CHAPTER 7

LONG-TERM OXYGEN TREATMENT

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OBJECTIVES

The general objective of this chapter is to help allied health care professionals understand the rationale behind and the safe use of long-term oxygen therapy (LTOT) in patients with chronic obstructive pulmonary disease (COPD). It is important that the health care practitioner teach this knowledge to patients who experience breathlessness so that they can understand why the use of oxygen may or may not be required in their situation.

After reading this chapter, the physician and the allied health care professional will be able to

- understand the use of oxygen and its role in stable patients with COPD;
- know how to assess oxygenation at rest, with exercise, and during sleep;
- prescribe the correct dose of oxygen;
- prescribe the best oxygen delivery system for the patient;
- teach the patient the role of oxygen and how to use it safely; and
- refer to specific professionals from the health care team when needed.

Hypoxemia is a common occurrence in patients with pulmonary impairment caused by COPD. The presence and severity of hypoxemia correlate with the severity of pulmonary impairment[1]; however, the relationships between hypoxemia and the severity of breathlessness,[2] degree of disability,[2] and impact on quality of life[3,4] all appear to be weak. Chronic hypoxemia does have clinical effects, some of which may be improved by treatment with oxygen. As COPD is largely irreversible and medication may have limited effects on respiratory symptoms such as dyspnea, oxygen is often sought by patients, family members, and health professionals when breathlessness occurs, even if hypoxemia is not present. Readily available measurements of oxyhemoglobin saturation (SpO_2) have aggravated the problem by generating a measure of oxygenation that many feel needs correction, when it is abnormal, even if there is no clinical rationale.

Although LTOT has been shown to have a number of physiologic benefits and is one of the few interventions that improves survival in selected patients with COPD,[5,6] it is not always effective in altering breathlessness, improving exercise capacity, or changing quality of life. Because oxygen is a prescription medication with attendant risks as well as possible benefits, the chronic use of it should be reserved for situations for which benefit has been clearly delineated.

In this chapter, we review the mechanisms and effects of hypoxemia, assessment and rationale for therapeutic intervention with LTOT, and oxygen delivery systems available.

MECHANISMS OF HYPOXEMIA

Although not all patients with COPD develop gas exchange abnormalities, the airway narrowing and lung destruction present often result in mismatching of ventilation (V) and perfusion (Q), that is, V/Q mismatch causing hypoxemia. Multiple inert gas studies show that V/Q mismatch is the most frequent and

most important cause of hypoxemia in COPD.[7] Other possible causes of hypoxemia in some individuals include diffusion abnormality, true right to left venous to arterial shunt, and areas in the lung where V/Q is 0, which acts like a shunt. Alveolar hypoventilation or the low FIO_2 of altitude may aggravate the hypoxemia in patients. The hypoxemia may also be aggravated by a low mixed venous PO_2, for example, secondary to a low cardiac output, which will magnify the effect of V/Q mismatch on arterial oxygen tension.[8]

In the absence of sleep apnea, a worsening of hypoxemia with sleep is probably attributable to a worsening of the V/Q mismatch,[9] accompanied by alveolar hypoventilation.[10] Hypoxemia seems to be most marked at the onset of sleep and during rapid eye movement (REM) sleep. At the onset of sleep, alveolar ventilation often decreases, causing an increase in $PaCO_2$.[10] In addition, a change in V/Q relationships will also occur if part of the tidal volume falls below closing volume,[8] the lung volume at which airways to the dependent areas of the lung close. This is particularly likely to happen if functional residual capacity falls when individuals assume a supine position.[11] Hypoventilation and change in V/Q relationships in the lung also occur during REM sleep.[10]

Studies using the multiple inert gas method also indicate that V/Q mismatch does not usually change significantly during exercise.[7,12] Similarly, the degree of shunt, defined in these studies as areas of the lung where V/Q was 0, plus true venous to arterial shunt, does not change significantly in most patients with COPD.[7] Worsening hypoxemia during exercise is probably caused by a combination of a rise in arterial PCO_2 and a fall in mixed venous PO_2. Mixed venous PO_2 will fall if the cardiac output does not increase to the same extent as the oxygen consumption, even if V/Q mismatch remains unchanged. A fall in mixed venous PO_2 will aggravate the effects of the V/Q abnormality.[8] Similarly, $PaCO_2$ will rise if ventilation does not increase to the same extent as CO_2 production. This will reduce alveolar oxygen tension (PAO_2) and thereby affect PaO_2 even if the relationship between ventilation and perfusion is stable. The simplified alveolar gas equation

$$PAO_2 = P_IO_2 - PaCO_2/R$$

where P_IO_2 = partial pressure of inspired oxygen and R = respiratory exchange ratio, explains the relationship between $PaCO_2$, P_IO_2, and PAO_2. A higher $PaCO_2$ will result in a lower alveolar oxygen tension. In addition, as $PaCO_2$ rises, a steady state no longer exists. Therefore, R falls, and this also impacts alveolar oxygen tension, thereby decreasing PaO_2.

In some individuals, hypoxemia during exercise may be worsened by true diffusion impairment or by the opening of a patent foramen ovale when pulmonary artery, right ventricular, and right atrial pressure increase, which occurs with the increase in cardiac output.

EFFECTS OF CHRONIC HYPOXEMIA

There are several well-defined physiologic and clinical effects of chronic hypoxemia (Figure 7–1). Perhaps the most significant ones are the result of vasoconstriction of the pulmonary vessels causing an increase in pulmonary vascular resistance (PVR).[13] If cardiac output is maintained, pulmonary artery pressure (PAP) increases. In the presence of chronic hypoxemia caused by COPD, pulmonary artery hypertension, right ventricular dilatation, and overt cor pulmonale may ensue.[14]

Polycythemia is another result of chronic hypoxemia,[15] and a high hemoglobin should be an indication of the need to assess for oxygenation with sleep and exercise. However, only when the hematocrit increases beyond 55 to 60% does blood viscosity affect perfusion of the major organs.[16]

Other possible effects of chronic hypoxemia are less well defined. Nevertheless, chronic airflow limitation is now recognized as a multisystem disease,[17] and it is possible that the peripheral muscle impairment, nutritional abnormalities, neurologic and cognitive problems, and endocrine changes are to some extent the result of chronic hypoxemia.

The major clinical manifestation of COPD is breathlessness, most prominent with exertion. However, the degree of breathlessness does not usually correlate with the presence or severity of hypoxemia. In the laboratory setting, ventilation increases with induced hypoxemia; however, breathlessness with exertion is more closely related to the work required of the respiratory muscles and the capacity of those muscles to generate force when contraction occurs.[18] The degree of breathlessness does not correlate well with the presence or severity of hypoxemia. Therefore, supplemental oxygen is not the initial treatment for breathlessness even if hypoxemia is present.

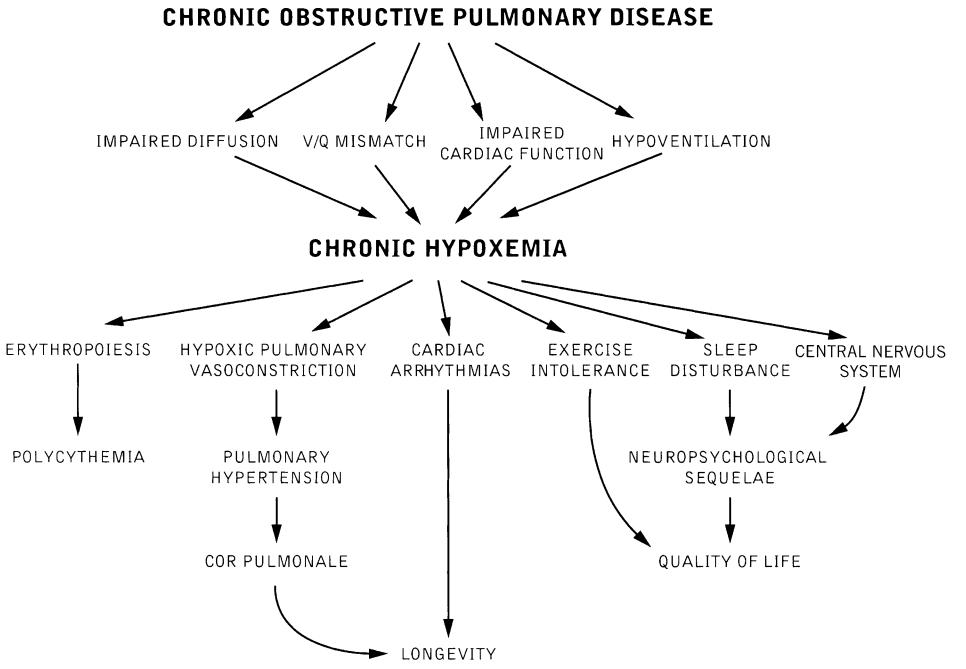

Figure 7–1 Schematic representation of the relationship between chronic obstructive lung disease, hypoxemia, and end organ effects.

