Oxygen Conservation and Oxygen-conserving Devices in Chronic Lung Disease*  
A Review  
Brian L. Tiep, M.D.; and Michael I. Lewis, M.D.

The efficacy of long-term oxygen therapy for hypoxemic COPD patients is well established. However, oxygen is expensive and the portability of home oxygen is limited by the weight and bulk of the oxygen source. As a result, there has been a recent surge of interest in creating oxygen-conserving devices and methods. The efficiency of oxygen therapy can be improved over steady flow delivery by focusing oxygen delivery to early inspiration. Three methods for improving oxygen delivery efficiency—trans-tracheal catheter, reservoir cannula and demand-pulse oxygen delivery—are currently available for patient use. Each has its own set of advantages and disadvantages. By using oxygen conservation methods, the oxygen required to achieve adequate blood oxygenation can be reduced by a factor of 2:1 to 7:1 compared to steady flow. Thus, the cost of oxygen can be substantially reduced while increasing the portability and range of home oxygen therapy.

HISTORIC PERSPECTIVE
Joseph Priestly discovered in 1774 that by focusing the sun's rays on mercuric oxide using a lens, he could liberate oxygen gas in glass tubes under water. He wrote: "The feeling of it to my lungs is not sensibly different from that of common air, but I fancied that my breast felt light and easy for some time afterward. Who can tell but that, in time, this pure air may be a fashionable article of luxury."

Thomas Beddoes, who founded the Pneumatic Institution in Bristol, England in 1798, used oxygen to treat a variety of maladies. He was probably the first to make medical use of the newly-discovered gas for a variety of conditions. J. S. Haldane used oxygen to treat chlorine poisoning during World War I. He suggested that oxygen should be used continuously if benefit is to be derived.

Oxygen was not used systematically in the treatment of patients until the 1920s when the late Alvan L. Barach, considered by many to be the father of modern oxygen therapy, began using it to treat patients with pneumonia. He noted that patients improved faster, and he observed a relationship between the edema associated with right heart failure and hypoxemia. Because he recognized that some patients could benefit from portable oxygen therapy, he designed several systems using small, lightweight cylinders which could be refilled from larger cylinders in the patient's home using special adaptive devices.

In the late 1960s, the value of low-flow oxygen for treating patients with pneumonia, chronic bronchitis and emphysema became established. In the 1970s, with the advent of liquid oxygen, portable oxygen for home use became a realistic therapeutic modality. Now the 1980s have experienced the widespread interest and use of oxygen-conserving devices to reduce the financial cost of oxygen while increasing the portability and range of ambulatory oxygen therapy.

LONG-TERM OXYGEN THERAPY
The use of long-term oxygen therapy (LTO2) in patients with severe hypoxemic chronic obstructive pulmonary disease (COPD) is commonly advocated. Early uncontrolled studies suggested that continuous O2 therapy in patients with severe hypoxemic COPD could result in a reduction in pulmonary arterial hypertension. LTO2 was also reported to result in a reduction in erythrocytosis and improved neuro-psychologic function. Neff and Petty (1970) suggested that LTO2 could improve the survival of patients with severe COPD when severe hypoxemia or cor pulmonale was present.

Two recent controlled studies, the British Medical Research Council (MRC) trial and the Nocturnal Oxygen Therapy Trial Group (NOTT) have provided some of the data on which the current recommenda-

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The senior author, Dr. Tiep, was instrumental in developing several of the devices mentioned in this review. These include the Oxymizer, Oxy-Wizer Pendant and the Oxymatic. He has a consultative arrangement with Chad Therapeutics, Inc, the manufacturer of these devices. Despite that fact, he has attempted to provide a fair presentation of the field of oxygen conservation, the mechanism of operation and appropriate clinical application of the various devices.  
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tions and justifications for the use of LTO₂ in hypoxemic COPD patients have been made. The British study,²⁸ randomly assigned patients to regimens of 15 hr continuous O₂ therapy/day, or no O₂ therapy. The NOTT study,¹³ in a similar experimental design, randomly assigned patients to regimens of 12 hr/day oxygen therapy or 24 (actually about 19) hr/day oxygen therapy. In both studies,²⁸,¹³ the patients enrolled had similar degrees of airflow limitation, severity of hypoxemia and pulmonary arterial hypertension. In both studies the patients received oxygen at night.

