CHEST

Official publication of the American College of Chest Physicians

Comparison of six oxygen delivery systems for COPD patients at rest and during exercise.

S R Braun, G Spratt, G C Scott and M Ellersieck

Chest 1992;102;694-698
DOI 10.1378/chest.102.3.694

Comparison of Six Oxygen Delivery Systems for COPD Patients at Rest and during Exercise*

Sheldon R. Braun, M.D., F.C.C.P.; Ginger Spratt, R.R.T.; Graham C. Scott, M.D., F.C.C.P.; and Mark Ellersieck, Ph.D.

Five different oxygen-conserving devices were tested in each of ten oxygen-dependent patients with COPD who had met the NOTT criteria for continuous oxygen use. They were tested on room air, their prescribed continuous oxygen flow and then on each of the five devices. The devices which delivered a bolus of oxygen during early inspiration or increased oxygen delivery as the respiratory rate increased did better than those devices which delivered oxygen at a normal flow rate during inspiration or a fixed portion of inspiration. In at least one of the subjects each device was associated with desaturation to less than 80 percent during a 12-min walk. It is concluded that oxygen-conserving devices vary in their ability to maintain SaO_2 levels during exercise. It is recommended that a home oxygen evaluation include measurement of an exercise SaO_2 utilizing the prescribed oxygen delivery system.

(Chest 1992; 102:694-98)

For many years, oxygen has been thought to be useful in the treatment of hypoxemic individuals with COPD.[1] Only recently has the use of oxygen been proven to prolong survival in these patients.[2,3] Since these reports, there has been a marked rise in the number of prescriptions of home oxygen for these individuals and in the total cost of oxygen to the government and insurance carriers.[4] The cost of oxygen at home, no matter how delivered, is much greater than in the hospital. Also, since improved quality of life is a goal of home treatment in these subjects, oxygen should be supplied by a system that allows mobility.

Reduction in the total number of liters used per minute is one effective way to reduce costs and increase mobility if the efficacy can be maintained. In order to reduce oxygen utilization, several devices have been tried.[5-11] The oxygen-conserving devices are designed to take advantage of the fact that oxygen is needed only during the initial phase of inspiration. Realizing that oxygen flow is not needed during the later part of inspiration or expiration, these devices were designed to halt oxygen flow during these phases of the respiratory cycle. Common approaches to conservation include (1) reducing the time of actual oxygen flow, or (2) using a lower flow and storing the oxygen during expiration which is then used as a bolus during inspiration.[4] The placement of a transtracheal catheter has been a third approach.[12] By decreasing the amount of oxygen used, the frequency of home oxygen delivery and thus the cost of home oxygen is lowered. The reduced amount of oxygen needed will lead to smaller portable systems that will allow increased mobility.

The present study was designed to evaluate the oxygen-conserving approach which utilizes electrical devices that sense inspiration and deliver oxygen only at that period of the respiratory cycle. These are capable of varying times and rates of oxygen delivery. To date, the authors are not aware of a comparison between these different units and continuous flow. Most studies evaluate only one specific unit in comparison with continuous flow.

The purpose of the present study was to compare five such systems, at rest and during exercise, in individuals who meet the accepted criteria of the NOTT study[3] for 24 h a day of oxygen use. The study was designed to compare each unit with the other units and with continuous flow.

Methods

Ten individuals with COPD were entered into the study. Entry criteria included an FEV_1/FVC ratio of less than 60 percent and a period of stability on chronic home oxygen after having met the NOTT criteria for home oxygen use.[3] The protocol was explained to each subject and they signed an informed consent as approved by the Institutional Review Board.

All individuals who entered the study came to the pulmonary research laboratory in the morning. They were allowed to rest in a chair while breathing room air for 30 min. After 30 min, their arterial blood gas levels were measured on a blood gas analyzer (model 168 Ciba-Corning Diagnostic Corporation, Medfield, Mass). The individuals then began receiving their usual oxygen flow rate as prescribed by their physicians (mean, 2.4 L/min). Spirometry was performed on a Micro-Loop 500 spirometer (Medical Graphics Corp, St. Paul, Minn). Normal predicted values[13] were used to determine the percent predicted for the spirometry. After 15 min, another blood gas value analysis was done.