ASSESSMENT OF HYPOXEMIA

Measurement of arterial blood gases remains the gold standard for assessing arterial oxygenation. Although this method is the standard for most jurisdictions when determining the need for long-term oxygen therapy,[19–25] the measurement is not practical in many patients, particularly when assessing nocturnal or exercise oxygenation. Noninvasive methods to assess oxygenation using photoplethysmography and spectrophotometry via an oximeter probe are more often used to obtain a continuous measure of oxygenation. Spectrophotometry is used to determine the amounts of oxyhemoglobin and deoxyhemoglobin, whereas photoplethysmography assesses pulse rate.[26] The data obtained are used to calculate a measure of SpO_2. Portable pulse oximeters are accurate (± 2 to 4%), particularly when SpO_2 is greater than 80%.[27] Oximeter readings may be less accurate when skin pigmentation is dark.[28] Ambient light,[29] poor peripheral blood flow,[30] certain nail lacquers,[31] and some intravascular dyes[32] may alter light transmission and affect the accuracy of oximeter readings. Elevated carboxyhemoglobin and methemoglobin levels may also affect the accuracy of observed measurements.[30] Some newer models of oximeters use a motion artifact reduction system, which is important when blood flow (pulse volume) is low or when movement occurs frequently, as with exercise.

If the use of long-term oxygen therapy is being considered, oximetry should be used to measure oxygenation continuously during sleep and to determine the appropriate dose of oxygen to prescribe. The patient should sleep overnight with the oximeter probe in place, from which a graphic display of continuous nocturnal oxygenation can be obtained. The testing should be repeated to determine the correct dose of oxygen to prescribe.

If the use of long-term oxygen therapy is being considered, oximetry should be used to assess oxygenation during exercise and the most appropriate dose of oxygen for that individual. Measurements made during steady-state exercise are the most appropriate for determining the dose of oxygen for individuals when they undertake activity or exercise.

Several different methods of exercise have been proposed. Steady-state exercise on either a treadmill or a cycle ergometer, at approximately 60% of the

individual's maximum exercise capacity, may be used. However, most patients use oxygen therapy just for ambulation; therefore, we have developed and tested a self-paced walk test where oxygenation is assessed continuously with the individual walking at a pace similar to one they would choose to use outside the home.[33] The traditional maximum 6-minute walk test, which is used as an outcome measure for pulmonary rehabilitation, is less suitable to determine oxygen dose for exercise as it is a maximum exercise test, not steady-state exercise.[34]

MANAGEMENT OF CHRONIC HYPOXEMIA

Principles Of Long-Term Oxygen Therapy

The aim of long-term oxygen therapy should be to prevent or reverse the complications of chronic hypoxemia. Oxygen, however, should be only one part of a comprehensive program of care that also includes other prescription medications, exercise, nutrition, psychosocial adjustment, and education. In patients with COPD, specialist referral should be sought, particularly if the use of LTOT is considered.

When LTOT is prescribed, the dose of oxygen used should aim to increase PaO_2 to approximately 60 mm Hg or SpO_2 to approximately 90%. Different doses or flow rates may be needed for rest, sleep, activity, and exercise. However, because of the risk of inducing or aggravating hypercapnia, care must be taken to ensure that the dose is the lowest required to achieve the goal of correcting hypoxemia. Dose-response curves of the oxygen's effect on hypoxemia should be performed during rest, during sleep, by monitoring nocturnal oximetry, and during exercise comparable to activities usually performed during daily living.

The results of the British Medical Research Council (MRC) Working Party Study[5] and the North American Nocturnal Oxygen Therapy Trial (NOTT)[6] indicate that in the presence of chronic hypoxemia, LTOT should be used for at least 15 continuous hours a day. Using oxygen for sleep alone may not result in any clinical benefit, and oxygen used only when breathlessness occurs is not justified and possible more deleterious than beneficial.

Oxygen may be delivered to the respiratory system at the nose by nasal cannulae, at the oropharynx by a mask, or directly to the trachea by a transtracheal catheter. Controlled oxygen, which provides a constant FIO_2, applied with a mask using the Venturi principle, is the safest method of delivering oxygen to patients, particularly during sleep and in those with an elevated $PaCO_2$. There is less likelihood of an increase in $PaCO_2$ using controlled oxygen than with uncontrolled oxygen applied by nasal cannulae.[35]

An oxygen prescription should include the dose required for resting, sleeping, activity, and exercise. It should also include the duration of use each day, the delivery mechanism both for in-home use and ambulatory oxygen, and the method of application to the respiratory tract whether it is by mask or nasal cannulae. If oxygen-conserving devices or pulsed-dose delivery systems are to be used, dose-finding assessment is required for each patient during rest, sleep, and activity as pulsed-dose units may not provide oxygenation equivalent to continuous flow.[36,37]

Eligibility for funding for long-term oxygen therapy is based on the presence of chronic hypoxemia when patients are optimally treated and free of exacerbation. Nevertheless, in the move toward ambulatory care and a reduction in the length of hospital stays, patients hospitalized for exacerbations of COPD are now being discharged even when their condition is not completely stabilized and they continue to present with significant hypoxemia. It is often felt necessary to prescribe oxygen for these patients at the time of discharge from hospital. If oxygen is to be prescribed for acute use during the recovery phase of an exacerbation, it should be made clear that this is for different reasons than LTOT. The physician, the patient, and the funding source should all be aware that the oxygen is being provided for acute use, hopefully during a short recovery period. Therefore, if oxygen is not discontinued once the patient has recovered from the exacerbation, a reassessment for LTOT is appropriate 2 to 3 months after the initiation of acute home oxygen. If these precautions are not in place, many patients feel dependent on oxygen, and inappropriate long-term use becomes difficult to avoid. Guyatt and colleagues recently assessed patients on LTOT and found that approximately 40% of these patients did not meet eligibility criteria for funding.[38] Many of these patients were probably started on oxygen during an acute exacerbation. Eligibility for LTOT may not have been reassessed when they were clinically stable.

Criteria For Funding Long-Term Oxygen Therapy

General Requirements

Before starting long-term oxygen therapy, the patient should be evaluated by a respirologist to optimize medical treatment and to ensure that hypoxemia is chronic and cannot be corrected otherwise. In collaboration with the patient's attending physician, the patient should be re-evaluated at least once a year by a respirologist to monitor the progress of the disease and the treatment received.

The patient must agree to have home oxygen and comply with the treatment by respecting the medical prescription, particularly the oxygen flow rate, as well as the daily duration of oxygen therapy. The patient must also agree to do minor maintenance on the equipment and to have maintenance visits at home, which are necessary to ensure that the equipment functions correctly. The patient's immediate family should also agree to have the oxygen equipment in the home. The patient's physical environment at home must be such that the equipment can be safely installed, with both the patient and family agreeing to respect the basic safety instructions (Table 7–1).

Specific Criteria

The prescription of LTOT is closely monitored and controlled in most health care jurisdictions. In Canada, provincial ministries of health monitor applications for LTOT and provide funding for those who meet eligibility criteria. The eligibility criteria for funding of LTOT is based on evidence from clinical trials. These criteria are similar in most provinces of Canada and in most other health care jurisdictions (Table 7–2).[19–25]

TABLE 7–1 Oxygen Do's and Don'ts

Description	*Do's*	*Don'ts*
Approximately 21% oxygen is naturally found in the air we breathe. It is clear, tasteless, and odorless. It is nonflammable; however, it does support combustion. This means that what may not usually burn in room air will burn in the presence of oxygen or what normally burns will burn much more violently. Oxygen is a safe drug as long as safety guidelines are followed.	Use your oxygen as directed by your doctor. Aim to use your oxygen for a minimum of 15 hours continuous. Clean or change your equipment regularly. Notify your provider if you have any concerns about your equipment. Notify your provider if your prescription is changed. Store your oxygen equipment safely and securely; always ensure the unit cannot fall or tip over. Visibly place a no smoking—oxygen in use sign. Keep your oxygen in a well-ventilated area. Only use water-based lubricants if your nose becomes dry (must not contain oils, ie,Vaseline). Allow only trained individuals to operate the oxygen equipment. Keep a fire extinguisher in your home. Plug concentrators directly to a grounded outlet; when possible use a separate circuit. Ensure cylinders are secure. Carry a spare battery if you use a conserving device that requires one.	Don't adjust the oxygen dose without a prescription from your doctor. Don't permit oil, grease, aerosol sprays, or any other flammable materials to come in contact with oxygen. Don't allow smoking of any kind in the area where oxygen is stored. Don't allow electrical equipment within 5 feet of the oxygen system. Don't allow heat sources or open flames to come within 5 feet of the oxygen. Don't store the oxygen near sources of heat (radiators, fireplaces, ovens, base heaters) Don't attempt to repair the oxygen equipment.

