Evaluation of the Pendant Oxygen-Conserving Nasal Cannula during Exercise*

Rick Carter, Ph.D.; James S. Williams, M.S.; Judy Berry, L.V.N.; Michael Peavler, R.Ph.; Dana Griner, B.S.; and Brian Tiep, M.D.

Vol. 89, p. 806-810
June 1986 Issue

Reprinted from CHEST

Evaluation of the Pendant Oxygen-Conserving Nasal Cannula during Exercise*

Rick Carter, Ph.D.; James S. Williams, M.S.; Judy Berry, L.V.N.; Michael Peavler, R.Ph.; Dana Griner, B.S.; and Brian Tiep, M.D.

There is much recent evidence that patients with chronic pulmonary disease who are hypoxemic benefit from continuous therapy with oxygen. These benefits include reduction in symptoms of cor pulmonale, reduction in mortality, and improvement in quality of life. Oxygen therapy is very expensive, and steady-flow delivery of oxygen is wasteful, since almost the entire benefit of the oxygen presented to the patient occurs at the very beginning of inspiration. We previously described a conserver nasal cannula (CNC) which stores oxygen during exhalation for delivery during subsequent inspirations. The CNC achieves adequate arterial oxygen saturation (SaO_2) at one fourth to one half of the flow in liters of steady-flow oxygen delivery. Because some patients found the mustache configuration objectionable, a pendant nasal cannula (PNC) was designed, displacing the reservoir off of the face and onto the anterior wall of the chest. While both cannulas require some breathing by nose to function, the PNC is more esthetically acceptable. No studies with exercise have been reported using the PNC. We evaluated the PNC during treadmill exercise in ten subjects with chronic obstructive pulmonary disease and hypoxemia on exercise. We compared the PNC with steady-flow oxygen during steady level treadmill walking sufficient to cause oxygen desaturation while breathing room air at oxygen presentations of 0.5 through 3.0 L/min. At comparable workloads the SaO_2 achieved by PNC required one third of the oxygen flow required by steady-flow oxygen to achieve an equivalent SaO_2. These differences were statistically significant ($p<0.01$). We conclude that the PNC provides effective delivery of oxygen during exercise, as well as at rest, while minimizing oxygen flow rate and thus substantially reducing the economic burden normally associated with supplemental oxygen delivery.

Some of the most serious complications of chronic obstructive pulmonary disease (COPD) are caused by hypoxemia.[1] Chronic hypoxemia can cause severe pulmonary vasoconstriction, resulting in elevation in pulmonary arterial pressure and pulmonary vascular resistance, as well as tissue hypoxia.[2] When the arterial oxygen saturation (SaO_2) drops below 90 percent, the pulmonary arterial pressure and pulmonary vascular resistance rise rapidly, resulting in cor pulmonale.[3] Burrows et al[4] demonstrated that survival in patients with COPD is inversely related to pulmonary vascular resistance, the clinical outcome of which is "cor pulmonale."[5,6]

For editorial comment, see page 770

The British study[7] and the nocturnal oxygen therapy trial study[8] have demonstrated that patients with COPD who have hypoxemia have improved survival when oxygen was provided during sleep, and further benefit was derived when oxygen therapy was provided continuously. Other studies have demonstrated that 15 to 18 hours of oxygen therapy daily may be as efficacious as 24 hours, provided the patient resumes adequate oxygen supplementation during sleep and exercise.

Oxygen therapy delivered via a steady-flow nasal cannula is inherently wasteful. This wastefulness results from the fact that steady-flow oxygen is delivered throughout the respiratory cycle, although only early inspiratory delivery contributes substantially to gas exchange.