The individuals all had severe obstruction as can be seen in Table 1. All were men. The mean room air PaO_2 was 50.0 mm Hg with a range from 40 to 53 mm Hg. Therefore, all individuals met the

*From the University of Missouri-Columbia, Department of Medicine, Division of Pulmonary, Environmental, and Critical Care Medicine (Drs. Braun and Scott and Ms. Spratt) and the Agriculture Experiment Station (Dr. Ellersieck), Columbia, Mo.
Supported by a grant from DeVilbiss Corporation, Somerset, Pa. Dr. Braun is a recipient of the Preventive Pulmonary Academic Award from the National Institutes of Health.
Manuscript received March 28, 1991; revision accepted December 16.

Table 1—*Entry Population Data*

Data	Mean	Standard Error of the Mean
Age (yr)	58.7	1.7
FEV_1 (L)	0.88	0.08
FEV_1 (% predicted)	27.2	2.2
	Room Air	
PaO_2 (mm Hg)	50.0	1.22
SaO_2 (%)	84.4	1.0
$PaCO_2$ (mm Hg)	48.8	2.4
pH	7.395	0.004
	Supplemental Oxygen	
PaO_2 (mm Hg)	72.2	4.1
SaO_2 (%)	93.2	0.99
$PaCO_2$ (mm Hg)	50.0	2.4
pH	7.384	0.01

NOTT criteria for home oxygen use. They had severe obstruction as can be seen by the very reduced mean FEV_1. Retention of CO_2 was also common; the mean resting $PaCO_2$ was 48.8 mm Hg.

In addition to spirometry, each individual performed six 12-min walks during the course of the study according to the description of McGavin and co-workers.[14] The 12-min walk was selected because it is a simple, accepted way to evaluate exercise in this population. We wanted a method which increased oxygen demand so we could test oxygen delivery. They were instructed to stop and rest whenever they became short of breath or felt they needed to stop. They were to continue when they subjectively felt they were able to do so. Each walk was carried out with a different method of oxygen delivery. The individual 12-min walks were performed two on each of three separate visits. The visit days were not consecutive. The subjects performed one walk in the morning and one in the afternoon. The devices to be tested were randomly assigned so that any learning effect would be minimized.

During the walk, the SaO_2, pulse rate and dyspnea level were monitored. The SaO_2 was determined throughout the study by oximetry (pulse oximeter model IVA, Ohmeda, Boulder, Colo). The SaO_2 was evaluated because it is a direct measure of adequate oxygenation of the blood. The dyspnea level was determined using the Borg scale.[15] Many factors can go into the development of dyspnea. Difficulty with oxygen delivery is one of them. For the purposes of this study, dyspnea was believed to be a good subjective measure of possible differences between the devices because it is such an important factor limiting exercise in these individuals. The oximeter recorded the SaO_2 and pulse rate every 6 s. Using the data from the chart readout, an "average" SaO_2 was determined by finding the means of all these values over the 12 min. The lowest SaO_2 was the lowest recorded during the 12-min walk. The SaO_2 values were considered as the lowest reached only if they appeared to be compatible with temporally related values. Thus, sudden short artifactual "dips" were eliminated. The total number of seconds during the 12 min that the SaO_2 was below 88 percent was also calculated. The total time spent resting was determined by using a stopwatch. Finally, using a metered measuring wheel we were able to record the actual distance walked by each subject.

The oxygen flow rate for standard nasal cannula used during exercise was the same as had been prescribed by the subject's own physician. Each of the other devices was set to a level recommended by the manufacturer to produce an equal or equivalent oxygen flow to that prescribed rate. The total amount of oxygen delivered, of course, varied from device to device. Oxygen savings were not calculated since the purpose of this study was to evaluate the effectiveness of delivery and not specific costs.