TABLE 7–2 Eligibility Criteria for Long-Term Oxygen Therapy

General Requirements	*Specific Criteria*	*Eligible in Some Jurisdictions*
Chronic airflow limitation Clinically stable Optimal medical treatment Nonsmoking	Resting PaO_2 55 mm Hg or less Resting PaO_2 56–60 mm Hg with polycythemia or cor pulmonale as shown by P pulmonale Edema Pulmonary artery hypertension Polycythemia	Resting PaO_2 56–60 mm Hg If nocturnal hypoxemia (usually > 30% of the night) or exercise hypoxemia*

*For exercise hypoxemia, oxygen must correct hypoxemia and improve exercise endurance and/or breathlessness with exertion.

Funding is usually provided if resting PaO_2 is 55 mm Hg or less in a stable patient who is receiving optimal therapy. Optimal therapy should include smoking cessation, and stability is usually defined as a patient being free of exacerbation of COPD for at least 3 months.

In the presence of cor pulmonale (as shown by P pulmonale on an electrocardiogram [ECG], edema, or right ventricular dysfunction or dilatation), pulmonary artery hypertension, or polycythemia, funding is also available if resting PaO_2 is greater than 55 mm Hg and not more than 60 mm Hg.

When PaO_2 at rest is greater than 55 mm Hg and not more than 60 mm Hg, a patient may also be eligible for funding when SpO_2 is less than 88% during exercise or sleep. For exercise hypoxemia, most jurisdictions require that oxygen be shown to correct the hypoxemia and to increase exercise endurance.

Special application is required for LTOT if resting PaO_2 is greater than 60 mm Hg. Certain individuals with prolonged nocturnal hypoxemia in the absence of sleep apnea may receive funding. Exercise-induced hypoxemia alone may also be an appropriate indication if oxygen corrects hypoxemia, increases exercise endurance, and decreases symptoms. The effects of oxygen for exercise hypoxemia are variable, and individualized testing will help determine who will benefit. It is important not to further disable or handicap individuals by prescribing long-term oxygen therapy if there is no evidence that a clinical benefit will ensue.

Home Oxygen Therapy and Active Smoking

This is a controversial subject that is generally avoided or ignored. The decision whether to offer home oxygen therapy to a patient who is an active smoker but otherwise meets all of the criteria for oxygen therapy is a dilemma faced by all respirologists.

There are very few studies on the effects of LTOT in individuals who continue to smoke. The MRC study[5] and the NOTT[6] enrolled only nonsmoking patients, and in these studies, polycythemia improved in those who were treated with LTOT. Calverley and colleagues reported that patients with COPD and secondary polycythemia saw no improvement in their polycythemia if they continued to smoke while they were receiving home oxygen therapy.[39] This study suggested that the link between carbon monoxide and hemoglobin decreases the transport of oxygen in smokers and does not enable the oxygen therapy to exercise its long-term beneficial effects. There are no studies showing that LTOT results in long-term beneficial effects for patients with hypoxemia who continue to smoke.

Safety is another important issue with home oxygen therapy. A patient receiving oxygen while simultaneously smoking is exposed to risks of facial and chest burns, especially when lighting a cigarette.[40] A patient who smokes while receiving oxygen also presents a potential fire hazard for the home. The risk is identical if a family member smokes close to the patient who is receiving oxygen. However, the risk of fire and burns can be minimized if the patient smokes only when not using the oxygen.

It could be argued that when the patient simultaneously behaves in a manner that runs completely counter to the treatment, the provision of oxygen is inappropriate. In the absence of a national or international consensus, we recommend giving home oxygen therapy to patients who do not smoke; however, if a patient continues to smoke, we recommend that everything be done to convince him/her to quit smoking by offering a structured, personalized smoking cessation program.

COPD with Isolated Nocturnal Hypoxemia

Nocturnal hypoxemia may occur even in the absence of daytime hypoxemia in patients with COPD. In this population, prior to assessment for LTOT, obstructive sleep apnea should be excluded. In the absence of sleep apnea, the hypoxemia is probably caused by a combination of hypoventilation and an increase in V/Q mismatch during sleep. In some patients, PAP has been found to increase during the episodes of hypoxemia. However, evidence is lacking to indicate that these changes result in chronic pulmonary artery hypertension or cor pulmonale.[41]

Nevertheless, because of these possible effects of hypoxemia during sleep, studies have been undertaken to assess the effects of LTOT in those who exhibit hypoxemia during sleep, despite the absence of significant daytime hypoxemia. In a double-blind, randomized, control trial lasting 3 years, Fletcher and colleagues assessed the effects of oxygen on pulmonary hemodynamics in 16 patients with chronic airflow limitation and nocturnal hypoxemia.[42] Nocturnal hypoxemia was defined as SpO_2 less than 90% for 5 minutes or a nadir SpO_2 less than 85%. Patients were randomized to oxygen at 3 L/min by nasal cannulae or to compressed air at 3 L/min. Primary outcomes were measures of pulmonary hemodynamics.

The pulmonary artery pressure increased from 22.5 to 26.4 mm Hg in the control group and decreased from 26.7 to 23.0 mm Hg in the treatment group. These changes were statistically significant. However, pulmonary vascular resistance, the primary result of hypoxic pulmonary vasoconstriction, increased significantly in both groups, with no difference between treatment and control groups.

In a 2-year randomized control trial, Chaouat and colleagues assessed the effect of long-term oxygen therapy on mortality in patients with nocturnal hypoxemia alone.[43] Seventy-six patients with COPD were studied in whom SpO_2 was less than 90% for 30% of the night. The PaO_2 was greater than 55 mm Hg but less than 70 mm Hg. Mean forced expiratory volume in 1 second (FEV_1) was 0.99 L. Forty-one subjects were randomized to nocturnal oxygen at a flow rate that corrected hypoxemia, whereas 35 were randomized to a control group.

Nocturnal oxygen had no effect on mortality in this study, and the mortality rate was similar in both groups ($p = .68$). The results of measurements of PAP were available in 46 patients who completed the 2-year follow-up. There were no differences in PAP at entry to the study, and nocturnal oxygen had no effect on the evolution of PAP during the study period.

These trials do not show any effect of LTOT used during sleep in patients who exhibit nocturnal hypoxemia in the absence of daytime hypoxemia. However, a limitation of these studies is the lack of statistical power to enable definitive assessment of the effect of nocturnal oxygen on mortality.

COPD with Isolated Hypoxemia during Exercise

In patients with COPD, breathlessness is heightened by activity or exercise; thus, the question on the role of oxygen to reduce breathlessness during exercise is often raised. Although oxygen may correct hypoxemia and may reduce breathlessness during exercise, the effects are variable, and some patients show no response. Even for those who have chronic hypoxemia and who meet eligibility criteria for funding, oxygen may have no effect during exercise.

Morrison and Stovall assessed the effect of oxygen on exercise in 33 stable patients who were chronically hypoxemic.[44] The exercise protocol was a gradual incremental exercise test, with the workload increasing every 4 minutes. Exercise studies were performed both on room air and with supplemental oxygen. Even though the subjects in the study were not blinded, 11 were considered nonresponders in the sense that exercise endurance did not improve when oxygen was breathed.

In double-blind, randomized trials, the results are similar in that a proportion of subjects show no change in breathlessness or exercise capacity; however, it should be noted that in most of these studies, a significant placebo effect is apparent. In patients who respond to supplemental oxygen as shown by an increased exercise endurance or a decrease in symptoms, the increase in exercise tolerance does not correlate with the degree of decrease in breathlessness. When oxygen is of benefit, the effect is mediated primarily through a decrease in minute ventilation,[45] which may be attributable to improved oxygen delivery or improved use of oxygen in the peripheral muscle.

In the absence of daytime hypoxemia, the effects of oxygen for exercise-induced hypoxemia are also variable. McDonald and colleagues studied 26 patients with COPD and exercise hypoxemia with resting

PaO_2 greater than 60 mm Hg.[46] Mean FEV_1 was 0.9 L, and a randomized, double-blind, crossover design was used. The exercise protocol was a 6-minute walk test. Compared to baseline, both room air and oxygen resulted in small but statistically significant increases in the distance walked. There was a reduction in exercise hypoxemia with oxygen but no change in breathlessness. However, the mean increase in the 6-minute walking distance was approximately 20 meters, much less than the distance considered to have any clinical relevance.[47]

On the other hand, in 12 patients with COPD and resting PaO_2 greater than 55 mm Hg with a mean FEV_1 of 0.9 L, Dean and colleagues reported that oxygen increased exercise endurance by 38%.[48] The exercise testing protocol was a gradual incremental test. However, on close analysis of the results, the use of oxygen resulted in major improvement in exercise endurance in only 4 of the 12 subjects, whereas 3 showed small changes, 4 showed little or no increase, and 1 subject exercised less with oxygen than when breathing room air.