Because of rising costs of medical care and of oxygen therapy in particular, there has been much recent interest in designing devices and methods of delivering oxygen to reduce the oxygen required to achieve adequate oxygen saturation. Tiep et al[9] described an oxygen-conserving nasal cannula which stores oxygen during exhalation for delivery during early inhalation. The conserver (Oxymizer, Chad Therapeutics, Inc) was found to reduce the flow of oxygen required to provide adequate saturation during both rest[9,10] and exercise;[10] however, the conserver was designed such that the reservoir was situated beneath the nose in the region of the mustache, which some patients found esthetically displeasing. Therefore, another conserver cannula was designed, displacing the reservoir off of the face and onto the anterior wall of the chest in a

*From the Department of Medicine, Exercise Physiology/Rehabilitation, the University of Texas Health Center at Tyler; and the Department of Medicine, Section of Respiratory Disease, City of Hope National Medical Center, Duarte, Calif.
Supported in part by a grant from Ray and Ipha Morrow.
Manuscript received October 9; revision accepted December 3.

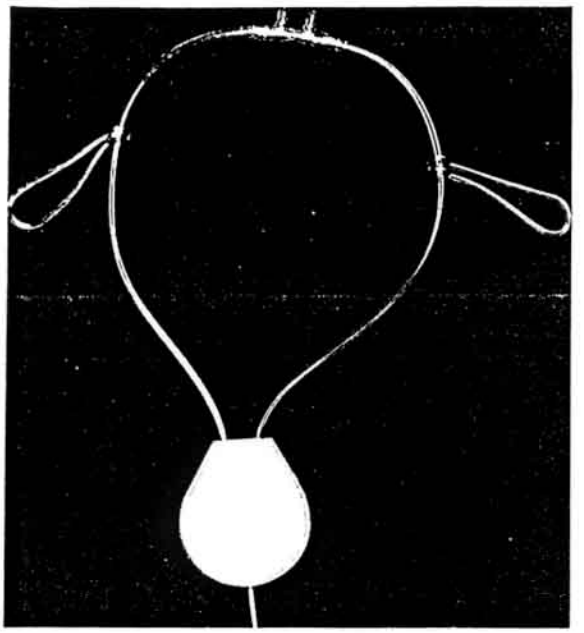

FIGURE 1. Pendant oxygen-conserving nasal cannula.

pendant configuration, where it could be obscured by the patient's clothing.[11] The oxygen-conserving advantage of the pendant, as compared to steady flow, was found to be similar to the mustache-shaped device during resting conditions, but no studies during exercise have been reported.

Because of widespread use of these cannulas, particularly in ambulatory patients, we believe that it is important to determine the effectiveness of this cannula during conditions other than rest. In the present study, we evaluated the efficacy of the pendant conserver nasal cannula as compared to steady-flow oxygen delivery during steady-state exercise.

MATERIALS AND METHODS

Pendant Conserver Cannula

The pendant conserving nasal cannula[11] (Oxymizer Pendant), as shown in Figure 1, consists of nasal prongs attached to tubular conduit leading to a reservoir bag. The oxygen inlet is located at the junction of the 40-ml reservoir bag and the tubular conduit. While the reservoir bag stores some oxygen, most of the oxygen storage occurs in the 20 ml of tubular conduit. When the patient exhales, sufficient time is allotted for the conducting tubing and reservoir to fill with supplemental oxygen. When the patient is ready to inhale, he will receive a 20-ml bolus of nearly pure oxygen from the conduit, followed by some of the contents of the reservoir.

Protocol

Ten subjects with COPD (seven male and three female subjects) with a mean age of 61 ± 11 years and a mean forced expiratory volume in one second (FEV_1) of 0.70 ± 0.19 L were recruited from the inpatient population of the pulmonary service at the University of Texas Health Center at Tyler. The subjects were mildly hypoxemic at rest, with a recent SaO_2 of 90 percent or less, and they were screened for their tendency to have desaturation during low-level cycle exercise. Exercise testing carried out while breathing room air demonstrated that all subjects had desaturation during low-level exercise, with a mean SaO_2 of 86.3 ± 2.0 percent at a mean power output of 30.5 ± 22.3 W (183 ± 133 kg·m). Informed consent was obtained in accordance with the standards set by the human subjects' investigation committee.