The devices used are described as follows:

1. Continuous flow (CF)—This system used nasal prongs with continuous oxygen flow as prescribed by their own physician.

2. A (Chad Oxymatic)—This system senses the end of expiration and the beginning of inspiration. It delivers a pulse of oxygen at the onset of inspiration. Each pulse delivers approximately a 35-ml bolus of oxygen, but the frequency of delivery will be varied from almost every breath to one in four breaths depending on the setting. For example, a setting of 1 delivers oxygen every fourth breath; 2, every other breath; 3, three out of four breaths; and 4, almost every breath. The setting used was the equivalent manufacturer recommendation for the prescribed continuous flow cannula. This system will increase the amount of oxygen delivered if the respiratory rate increases such as occurs during exercise.

3. B (Bunn Portamate)—This device allows the flow of oxygen to occur during inspiration only. A microprocessor determines the respiratory rate, and based on the flow rate, varies the volume delivered per breath. Thus, if the flow rate is set on 2 L, the unit will deliver 2 L/min during inspiration. A change in respiratory rate will change the volume delivered per breath. The increase in respiratory rate does not change the amount of oxygen delivered per minute.

4. C (Bolus Dose Device, Investigational)—This unit delivers a fixed volume per time per breath according to the setting selected. The flow rate as well as the time the flow rate is given increases with an increase in the setting. At a setting of 1, 16.5 ml/ms are delivered for 100 ms. At 2, this increases to a flow rate of 35.5 ml/ms for 228 ms and at 3, the flow reaches a level of 50.0 ml/ms for 360 ms. This system will increase oxygen delivery with an increased respiratory rate by increasing the number of "boluses" delivered per minute since each inspiration will trigger delivery of a given volume.

5. D (Timed Dose Device, Investigational)—Oxygen delivery from this device is limited to a set percentage of the respiratory cycle. The unit calculates its oxygen delivery time by averaging the total time of each breath for the last three breaths. It then delivers oxygen at the beginning of each breath and stops when it reaches the pre-set percentage of the total respiratory cycle. The oxygen delivery time used in this study was 31.25 percent of the respiratory cycle. If, for example, the average time per breath for the last three breaths was 3 s, oxygen will be delivered at the pre-set flow rate for the first 0.3125 percent of 3 s or 0.9375 s. It will not increase oxygen delivered during exercise.

6. E (Puritan Bennett Companion Oxygen Saver)—This device delivers a metered dose (pulse volume) of oxygen when inspiratory effort is sensed (-0.02 cm H_2O). The pulse ends approximately within the first 25 percent of inspiration. The pulse volume is varied automatically based on the patient's respiratory rate and oxygen flow setting. By varying the pulse volume based on respiratory rate and set flow rate, a constant functional supplemental minute volume of oxygen is maintained over the range of 8 to 50 breaths per minute.

Comparison between devices was made by the paired t test.

Results

The initial resting SaO_2 was similar with each of the six oxygen delivery systems evaluated (Table 2). This supports each manufacturer's claim that their recom-

Table 2—*Initial Resting Percent Oxygen Saturation*

Device	Mean	Standard Error of the Mean	Range
Continuous flow	92.0	1.0	89-98
A	91.3	0.86	88-98
B	91.4	0.82	87-96
C	93.0	1.0	89-100
D	91.4	1.0	87-98
E	92.3	1.2	87-98

Table 3—*Oxygen Saturation during Exercise*

Device	Average Saturation		Lowest Saturation	
	Mean	Range	Mean	Range
Continuous flow	90.3+1.0*	87-96	83.7+1.8	73-93
A	89.8+1.0	87-96	83.0+1.7	75-92
B	88.4+0.9	84-92	82.3+1.6	75-88
C	90.3+1.1	86-97	83.9+1.2	77-90
D	88.9+1.0	85-94	82.8+1.2	77-90
E	90.8+1.1	85-95	85.0+1.7	75-93

*Standard error of the mean.

mended settings did approximate the same levels obtained using continuous O_2 flow by nasal cannula at rest. Also, resting heart rates were similar in all groups ($p>0.05$).

During exercise, several of the parameters varied between the devices. Mean values of the average SaO_2 recorded during exercise with each device can be seen in Table 3. While the differences are small, so are the standard errors. There were significant differences with values for device D being significantly lower than those for C ($p<0.04$), E ($p<0.03$) and continuous flow ($p<0.02$). In addition, the B unit produced significantly lower average SaO_2 values than did device E ($p<0.03$). Continuous flow and devices C and E appear to be superior to B and D devices. The ranges indicate there is a wide variation between individual responses.