Both studies showed a significant reduction in mortality in the groups receiving oxygen therapy. In the British MRC study,²⁸ no differences in mortality were evident until 500 days of the study had elapsed. At five years, 19 of the 42 oxygen-treated patients had died compared with 30 of the 45 control patients receiving no oxygen. In the NOTT study,¹³ differences in mortality were noted earlier in the study period. At 26 months overall mortality in the continuous oxygen group was nearly half that of the nocturnal oxygen group.¹³ Combining the results from the two studies,²⁸,¹³ it is clear that oxygen therapy has a clear survival advantage over no oxygen therapy and that continuous (19 + hr/day) oxygen therapy results in the greatest benefit in terms of improved survival. Hence the dictum: "no oxygen is bad, oxygen some of the time is better but oxygen most of the time is best."¹³ Classic Factors accounting for the decrease in mortality in the area were received oxygen therapy in the British MRC and NOTT studies²⁸,¹³ are unclear and were thought not to be related to changes in pulmonary hemodynamics.

The question of whether LTO₂ (15 to 18 hr/day) influences the progression of pulmonary arterial hypertension in patients with severe hypoxemic COPD was recently addressed in a French study by Weitzenblum et al.¹⁴ They studied 16 patients in whom right heart catheterization was performed 47 ± 28 months prior to the onset of LTO₂ (T₀), just before the onset of LTO₂ (T₁) and 31 ± 19 months after the introduction of LTO₂ therapy (T₂) in these patients. From T₀ to T₁ there was an annual increase in mean pulmonary arterial pressure (Ppa) of 1.47 ± 2.3 mm Hg. Between T₁ and T₂ the annual significant decrement of 2.15 ± 4.4 mm Hg Ppa was observed.

These results are at variance with the pulmonary hemodynamic data reported in the MRC and NOTT studies.²⁸,¹³ Initial Ppa in the MRC study was higher than in the French study.¹⁴ The stability of Ppa in the MRC patients who received oxygen therapy might therefore represent a satisfactory therapeutic response.²⁸ In the NOTT study, hemodynamic data were obtained only after six months, which might well have been too short for measurable changes in the pulmonary hemodynamics to have transpired.

The conclusion drawn from the French study¹⁴ was that 15 to 18 hr/day of oxygen therapy can reverse the progression of pulmonary arterial hypertension in a significant proportion of patients, but normalization of pulmonary hemodynamics was rarely observed. It was also pointed out that the small mean decrement in Ppa of 6 mm Hg may well have minimal clinical or prognostic importance.¹⁴

Both the NOTT study¹³,¹⁵ and a recent French study¹⁶ have stressed the importance of establishing persistent hypoxemia in stable prospective candidates for LTO₂. In the NOTT study,¹³ 45 percent of hypoxemic stable patients initially screened to enter the study were no longer eligible after retesting at four weeks due to an increase in PaO₂. In the French study,¹⁶ 30 percent of stable hypoxic patients judged to be suitable candidates for LTO₂ demonstrated an increase in PaO₂ to >59 mm Hg after three months of followup. In a proportion of patients, improvement in PaO₂ was noted only after an observation period of two to three months.¹⁶ We may conclude from these studies¹³,¹⁵,¹⁶ that potential candidates for LTO₂, whose PaO₂ range between 50 and 55 mm Hg should be closely monitored on an outpatient basis over a period of at least four weeks prior to committing to LTO₂ therapy.

There are two other circumstances in which oxygen therapy may be desirable in patients with COPD: during sleep and during exercise.

