Evaluation of an Oxygen-Conserving Nasal Cannula

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Multicenter long-term oxygen therapy trials have established that low-flow oxygen is beneficial to hypoxemic patients with chronic obstructive pulmonary disease (COPD). A large percentage of these patients receive oxygen via steady-flow nasal cannula (SNC). Because of the rising cost of medical care and particularly the cost of oxygen therapy, we designed an oxygen-conserving nasal cannula (CNC). In a previous study, we demonstrated by ear oximetry that the CNC required substantially less oxygen to achieve adequate oxygen saturation than did the SNC. In this paper we describe the principles of operation of the CNC and present data comparing the CNC and SNC. Methods: We studied 4 subjects with COPD, simultaneously measuring SaO2 by ear oximetry and SaO2 and PaO2 by standard blood analysis, with the subjects breathing first room air and then supplemental oxygen at 0.5, 1.0, and 2.0 L/min with both the SNC and CNC. Ten minutes was allowed between tests for equilibration. Results: The CNC achieved significantly higher (P < 0.001) saturations than did the SNC at equivalent oxygen supply flows. Absolute improvements in PaO2 were 10.9 torr at 0.5 L/min, 18.2 torr at 1.0 L/min, and 27 torr at 2 L/min. There was a high correlation between ear oximetry and blood analysis readings. Conclusion: We conclude that the widespread use of the CNC could result in a significant financial savings while increasing the range and portability of oxygen therapy devices. (Respir Care 1985;30:19-25.)

Introduction

Deterioration of lung function due to chronic bronchitis, emphysema, and pulmonary fibrosis is a problem of growing magnitude. Often, deterioration leads to a patient’s becoming hypoxemic, at which time the clinician will consider prescribing supplemental oxygen, usually at low flowrates through a nasal cannula. There is usually considerable value in providing such a patient with supplemental oxygen. (It has been shown to be beneficial when hypoxemia is accompanied by an oxygen saturation of less than 90%).1 The British2 and NOTT3 studies showed that survival could be improved if oxygen was provided at night while the patient was sleeping and that survival could be prolonged even further by oxygen therapy approaching 24 hours per day. Other studies have demonstrated that low-flow oxygen therapy reduces pulmonary hypertension, polycythemia, and depression and improves cor pulmonale and psychomotor skills. Based on the results of the cited studies, 15 to 18 hours of oxygen may be as efficacious as 24 hours, provided the patient receives oxygen while asleep and during exercise.

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The actual required flow of nasal oxygen is usually quite small. For example, 2 L/min will increase the inspired oxygen percentage from 20.9% (atmospheric) to approximately 27%. A small increment of oxygen can make an enormous difference to the well-being of many hypoxic patients because it raises arterial saturation to a physiologically acceptable level. Many of these patients then improve to the point at which a portable oxygen source becomes a consideration.

Providing supplemental oxygen to ambulatory patients presents unique problems. Portable oxygen is expensive. Its cost usually ranges from $200 to $1,000 per month, with the average around $300. A portable oxygen source capable of providing 2 L/min is relatively heavy and bulky. The weight of a typical liquid-oxygen canister that lasts about 8 hours at 2 L/min ranges from 9 to 14 pounds, and cylinders of that weight will last less than 4 hours. Smaller and lighter gas cylinders are available, but they last only about 2 hours at 2 L/min. So unless a flow of 1 L/min or less is prescribed, most patients require the large cylinder or the liquid-oxygen canister, both of which must usually be transported on a cart rather than strapped over the shoulder of the often weak and debilitated user. In addition to the heavy, bulky canister that the patient must transport, the nasal cannula can be a source of discomfort to the patient. Pressure and rubbing often cause chronic inflammation and at times the breakdown of tissue at the nares, nasal bridge, and earloop-contact areas.