The mean of the lowest single SaO_2 level reached during exercise (Table 3) was not significantly different among any of the six groups. All six modes of oxygen delivery resulted in severe desaturation in some of the patients at the physician-prescribed oxygen flow levels. The lowest levels ranged from 73 to 77 percent with the six modes. However, the total time during the 12-min walk, when the subjects' levels were less than 88 percent, does show some difference (Fig 1). Using these criteria, both B and D units appear to have worse oxygen delivery during exercise. However, only with unit D were the differences significant. It is important to note that there was a great variation in the individual responses. In comparison with the E device and continuous flow, the D unit produced a longer time with desaturation to less than 88 percent (E, $p<0.04$; continuous flow, $p<0.02$). Again the figure demonstrates that the individual responses vary a great deal.

The distance walked during the 12 min suggests that again the B and D units were less effective (Fig 2). Significant differences were found between the D and C units ($p<0.05$), as well as continuous flow ($p<0.04$). It is important to note that there is marked variability between individual responses to each system tested. Comparing which unit works better as defined by the distance walked reveals that each system has at least one individual who reached the greatest distance with that individual system. However, at least one half of the individuals had the worst or second worst distance with both the B and D systems. The same thing can be said about individuals with the greatest amount of time spent with an SaO_2 lower than 88 percent. Again, all six oxygen delivery systems performed best in at least one individual. However, the B and the D devices performed consistently worst. The B device was the fifth or sixth worst in six out of the ten subjects.

The mean dyspneic index was similar with all methods of oxygen delivery. The time spent resting during each of the walks was not significantly different between any of the groups.

Discussion

The electronic devices evaluated in the study utilize two different strategies in reducing the amount of oxygen needed. One of these is to provide a "burst" of oxygen at the onset of inspiration. If the number of breaths increase, the number of "bursts" increase, as does the amount of oxygen delivered. Thus, if the respiratory rate goes from 15 to 30/min, the number of oxygen boluses would double, thus effectively increasing the oxygen delivery. Devices A and C fall into this category. Oxygen delivery with devices B

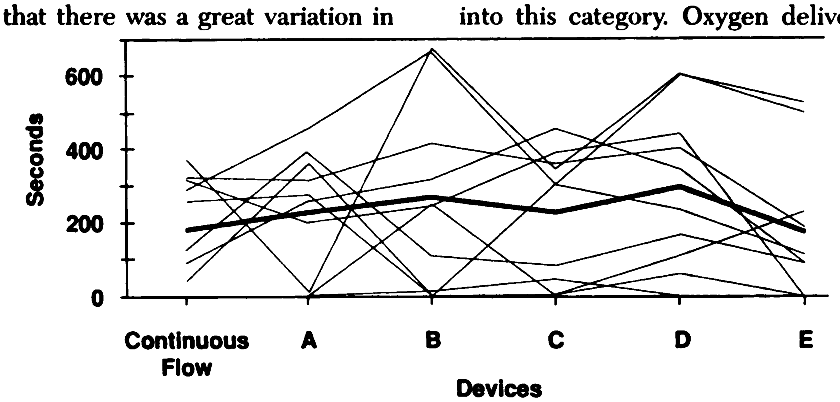

FIGURE 1. The total number of seconds during the 12-min walk the subjects desaturated to <88 percent for each of the devices studied for each subject is represented by the *fine lines* while the mean of the 10 subject responses is represented by the *bold line*. The D unit produced significantly lower desaturation times when compared with continuous flow ($p<0.02$) and device E ($p<0.04$).

