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

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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 (SaO₂) 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 SaO₂ achieved by PNC required one third of the oxygen flow required by steady-flow oxygen to achieve an equivalent SaO₂. 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 (SaO₂) drops below 90 percent, the pulmonary arterial pressure and pulmonary vascular resistance rise rapidly, resulting in cor pulmonale.³ Burrows et al⁴ demonstrated that survival in patients with COPD is inversely related to pulmonary vascular resistance, the clinical outcome of which is “cor pulmonale.”⁵

The British study⁶ and the nocturnal oxygen therapy trial study⁷ 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 al⁸ 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 rest⁹ 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

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The pendant conserving nasal cannula⁹ (Oxymini 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 (FEV₁) 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 SaO₂ 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 SaO₂ 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.¹⁰ Actual values for D were then compared to predicted values using the data presented by Salorinne.¹¹ 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 SaO₂ 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 SaO₂ was allowed to fall below 80 percent at any time during the study.

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

![Figure 1](pendant-oxygen-conserving-nasal-cannula)
Table 2—Respiratory Rate, Heart Rate, and SaO₂ in Patients Exercising at Isoexercise Loads and Receiving Various Oxygen Supply Flows

<table>
<thead>
<tr>
<th>Flow, L/min</th>
<th>SaO₂, percent</th>
<th>Respiratory Rate, breaths per min</th>
<th>Heart Rate, beats per min</th>
<th>SaO₂, percent</th>
<th>Respiratory Rate, breaths per min</th>
<th>Heart Rate, beats per min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room air</td>
<td>93.0 ± 2.4</td>
<td>23.4 ± 15.4</td>
<td>93.8 ± 4.0</td>
<td>93.5 ± 2.3</td>
<td>21.1 ± 6.1</td>
<td>95.0 ± 13.7</td>
</tr>
<tr>
<td>0.5</td>
<td>93.4 ± 3.5</td>
<td>20.8 ± 16.1</td>
<td>103.2 ± 4.1</td>
<td>91.2 ± 3.4</td>
<td>22.4 ± 7.0</td>
<td>104.5 ± 15.2</td>
</tr>
<tr>
<td>1.0</td>
<td>95.2 ± 2.7</td>
<td>18.8 ± 15.3</td>
<td>101.2 ± 3.3</td>
<td>92.1 ± 3.1</td>
<td>22.9 ± 7.1</td>
<td>105.9 ± 15.8</td>
</tr>
<tr>
<td>1.5</td>
<td>96.0 ± 2.3</td>
<td>20.2 ± 16.2</td>
<td>102.1 ± 3.1</td>
<td>93.7 ± 2.8</td>
<td>21.6 ± 8.0</td>
<td>100.1 ± 15.8</td>
</tr>
<tr>
<td>2.0</td>
<td>96.7 ± 2.0</td>
<td>18.4 ± 17.2</td>
<td>103.9 ± 2.7</td>
<td>94.4 ± 2.9</td>
<td>24.0 ± 7.4</td>
<td>106.9 ± 13.8</td>
</tr>
<tr>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
<td>95.7 ± 2.2</td>
<td>21.2 ± 6.6</td>
<td>104.7 ± 16.0</td>
</tr>
</tbody>
</table>

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 SaO₂ were taken only after the value stabilized for more than two minutes.

Oxygen saturations were measured using an ear oximeter (Biox II A), with readings being recorded when the instrument's SaO₂ readings had stabilized. Oxygen supply flow was metered via spirometrically calibrated rotameter (Gilmore) which could be adjusted within ±0.01 L/min. We measured SaO₂ with 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 CM₂ 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 SaO₂, heart rate, and respiratory rate for each level of oxygen administration for all subjects are shown in Table 2. The mean SaO₂ 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 SaO₂ 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 SaO₂ 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 SaO₂ than the steady-flow cannula. In Figure 3, the mean SaO₂ 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 SaO₂ 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](image-url)  
**Figure 2.** Comparison of values for SaO₂ in 20 patients with exercise-induced hypoxemia using standard nasal cannula (squares) and pendant conserving nasal cannula (pluses).
nasal cannula can achieve significantly better $\text{SaO}_2$ than the steady-flow cannula at the same supply flows during exercise. A previous study has shown that the pendant conservator nasal cannula is efficacious during resting conditions. In that study the savings benefit of the pendant conservator 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 conservator nasal cannula during exercise. In the present study the savings benefit of the pendant conservator cannula over the steady-flow cannula during exercise was 3:1. These findings are consistent with those reported by Soffer et al using the mustache-shaped conservator cannula, in which they also found a savings benefit of 3:1 over steady flow. Thus, the pendant conservator cannula maintains the same savings advantages over steady-flow cannulas as the mustache-shaped conservator cannula, although it is less noticeable on the patient's face.

These oxygen-saving benefits of both conservator 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 conservator 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 conservator cannulas, 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 conservator 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 conservator 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 $\text{SaO}_2$ 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.

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