Patients with severe COPD may have episodes of sleep-disordered breathing associated with profound hypoxemia.¹⁷,¹⁸ These episodes may be associated with further transient increases in pulmonary arterial pressure,¹⁹,²⁰ and repeated episodes over many years may well contribute to progressive sustained pulmonary hypertension and the genesis of cor pulmonale.²¹ Administration of oxygen to patients with hypoxemic COPD may reverse significant hypoxemia and improve sleep quality.²² Nighttime oxygen therapy in this context has not been reported to result in further significant elevation of Pco₂ with the development of respiratory acidosis.

Most COPD patients who exercise and desaturate or are significantly hypoxemic prior to exercise will improve in exercise endurance when given oxygen during exercise.²³,²⁴

The High Cost of Oxygen

In recent years, there has been an unprecedented appreciation of the cost constraints involved in the practice of medicine. In 1982, Health Care Finance Administration¹⁹ reported that Medicare spent about $800 million for home care durable medical equipment, half of which ($400 million) was home oxygen. As a result of recently-acquired physiologic data regarding oxygen therapy, along with the realization of the necessity to reduce the financial burden of oxygen
therapy, standards for prescribing and reimbursing oxygen therapy have been generated. The American Thoracic Society standards formulated in 1977\textsuperscript{2} became the basis for reimbursement by governmental as well as private insurance carriers.

New oxygen reimbursement guidelines became effective in October, 1985 to further define acceptable use of oxygen and avoid oxygen therapy when not medically necessary.\textsuperscript{2} The oxygen prescription must include a diagnosis of disease necessitating home oxygen therapy, and duration of oxygen need. Diagnostic requirements are quite specific. The patient must be significantly hypoxemic as evidenced by arterial blood gas level. Primary lung diseases such as COPD, diffuse interstitial lung disease, cystic fibrosis, bronchiectasis and pulmonary neoplasm are covered. Also covered are hypoxia-related symptoms or findings that might be expected to improve with oxygen therapy such as pulmonary hypertension, erythrocytosis, nocturnal restlessness or morning headache, recurring congestive heart failure due to cor pulmonale and impairment of cognitive processes. Conditions not covered include angina pectoris, peripheral vascular disease and other conditions in which hypoxemia are absent.

Arterial blood gas criteria are quite specific. PaO\textsubscript{2} $\leq$ 55 mm Hg or SaO\textsubscript{2} $\leq$ 85 percent immediately qualifies the patient for oxygen. PaO\textsubscript{2} 56 to 59 mm Hg or SaO\textsubscript{2} 86 to 89 percent is acceptable if there is edema from right heart failure, cor pulmonale or polycythemia. PaO\textsubscript{2} of 60 to 64 mm Hg is only acceptable with a compelling explanation of need from the patient's physician. PaO\textsubscript{2} $\geq$ 65 mm Hg is unacceptable. Moreover, "PRN" oxygen prescriptions are unacceptable. The necessity for portable oxygen during exercise should be documented by blood gas measurements during an exercise test.

**Oxygen Conservation**

Because of the high costs involved in administering LTO\textsubscript{4} to patients with chronic lung diseases, attempts have been made to improve the efficiency by which oxygen is delivered to the patient. Low-flow oxygen therapy, using steady flow nasal cannula, is inherently inefficient. Standard nasal oxygen flows continuously throughout the respiratory cycle. As a result, a considerable proportion of the oxygen is wasted to the atmosphere. Specifically, oxygen flowing during exhalation, which constitutes 60 to 70 percent of the cycle as well as the last 30 percent of inhalation, fills anatomic dead space and is wasted. Thus, only 15 to 20 percent of the respiratory cycle effectively delivers fresh gas to the alveoli for participation in gas exchange. It would therefore appear logical to try to restrict oxygen delivery to early inhalation.

**Oxygen Conservation Methods**

There are three commercially available means for improving the efficiency of oxygen delivery: transtracheal oxygen delivery (transtracheal catheter), reservoir cannula and demand oxygen delivery. Each method attempts to reduce oxygen wastage during exhalation and each has its own advantages and drawbacks.