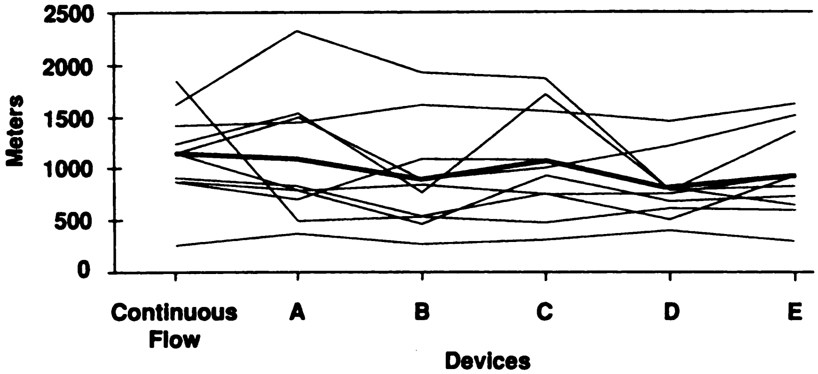

FIGURE 2. The total distance walked during the 12 min for each subject for each device tested is represented by the *fine lines* while the mean of all the subjects is represented by the *bold line*. The D unit produced significantly lower distances when compared with the E unit ($p<0.05$) and continuous flow ($p<0.04$).

and D represents another approach where there is flow only during inspiration or a portion of it. Since inspiratory time tends to stay the same or may actually decrease with the increase in respiratory rate, the actual amount of oxygen delivered stays approximately the same. They do not produce a bolus of oxygen at the onset of inspiration. Device E also delivers a bolus of oxygen at the onset of inspiration but at rates between 8 and 50/min the total oxygen delivered is unchanged.

The present study does support earlier work that these systems can replace continuous flow while the individual is resting.[7,9,11,16,17] Also, at least while at rest, the numerical system used by these systems is equivalent to the liter per minute of continuous flow. Thus, selection of any of these systems for use at rest, alone, would provide an adequate supplemental oxygen source.

Previous reports have suggested these devices are usually adequate with exercise.[16-18] However, in our study, with exercise, these findings are not true with all units. Some clearly function better (devices A, C and E). However, even these allow some of the subjects to desaturate with exercise. Even continuous flow was a problem. This finding reaffirms that an oxygen prescription must include consideration of an increase of oxygen flow rates with exercise as well as the system which will be used at home. Also for this study, the observation of the presence or absence of effective delivery is valid only when one considers all subjects were tested at what were equivalent flow rates based on manufacturer recommendations. The study design evaluated recommended equivalencies of the device and did not attempt to adjust the flows to establish equivalent delivery.

It is difficult to explain why three of the units appeared to deliver oxygen more effectively than the other units. Two of these units function similarly in that they give a "burst" with each breath, and delivery is not related to the inspiratory time. Thus, there is effectively an increase in oxygen delivered with increased respiratory rate. This is not true for devices B, D and E. This obviously would not explain why device E appears to be effective. Device E can default to constant flow under certain circumstances but it is doubtful rates of 50 were reached. Another mechanism could be that the bolus delivered at the onset of inspiration enhances oxygen delivery.

The present study used the 12-min walk while others that evaluated these devices during exercise usually used either a treadmill or a bicycle ergometer. The two mechanical devices have the advantage that the exercise loads can be quantified. Therefore, comparisons between like loads can be made. The 12-min walk is not as exact. However, it does give the advantage that it more closely resembles the normal activity that an individual performs. The 12-min walk is much more susceptible to the use of different strategies by the patient. In spite of this, we feel it is a useful way of comparing the responses of the different delivery systems. It certainly has been demonstrated to be useful in evaluating individuals with COPD.[14]

The other interesting finding was the great variability seen with each of the devices. All devices functioned poorly in at least one subject. This could be explained by the fact the studies were done on different days. However, we did assure that resting initial resting SaO_2 levels were comparable. Also, if in the opinion of the physician the individual was having an acute exacerbation, that individual was not studied until the patient had recovered. It is also possible that the poor response was due to fatigue occurring during the second exercise test of the day. This does not appear to be the case. Another consideration is the inherent variability in the oximeter during exercise.[19] However, some of the factors leading to these changes such as peripheral vasoconstriction should be the same with each exercise load in a given individual.

Part of the individual variation may be secondary to the response to exercise seen in these individuals.

The multiple causes of hypoxemia in these individuals include hypoventilation, ventilation-perfusion mismatch and even possibly diffusion limitation. Since we insisted that they were clinically stable before each exercise study, it is unlikely that these factors changed markedly during the study.