The results of all of these studies indicate that although oxygen may improve exercise hypoxemia and exercise endurance in some individuals with COPD, other patients do not benefit from using oxygen with exercise. Because of this variability, a blanket eligibility statement for the funding of oxygen with exercise is inappropriate; cases must be assessed on an individual basis. There is no role for the use of supplemental oxygen prior to exercise or after activity has induced breathlessness.

In patients with COPD and exercise hypoxemia, the individual assessment should be performed in a laboratory accustomed to the testing procedures. An endurance exercise protocol should be used, ideally one that correlates with the usual activities of daily living. Steady-state exercise at approximately 60% of maximum exercise can be used, either on a cycle ergometer or on a treadmill; alternately, a self-paced walking protocol may be applied.[33] The studies should be blinded, with room air and oxygen applied in random order. A positive response requires correction of exercise hypoxemia and either a significant increase in exercise endurance time or a decrease in symptoms. The magnitude of this change may vary from patient to patient depending on the baseline severity of exercise impairment. When the test is positive, a similar exercise protocol should be used to determine the appropriate dose of oxygen or flow rate to be prescribed.

EFFECTS OF LONG-TERM OXYGEN THERAPY

The role of LTOT in patients with COPD is based on the results of the MRC trial[5] and the NOTT.[6] These landmark studies showed a reduction in mortality with the use of LTOT in patients with COPD, who were chronically hypoxemic. The MRC trial randomized 87 patients either to receive oxygen for 15 hours at 2 L/min by nasal cannulae or to a control group. Entry criteria included a diagnosis of stable irreversible airway obstruction and hypoxemia with PaO_2 between 40 and 60 mm Hg. The mean FEV_1 was 0.68 L. The NOTT used similar entry criteria of PaO_2 less than or equal to 55 mm Hg or PaO_2 less than 60 mm Hg in the presence of edema, P pulmonale on ECG, or hematocrit greater than 55%. The dose of oxygen was titrated to obtain a resting arterial PaO_2 between 60 and 80 mm Hg. Two hundred and three patients were randomized either to nocturnal or continuous oxygen. The mean FEV_1 was 29.7% of predicted.

In the MRC trial, there was a significant reduction in mortality in those treated with oxygen for 15 hours. In the NOTT, continuous oxygen (mean 19.7 hours) conferred a reduction in mortality when compared with nocturnal oxygen alone (mean 12 hours). When the two trials were compared, the mortality rate for nocturnal oxygen in the NOTT was similar to the mortality in the control group (no oxygen) in the MRC trial (Figure 7–2). In addition to a reduction in mortality, both studies showed a reduction in hematocrit in those receiving oxygen for more than 12 hours per day. Pulmonary vascular resistance and PAP increased in the control group (MRC trial) and in those receiving nocturnal oxygen (NOTT), whereas in those using oxygen for more than 15 hours, PVR and PAP did not increase. In those treated with continuous oxygen, pulmonary vascular resistance fell significantly.

There are other potential benefits of supplemental oxygen in those who are chronically hypoxemic. In patients with COPD and chronic hypoxemia, LTOT reverses the nocturnal hypoxemia and may improve sleep quality.[49] Significant cardiac arrhythmia sometimes occurs during sleep hypoxemia and may be reduced in frequency by the use of oxygen during sleep.[50] In both the MRC study[5] and the NOTT,[6] there was a reduction in hematocrit in those treated with oxygen. Oxygen has not been

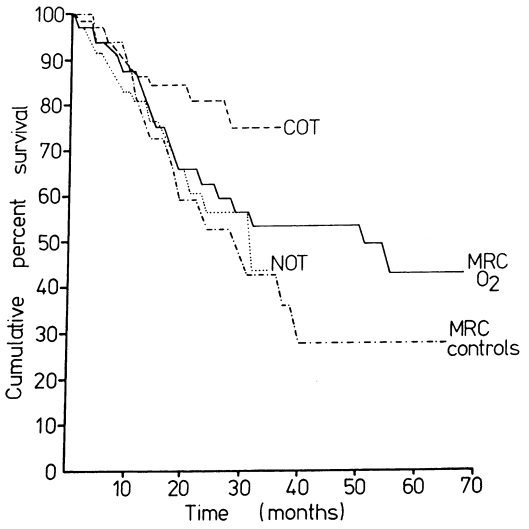

Figure 7–2 Combined results from the Medical Research Council study and Nocturnal Oxygen Therapy Trial showing survival during the study period. The effect of oxygen on survival was greatest in those who used continuous oxygen. Survival using nocturnal oxygen alone was similar to survival in those who used no oxygen. COT = continuous oxygen therapy; MRC O_2 = 15 hours per day of oxygen; NOT = nocturnal oxygen therapy alone (12 hours); MRC controls = no oxygen. (Reproduced with permission from Flenley DC. Chronic obstructive pulmonary disease. In: Cherniack NS. Oxygen therapy in the treatment of COPD. Philadelphia: WB Saunders Company, 1991:468–76.)

shown to have a significant effect on the neuropsychiatric problems that are often present in patients with chronic hypoxemia.[51] Similarly, even though quality of life is often impaired in these patients, the limited studies that have been performed do not show a beneficial effect.[4]

OXYGEN SUPPLY

Oxygen Supply Systems

Oxygen systems have developed over the last decade to better suit both the consumer and the provider (Tables 7–3 and 7–4). Systems are being designed smaller, with the user in mind, while at the same time conserving as much oxygen as possible to allow for the least amount of maintenance, refilling, and cost. Each system will be described with mention of the care and maintenance involved for the various delivery methods. It should be emphasized that the choice of the oxygen delivery system should be based on the patient's needs. However, funding structures may favor less expensive units to maximize profit for the provider. It is therefore incumbent on the prescriber to recommend a unit or to have a respiratory care practitioner assess patient suitability to different oxygen systems to help aid in the decision process. Many factors may be taken into account when deciding not only what is most therapeutic but also what best suits the individual and his/her lifestyle.

Concentrators

Oxygen concentrators are stationary units powered by electricity that produce a high concentration of oxygen from filtered room air (see Table 7–3, Figure 7–3).[26] Either a molecular sieve bed or a permeable plastic membrane is used to obtain nearly pure oxygen. The latter is used infrequently as it is less efficient at extracting the nitrogen from room air. Most manufacturers' specifications state that the oxygen concentrations that concentrators can produce are in the range of 92 to 96 percent, varying somewhat on the set flow rate. The FIO_2 obtained is inversely proportional to the flow rate used. Simply put, the faster the unit has to output oxygen, the less efficient the unit is at extracting all of the nitrogen. The molecular sieve also becomes less efficient with use, resulting in a reduction in FIO_2 generated as the concentrator ages (Figure 7–4).[52]

Concentrators are the most cost-efficient system as they require little maintenance and no refilling. A regular maintenance schedule is needed to monitor the oxygen concentration being produced, the accuracy of the flow rate (to change any necessary filters) and to check the operation of the battery, which operates the audible alarm to notify a power loss. Patients may often have the responsibility of washing an external gross particle filter. This should be performed weekly using a mild dish detergent, rinsing it, and thoroughly drying it before it is replaced. Weekly dusting of the exterior should also be performed with a damp cloth.