**Transtracheal Oxygen Delivery**

The transtracheal method\textsuperscript{20,29} was derived from the hypothesis that oxygen delivery could become much more efficient if the oxygen was introduced intrabronchially as close to blood-gas interface as possible. In this manner, dead space could be bypassed and, additionally, the upper airways could serve as a reservoir towards the end of expiration (Fig 1). A small plastic catheter was designed by Heimlich\textsuperscript{28} which

![Figure 1. The transtracheal catheter is positioned into the trachea.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21565/ on 04/04/2017)
could be introduced via a transtracheal puncture and can be directed toward the carina.

In animal studies using dogs, Heimlich\(^a\) demonstrated a proportionate increase in \(\text{PaO}_2\), the farther the catheter, delivering 100 percent oxygen, was directed down the respiratory passages. Compressed air caused no change in \(\text{PaO}_2\). In the initial clinical study there was a mean 2:3:1 savings (ie, 2.3 times the oxygen flow is required via steady state delivery vs transtracheal delivery to achieve equivalent oxygen saturation) in oxygen.\(^{28,29}\) As a result, adequate oxygen saturation could be achieved at lower oxygen flows. In a recent study by Kiriloff et al\(^a\) an 18-gauge catheter was introduced at the level of the second tracheal ring level in hypoxemic patients with COPD. They achieved a 1.8:1 oxygen savings compared to steady flow delivery.

Other studies\(^{30-33}\) have demonstrated between a 2:1 and 3:1 benefit over steady flow, as well as good tolerance to the transtracheal catheter for up to ten months. Leger et al\(^a\) demonstrated that, by coupling transtracheal oxygen delivery with pulsed oxygen delivery during inspiration, he was able to double the savings achieved by transtracheal oxygen delivery alone.

A variant of the transtracheal approach is oxygen delivery via a previously-established tracheostomy.\(^a\) Again, 2:1 savings in oxygen was accomplished using a decannulation plug modified for transtracheal oxygen delivery. There was, however, little added benefit from using a demand delivery device through the cannula.

An important attribute of transtracheal oxygen delivery is the fact that the transtracheal catheter can be completely hidden from view by a scarf. As a result, there is reason to believe that patients might be more compliant in following their oxygen prescription.

Complications of the transtracheal puncture include hemoptysis, subcutaneous emphysema, cellulitis and clogging of the catheter.\(^a\) Some of these complications will no doubt be minimized with further experience in performing the procedure. It should be noted that special transtracheal catheters and insertion techniques have been developed and are commercially available (Erie Controls, Milwaukee and Transtracheal Systems, Denver). Use of the newer transtracheal catheters might result in a reduction in some of the complications of the technique reported to date.

**Reservoir Oxygen Delivery**

Oxygen delivery using a reservoir cannula was the first method of oxygen conservation to achieve widespread use.\(^{34-43}\) By using the reservoir device, oxygen is stored during expiration in the cannula reservoir and is made available to the patient at the beginning of inhalation. A lower flow is required to achieve adequate oxygen saturation in the blood because of the addition of this highly concentrated oxygen bolus to

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**Figure 2.** The Oxymizer cannula is shown with a cut-away section of the front panel. At this time, the patient has just commenced expiration. The early dead-space gas has thrust the membrane forward forming a chamber between the membrane and the back wall of the reservoir. The effect is to allow oxygen storage to take place during the rest of exhalation. When the patient is ready to inhale, he will receive 20 ml of oxygen-enriched gas early in the cycle.

**Figure 3.** The Oxymizer, as shown in Figure 2, at the beginning of inhalation. Having stored oxygen-enriched gas in the reservoir, the patient has begun to inhale, thus receiving 20 ml of oxygen-enriched gas at the very beginning of inhalation.
the steady supply flow during early inhalation.

There are two configurations of reservoir cannulas presently available: the mustache-configured Oxymizer and the pendant-configured Oxymizer Pendant. The principle of operation of these two configurations is similar, but there are some differences. They will be addressed separately.

