Delivery Systems for Long-Term Oxygen Therapy

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Introduction

Oxygen was originally discovered by Joseph Priestley in 1774 and named by Lavoisier shortly thereafter.[1] For over 200 years there have been reports on the use of oxygen in the medical literature. However, it wasn't until 1888 that practical systems allowed oxygen delivery to became available on a widespread basis. Cylinders of compressed gaseous oxygen were introduced for medical as well as commercial use in 1888.[1] Liquid oxygen systems for hospital use became available in the early 1900s but it was not until the 1960s and 1970s that liquid oxygen for use outside the hospital became readily available. In 1974 the first oxygen concentrator was introduced for delivery of home oxygen therapy.[1] Today three systems (gas cylinders, liquid oxygen systems, and oxygen concentrators) are available for delivery of long-term oxygen therapy (LTOT) in the home.

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Gas Cylinders

In spite of gas cylinders being large, awkward, and heavy, they remain the primary method of providing LTOT worldwide. However, in the United States, most would consider them second in frequency, behind oxygen concentrators. This discrepancy is essentially based on the relationship between the cost of labor versus the cost of technology in a given country. In the highly developed countries of North America, Western Europe, and Japan, the use of cylinders in the home is low, estimated at $\leq$ 10% of total home LTOT use. In less developed countries, where labor costs are lower but technology costs are higher, cylinders are the primary method of providing ($>$ 90%) home oxygen therapy.

Available Cylinder Sizes

As illustrated in Figure 1, there are numerous different cylinder sizes available for home use, ranging from the

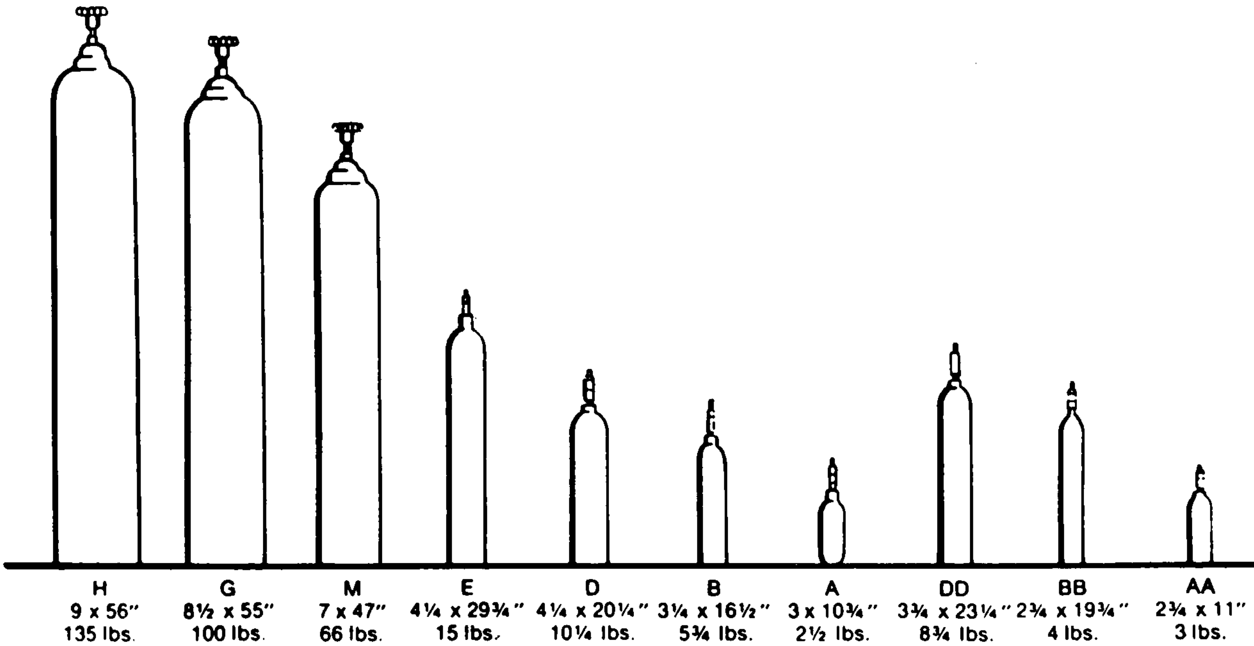

Fig. 1. Letter designation and approximate dimensions of high-pressure medical gas cylinders. (From Reference 2, with permission.)

very large H cylinders to the quite small A cylinders.[2] In addition to the sizes mentioned in Figure 1, many manufacturers have developed alternative sizes of small portable cylinders. Specifically for use in the home, many manufacturers have developed aluminum cylinders that are $<$ 50% of the weight of similar size steel cylinders (Fig. 2). In spite of the size variability, the biggest problem associated with cylinders is their limited gas volume. As shown in Table 1, even the large H cylinders can provide a continuous oxygen flow of 2 L/min for only slightly longer than 2 days. As a result, patients with H cylinders in the home must have adequate space to store several cylinders, so as to limit cylinder delivery to once a week.

An additional problem with cylinders is changing the regulator from one cylinder to the next. This task is considered formidable by many hospital staff and can be daunting for patients and family. Storage and maintenance of compressed gas cylinders in the home also present the same hazards that exist in the hospital: concern regarding fire hazard, avoidance of the use of oils or grease near the cylinders, and care in handling the cylinders to avoid injury from the weight of the cylinder or as a result of fracture of the cylinder stem.

Fig. 2. Aluminum oxygen cylinders for home use. (Courtesy of Invacare, Elyria, Ohio.)