TABLE 7–3 Types of Oxygen Supply Systems

Type of Delivery System	*Advantages*	*Disadvantages*	*Application*
Concentrator (see Figure 7–3) A device that uses room air, filters out the nitrogen, and leaves nearly pure O_2 to be delivered to the patient	No fills required Cost efficient Low maintenance Easy to use Low pressure system No O_2 stored when not in use	Requires electricity Low flow range (1–3 Lpm or 1–5 Lpm) Not very portable (37–59 lb) Relatively noisy May generate heat Lower purity of O_2 Back-up system required	Often used in the home when portability is not required or as part of a dual system In rural areas
Cylinders (see Figure 7–5) Oxygen in the gaseous form compressed under a high pressure (2,000–2,200 psi) in an aluminum or steel tank	High flow rates possible Gas does not evaporate Quiet High purity of O_2 Aluminum is lightweight No electricity required	Usage time limited Steel cylinders are heavy Skill required to use and change regulator High-pressure system Special storage required	Smaller cylinders may be used for portability or for back-up for other systems
Liquid (see Figures 7–6 and 7–7) Oxygen stored in its liquid form in an insulated container. Available as a base unit and a portable unit	High storage volume of O_2. Quiet High purity of O_2 Able to transfill into portable units Lightweight portables Low pressure system (~ 25 psi)	Base units require filling Evaporates whether used or not Extremely cold in the liquid state Knowledge and skill required to transfill portables More expensive	Good for portability Can be used for devices requiring higher flow rates

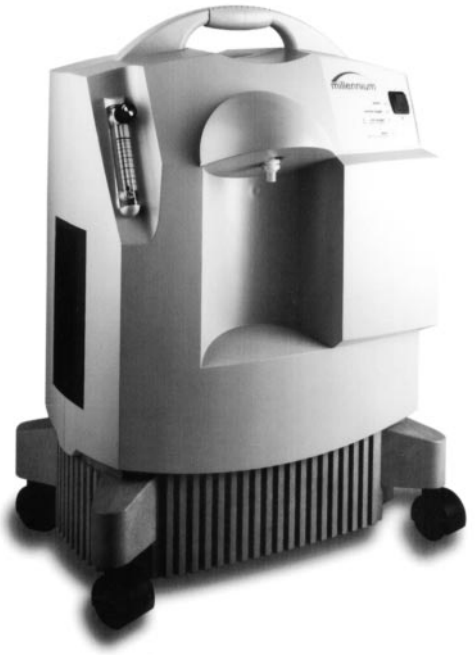

Figure 7–3 Oxygen concentrator (Millineum™). (Reproduced with permission from Respironics®, Pittsburg, PA.)

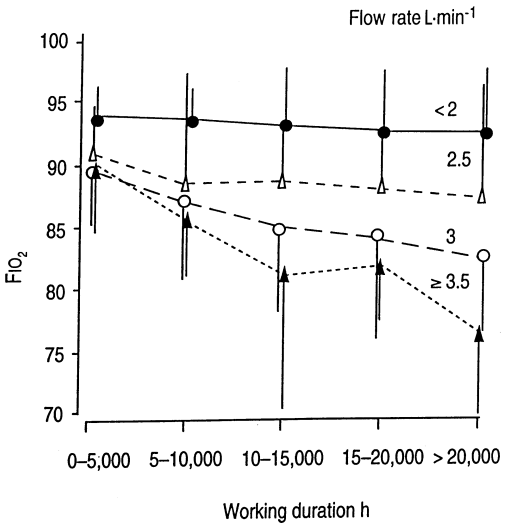

Figure 7–4 FIO_2 produced by oxygen concentrators. The FIO_2 is seen to vary with flow rate and with the working duration of the concentrator. (Reproduced with permission from Pepin JL, Dautzenberg B, Levy P, Brambilla C. What should we expect from an oxygen concentrator in 1995? Eur Respir Buyers 1995;1:21–6.)

TABLE 7–4 Types of Oxygen-Conserving Devices

Type of Delivery System	*Advantages*	*Disadvantages*	*Application*
Demand/pulse flow systems Oxygen is delivered intermittently during the respiratory cycle. Some deliver O_2 for a portion of inspiration, others throughout inspiration, and some either add a bolus of O_2 or use an algorithm of the set flow rate. Some may do this with each inspiration while others may skip breaths	Increases duration of O_2 supply Less drying/irritation of nasal mucosa Frequency of deliveries reduced Saves oxygen	Devices are expensive Synchronization with breathing pattern may be a concern Many require battery for power Cannot use humidification with unit May not oxygenate as well—patient-dependent variables	Can be used with cylinders or liquid units Greatly extends portability time and allows for smaller lighter O_2 portable units
Conserving cannulae Oxygen delivery devices that incorporate a reservoir that stores O_2 during exhalation and prior to inhalation. This provides a bolus for the next breath	May conserve O_2 by allowing for a lower flow rate to be used May improve oxygenation May increase portable time	Does not work when mouth breathing Obtrusive More expensive than regular nasal cannulae	When a system that may allow for lower flow rates than regular nasal cannulae is desired Refractory hypoxemia on regular nasal cannulae
Transtracheal system Oxygen delivered via a catheter inserted directly into the trachea	O_2 delivered throughout inspiration and expiration May provide effective oxygenation on lower flow rates Increases portable time Obliterates nasal complications Less obtrusive	Invasive Minor surgical procedure More costly to initiate and maintain Potential short- and long-term complications Requires knowledge and skill to care for device	Refractory hypoxemia Cosmetic reasons Noncompliance because of nasal cannulae Complications because of nasal cannulae
High-flow system (eg, Venturi masks, Vickers masks) Oxygen system that provides flow to meet or exceed inspiratory demand and provides a controlled FIO_2	FIO_2 constant irrespective of breathing pattern Able to provide high humidity	Often requires higher flow rates to drive the system Decreases duration of portable O_2 systems	When oxygen requirements exceed capability of low flow systems (ie, nasal cannulae) When hypercarbia/hypoxic drive is a concern Acute exacerbations
Low-flow system (eg, nasal cannulae, simple O_2 mask) The flow from the device does not meet the inspiratory flow rate. Room air is entrained along with the O_2 flow from the system. FIO_2 is variable and depends on the set flow rate and the respiratory pattern	Simple to use Nasal cannulae less obtrusive Can operate with devices that produce only low-flow oxygen Compatible with most home systems	Variable FIO_2 May not be sufficient to oxygenate Nasal cannulae can cause nasal complications	Often used in the home because of the convenience Less obtrusive than mask systems

Many new models of concentrators have the option of having a sensor to monitor the purity of the oxygen being produced. Some refer to it as an oxygen sensing device (Devilbiss™, Somerset, PA) or an oxygen percentage indicator (Respironics®, Pittsburg, PA). These sensing devices do not actually measure the oxygen concentration but use an alternate technology to reference the gas purity, which then translates into an electrical signal that feeds a warning light. The warning and alarm ranges are quite large and may not audibly alarm until oxygen concentration falls below 75%.

Many vendors will provide a concentrator for home use in conjunction with a second system to allow for portability. This will reduce the cost of the consumable oxygen and decrease the number of visits required to replenish stock. It is possible to travel with a concentrator, but assistance may be required to help move the unit. As long as electricity is available at the destination, the patient will have oxygen available. Provisions need to be made for portable oxygen to and from the destination as battery-operated concentrators require special electrical adapters to provide the power needed. It should be noted that patients have had concerns that concentrators produce unwanted noise (average 50 dBA) (Devilbiss™), that they might generate heat, which could be of concern in smaller rooms, and that they will increase the electricity bill. These issues should be discussed with patients prior to initiating treatment to allow for appropriate alternatives if necessary.

Oxygen concentrators commonly used to provide long-term oxygen in the home are an economical and safe method of oxygen delivery. When the unit is not running there is no oxygen stored in the system. The flow rate of oxygen is limited to the range of 1 to 5 liters per minute (Lpm), and it is a low-pressure system. Delivery devices that have a high resistance to flow (eg, mininebulizers or oxygen tubing more than approximately 50 feet in length) should not be used with concentrators as the added resistance makes it impossible for the concentrator to generate adequate flow to drive the device. Oxygen concentrators are best suited for use with nasal cannulae, although the lower FIO_2 range Venturi masks that require less than 5 Lpm of flow can be used with these units even though the resistance is greater than with nasal cannulae. It is important to note that the Venturi is based on the principle that the driving gas is 100% oxygen; the entrainment ratio of air produces the prescribed amount of oxygen. Since concentrators do not produce 100% oxygen, the entrainment ratio may result in a lower FIO_2 than desired. Hence, it is not only vital to maintain the concentrator efficiency but also to test the patient on the system he/she is using.

Cylinders

One of the first methods used to provide portable oxygen was via a steel cylinder that held many litres of oxygen compressed into it under a high pressure (see Table 7–3, Figure 7–5).[26] Pressures of 2,000 to 2,200 pounds per square inch (psi) are used, which allows for 690 L of gaseous oxygen to be held in an E size cylinder. This would be a typical size used in hospital as a source for transport or emergency. Cylinders under such high pressures pose a safety risk should the cylinder valve break. Hence, safe practice is essential not only with oxygen but also with the handling and storing of the cylinders. Cylinders should always be stored securely in the upright or horizontal position. For ambulation, a cart should be used to secure the cylinder. The cylinders are heavy and, depending on the size, can be quite cumbersome to maneuver. This may impede individuals from venturing far from their main source of oxygen and thus further disable them.

Figure 7–5 Three different size oxygen cylinders. E size (largest), D size, and M6 (smallest). (Reproduced with permission from VitalAire®, Edmonton, AB.)

Originally, large cylinders were used in the home as the primary oxygen source. This method fell out of favor as concentrators became popular. Cylinders may still be needed if high flow rates are required. Smaller cylinders are also often used as a back-up system of oxygen should the primary source fail. Recently, however, an increase in the use of cylinders for portability is occurring as cylinders are being made of aluminum, which is significantly lighter. They are also being made in several smaller sizes: D, M6, C, and so on. These attributes make them attractive for portable use but are limiting because of the smaller gaseous liter capacity (Table 7–5). However, when used in conjunction with a conserving device, the duration increases, making it a very attractive portable option.