**Oxymizer:** The Oxymizer (Fig 2 and 3) is composed of nasal prongs, a closely coupled 20 ml reservoir with a collapsible membrane, and oxygen supply conduit at the distal-lateral ends of the reservoir. The cannula with its reservoir is situated under the nose, covering the mustache area of the face. The membrane is highly compliant and responds to minimal changes in nasal air flow for its operation as an oxygen-conserving device. The Oxymizer operates in the following manner. During early exhalation, the dead space gas pushes the membrane forward, forming a reservoir chamber between the membrane and the back wall of the reservoir. As exhalation continues, oxygen—entering from the lateral ends of the reservoir—forces the dead space gas medially, venting it through the nasal prongs. Hence, at the end of exhalation the reservoir is filled with oxygen. Thus, when the patient is ready to inhale, he receives a 20 ml bolus of oxygen-enriched gas in addition to the steady-flow oxygen.

A comparison of the oxygen saturation performance curves for the steady flow cannula and the Oxymizer is shown in Figure 4. The mean values for oxygen saturation at each flow are plotted for ten hypoxemic patients with COPD. It should be noted that when the supply low is set at 0.5 L/min, saturation is equivalent to that achieved by the steady flow cannula set at about 2 L/min. When the supply flow is set at 2 L/min, the saturation is equivalent to saturations achieved by steady flow set in excess of 4 L/min. The mean Oxymizer/steady flow benefit ratios at oxygen flow rates of 0.5 L/min and 2.0 L/min are therefore about 4:1 and 2:1, respectively.

**Oxymizer Pendant:** While the Oxymizer requires less oxygen than steady flow to achieve adequate...
Figure 6. Diagram of the Oxymizer Pendant. A) During early exhalation, dead space gas moves from the nasal prongs toward the reservoir. B) During the ensuing (larger) portion of exhalation, and once the reservoir chamber is filled to capacity, the oxygen, which enters the conduit near the reservoir chamber, fills the conduit. C) When the patient is ready to inhale, he receives 20 ml of oxygen-enriched gas.

Oxygen saturation, some patients found its mustache configuration aesthetically displeasing. Therefore, the Oxymizer was redesigned by displacing the reservoir off the face and onto the anterior chest wall in a pendant configuration, where it can be obscured by the patient's clothing. The Pendant is shown in Figure 5.

The principle of operation of the Pendant, while similar to the Oxymizer, has important differences, as diagrammed in Figure 6. The Pendant has a reservoir chamber, but the actual oxygen storage resides in the 20 ml conduit connecting the reservoir chamber with the nasal prongs. During early exhalation, dead space gas moves from the nasal prongs toward the reservoir (Fig 6A). During the ensuing (larger) portion of exhalation, and once the reservoir chamber is filled to capacity, oxygen which enters the conduit near the junction of the reservoir chamber fills the conduit (Fig 6B). When the patient is ready to inhale, he receives 20 ml of oxygen-enriched gas (Fig 6C). The Pendant and Oxymizer provide equivalent oxygen savings at flows of 0.5 L/min. However, due to its tubular storage (resulting in less gas mixing than occurs in the Oxymizer reservoir), it is possible to operate the Pendant at 0.25 L/min, where it achieves oxygen saturations equivalent to 1 L/min using a steady flow delivery system. The Pendant maintains its savings benefit during exercise. Studies have demonstrated the effectiveness of the Pendant over the long term.

Reservoir Oxygen Delivery Model: A conceptual model on which the operation of the reservoir delivery system is based is depicted in Figure 7. This model is based on the assumption that the first 200 ml of inspired gas is the delivery volume critical to effective gas exchange. It is further assumed that this volume is inspired in the first 0.5 sec of inspiration. Moreover, the model assumes that the patient is breathing at 20 breaths/min with an I/E ratio of 1:2.

Based on the foregoing assumptions, breathing room air would provide the patient with about 42 ml of oxygen; steady flow at 2 L/min and 4 L/min would be expected to provide the patient with about 54 ml and 68 ml of oxygen respectively. From these values we can calculate the FIO2 of the first 200 ml of inspired gas by dividing the volume of oxygen delivered by 200 ml then multiply by 100 (ml of oxygen/200 ml×100). By these calculations, the FIO2 achieved by steady flows of 2 L/min and 4 L/min would be about 24 and 34 percent respectively—which is about what one would expect from steady flow delivery.