Duration of Flow

As a result of the limited gas volume in cylinders, it is critical that the duration of flow be accurately estimated regardless of cylinder size. Table 2 shows the two formulas needed to estimate the duration of flow from any cylinder.[3] A duration of flow factor for specific cylinder sizes can be determined by multiplying the number of cubic feet present in a cylinder by 28.3 L/ft^3 (to convert cubic feet to

Table 1. Duration of Oxygen Flow from Cylinders at 2 L/min

Size	Factor	Liters	Time
H	3.14	6908	57 h, 33 min
G	2.41	5302	44 h, 11 min
M	1.65	3625	30 h, 12 min
E	0.28	616	5 h, 8 min
D	0.16	352	2 h, 56 min
B	0.068	150	1 h, 15 min
A	0.035	76	38 min

liters) and then dividing the result by the maximum cylinder operating pressure. The duration of flow factors for all common cylinder sizes are listed in Table 1.[3] To determine how long a cylinder will last at a given flow, the pounds per square inch (psi) pressure in the cylinder is multiplied by the duration of flow factor and then divided by the set liter flow. As illustrated in Table 1, the duration of flow with small cylinder sizes at 2 L/min is extremely short. A D size cylinder will last only 2 hours and 56 minutes at 2 L/min.[4]

Advantages of Gas Cylinders

Gas cylinders always provide 100% oxygen and are capable of delivering whatever liter flow is indicated to meet the oxygenation requirements of a given patient. Regardless of the type of oxygen therapy equipment in the home, gas cylinders are capable of providing the driving pressure necessary for operation. In addition, gas cylinders are universally available.

Liquid Oxygen

The use of liquid oxygen has been promoted based on the ability of these systems to contain a very large reservoir of gas in a very small space (Fig. 3), because 1 ft^3 of liquid oxygen is equal to 860.6 ft^3 (24,355 L) of gaseous oxygen.[3] A more convenient relationship is that 1 L of liquid oxygen equals 840 L of gaseous oxygen. A typical

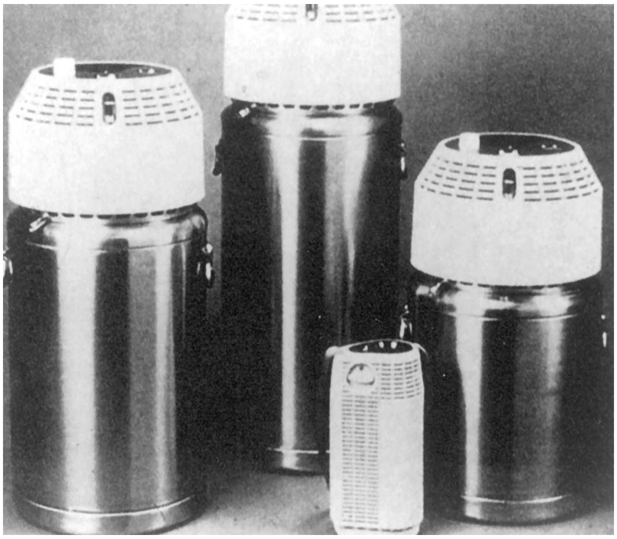

Fig. 3. Typical stationary liquid oxygen system with a portable liquid oxygen system. (Courtesy of Mallinckrodt, Pleasanton, California.)

home liquid oxygen system contains at maximum about 40 L of liquid oxygen (33,600 L of gaseous oxygen). At 2 L/min that system will provide oxygen for $>$ 11 days. An additional advantage of liquid oxygen systems is that every manufacturer of these systems also provides portable liquid oxygen systems that can be transfilled from the in-home stationary system.[1,5,6] Today most in-home stationary systems are relatively compact and have wheels that allow some mobility about the house.

Operation of Liquid Oxygen Systems

In-home liquid oxygen systems are essentially a miniaturized version of the large liquid oxygen reservoirs used by hospitals. The container is designed like a thermos bottle to prevent heat transfer, keeping the liquid at –297.3° F.[7] As with all thermos bottles, the insulating capability is not perfect and there is continual loss of oxygen if not in use. Loss from most systems is estimated at 0.055 lbs/h or 40–50 L of gaseous oxygen per hour.[4] Typically, the pressure over the liquid oxygen in these systems is 20 psi.[4]

Figure 4 illustrates the structure of a home liquid oxygen reservoir system. These units incorporate a flow control valve for direct delivery of oxygen and a quick-connect attachment with which to fill small portable liquid oxygen systems (Fig. 5). The direct flow of oxygen from the unit is provided from the gas sitting over the liquid via an economizer valve and warming coils that lead to the flow control valve.[4–6] When the gas pressure over the liquid decreases to 0.5 psi, the economizer valve closes and liquid oxygen is drawn up the liquid withdrawal tube through the vaporizing and warming coils where it is con-

Table 2. Determination of Available Flow from Gas Cylinder

Calculation of L/psi conversion factor	$\text{Conversion factor} = \dfrac{\text{(cu ft full) (28.3 L/cu ft)}}{\text{psi full}}$
Example: H cylinder	$3.14\ \text{L/psi} = \dfrac{\text{(344 cu ft) (28.3 L/cu ft)}}{\text{2200 psi}}$
Duration of Flow Formula	$\text{Minutes} = \dfrac{\text{(psi) (factor)}}{\text{flow}}$
Example: H cylinder	$2355\ \text{min (39 h 15 min)} = \dfrac{\text{(1500 psi) (3.14)}}{\text{2 L/min}}$