Measurements of pulmonary function were obtained using a rolling-seal spirometer (Cardio Pulmonary Instruments 220). The best of three forced expiratory efforts was recorded for each subject. The carbon monoxide diffusing capacity (D) was obtained using a gas chromatograph (Tensor 7800) according to the method of Jones and Meade.[12] Actual values for D were then compared to predicted values using the data presented by Salorinne.[13] The data on pulmonary function are shown in Table 1.

All subjects entered into this study were prior participants of a pulmonary rehabilitation program and had demonstrated good exercise tolerance. The exercise consisted of a well-tolerated low steady level walking exercise on a treadmill (Quinton Q-55), with approximately 15 minutes of recovery between each session of exercise. The subjects walked at 1.0 or 1.5 mph for five minutes or until SaO_2 stabilized at each oxygen flow setting. On completion of each stage for testing, for each device, the subject entered immediately into the next higher level of oxygen administration. The performances of the cannulas were compared using identical workloads and time intervals. No patient's SaO_2 was allowed to fall below 80 percent at any time during the study.

The order of choice of presentation of the cannulas was ran-

Table 1—*Data from Pulmonary Function Tests*

Subject	FVC, L	FEV_1, L/min	FEV_1/FVC, percent	D, ml/min/mm Hg	D, percent of predicted
Male subjects					
1	1.32	0.72	55	8.24	30
2	2.68	0.88	33	10.84	49
3	1.76	0.76	43	9.45	39
4	1.80	0.64	36	7.21	26
5	2.16	0.88	41	9.56	32
6	1.44	0.60	42	5.31	21
7	3.04	1.04	44	11.25	45
Mean	2.03 ± 0.64	0.79 ± 0.15	42 ± 7	8.84 ± 2.09	35 ± 10
Female subjects					
8	1.52	0.56	37	2.86	13
9	1.68	0.56	33	5.94	26
10	1.28	0.40	31	8.24	31
Mean	1.49 ± 0.20	0.51 ± 0.09	34 ± 3	5.68 ± 2.70	23 ± 9

Table 2—*Respiratory Rate, Heart Rate, and SaO_2 in Patients Exercising at Isoexercise Loads and Receiving Various Oxygen Supply Flows*

	Pendant			Standard Nasal Cannula		
Flow, L/min	SaO_2, percent	Respiratory Rate, breaths per min	Heart Rate, beats per min	SaO_2, percent	Respiratory Rate, breaths per min	Heart Rate, beats per min
Room air	93.0 ± 2.4	23.4 ± 15.4	93.8 ± 4.0	93.5 ± 2.3	21.1 ± 6.1	95.0 ± 13.7
0.5	93.4 ± 3.5	20.8 ± 16.1	103.2 ± 4.1	91.2 ± 3.4	22.4 ± 7.0	104.5 ± 15.2
1.0	95.2 ± 2.7	18.8 ± 15.3	101.4 ± 3.3	92.1 ± 3.1	22.9 ± 7.1	105.9 ± 15.8
1.5	96.0 ± 2.3	20.2 ± 16.2	102.1 ± 3.1	93.7 ± 2.8	21.6 ± 8.0	100.1 ± 15.8
2.0	96.7 ± 2.0	18.8 ± 17.2	103.9 ± 2.7	94.4 ± 2.9	24.0 ± 7.4	106.9 ± 13.8
3.0	. . .	. . .	. . .	95.7 ± 2.2	21.2 ± 6.6	104.7 ± 16.0

domized. Oxygen flow was initiated at the lowest level for the first session and then increased to the next level for each successive session. Readings for SaO_2 were taken only after the value stabilized for more than two minutes.