The family of curves in Figure 7 labeled RB10, RB15 and RB20 (reservoir bolus of 10, 15 and 20 ml) were calculated to include mixed 10 ml, 15 ml and 20 ml of 100 percent oxygen respectively in the first 200 ml of inspired gas. These boluses of oxygen occur because the reservoir is able to store these volumes of oxygen during the expiration period of approximately 2 sec. Although the reservoir volumes of the Oxymizer and Pendant are 20 ml, the actual benefit tends to lie along the 15 ml curve. The reason for this loss in efficiency is that, at the lowest oxygen flows, the reservoir contains 85 rather than 100 percent oxygen due to some mixing with dead space gas. At higher flows, there is some oxygen loss through overboarding because the resulting volume of oxygen exceeds the limited storage capacity of the reservoir. Thus, the reservoir cannulas improve oxygen delivery over steady flow in an additive fashion as opposed to a fixed ratio or proportionate improvement over the oxygen flow spectrum.

Reservoir Cannulas During Exercise and Extended

Figure 7. Oxygen delivery model. The model is based on the assumptions that the patient is breathing 20 breaths per minute with an I/E of 1:2. The critical delivery volume is the first 200 ml of inhalation and the time required to deliver that volume is 0.5 sec. The effective inspired oxygen volumes received by the patient are shown for the steady flow cannula and the conserver cannulas with additional 10, 15 and 20 ml oxygen boluses.
Use:} The reservoir cannulas have been studied during exercise. During exercise, the Oxymer maintained at least 2.9:1 savings over steady flow in achieving equivalent oxygen saturation. The Pendant achieved 3:1 to 4:1 savings over steady flow in equivalent treadmill exercise efforts to achieve equivalent oxygen saturations. Long-term studies evaluating the continued use of the Pendant over one month extended the 2:1 to 3:1 oxygen savings over that time. Patient acceptance of the Pendant was not uniform. A possible site of failure of the reservoir cannula is the membrane. Since a patient accomplishes about 200,000 respiratory cycles per week, the manufacturer recommends changing the cannula weekly. We have found that they last several weeks with no signs of membrane failure. The exception to this is the patient placing his fingers over the nasal prongs which occludes the pressure escape, resulting in a ruptured membrane. This is a rare occurrence.

**Demand Oxygen Delivery Devices**

The demand devices deliver oxygen only when the patient inhales, thus conserving valuable oxygen while the patient is exhaling. They function by opening a solenoid valve which allows pressurized oxygen to flow to the patient, aiming for the most opportune moment for delivery. The demand devices differ from one another largely by the method in which they detect the crossover between the end of exhalation and the beginning of the next inhalation. Cotes et al. (1956) described a portable oxygen delivery system which incorporated a special mask with an inhalational pressure detector, which was thus able to deliver oxygen during inhalation only. Since that time several methods have been studied. Pflug et al. described a portable demand device in which the movement of the patient’s chest during inspiration could activate a switch in an expanding thoracic belt, which in turn opened a solenoid valve during inhalation and closed it during exhalation. Roberts et al. described a uniquely constructed cannula comprised of a thermistor within the nasal prongs which detected the end of exhalation and opened the solenoid valve at the beginning of the next inhalation. This battery-operated device is reported to provide 2:1 oxygen savings vs steady flow oxygen using a standard nasal cannula. There are a number of other demand devices which operate using either electronic, fluidic or combined fluidic-electronic sensors. Most provide between 2:1 and 3:1 benefit over steady flow.