Individuals using such a system do require some knowledge and skill to be able to operate the cylinder gauge. A pressure gauge is necessary to control the pressure and flow rate from the cylinder, and skill is required to change the gauge when the cylinder gas has been depleted. To make further use of cylinders applicable for ambulation, some concentrators allow for transfilling of the cylinder directly from the concentrator.

Liquid Oxygen

With the invention of fractional distillation of liquid air by Karl von Linde in 1907, the ability to store oxygen in a liquid form became possible.[26,53] The liquid form allows for the storage of large amounts of oxygen in a relatively small container (see Table 7–3). This is because of the expansion ratio of liquid to gaseous oxygen. One liquid liter of oxygen expands to approximately 862 gaseous liters of oxygen. Because of this expansion ratio, small portable units are able to provide substantial time away from a base unit of liquid oxygen supply. This attribute makes liquid oxygen an ideal method for ambulatory use (Figure 7–6).

Although the favorable characteristics of liquid oxygen make it attractive as a method of providing home oxygen, there are also some drawbacks that require careful attention. Oxygen in its liquid state

Figure 7–6 Individual using a liquid-filled oxygen stroller. (Reproduced with permission from VitalAire®.)

TABLE 7–5 Portable Oxygen Duration Time for D and E Size Cylinders (h)*

Oxygen Setting (Lpm)	*1*	*2*	*3*	*4*	*5*	*6*
Cylinder Pressure (psi)						
D size						
Full (2,000)	6	3	2	1½	1¼	1
¾ (1,500)	4½	½	1½	1	54 min.	45 min
½ (1,000)	3	1¼	1	45 min	36 min	30 min
¼ (500)	1½	45 min	30 min	22 min	18 min	15 min
E size						
Full (2,000)	10	5	3⅓	2½	2	1¾
¾ (1,500)	7½	3¾	2½	2	1½	1¼
½ (1,000)	5	2½	1¾	1¼	1	50 min
¼ (500)	2½	1¼	50 min	38 min	30 min	25 min

*Hours of duration may vary because of different factors. Always account for a safety margin or have a back-up.
Lpm = liter per minute.

Figure 7–7 Liquid oxygen base unit (Liberator). Stroller unit in position for filling. (Reproduced with permission from VitalAire®.)

Figure 7–8 Small lightweight liquid oxygen demand flow system (HELiOS™). (Reproduced with permission from Mallinckrodt, Mississauga, ON, Canada, Inc.®.)

has a temperature of –185°C and has to be maintained at this temperature to keep it from turning into gaseous form. Stainless steel, double-walled, vacuum-insulated containers are used to store the liquid oxygen at a pressure of approximately 25 psi (Figure 7–7). The containers act much like a thermos bottle trying to keep the liquid cold. As no thermos is perfect, some warming will occur, and there is a transfer from liquid to gas, resulting in a pressure increase in the container. Therefore, all liquid units are equipped with a pressure relief that continuously bleeds off gas as the liquid oxygen evaporates. The rate of transfer from liquid to gas is referred to as the normal evaporation rate. Because of this evaporation, even if liquid tanks are never turned on, all of the oxygen will eventually bleed out of the system.

Liquid oxygen tends to be more expensive than other delivery systems. The manufacturing of liquid oxygen, equipment required, and need for deliveries all add to the cost. One method of reducing costs is to use liquid oxygen in conjunction with pulse or demand flow devices to conserve the oxygen and increase the portable time. The best method to calculate how long liquid oxygen will last is by its weight; most systems have a gauge or a weight scale to indicate how much oxygen remains in the system (Table 7–6). New technology incorporating oxygen conservation devices has allowed the development of longer lasting, smaller, lighter weight, portable liquid oxygen canisters, which many patients find more convenient than the usual stroller and less conspicuous for use when walking (Figure 7–8).

Precaution needs to be taken because of the extremely low temperature of liquid oxygen. Contact with the eyes and skin must be avoided as burns are possible even after a brief exposure to liquid oxygen at this temperature. Skill is required to be able to transfill the portable unit from its base unit. Some individuals may not have the ability or the strength to be able to do this on their own. It may also be quite intimidating at first as the process of transfilling can be quite noisy. As for all oxygen systems, proper education with testing of patients and caregivers is essential to ensure that the equipment is used safely and effectively.

Oxygen-Conserving Devices

Conserving Cannula

Reservoir cannula would be a more appropriate name for this type of device, which consists of nasal cannulae, a reservoir, and lariat oxygen tubing (see Table 7–4).[54,55] The reservoirs store approximately 20 to 50 cc of oxygen. The reservoir fills during exhalation, and this oxygen store is accessed at the start of inspi-

TABLE 7–6 Portable Oxygen Duration Time for Liquid Oxygen Stroller (h)*

Oxygen Setting (Lpm)	*¼*	*½*	*¾*	*1*	*1½*	*2*	*2½*	*3*	*4*	*5*	*6*
Gauge contents											
Full	62	31	20	15	10	7	6	5	3	3	2½
¾	46	23	15	11	7	5	4	3¾	2¾	2½	1¾
½	31	15	10	7	5	3	3	2½	1¾	1½	1¼
¼	15	7	5	3	2	1¾	1½	1¼	¾	¾	½

*Hours of duration may vary because of different factors. Always account for a safety margin or have a back-up.

Lpm = liter per minute.

ration in addition to the usual oxygen flow through the nasal cannulae. With conserving cannulae, oxygen continues to flow throughout the respiratory cycle. Hence, oxygen is conserved only if the device allows for a lower flow rate. A lower flow rate may oxygenate as effectively as conventional cannulae because of the bolus received from the reservoir.

There are two types of conserving cannulae available. One provides the reservoir under the nose much like a moustache (Figure 7–9), and the other has a pendant further downstream in an attempt to reduce the obtrusive quality of such cannulae (Figure 7–10). The cannulae themselves are larger than usual nasal cannulae, and the weight and comfort of the devices can be a concern. They are more expensive than traditional nasal cannulae, but the savings in oxygen use may outweigh this cost.

The major problem with the reservoir cannulae occurs when the patient breathes through the mouth as the oxygen bolus is accessed only during nasal breathing. Mouth breathing negates the function of the reservoir, thus rendering the conserving cannulae's function similar to that of the standard nasal cannulae. This may become a significant concern only during exercise and sleep. If an increasing FIO_2 is needed, by providing better oxygenation the con-

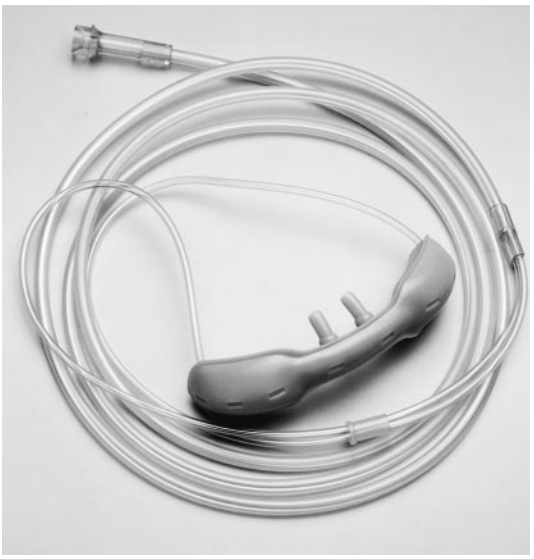

Figure 7–9 Oxymizer® moustache-type oxygen conserving cannulae. (Reproduced with permission from Chad® Therapeutics, Inc., Chatsworth, CA.)

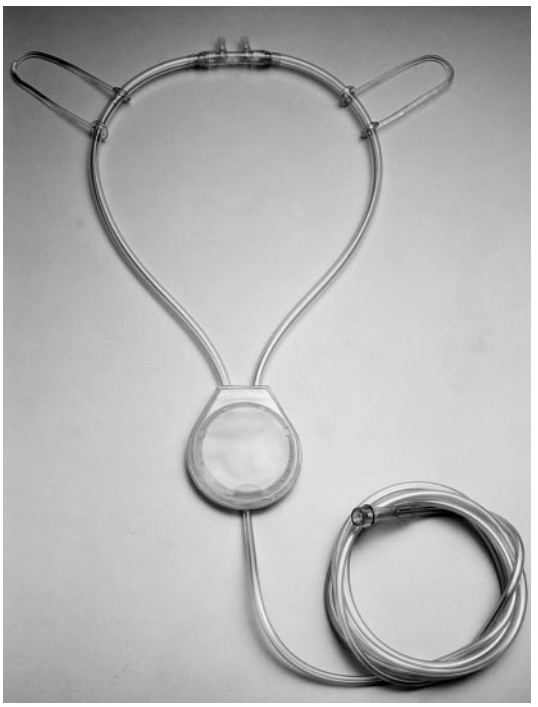

Figure 7–10 Oxymizer® pendant-type oxygen conserving cannulae. (Reproduced with permission from Chad® Therapeutics, Inc., Chatsworth, CA.)

serving cannulae may negate the need to change to a high-flow delivery system.