Conventional oxygen delivery via nasal prongs is inefficient and wasteful because oxygen flows continuously throughout the respiratory cycle even though exhalation constitutes 60 to 70% of the cycle. When one considers that the anatomical dead space at end expiration is filled with alveolar gas that constitutes the first one third of the volume of the next breath to reach the alveoli, and that the last one third of an inspired resting tidal volume serves to fill the anatomical dead space, one realizes that only 15 to 20% of the respiratory cycle brings fresh gas to the alveolar level where it can participate in gas exchange. As a result, most continuous-flow oxygen is lost to the atmosphere. If oxygen delivery could be confined to early inspiration, the oxygen requirement would be reduced considerably and that would translate to a reduction in the weight and bulk of equipment and the cost of oxygen.

Other investigators have examined methods of delivering oxygen during inhalation. Altman and Block and Flick et al., using experimental devices with nasal-pressure sensing and solenoid valves to deliver oxygen during inspiration, were able to reduce oxygen consumption by 20 to 50%. Other similar devices, most of which sense the beginning of inhalation via pressure changes transmitted through the oxygen conduit, have come to our attention. However, the device used by Robert et al. had a thermistor attached to a specialized cannula at the nasal prongs to sense the crossover between exhalation and inhalation, and by this technique these investigators were able to reduce the oxygen flowrate to half that required by the steady-flow cannula.

We have taken a different approach by designing a cannula that stores oxygen during exhalation and delivers it during inhalation. It is composed of a reservoir that is closely coupled to the nasal prongs and into which oxygen flows continuously at a low flowrate. During exhalation, oxygen builds up in the reservoir, and the next inspiration delivers a bolus of oxygen-enriched gas in addition to the continuous low-flow oxygen. A lower oxygen flow is required to achieve adequate saturation because of the addition of this bolus of oxygen during inspiration. We have previously used ear oximetry to establish the efficacy of the oxygen-conserving nasal cannula (CNC).

In this paper we will describe the CNC and its principles of operation and then, using arterial blood gas analysis and CO-Oximetry data in addition to ear oximetry, compare the CNC and a standard steady-flow nasal cannula (SNC).

The Oxygen-Conserving Nasal Cannula (CNC)

Physical Description

The Oxymizer CNC, shown in Figure 1, is composed of nasal prongs, a closely coupled 20-ml reservoir with a collapsible membrane, and an oxygen supply line at the distal end of the reservoir on each side. The conserver cannula with its reservoir is positioned under the nose and above the upper lip and extends laterally to the cheeks. The oxygen
oxygen displaces the original dead space gas, venting it through the nasal prongs. When the patient next inhales, he receives a 20-ml bolus of oxygen-enriched gas in addition to the steady-flow oxygen.

**Oxygen-Delivery Model**

Figures 2 & 3 present a model of oxygen delivery. For this presentation we assumed a respiratory rate of 20 breaths per minute and an I/E of 1:2. Both figures depict families of oxygen supply curves, with the base curve representing steady flow through an SNC. Figure 2 shows the calculated volume of oxygen (from all sources) in 200 ml of gas received at the threshold of the airway in 0.5 seconds with each of three different supply flows. Both room-air—and supplemental—oxygen contributions are included. Similarly, Figure 3 shows the calculated percentage of oxygen (from all sources) in 200 ml of gas received at the threshold of the airway in 0.5 second with the same three supply flows. It should be noted in Figure 3 that the percentages of inspired oxygen provided with the use of the steady-flow cannula are those one would expect with that device (eg, 1 L/min = 24% and 2 L/min = 27%). The curves that are labeled “SR” (storage reflux) in the figures were calculated at the additional volume (Fig. 2) and high-

supply lines attached to both ends of the reservoir extend laterally over the ears and merge into a single supply tube similar to that of most cannulas. The system requires at least minimal nasal breathing to trigger its operation.