Several demand oxygen delivery devices are currently on the market. Using the Pulsair (CryO2 Inc, Fort Pierce, FL), oxygen may be delivered by either steady flow or in a pulsed delivery fashion. The hospital unit, the demand oxygen controller (CryO2 Inc, Fort Pierce, FL) is attached to a 50 psi wall outlet and can be set to steady flow or pulsed flow. In addition, the demand oxygen controller comes with an apnea alarm, a desirable feature for hospital oxygen administration. In both configurations the settings 1 through 5 are matched and contoured to the customary steady flow settings of 1 through 5 L/min, as shown in Figure 8, while consuming only one-third the oxygen required by steady flow to achieve equivalent oxygen saturations. A pulse volume of 16.5 ml was found to match the efficacy of 1 L/min steady flow. The oxygen pulse arrives in early inhalation and its duration ranges from about 100 to about 500 milliseconds, with the shortest delivery pulse at the first setting lengthening incrementally to the longest pulse at the fifth setting. Because of its 3:1 savings over steady flow delivery, the Pulsair liquid oxygen system weighing 7.5 lbs can provide enough oxygen to last up to 12 hr at the steady flow equivalent of 2 L/min.

The DO5S (AMT Inc, Minnetonka, MN) is another electronic demand oxygen delivery system which provides oxygen savings of 2:1 to 3:1 over steady flow oxygen delivery. A unique feature of the DO5S is that it is able to determine the patient’s respiratory rate and auto-adjust the delivery pulse size so that the total oxygen delivery per minute is constant despite changes in the respiratory rate. It is a separate electronic unit which adapts to liquid or compressed oxygen bottles and comes equipped with an adjustable apnea alarm.

The Oxymatic (Chad Therapeutics Inc, Chatsworth, CA) is an electronic demand device which delivers a short pulse of oxygen from a compressed oxygen cylinder or liquid oxygen source to the patient only during early inhalation so as to exclude delivery during exhalation and late (dead space) inhalation. The

![Figure 8. The comparison of PaO2 via demand oxygen controller (CryO2) vs PaO2 via steady flow at the same numeric settings are shown for 16 subjects. This represents a convenient matching of steady flow and demand settings.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21565/)
total oxygen the patient receives per minute is determined by settings which allow a delivery pulse to occur once in four breaths, once in three breaths, one in two breaths or with every breath. Using this device attached to a small portable compressed gas cylinder, savings of 4:1 to 7:1 over steady flow delivery has been achieved as shown in Figure 9. Recent studies comparing the Oxymatic with steady flow oxygen delivery during 1 to 2 mph zero grade treadmill exercise demonstrated that steady flow delivery required seven times the volume of oxygen per minute as Oxymatic oxygen delivery to achieve an oxygen saturation of 90 percent.

CONCLUSIONS

The three available oxygen conservation methods have their advantages and drawbacks. A summary of advantages and drawbacks is summarized in Table 1. The transtracheal method is least obstructive, thereby encouraging improved patient compliance, but it is the most invasive method. The reservoir cannulas are least expensive, simplest in their operation, and least subject to failure, but are most obstructive. The demand devices can be most efficacious, but probably most subject to mechanical failure. Coupled with transtracheal delivery, pulsed demand delivery could extend the oxygen savings even further. As Block pointed out, all of these devices have been tested on a short-term basis, but long-term studies are necessary to establish long-term efficacy. This requirement has been met only in the Pendant reservoir cannula.

All of the conservation devices obviate the need for a humidifier (commonly employed in patients who require oxygen flows of greater than 2 L/min) because they require smaller amounts of oxygen to be delivered per breath, resulting in less mucosal drying. This is particularly true of reservoir cannulas in which the patient rebreathes warmed and humidified gas. This fact increases the financial savings of conserving oxygen. In addition, removing the humidifier removes a possible source of infection.

Presently available oxygen conservation methods provide oxygen savings in the range of 2:1 to 7:1 over steady flow delivery. Calculated reduction in the cost of compressed gas oxygen using devices which provide the above range of oxygen savings as compared to steady flow is shown in Table 2. In this table, a comparison of monthly costs is figured in a typical patient requiring 2 L/min of steady flow oxygen. Because of fixed costs involved in home oxygen, the cost savings afforded by a conserving device is not simply proportional to the reduction in oxygen usage. Moreover, the cost of the conserving device should be included. This cost could vary from $28 to $50 per month.