Pulsers and Demand Flow Systems

The duration for which portable liquid systems and gas cylinders provide oxygen is limited, but pulsers and demand flow systems may provide adequate ambulatory oxygenation for longer duration (see Table 7–4).[54,55] This reduces the amount of oxygen used and the cost of oxygen therapy.

Most pulsers provide a fixed bolus of oxygen at the start of each breath. The size of the bolus can be altered by changing the settings on the device. The size of the bolus differs with different systems, with the oxygen flow rate, and with the respiratory rate. Some pulsers do not provide oxygen with every breath in an attempt to conserve even more oxygen. Even though the volume of oxygen delivered varies with each device, the manufacturers generally claim that the effect on PaO_2 or SpO_2 is equivalent to continuous flow; however, the oxygenation achieved will vary with the different devices, and this variability is attributable at least in part to the size of the bolus. Changes in the pattern of breathing adopted by the patient will also alter the effectiveness of oxygenation with this type of delivery system. In some individuals, the respiratory effort may not be detected by the pulser. If this occurs, no oxygen will be delivered to the patient.

Demand flow systems deliver continuous flow throughout inspiration, often with a bolus of oxygen at the start of the breath. The continuous flow throughout inspiration may provide a greater volume of delivered oxygen than pulser-type devices.

Braun and colleagues assessed the effectiveness of five different oxygen-conserving systems during exercise in patients with COPD; the 12-minute walking distance, average SpO_2, and nadir SpO_2 differed with different conserving devices.[36] Roberts and colleagues compared a demand flow system with continuous flow in 15 patients with COPD.[56] Continuous oxygen provided better oxygenation during exercise. The time with SpO_2 less than 90% and the recovery time were both longer when the demand flow system was used.

The results of bench studies and clinical studies, as well as the differences between the systems provided by each manufacturer, reinforce the need to assess oxygenation with the prescribed delivery system. If the delivery system is changed, a dose-finding study must be performed to ensure effective oxygenation.

Transtracheal Oxygen Delivery

Transtracheal oxygen delivered by a catheter introduced directly into the trachea is a method of delivery that may be applicable for selected patients (see Table 7–4).[57] Continuous oxygen flow during exhalation results in a reservoir of oxygen in the upper airway before the start of the next inspiration, thus resulting in a higher initial FIO_2 and more effective oxygenation. Transtracheal oxygen delivery may be appropriate in those with refractory hypoxemia requiring very high oxygen flow rates.[58] In the United States, transtracheal oxygen is also frequently used for cosmetic reasons as it is less visible than nasal cannulae. In some patients, the fact that the oxygen system is not visible increases compliance with the prescription.

Several complications related to the use of the transtracheal catheter have been reported.[58] These risks include accidental displacement of the catheter, cough, increased sputum production, transitory hoarseness, formation of balls of mucus, and infection at the insertion site. Because of the invasive nature of the delivery system and the attendant risks, it should be used only in specialized respiratory centers where the health professionals are trained in the technique.[59]

WHEN TO REFER

Referral to a physician is essential to evaluate the patient's oxygen requirement. When possible, referral to a respirologist should be considered if long-term oxygen is considered for a patient with COPD. The aim is to ensure that optimal therapy including rehabilitation has been considered and that the patient is clinically stable. Blood gas analysis for determining eligibility should be performed in an accredited hospital-based laboratory. Specific assessments are also necessary to determine the correct dose for rest, sleep, activity, and exercise.

An oxygen vendor or regional/local government health organization will provide oxygen and the delivery equipment. As well, technical support and regular monitoring are provided at home by a team including respiratory/inhalation therapists and nurses. All provinces, states, or countries have programs for funding home oxygen. You may contact these programs or your Lung Association to obtain information regarding the available oxygen services in your area.

SUMMARY

Long-term oxygen therapy improves longevity in patients with COPD who are chronically hypoxemic; it may also decrease morbidity, decrease disability, and improve handicap in some patients. Oxygen should be considered as a pharmaceutical intervention and only one component of a comprehensive plan of management that includes the following: referral to a respiratory specialist, use of other prescribed medications, and pulmonary rehabilitation. The specific criteria for which funding is available for LTOT should be carefully defined based on scientific data from appropriate clinical trials. Only a small proportion of patients who do not meet these criteria seem to benefit from treatment with oxygen. A prescription for LTOT should outline the dose of oxygen for rest, sleep, activity, and exercise; the duration of continuous use; and the delivery devices required.

The delivery systems should be tailored to each patient so that effective correction of hypoxemia is obtained, while at the same time optimizing compliance with the use of oxygen. Ideally, home oxygen therapy should be used within a structured regional program that includes a regular home-based assessment of the patient and technical supervision of the apparatus. Equally important is regular clinical monitoring of oxygen-dependent patients by a multidisciplinary team under the supervision of a respirologist.

CASE STUDY

Ms. Cope, a 60-year-old female, presented for follow-up because of breathlessness.

Medical History, Physical Examination, and Test Results

Medical History

- Her breathlessness had gradually deteriorated over 10 years.
- She is a lifelong nonsmoker.
- She has alpha$_1$-antitrypsin deficiency.
- Self-care activities are not difficult, but household chores occasionally require a rest period; walking quickly results in breathlessness, and recreational activities such as gardening and camping are undertaken less frequently than in the past.
- She has had no previous acute exacerbations or previous need of antibiotics or corticosteroids.
- Medications taken include metered-dose inhalers: ipratropium two puffs four times a day and salbutamol two puffs as needed.

Physical Examination

- Her height is 168 cm and weight is 62 kg.
- She has no acute respiratory distress: pulse regular at 88 bpm and respiratory rate at 22/min.
- JVP (jugular venous pressure) is not elevated.
- Chest wall shows signs of accessory muscle activity, soft tissue indrawing, and hyperinflation.
- Diminished but equal breath sounds throughout
- Cardiac examination with pulmonic second sound is loud.
- She has no peripheral edema but shows the presence of cyanosis.

Test Results

- Hemoglobin is 173 g/L.
- Spirometry is indicative of moderately severe airflow obstruction:
  - FEV_1 1.3 L (48% of predicted)
  - Vital capacity (VC) 2.8 L (82% of predicted)
  - Lung volumes increased with diffusion impaired (diffusion capacity of the lung for carbon monoxide 21% of predicted)
- Chest radiograph shows hyperinflation with areas of diminished vascularity.
- Electrocardiogram shows sinus rhythm and P pulmonale.
- Echocardiogram shows normal right ventricular function and size. Pulmonary artery pressure could not be estimated.
- Oxygenation after optimal pharmacologic treatment is as follows:
  - Resting oximetry on room air showed SpO_2 88%
  - Blood gases showed pH 7.39, $PaCO_2$ 44 mm Hg, HCO_3, 25 mmol/L, PaO_2 52 mm Hg, and SaO_2 87%
  - Nocturnal oximetry showed SpO_2 less than 88% for 70% of the night. The nadir is 77% (Figure 7–11). Oxygenation during sleep is corrected by oxygen at 2 L/min.