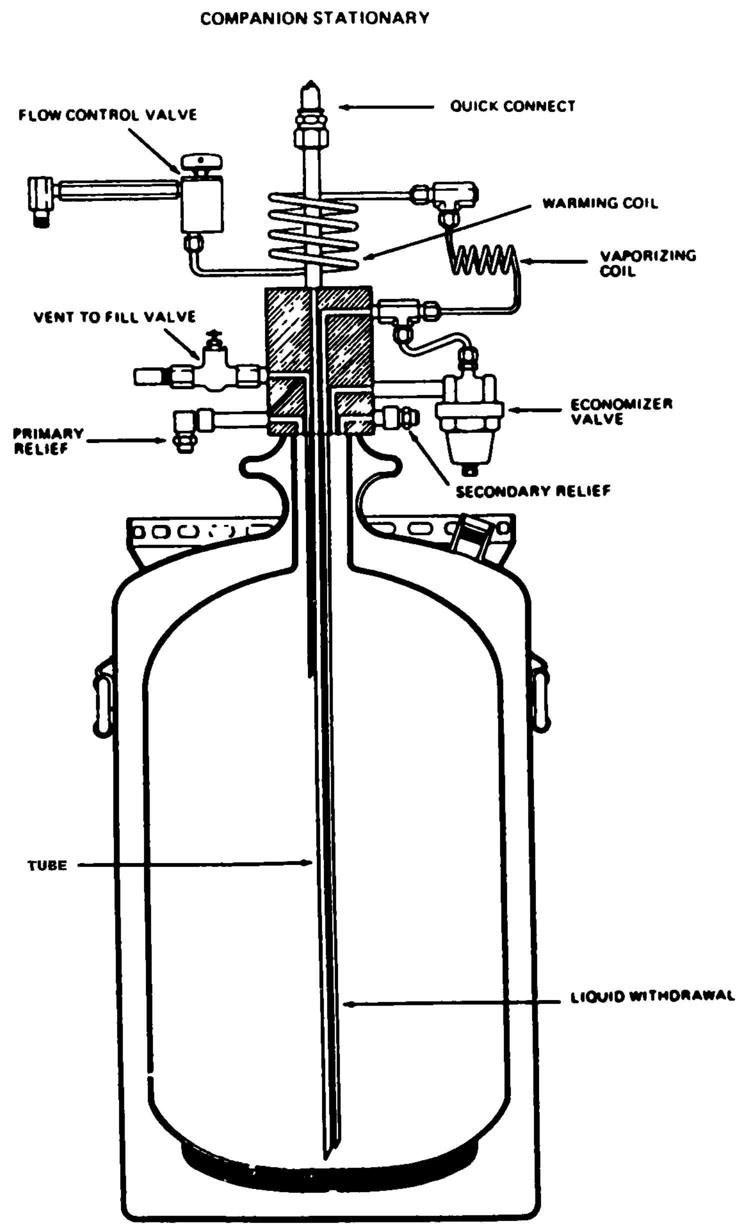

Fig. 4. Structure of a stationary liquid oxygen container. See text for discussion (Courtesy of Mallinckrodt, Pleasanton, California.)

verted to a gas. As a result, a constant flow of oxygen is maintained. When not in use, gas formed by evaporation is released from the primary pressure relief valve (2 psi over maximum working pressure) or the secondary pressure relief valve (10 psi over maximum working pressure) if the primary valve fails.[4–6]

Advantages/Disadvantages

Liquid oxygen systems have the advantage of storing a large quantity of 100% oxygen in a small place. They also allow for moderate gas flows of ≤ 8 L/min and all have small companion portable systems.[7] However, many home care providers consider liquid oxygen systems very expensive. The capital investment is very high. Not only must the actual reservoir and portable unit be purchased, but trucks capable of transporting liquid oxygen must also be purchased. In addition, labor costs are high since most of these units must be filled every 10–14 days. Transfilling of portable liquid oxygen systems (see Fig. 5) is complex and frightening to many patients. Thermal burns are possible during transfilling,[6,7] and there is the potential of

Fig. 5. Transfilling of a portable liquid oxygen system. (From Reference 1, with permission.)

Fig. 6. Typical oxygen concentrators. (Courtesy of Invacare, Elyria, Ohio.)

liquid oxygen exiting the unit during prolonged high-flow use, which can also lead to thermal burns. Spillage of liquid oxygen is possible if the unit is tipped. Also, during transfilling and high-flow use, units may freeze, preventing further operation.[4–7]

Concentrators

The most commonly used home oxygen delivery system in the United States is the oxygen concentrator (Fig. 6). Currently, at least a half dozen companies manufacture oxygen concentrators. Figure 7 shows a schematic of a typical oxygen concentrator.[8] Room air is drawn into the unit through a series of particle filters, into a compressor, through an additional particle filter, then to a heat exchanger to dissipate the heat of compression.[4,8] Gas is then directed to one of a series of molecular sieve beds by a solenoid controller. Within the molecular sieve, room air is separated into oxygen and nitrogen plus trace gases.[4,7,8] This is accomplished by granular crystal zeolite, which is approximately 5 angstroms in diameter. Zeolite can separate gases based on size and polarity. The concentrated oxygen is stored in a small cylinder for delivery to a flow meter. When a sieve bed is filled, room air is diverted to another bed while nitrogen and other gases are exhausted to the atmosphere.[4,5]