Oxygen saturations were measured using an ear oximeter (Biox IIA), with readings being recorded when the instrument's SaO_2 readings had stabilized. Oxygen supply flow was metered via spirometrically calibrated rotameter (Gilmont, Inc) which could be adjusted within ±0.05 L/min. We measured SaO_2 with the subject breathing room air and at 0.5, 1.0, 1.5, 2.0, and 3.0 L/min using the standard steady-flow nasal cannula and with room air and at 0.5, 1.0, 1.5, and 2.0 L/min using the pendant conserver nasal cannula. The electrocardiogram was monitored via telemetry (Spacelabs) employing a CM_5 lead placement. Respiratory rate was visually monitored, recording multiple one-minute counts. Data were compared by an analysis-of-variance techniques, followed by Duncan's multiple-range comparison.

Results

The SaO_2, heart rate, and respiratory rate for each level of oxygen administration for all subjects are shown in Table 2. The mean SaO_2 with room air for both cannulas was not significantly different. Oxygen desaturation was improved using supplemental oxygen delivered by either cannula. At 0.5-L/min oxygen supply flow, the pendant achieved a 2.2 percent higher SaO_2 as compared to the steady-flow cannula. At 1.0, 1.5, and 2.0 L/min, the pendant achieved 3.2 percent, 3.3 percent, and 2.3 percent higher than the steady-flow cannula, respectively. These differences were statistically significant ($p<0.001$). No differences were noted for data on heart rate. Respiratory rates were from 1.6 to 5.7 breaths per minute lower for the pendant when compared to the standard nasal cannula.

A comparison of values for SaO_2 achieved using the pendant and steady-flow cannulas at the various supply flows for each subject at isoworkload is shown in Figure 2. The first point in each panel represents the steady-flow cannula, and the second point represents the pendant conserver at each supply flow. In almost every instance the pendant conserver yields a higher SaO_2 than the steady-flow cannula. In Figure 3, the mean SaO_2 performance curves for the pendant conserver and steady-flow cannula are compared. At 0.5 L/min, the benefit of supplemental oxygen via the pendant conserver is equivalent to that achieved by the standard nasal cannula at 1.5 L/min. At 1.0 L/min the pendant conserver achieved an SaO_2 equivalent to the steady-flow cannula at 3.0 L/min. Therefore, the savings benefit of the pendant was 3:1 when comparing the pendant conserver to steady-flow oxygen delivery.

Discussion

This study demonstrated that the pendant conserver

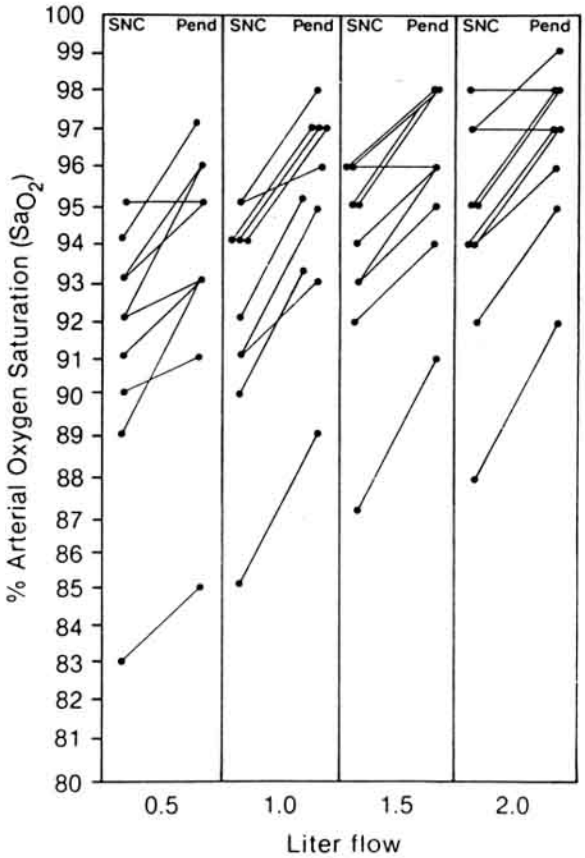

Figure 2. Comparison of values for SaO_2 in 20 patients with exercise-induced hypoxemia using standard nasal cannula *(squares)* and pendant conserving nasal cannula *(pluses)*.