The same type of analysis could be performed on liquid oxygen with similar results. However, there are two factors which would impact upon the actual cost savings of using an oxygen-conserving device with liquid oxygen. The fixed costs of liquid systems are often higher than compressed gas and there is a slow leak in liquid oxygen, all of which amounts to less impressive cost savings.

<table>
<thead>
<tr>
<th>Table 1—Characteristics of Three Oxygen Conservation Methods</th>
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<tr>
<td><strong>Mechanism of conservation</strong></td>
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<tr>
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<tr>
<td>Transtracheal</td>
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<tr>
<td>Advantages</td>
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<td>Oxygen savings</td>
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<tr>
<td>Necessity for humidification</td>
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<tr>
<td>Obtrusiveness</td>
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<td>Disadvantages</td>
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O₂ Conservation and Conserving Devices (Tiep, Lewis)
Table 2—Oxygen Savings per Month using Oxygen Savings Methods of Various Savings Ratios

<table>
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<tr>
<th>Savings ratio</th>
<th>No. of O2 cylinders per month</th>
<th>Cost of O2 per month ($)</th>
<th>Cost savings per month ($)</th>
<th>Total cost savings (%)</th>
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<td>6.25</td>
<td>125.00</td>
<td>125.00</td>
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<td>4.2</td>
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<td>1.8</td>
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<td>214.00</td>
<td>76</td>
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*Comparison of monthly oxygen costs is made in a patient using the equivalent of 2 L/min steady flow oxygen by various oxygen conserving techniques. Calculations are based on 12.5 oxygen cylinders at $20 per month. Fixed costs are about $30 per month. Total cost is $280.00 per month.

As a result of these oxygen savings, smaller volumes of oxygen are required to meet oxygen needs, thus increasing the portability of ambulatory oxygen and the patient's range of movement. Significant financial savings for both inpatient and home oxygen utilization is an important end-result of oxygen conservation.

The oxygen concentrator is presently regarded as a relatively inexpensive source of oxygen for the home-bound patient. The use of an oxygen-conserving device in patients with an oxygen concentrator in their home might not appear advantageous. However, these patients are usually provided small compressed oxygen cylinders to meet their portable oxygen needs. If these small cylinders are refilled multiple times per month, the expense of such refills would quickly negate the economic advantage of using the concentrator. Using an oxygen conserving device in these patients could extend the life of a cylinder several-fold, which would reduce the frequency of refills. When the monthly cost of a concentrator is considered, home oxygen patients could still derive economic benefit from using a combination of oxygen concentrator and small portable oxygen cylinders with an oxygen conserving device attached.

There have been several efforts to develop portable concentrators. The technical limitation of weight is partially alleviated by reducing the liter flow necessary to meet the patient’s oxygen requirements. A conserving device could be helpful in this regard, thus facilitating this important technologic development.

Previously, inhospital oxygen costs have been passed on to the patient; therefore, there has been little enthusiasm for saving oxygen in the hospital. However, with Medicare's introduction of DRGs (Diagnosis Related Groups) and limitation of payments to specified amounts for a given disease, hospital oxygen will be regarded as a cost overhead, the reduction of which will be highly desirable.

When considering portable oxygen, the fiscal savings of oxygen conservation are very substantial. The actual savings may be more than 50 percent, which is significant if these devices are used on a widespread basis. A rough cost estimate of 500,000 patients receiving home oxygen at an average cost of $350 per month is about $2 billion annually. There are already limits to reimbursement based on physiologic necessity, and it may be only a matter of time until these reimbursement limitations will extend to placing a ceiling on total oxygen use. Oxygen conservation is an ideal means of cutting medical care costs because the financial benefit is combined with improvement in oxygen delivery, increased portability and enhanced range of patient mobility. Oxygen cost curtailment utilizing the various oxygen conserving devices will ensure the continued use of oxygen in severely hypoxic patients with chronic lung diseases in whom the impact of LTO₂ on both morbidity and mortality is now well established.

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