Oxygen concentrators are able to deliver high oxygen concentrations but not 100% oxygen.[9–11] As shown in Table 3, the fraction of inspired oxygen (F_{IO_2}) depends on the flow rate. Flow rates of $\leq$ 2 L/min are most efficient in maintaining high oxygen concentration.[12]

Oxygen Enricher

An alternative approach to providing oxygen from room air is the oxygen enricher.[1,4,7] Although there still are a few of these devices in use, I do not believe anyone is manufacturing them today. The major difference between concentrators and enrichers is the concentration of oxygen available. With concentrators the F_{IO_2} is generally $\geq$ 90%, but with enrichers the F_{IO_2} is about 40%.[7] As a result, only the equivalent of about 2 L/min of oxygen is available. The recommendation is to set the delivered flow 3 times the desired setting with 100% oxygen.[1] That is, if 2 L/min of oxygen is prescribed, a flow of 6 L/min is set on the enricher.

The difference in F_{IO_2} is based on the mechanism of action. Enrichers separate oxygen and water vapor from other environmental gases by diffusion across a 1-mm-thick plastic membrane.[3,4,7] One advantage of the enricher is that it also concentrates water vapor to 3 times the ambient level.[4] In actual operation, water vapor has to be removed from the filtered gas prior to delivery to the patient. It was the inability of enrichers to provide an $F_{IO_2} > 0.40$ that drove them from the market.

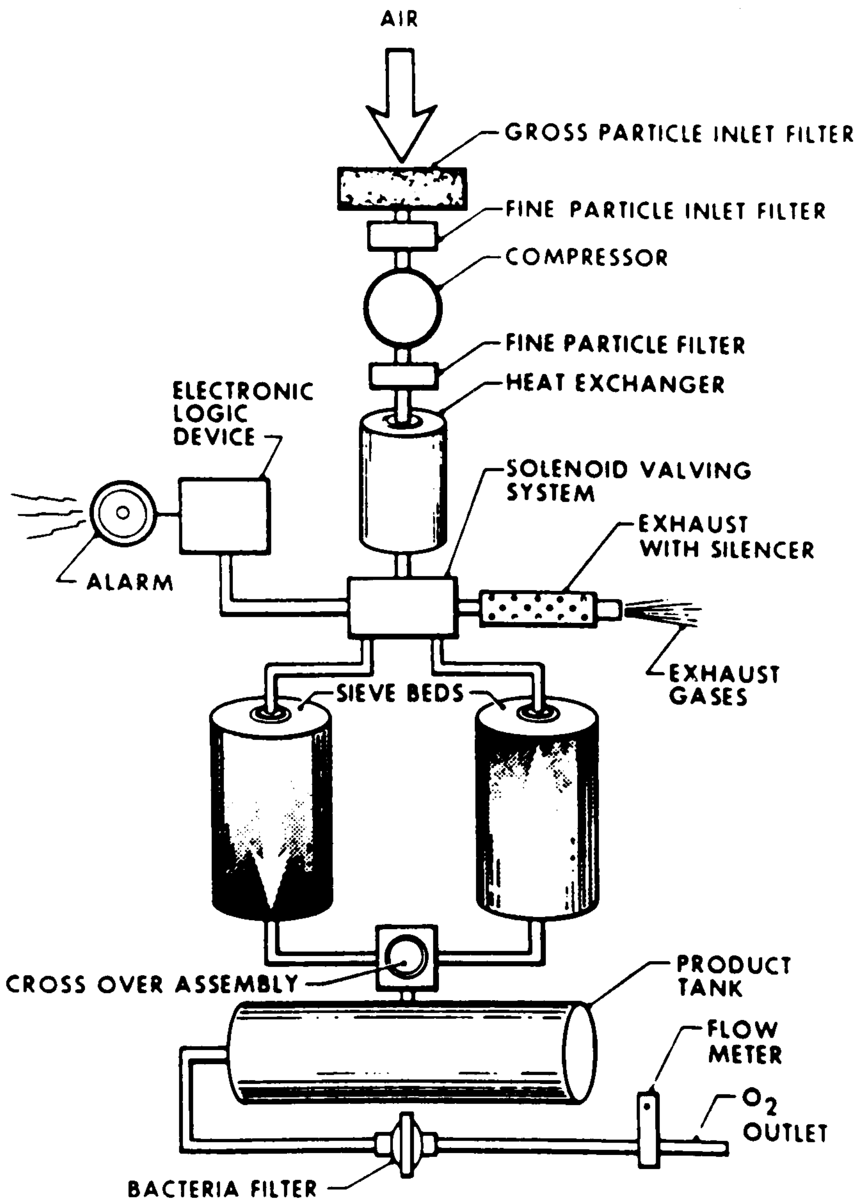

Fig. 7. Molecular sieve oxygen concentrator. See text for discussion. (From Reference 8, with permission.)

Portable Systems

Although all home oxygen delivery systems can be classified as moveable, a truly portable system requires very specific features. These systems must be both lightweight and compact, and capable of providing oxygen for extended periods. At least theoretically, all three delivery

Table 3. Output of Oxygen Concentrators

Liter Flow	Concentration
≤ 2 L/min	$F_{IO_2} \geq 0.95$
3–5 L/min	$F_{IO_2} \geq 0.90$
> 5 L/min	$F_{IO_2} < 0.90$

Table 4. Portable Oxygen Therapy Delivery Systems

System	Weight	Maximum Duration of Flow at 2 L/min
Gas tank (aluminum E cylinder)	7.5 lbs	5 h, 8 min
Liquid oxygen (1 L system)	4–7 lbs	7 h
Concentrator	≤ 30 lbs	Depends on battery size

systems (cylinders, liquid oxygen, and concentrators) can be portable. Table 4 compares the three approaches.