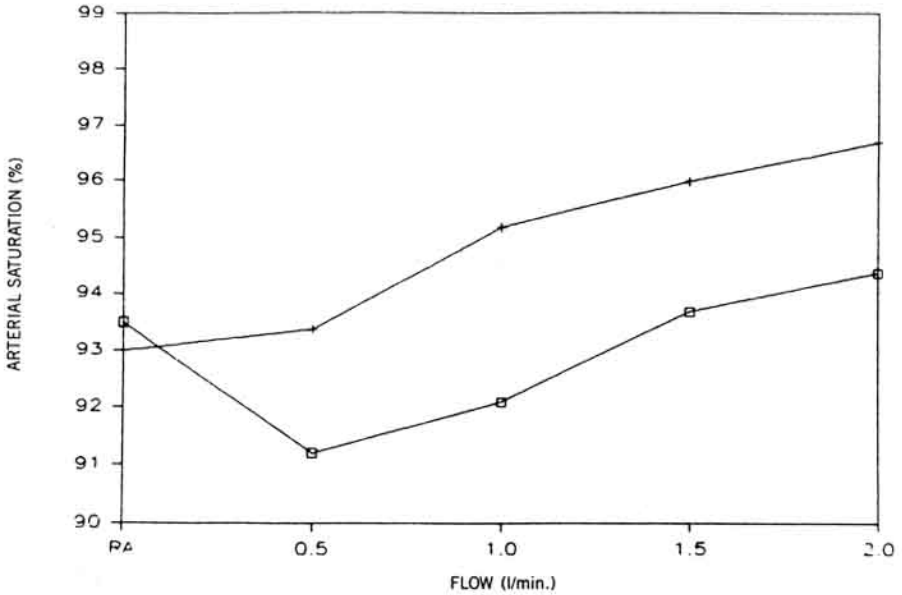

FIGURE 3. Comparison of SaO_2 during exercise for standard nasal cannula (SNC) and pendant cannula (Pend) at 0.5, 1.0, 1.5, and 2.0 L/min of oxygen delivery.

nasal cannula can achieve significantly better SaO_2 than the steady-flow cannula at the same supply flows during exercise. A previous study[11] has shown that the pendant conserver nasal cannula is efficacious during resting conditions. In that study the savings benefit of the pendant conserver cannula over the steady-flow cannula was nearly 4:1 at the lowest flows and 2:1 at higher flows. Those findings were consistent with the savings benefit observed in the mustache-shaped conserver nasal cannula during rest.[9,10,14] In the present study the savings benefit of the pendant conserver cannula over the steady-flow cannula during exercise was 3:1. These findings are consistent with those reported by Soffer et al[10] using the mustache-shaped conserver cannula, in which they also found a savings benefit of 3:1 over steady flow. Thus, the pendant conserver cannula maintains the same savings advantages over steady-flow cannulas as the mustache-shaped conserver cannula, although it is less noticeable on the patient's face.

These oxygen-saving benefits of both conserver cannulas, as compared to steady-flow cannulas, are somewhat predictable. Oxygen delivery by steady flow is inherently wasteful, since only the oxygen delivered during the first portion of inspiration contributes substantially to oxygenation. The conserver cannulas function by storing oxygen during exhalation so that upon early inhalation a bolus of oxygen is added to the steady supply flow. In a previous description of the conserver cannulas,[14] a model was constructed which conceptualized the manner in which the stored oxygen from the reservoir was added to steady supply flow during early inspiration. If 15 to 20 ml of oxygen could be added to any steady flow, the predicted advantage would be substantial. As the supply flow to the conserver is increased, the margin of advantage would remain substantially the same, but the ratio of savings would tend to diminish.

