vgmdclink.com/pdffiles/MorrisonOxygenCostStudyJune2006.pdf. *Accessed October 11, 2011.*
4. American Thoracic Society and European Respiratory Society. Standards for the diagnosis and management of COPD: 2004. http://www.thoracic.org/clinical/copd-guidelines/resources/copddoc.pdf. *Accessed September 21, 2011.*
5. Nocturnal Oxygen Therapy Trial Group. Continuous or nocturnal oxygen therapy in hypoxemic chronic obstructive lung disease. Ann Intern Med 1980;93(3):391-398.
6. Gorecka D, Gorzelak K, Sliwinski P, Tobiasz M, Zielinski J. Effect of long term oxygen therapy on survival in patients with chronic obstructive pulmonary disease with moderate hypoxaemia. Thorax 1997;52(8):674-679.
7. Decker M, Arnold JL, Haney D, Masny J, Strohl KP. Extended monitoring of oxygen saturation in chronic lung disease. Chest 1992;102(4):1075-1079.
8. Hagarty EM, Skorodin MS, Stiers WM, Mamdani MB, Jessen JA, Belingon EC. Performance of a reservoir nasal cannula during sleep in hypoxemic patients with COPD. Chest 1993;103(4):1129-1134.
9. Sliwinski P, Lagosz M, Gorecka D, Zielinski J. The adequacy of oxygenation in COPD patients undergoing long-term oxygen therapy assessed by pulse oximetry at home. Eur Respir J 1994;7(2):274-278.
10. Plywaczewski R, Sliwinski P, Nowinski A, Kaminski D, Zieliński J. Incidence of nocturnal desaturation while breathing oxygen in COPD patients undergoing long-term oxygen therapy. Chest 2000;117(3):679-683.
11. Beddis IR, Collins P, Levy NM, Godfrey S, Silverman M. New technique for servo-control of arterial oxygen tension in preterm infants. Arch Dis Child 1979;54(4):278-280.
12. Morozoff PE, Evans RW. Closed-loop control of SaO_2 in the neonate. Biomed Instr Tech 1992;26(2):117-123.
13. Sano A, Kikucki M. Adaptive control of arterial oxygen pressure of newborn infants under incubator oxygen treatments. IEE Proc Pt 1985;132(5):205-211.