Oxygen Cylinders

Again, worldwide as well as in the United States, small oxygen cylinders are the most common method of providing portable oxygen. From a practical perspective, portable oxygen cylinders should be of E size to ensure that oxygen therapy is available for an extended period. With an E-size cylinder, a maximum of 5 hours of oxygen at 2 L/min is available. As shown in Figure 8, a major problem with portable gas cylinders is size and ease of movement. Although portable gas cylinders can be made lighter, they cannot be made smaller. As discussed in other papers of this conference, some patients requiring oxygen therapy have poor self-images and are concerned about the reaction of the public to their need for oxygen. As stated by Thomas Petty at this conference, patients having to "schlep" an E cylinder around tend to draw attention to themselves. As shown in Figure 1 and Table 1, smaller cylinders, which can be carried in a backpack, are available but, of course, their flow duration is very limited.

Liquid Oxygen System

Liquid oxygen systems would seem the ideal portable oxygen delivery system. They are small, compact, can carry a large volume of oxygen in a small space, and many incorporate oxygen-conserving devices (Fig. 9). As shown in Table 4, the typical portable liquid oxygen system holds 1 L of liquid oxygen (840 L of gaseous oxygen), weighs 4–7 lbs, and is capable of providing oxygen at 2 L/min for a maximum of 7 hours.[1,3] Much longer times are available if an oxygen-conserving device is included.[6] Other portable liquid oxygen systems hold 1.5 L of liquid oxygen, increasing the system weight by about 40% but also increasing the duration of available 2 L/min oxygen flow to over 10 hours.

The primary drawback to liquid oxygen systems is cost of operation. The capital cost, ongoing labor costs, and continually decreasing reimbursement for home oxygen therapy have reduced the percentage of patients using liquid oxygen systems in the United States to $<$ 10% and have prevented liquid oxygen systems from being introduced into many parts of the world.

Concentrators

Although at first discussion it would not seem feasible to use a concentrator for portable oxygen, portable systems are nevertheless available (Fig. 10).[1] Size and weight are of primary concern with these systems. However, airlines now have access to concentrators that can be placed under the patient's airplane seat. Even smaller concentrators will probably become available, making them yet more portable, and when this occurs, the primary limitation of these systems will be battery life. Once a lightweight, long-duration, rapidly-rechargeable, inexpensive battery is available, I would expect concentrators will become the standard for portable oxygen therapy.

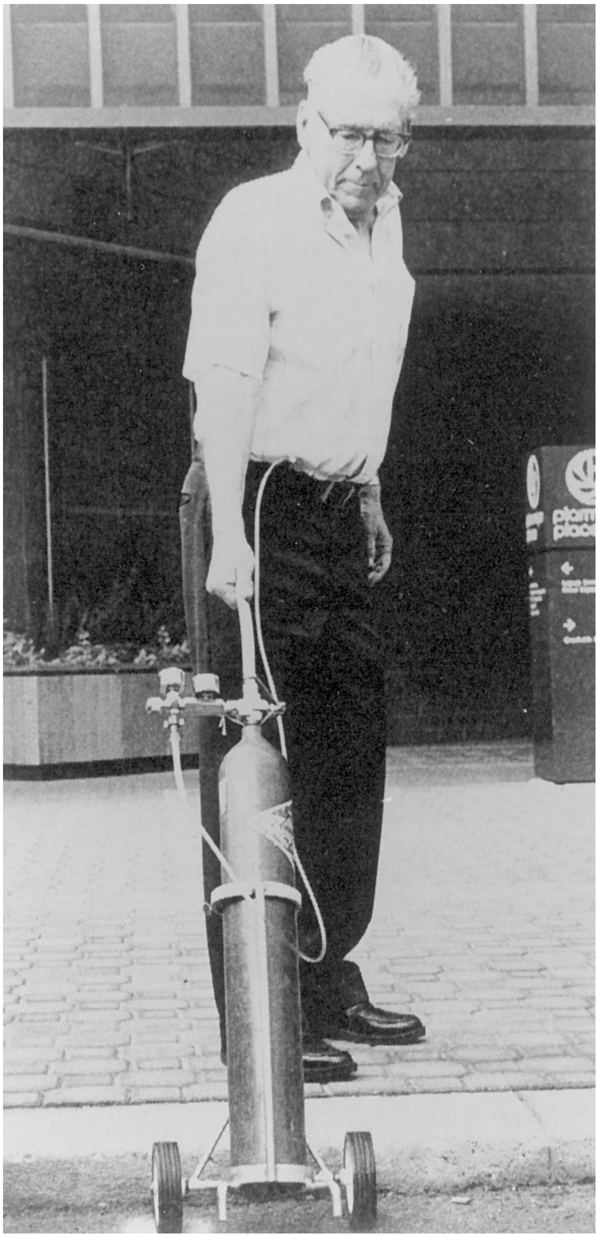

Fig. 8. Portable oxygen E cylinder. (From Reference 1, with permission.)