In summary, testing of five separate oxygen-conserving devices indicated that they were comparable at rest but not with exercise. Devices that have some ability to increase the oxygen supplied during exercise did better. An alternate explanation is that units that provide an initial bolus may provide improved oxygenation with exercise. Continuous flow also may do this using dead space as a reservoir. This would be comparable to the effect of the moustache or pendant systems.[4] The role of mouth breathing, valve function and responsiveness was not looked at specifically, but could be an alternative example.

It is important to observe that desaturation was common in many of the subjects during exercise. This supports the concept that individuals with COPD who receive home oxygen should be tested while walking using the oxygen delivery system with which they will be going home. This will ensure adequate oxygenation during exercise.

References

1 Levine BE, Bigelow DB, Hamstra RD, Beckwith HJ, Mitchell RS, Nett LM, et al. The role of long-term continuous oxygen administration in patients with chronic airway obstruction with hypoxemia. Ann Intern Med 1967; 66:639-50

2 Report of the Medical Research Council Working Party. Long term domiciliary oxygen therapy in chronic hypoxic cor pulmonale complicating chronic bronchitis and emphysema. Lancet 1981; 1:681-86

3 Nocturnal oxygen therapy trial group. Continuous or nocturnal oxygen therapy in hypoxemic chronic obstructive lung disease: a clinical trial. Ann Intern Med 1980; 93:391-98

4 Tiep BL, Lewis MI. Oxygen conservation and oxygen conserving devices in chronic lung disease—a review. Chest 1987; 92:263-72

5 Pflug AE, Cheney FW, Butler J. Evaluation of an intermittent oxygen flow system. Am Rev Respir Dis 1972; 105:449-52

6 Auerbach D, Flick MR, Block AJ. A new oxygen cannula system using intermittent-demand nasal flow. Chest 1978; 74:39-44

7 Rinow ME, Saltzman AR. Effectiveness of a new oxygen demand valve in chronic hypoxemia. Chest 1984; 86:312

8 Tiep BL, Nicotra B, Carter R, Belman MJ, Mittman C. Evaluation of a low-flow oxygen-conserving nasal cannula. Am Rev Respir Dis 1984; 130:500-02

9 Mecikalski M, Shigeoka JW. A demand valve conserves oxygen in subjects with chronic obstructive pulmonary disease. Chest 1984; 86:667-70

10 Tiep BL, Belman MJ, Mittman C, Phillips R, Otsap B. A new pendant storage oxygen-conserving nasal cannula. Chest 1984; 87:381-83

11 Tiep BL, Nicotra B, Carter R, Phillips R, Otsap B. Low-concentration oxygen therapy via a demand oxygen delivery system. Chest 1985; 87:636-38

12 Heimlich HJ. Respiratory rehabilitation with transtracheal delivery of oxygen. Ann Otol Rhinol Laryngol 1982; 91:643-47

13 Crapo RO, Morris AH, Gardner RM. Reference spirometry values using techniques and equipment that meets ATS recommendations. Am Rev Respir Dis 1981; 123:659-64

14 McGavin GR, Gupta SP, McHardy GJR. Twelve minute walking tests for assessing disability in chronic bronchitis. Br Med J 1976; 1:822-23

15 Borg G. Subjective effort in relation to physical performance and working capacity. In Pick HL Jr, ed. Psychology: from research to practice. New York: Plenum Publishing Corp, 1978: 333-61

16 Robert D, Perrin F, Leger P. O_2 savings device for COPD patients under oxygen therapy. Am Rev Respir Dis 1988; 127:111S

17 Bower JS, Brook CJ, Zimmer K, Davis D. Performance of a demand oxygen saver system during rest, exercise, and sleep in hypoxemic patients. Chest 1988; 94:77-80

18 Tiep BL, Carter R, Nicotra B, Berry J, Phillips RD, Otsap B. Demand oxygen delivery during exercise. Chest 1987; 91:15-20

19 Ries AL, Farrow JT, Clausen JL. Accuracy of two ear oximeters at rest and during exercise in pulmonary patients. Am Rev Respir Dis 1985; 132:685-89