**Principles of Operation**

The CNC (Fig. 1) stores oxygen in the following manner: During early exhalation, the dead space gas pushes the reservoir membrane out, allowing the reservoir to start filling with oxygen, which enters from the lateral ends and flows medially, toward the nasal prongs. During the remainder of exhalation,
er percentage (Fig. 3) of received oxygen resulting from the inclusion of 10, 15, and 20 ml of reservoir oxygen stored during 2 seconds of exhalation. The actual gain from the reservoir storage reflux via the CNC was less than calculated at the lower oxygen flow rates because of some mixing of 100% oxygen with dead space gas exhaled into the reservoir at the beginning of exhalation. However, at higher oxygen flows, such as 2 L/min, the actual gain was close to the calculated gain because the mixed gases were washed out by the supply oxygen. Also, at the higher flows there was some oxygen lost to the atmosphere through overboarding because the resulting volume of oxygen exceeded the limited storage volume of the reservoir; thus, the improvement ratio of the CNC to the SNC was smaller at the higher flows.

Clinical Study

Subjects

We recruited four subjects from the inpatient Chronic Respiratory Disease Service at the University of Texas Health Science Center at Tyler. Each subject had obstructive lung disease as determined by spirometry (FEV1 < 0.9 L and FEV1/FVC% < 60). The subjects gave their written informed consent consistent with the standards of the Center's Institutional Review Board. The only change in the clinical management of these patients was the withholding of inhaled bronchodilators for 1 hour prior to the study.

Materials

We used a Biox IIA ear oximeter to measure oxygen saturation noninvasively and an Instrumentation Laboratory Model 282 CO-Oximeter to measure oxygen saturation in arterial blood samples. Arterial PO2 was measured in duplicate by two Instrumentation Laboratory blood gas analyzers, with each instrument carefully calibrated prior to the introduction of each sample. We used an indwelling radial artery cannula with a 3-way stopcock to withdraw arterial blood samples conveniently. The oxygen supply flow was metered with a spirometrically calibrated rotometer accurate to within ± 0.05 L/min. During the study, the subjects were in a comfortable, reclining position and movement was kept to a minimum.

Methods

Using ear oximetry readings and analyses of arterial blood samples taken simultaneously, we compared the CNC and SNC at room-air oxygen and 0.5, 1.0, and 2.0 L/min of supplemental oxygen. The order of use of the two cannulas was randomized, but flow settings started at the lowest level and were incrementally increased to the highest level. We allowed at least 10 minutes between cannulas for the return to baseline on room air. We determined the equilibration time at each flow level and then added 2 minutes as insurance. Statistical comparisons were made by analysis of variance, followed by the Duncan multiple-comparison technique.

Results

Saturation and PaO2 can be seen in Table 1. Figure 4 compares mean PO2 levels achieved by the two cannulas at 0.5, 1.0, and 2.0 L/min oxygen supply; absolute improvements were 10.9 torr at 0.5 L/min, 18.4 torr at 1 L/min, and 27 torr at 2 L/min. At each
flow, oxygenation was significantly better (P < 0.001) with the CNC than with the SNC. Likewise, as can be seen in Figures 5 and 6, which compare the two cannulas through ear oximetry and CO-Oximetry, respectively, saturation was better with CNC. The curves in Figures 5 and 6 look quite similar, suggesting a similarity between these two techniques for measuring oxygen saturation. The degree of agreement between the readings of the two oximeters can be seen in the graph in Figure 7, on which both sets of saturation measurements are plotted.

Discussion

In this study we used arterial PO₂ analyses, CO-Oximetry, and ear oximetry to compare the conserver cannula with the steady-flow cannula. Although better oxygenation resulted from supplemental oxygen administration through both types of cannulas, the CNC provided greater improvement as measured by all three techniques. We caution the reader to remember that the study was performed with only four subjects. However, these results confirmed our earlier findings, with ear oximetry alone, that the mean benefit ratio of the CNC to the SNC was greater than 3:1. As to the advisability of using an ear oximeter to compare the CNC with the SNC, a previous study has established a close relationship and a cross-predictive value between the oxygen saturation values obtained by arterial blood gas analysis and those obtained by ear oximetry. This study confirms this relationship. Additionally, the ear oximeter provides continuous measurement that makes trend analysis convenient. Our observation of patients in this and other studies revealed that patient body movement, coughing, and talking cause momentary peaks and troughs in saturation. A small percentage change in saturation, particularly below 90%, corresponds to a large change in PO₂. The small variability can be easily detected on a continuous ear oximeter printout, and a mean value can be determined by averaging peaks and troughs. Conversely, the PO₂ measured in a single blood sample might reflect the peak or trough extreme. Despite the fact