Innovation

As with all aspects of medicine, ongoing research to improve home oxygen delivery systems is active. The most

Fig. 9. Portable liquid oxygen system. (Courtesy of Mallinckrodt, Pleasanton, California.)

recent innovation is depicted in Figure 11.[13] Two companies make oxygen concentrators that are also able to fill portable oxygen cylinders. This ability greatly reduces the cost and inconvenience of portable systems. It can be expected that additional such systems, operating more efficiently, will be available in the future.

In addition, there is at least one group working on an oxygen concentrator system capable of producing liquid oxygen while gaseous oxygen is delivered to the patient (personal communication, Thomas Petty, 1999). This system may be many years from general clinical use, but does demonstrate the ongoing innovation in this area.

A number of groups have also developed or are developing systems connecting the home unit to the home care company or physician by telemetry.[13] Information regarding the operation of the equipment, compliance with the prescription, and need for preventive maintenance can easily be provided. In addition, information about the patient's clinical status could be made available. Although there are problems with pulse oximetry, continued innovation in this technology may make oximeters suitable for periodic telemetric monitoring of patients in the home. In addition, heart rate, respiratory rate, and breath sounds could be made available via telemetry. It can be expected that over the next 10 years considerable innovation in the area of home oxygen delivery systems will be introduced,

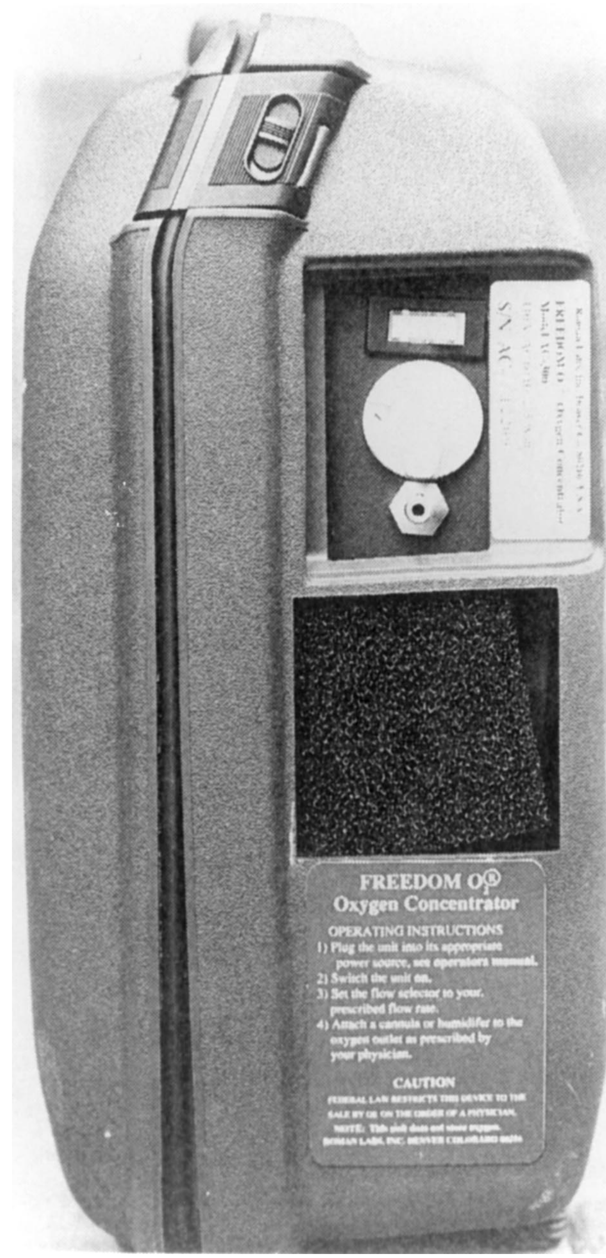

Fig. 10. Portable oxygen concentrator. (From Reference 1, with permission.)

since the number of patients at home on LTOT therapy is increasing. At this meeting, it was estimated by Patrick Dunne and Thomas Petty that about 750,000–1 million Americans currently receive home oxygen therapy.

Summary

Table 5 summarizes my current perspective on home oxygen delivery systems in the United States. As I already indicated, scoring for cost and labor may be very different in other countries. As noted, all things considered, today

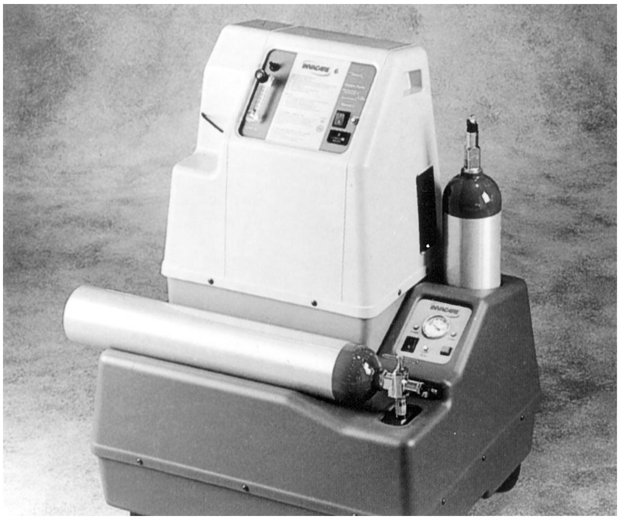

Fig. 11. Oxygen concentrator capable of transfilling an oxygen cylinder. (Courtesy of Invacare, Elyria, Ohio.)