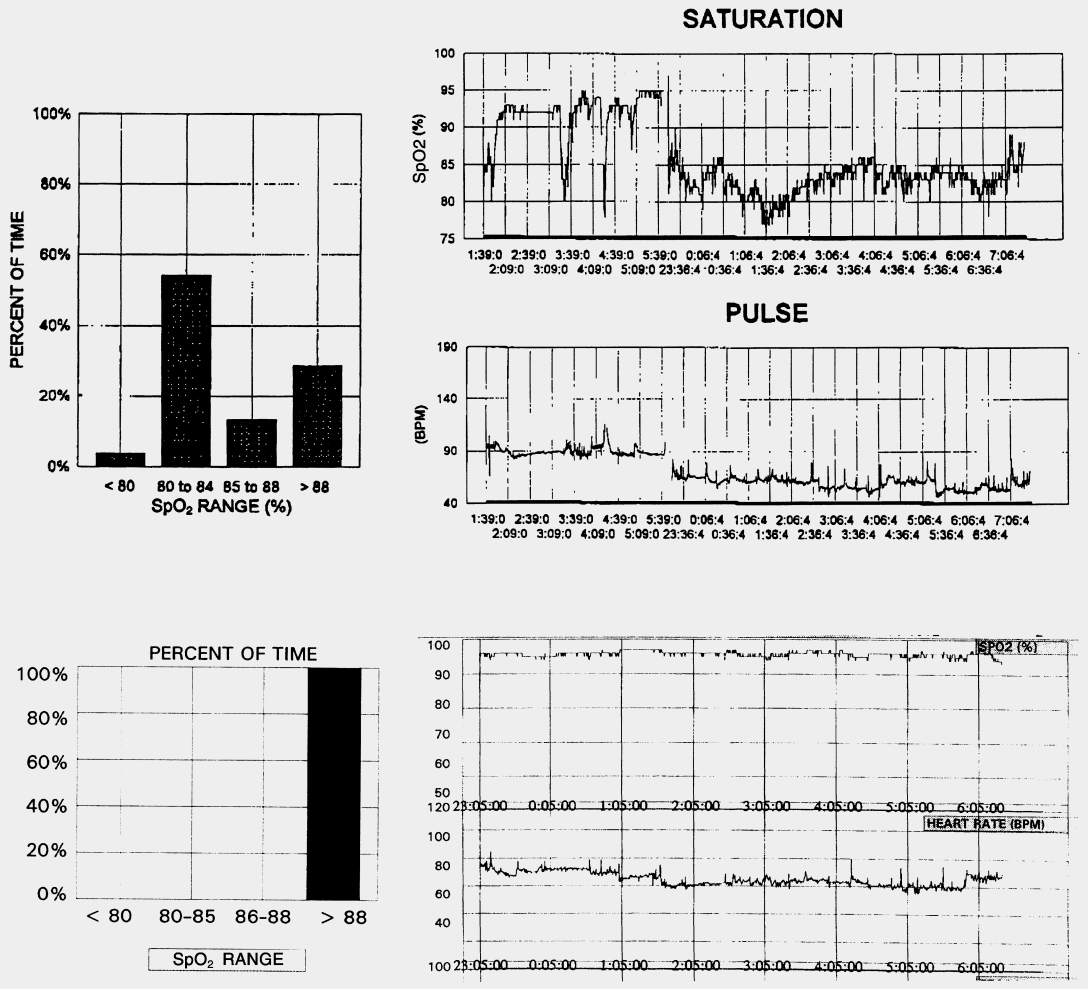

Figure 7–11 Results of nocturnal oximetry on room air and on continuous oxygen at 2 Lpm. The upper panel shows a histogram and continuous oximetry on room air, indicating significant hypoxemia with sleep. The lower panel shows a histogram and continuous oximetry on oxygen at 2 Lpm indicating complete correction of hypoxemia during sleep.

- Walk testing shows significant hypoxemia with walking, even on oxygen. Walking distance during a self-paced walk is 358 m on both 2 L/min and 4 L/min with similar hypoxemia and symptom scores on each occasion.

Questions and Discussion

Ms. Cope has emphysema secondary to α_1-antitrypsin deficiency. There is a family history of emphysema. The patient is in no acute respiratory distress. She described herself as being in her usual state of health, although her breathlessness has gradually become worse over 10 years.

Is there any urgency to prescribe oxygen?

This patient has a chronic respiratory condition without any evidence of an acute exacerbation. There is no urgency to prescribe oxygen, but it is more than

likely that she will benefit from long-term oxygen treatment; furthermore, considering a primary diagnosis of emphysema in this patient, you will have all of the reasons to expect a nonreversible airflow obstruction. Trials with different combinations of bronchodilators are unsuccessful in improving her breathlessness and her lung function tests.

What is the management that should be recommended in this patient?
Oxygen is indicated for long-term use. It is prescribed as follows: 1 L/min for rest and 2 L/min for sleep and exercise for a minimum of 15 h/day. A concentrator is prescribed with liquid oxygen for portability.

What is the patient's response to the treatment that included long-term oxygen?
After starting home oxygen, there is a noticeable improvement in sleep quality, a general feeling of improved health, and a lower heart rate with exercise. Her lips and fingers are no longer blue. She is more able to undertake activity, can sing with fewer pauses, and notices that her memory has improved. The liquid oxygen stroller caused some difficulty when she performed chores outside of the home.

Is there anything else that could be done for this patient?
You refer the patient for a formal comprehensive pulmonary rehabilitation program. Her 6-minute walking distance improves, as well as breathlessness on exertion. At the time of discharge from the rehabilitation program, the oxygen prescription remained at 1 L/min for rest and 2 L/min for sleep, activity, and exercise. Oxygen 2 L/min is recommended for the regimented exercise program.

Follow-up

One year later, her hemoglobin is 157 g/L, and lung function is unchanged. She is doing well, using oxygen as prescribed for 15 hours continuous, including sleep and for her exercise program.

Three years later, at age 63, further assessment takes place. There has been a slight decline in her ability to undertake activity.

Test Results

- The hemoglobin remains lower at 156 g/L.
- The electrocardiogram shows P pulmonale.
- Right ventricular size is normal but two-dimensional echocardiogram estimation of pulmonary artery pressure is 54 mm Hg.
- Pulmonary function shows FEV_1 1.3 L (50% of predicted) and VC 2.7 L (85% of predicted).
- Maximum 6-minute walking distance is well preserved at 475 meters.
- Oxygenation:
  - Room air SpO_2 is 81 to 82%
  - With walking, on room air SpO_2 falls to 65%; using oxygen at 4 L/min, resting SpO_2 is 96% and falls only to 82% with a 400-meter self-paced 6-minute walk. There is also reduction in symptom scores for both breathlessness and leg effort when walking on oxygen. When tested on continuous oxygen at 6 L/min, there is further correction of the low SpO_2 but no improvement in walking distance, heart rate, or symptoms of breathlessness and leg effort.

What are your recommendations with regard to the above changes?
It is recommended that oxygen be used for as much of the day as possible, but difficulty is still noted with undertaking tasks when having to pull or carry the liquid oxygen system. Liquid oxygen is therefore provided for ambulation using a HELiOS™ (Mallinkrodt, Mississauga, ON) system (see Figure 7–8) following testing to ensure that oxygenation is adequate. The oxygen prescription is 1 L/min for rest, 2 L/min for sleep, 4 L/min on the HELiOS™ demand flow system for exercise, and 2 L/min for simple activities. It is recommended that oxygen be used for as close to 24 hours of the day as possible.

What is the patient's response to the oxygen prescription?
The patient returned to the clinic praising the HELiOS. Her energy is increased, and walking is easier. The HELiOS with a belt pack allows for undertaking activities more easily as both hands are free for carrying garbage or groceries and for performing gardening or other activities (Figure 7–12). The result is that oxygen is used for much more of the day. The system also allows for longer portable use than the usual liquid oxygen stroller.

She continues to use oxygen with the concentrator overnight and with the HELiOS liquid oxygen system for ambulation and exercise. She maintains a regular exercise program and feels better now.

Figure 7–12 Individual using a small portable liquid demand flow oxygen unit (HELiOS™). (Reproduced with permission from Mallinkrodt, Mississauga, ON.)

KEY POINTS TO REMEMBER

- It is essential to ensure that patient treatment is optimized and the lung disease is stable prior to assessing the need for long-term oxygen treatment.
- Respirology assessment should include (1) pulmonary function testing; (2) arterial blood gases; (3) pulse oximetry during rest, sleep, activity, and exercise; (4) electrolytes and complete blood count; (5) ECG; and (6) echocardiogram to measure right ventricular function and PAP.
- There are well-established criteria supported by evidence in the medical literature as to when long-term oxygen treatment should be prescribed and what effect the patient should expect; there are also situations for which it is still unknown if correcting low arterial oxygen level will have an effect on the patient's health.
- Oxygen is a drug; the dose requires proper assessment for each time of day, that is, rest, sleep, activity, and exercise.
- Proper use by the patient is vital for effective therapy; teach the patients to ensure that they understand the proper use, safety, and role of oxygen; and make sure that you address the patient's concerns and fears.
- Long-term oxygen therapy assessment should include the appropriate oxygen system to best suit the patient's needs.

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SUGGESTED READINGS

Petty TL, Casaburi R. Recommendations of the Fifth Oxygen Consensus Conference. Respir Care 2000; 45:957–61. *This article presents the recommendations of a consensus development conference on the role of LTOT in the management of COPD.*

Respir Care 2000;45:29–245. Issues of January and February. *A series of articles that represent the proceedings of a state-of-the-art conference on LTOT held in 1999. Subjects covered include the effects of hypoxemia, the benefits of LTOT, the adverse effects of low flow oxygen, and the delivery devices that are available.*

Cairo JM, Pilbeam P. Mosby's respiratory care equipment. 6th ed. St. Louis, MO: Mosby, 1999. *This book provides a comprehensive guide of the methods available for the assessment of hypoxemia, and of the equipment available for the provision of home oxygen.*