Because the benefits over steady flow for both rest and exercise are similar, it would be tempting to prescribe oxygen for patients knowing only their oxygen saturation response to the standard cannula at rest. We believe that patients who receive prescriptions for oxygen via either conserver cannula should have their arterial blood gas levels or oxygen saturation tested during both rest and exercise, since individual variation in nasal anatomy and respiratory pattern could affect the delivery of oxygen. Patients who breathe strictly by mouth will probably not derive the added benefit of oxygen conservation, since they must do at least some nasal breathing on both inspiration and expiration to operate the cannula's reservoir membrane. Proper testing will assure adequate oxygen saturation, maximizing effective delivery of oxygen while minimizing the economic burden of oxygen therapy.

Because of the oxygen-saving advantage of the pendant, numerous patients who currently require higher flow rates of oxygen may be able to reduce oxygen flow to lower levels while maintaining their SaO_2 above 90 percent. Perhaps one of the most important aspects of minimizing oxygen flow during ambulation is that it allows the patient to use smaller, more portable oxygen reservoirs or to increase the length of use of existing reservoirs. By using smaller, less cumbersome oxygen reservoirs, patients may then be able

to increase their activities of daily living and assume a more active role in society while at the same time reduce the financial burden of oxygen therapy.

We compared oxygen delivery using the pendant conserver cannula with the steady-flow cannula during treadmill exercise in patients with COPD. Our findings confirm that the pendant conserver cannula is an effective oxygen conserver during exercise as well as rest. These advantages over steady flow could translate into substantial cost savings, improved portability, and extended time away from a stationary oxygen source.

ACKNOWLEDGMENT: We thank Ms. Gerri Dingler for her contributions to the preparation of this manuscript and Ms. Vicki Garcia, Mr. Willie Blevins, Mr. Sam Fields, Mr. David Campbell, and Ms. Marla Harter for their technical support and interest.

References

1 Anthonisen RN. Hypoxemia and O_2 therapy. Am Rev Respir Dis 1982; 126:729

2 Yu PN, Goodwin JF, eds. Progress in audiology. vol 4. Philadelphia: Lea and Febiger, 1985

3 Green JF. Fundamental cardiovascular and pulmonary physiology: an integrated approach to medicine. Philadelphia: Lea and Febiger, 1982; 16:175-80

4 Burrows B, Kettel LJ, Neden AH, et al. Patterns of cardiovascular dysfunction in chronic obstructive lung disease. N Engl J Med 1972; 286:912

5 Fishmen AP. Chronic cor pulmonale. Am Rev Respir Dis 1976; 114:775

6 Matthay RA, Berges HJ. Cardiovascular function in cor pulmonale. Clin Chest Med 1983; 4:269

7 Long term domiciliary oxygen therapy in chronic hypoxemic cor pulmonale complicating chronic bronchitis and emphysema: report of the Medical Research Council waking party. Lancet 1981; 1:681-86

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

9 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

10 Soffer M, Tashkin DP, Shapiro BJ, Littner M, Harvey E, Farr S. Conservation of oxygen supply using a reservoir nasal cannula in hypoxemic patients at rest and during exercise. Chest (in press)

11 Tiep BL, Belman MJ, Mittman C, Phillips RE, Otsap B. A new pendant storage oxygen-conserving nasal cannula. Chest 1985; 87:381-83

12 Jones RS, Meade F. A theoretical and experimental analysis of anemities in the estimation of pulmonary diffusing capacity by the single-breath holding method. Q J Exp Physiol 1961; 46: 131-43

13 Saloinne Y. Single breath diffusing capacity: reference values and application in connective tissue diseases and in various lung diseases. Scand J Respir Dis 1976; 961-84

14 Tiep BL, Nicotra B, Carter R, Phillips RE, Otsap B. Evaluation of an oxygen-conserving nasal cannula. Respir Care 1985; 30: 19-25