Table 5. Comparison of Home Oxygen Therapy Delivery Systems

	Cylinder	Liquid Oxygen	Concentrator
F_{IO_2}	+++	+++	+
Liter flow	+++	++	+
Portability	++	+++	+
Labor requirements	+	++	+++
Cost	+	+	+++
Innovation	+	++	+++
Ease of use	++	+	+++
Hazard potential	++	+	+++
Total score	15	15	18

+++ Highest, most favorable score
+ Lowest, least favorable score

the most reasonable system for home oxygen therapy is the concentrator. Problems with F_{IO_2}, liter flow, and portability are clearly overshadowed by cost, labor, ease of use, and lack of potential hazard, as well as potential for future innovation. I would expect with future development that the concentrator will score higher on F_{IO_2}, liter flow, and portability. As a result of the anticipated large number of patients worldwide expected to require home oxygen therapy, ongoing improvement in this technology will be evident in the next few years.

REFERENCES

1. Christopher KL. Long term oxygen therapy. In: Pierson DJ, Kacmarek RM, editors. Foundations of respiratory care. New York: Churchill Livingstone; 1992:1155–1174.
2. Ward JJ. Equipment for mixed gas and oxygen therapy. In: Barnes TA, editor. Core textbook of respiratory care practice, 2nd ed. St Louis: Mosby; 1994:353–440.
3. Kacmarek RM. Supplimental oxygen and other medical gas therapy. In: Pierson DJ, Kacmarek RM, editors. Foundations of respiratory care. New York: Churchill Livingstone; 1992:859–890.
4. Langenderfer R, Branson RD. Compressed gases: manufacture, storage, and piping systems. In: Branson RD, Hess D, Chatburn RL, editors. Respiratory care equipment, 2nd ed. Philadelphia: Lippincott; 21–54.
5. Ward J. Medical gas therapy. In: Burton GG, Hodgkin JE, Ward JJ. Respiratory care: a guide to clinical practice. Philadelphia: Lippincott; 1997:335–404.
6. Thalken R. Production, storage and delivery of medical gases. In: Scanlan CG, Spearman CB, Sheldon RL. Egan's fundamentals of respiratory care, 6th ed. St Louis: Mosby; 1995:633–655.
7. Kacmarek RM. Oxygen delivery systems for long-term oxygen therapy. In: O'Donohue WV, editor. Long term oxygen therapy. New York: Marcel Dekker; 1995:219–234.
8. Lucas J, Golish J, Sheeper G, O'Rayne J. Home respiratory care. East Norwalk CT: Appleton & Lange; 1987.
9. Johns DP, Rochford PD, Streeton JA. Evaluation of six oxygen concentrators. Thorax 1985;40(11):806–810.
10. Gould GA, Scott W, Hayhurst MD, Flenley DC. Technical and clinical assessment of oxygen concentrators. Thorax 1985;40(23):811–813.
11. Bongard JP, Pahud C, De Haller R. Insufficient oxygen concentration obtained at domiciliary controls of eighteen concentrators. Eur Respiratory J 1989;2(3):280–282.
12. Evans TW, Waterhouse J, Howard P. Clinical experience with the oxygen concentrator. Br Med J (Clin Res Ed) 1983;287(6390):459–461.
13. Invacare Corporation Product Literature, Form No. 98–47, Elyria, Ohio, 1998.

Discussion

MacIntyre: How dangerous are tank or liquid oxygen systems? Do they ever fall over and have connectors break off, or do the liquids ever explode? Are there any fires?

Kacmarek: If you go back to the literature of the 1960s and 1970s reporting instances where tanks fell, at that time huge regulators were used, and if they fell with enough force, the top of the cylinder was reported to break off. The cylinder acted like a torpedo and could go through a wall. Although I do not know of any *recent* report of this problem, it is clearly a possibility.

MacIntyre: There are no reports of people in the home having these things.

Kacmarek: I don't know of *any* recent reports. Do any of you know of a liquid oxygen system in the home exploding?

O'Donohue: Trucks mostly—one that burned and caused a nearby house fire.

Kacmarek: OK. What happened?

O'Donohue: Recently, a truck that was transporting liquid oxygen and was possibly leaking oxygen or may not have had the oxygen system properly closed was involved in a fire that destroyed a nearby home.

Kacmarek: This was a home delivery truck?

O'Donohue: Yes, a liquid oxygen delivery truck.

Kacmarek: Theoretically, the same thing could happen to delivery trucks going to the hospital, the large liquid oxygen trucks.

McLellan: That has happened more with large delivery vehicles where an individual has gotten into a vehicle after it has been sitting for a period of time. You know, liquid oxygen has a tendency to evaporate; they call that a normal evaporation time. Lighting a cigarette upon entering the vehicle is somewhat of a contraindication.

Kacmarek: Wasn't there a situation in Boston where an oxygen truck caught on fire? I believe I heard it on the news. But as far as problems in patients' homes, I do not know of any recent reports, or within a hospital setting, for that matter.

McLellan: We occasionally receive cannulas that have been burned. Generally, the problem is on the last second or third drag of a cigarette, when it becomes very short, toward the end of the nasal cannula is when it begins to melt. The only difference between a liquid oxygen system and a concentrator is that the pressure at which air exits a liquid is a little bit higher than when it comes out of a concentrator, and it serves as a fuse. The cannula serves as more of a fuse coming from a liquid oxygen system versus a cannula. It burns quicker coming from a liquid system. But as far as it actually entering the device and exploding, that has never happened.

Kacmarek: But you are relaying a user problem. That isn't an equipment problem—no malfunctioning of the equipment. This is clearly an avoidable problem.