![Graph showing PO₂ values with the conserver nasal cannula (CNC) and the standard nasal cannula (SNC).]
that a small change in oxygen saturation can represent a large change in \( \text{PaO}_2 \), an argument can be made that oximetry readings represent the actual trend more accurately than do single blood gas measurements, particularly if a digital voltmeter is used, which increases the accuracy by a significant digit. These considerations, added to the ease of application of the oximeter probe and the fact that arterial cannulation is unnecessary, make oximetry an attractive method of comparing oxygen-delivery devices.

The most common oxygen prescription is 2 L/min, and the average patient breathes between 16 and 20 breaths per minute with a typical inspiration/expiration ratio of about 1:2. The CNC was designed to provide the same benefit at 0.5 to 1.0 L/min that the SNC provides at 2 L/min. By referring to Figure 2, one can see that to accomplish this goal, the CNC must store 16.6 ml of oxygen during exhalation and be able to deliver this bolus to the threshold of the airway in the first half second of inhalation. The reservoir’s storage capacity is 20 ml; therefore the calculated benefit ratio of the CNC to the SNC is greatest at 0.5 L/min. Actually, there is some mixing of oxygen and dead space gas in the reservoir at 0.5 L/min (eg, at 0.5 L/min the oxygen concentration in the reservoir is approximately 85% and at 2 L/min it is about 97%), but this mixing decreases as the supply flow increases. Because the CNC and its reservoir are also supplied with steady-flow oxygen, the oxygen in the storage reservoir is an extra benefit. However, because the benefit is additive rather than proportional, and because there is reservoir over-
boarding at high flows, the benefit ratio of the CNC to SNC decreases as the supply flow increases, although the CNC continues to be an improvement. Thus, curves in the oxygen-delivery model in Figures 2 and 3 are parallel, and our data confirm that fact.

Arterial blood should be analyzed when the CNC is used, as the high oxygen saturation the CNC effects at a low supply flow could result in respiratory-drive depression from oxygen overdosing.

Patient acceptance of the CNC is an issue that has not been investigated in a rigorous fashion. The CNC covers the moustache area of the face and so is more obtrusive, but the reduction it allows in the size of the oxygen canister source makes it possible for the patient to carry a canister or cylinder rather than pulling it in a cart, which is cumbersome and draws attention to the patient. Some find the appearance of the facial apparatus objectionable, while others feel that the larger cannula is an insignificant factor in the overall appearance of taking oxygen. Almost every patient found the CNC more comfortable; the reservoir is soft and does not cut into the nose or the side of the face. Some patients reported that areas on the face that were chafed from use of an SNC cleared when they began to use the CNC.

In summary, the CNC operates more efficiently than the SNC, achieving adequate oxygen saturation at substantially reduced supply flows. It accomplishes this by storing oxygen during exhalation and releasing it early in the next inhalation, the time of greatest benefit to the patient. Although the CNC is more conspicuous, most patients find it quite comfortable because it is less irritating and its weight is distributed over more of the face. Because the flow of oxygen can be reduced, the CNC can bring about significant financial savings by reducing oxygen usage and making less costly oxygen sources feasible. Also, the portability of the oxygen source can be improved, as smaller oxygen canisters may adequately replace larger ones for the same flow-time requirements.

**PRODUCT SOURCES**

Oxymizer: Chad Therapeutics Inc, Woodland Hills CA
Biox IIA ear oximeter: Ohmeda (BTI) Boulder CO

* A later model of the Oxymizer has the reservoir in a pendant, lying on the chest, making the cannula less bulky.

CO-Oximeter: Instrumentation Laboratory Inc, Lexington MA
Blood gas analyzers: Instrumentation Laboratory Inc, Lexington MA
Rotometer: Gilmore Inc, Great Neck NY

**REFERENCES**