Dunne: Nice overview, Bob. However, an important point that you might consider in your summary slide is the ease of use of a concentrator by the medically naive user or caregiver. I would argue that the ease of use of the concentrator probably warrants a few more pluses. However, I do have a more provocative question. For about two or three years now the buzz with concentrators has been that some type of oxygen-sensing technology should be included as a standard feature. Do you have any thoughts about whether or not that should be mandated?

Kacmarek: As you know, most companies who make concentrators do have oxygen-sensing devices that can be an option. It seems to me a useful option, but does the problem of inadequate F_{IO_2} still exist? I ask the manufacturers (perhaps they'd like to comment) how likely with today's systems is failure to produce the target F_{IO_2}? Clearly, if filters are not changed and they clog and you cannot draw in room air at the appropriate rate, the efficiency of the concentrator is decreased considerably. However, I'm led to believe that the efficiency of operations of today's concentrators is much better than it was 20 years ago and that the problems that we saw then are not problems that exist now on a regular basis. But I'd ask people who know better than me to comment.

McLellan: Excellent material. In regard to the telemonitoring, several manufacturers are obviously moving forward with projects to telemonitor liquid as well as concentrator devices. Do you see any issues that might occur in the future as a result of monitoring? Is the physician going to be liable if he knowingly is aware of a patient who does not use oxygen in the home? I mean, what sort of implications is this going to have, perhaps, down the road? When a home care provider obviously knowingly continues to bill for oxygen therapy in those patients not using it.

Kacmarek: That same problem exists today. If the therapist going into the home knows that a patient has been ordered oxygen therapy for the last 6 months or a year, and the concentrator is always in the closet and obviously is not being used, and that patient is being continuously charged, it is a clear case of fraud as far as I'm concerned. I'm sure it will be considered fraud and abuse in the future, even more so if you have specific data to imply that this patient is simply *not* utilizing the device. Now, the liability issue—I really don't have any idea how that would come into play. As you talk to patients and discuss their compliance with most anything that is ordered, it is nowhere near the level of compliance that anybody would expect from a given patient. Every time you put some type of device on equipment that will truly tell you how frequently patients use devices, you're always surprised at how infrequently patients do, in fact, use it.

Zielinski: I also have a question about telemonitoring. I heard that some years ago in Japan they tried to monitor the use of oxygen concentrators from a central station, and also of patients' oxygenation during oxygen breathing using pulse oximetry. Do you, or anybody else, know the results of that trial?

Kacmarek: I do not.

Wedzicha: Nothing on that one, no. I don't have any results; sorry.

Pierson: In our planning for this conference, Tom and I wanted very much to have a participant from Japan, and we thought the presentation we would most like to hear from them was exactly on what you mentioned. A company there has had prototypes on trial in patients' homes that electronically monitor, through the phone line, the use of oxygen by the patient, which means the data could be collected and evaluated in some simple fashion. From our discussions, it appears that these devices are still in the prototype stage and that they do not yet have data that can be shared with us in a forum like this.

Wedzicha: Can I ask you about settings on the oxygen concentrator? You always start at 2 L/min. However, we very often have the need, because of hypercapnia in chest wall disease in neuromuscular patients, to use 1 L/min of oxygen therapy with a concentrator. Occasionally, we go to their homes and monitor patients on oxygen, and very often find the concentrators are not actually delivering 1 L/min or the equivalent. What settings do you recommend, and are regular checks done on the lower flow rates in concentrators?

Kacmarek: That's really a question for the oxygen therapy companies in the United States. I would assume that a device that was designed to provide oxygen flow from 1 L/min up to whatever was the maximum flow would accurately deliver that flow. My understanding is that most of these devices will give you *reasonably* accurate flow at less than 1 L/min. Also, if you've ever taken a typical flow meter that's used in the hospital and measured the flow that is provided, you will find that one liter does not equal one liter. There is a certain level of error in all these devices, because they are not precision laboratory instruments. A 20% error is not unusual. As far as the frequency with which companies go into the home, it really depends on the type of oxygen therapy the patient is receiving. Those patients on a liquid oxygen system—personal visits on a 1 to 2 per week basis. As I said, with a 40-liter system, the 2-L/min flow will last approximately 11 days. Patients who have concentrators, much less frequent; the preventive maintenance may call for someone to come in monthly, and in some cases every 2 months to reassess the system or change the filter. So it becomes less frequent the more reliable the system.

Stoller: Although the subject of our discussion is home oxygen, I can't resist the temptation to discuss some of the shortcomings of hospital central supply systems. We recently became interested in this because we've been examining the adequacy—or lack thereof—of the oxygen central supply and backup systems. This led to our conducting a survey of hospitals in Columbus and Cleveland, Ohio. We contacted by phone people and physicians who know the hospital oxygen systems and asked about mishaps in their hospitals. Of course, the literature contains some anecdotal reports of terrible mishaps in cutting lines, putting argon gas into the bulk vessel, and so on. I would submit that the same hazards that exist in the home, with a surprising and alarming frequency, occur in hospital central supply systems.

Kacmarek: Just as a final comment, I would agree with Jamie. Fifteen years ago when I came to Massachusetts General Hospital, we had similar types of problems. Every time we went to repair or expand the piping system, we never were sure of the effect of cutting a line. Gas from air could be fed into an oxygen line by a malfunctioning ventilator. Clearly, those types of problems have existed in the past, but most of us have focused on cleaning them up in the hospital. The older the building, the bigger was the problem.

Stoller: Because it will require big expenditures of resources to fix this, we call this the "O_2K" problem.