Review Article

Home-based long-term oxygen therapy and oxygen conservation devices: An updated review

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Abstract

Oxygen therapy has long become a cornerstone in the treatment of patients with chronic obstructive pulmonary diseases and other hypoxemic and hypercapnic chronic respiratory diseases. Studies have clearly shown benefits in terms of survival, improvement in dyspnea, exercise tolerance, and other associated conditions like pulmonary hypertension that arise due to the disease. However, guidelines regarding prescription of oxygen and to make choice of the delivery devices are not explicit. Furthermore, there still prevails a large unawareness and confusion among physicians to properly prescribe and advise patients about the use of oxygen for home therapy customized as per individual needs. The availability of several new oxygen delivery and conservation devices and techniques over the past few decades has provided a wide spectrum of options to be used in combinations or alone. This article retrospectively tries to review the studies, trials, and researches published so far in this field to give a broad idea based on consistent scientific evidence to help physicians frame their set of guidelines for prescribing long-term oxygen therapy.

KEY WORDS: Oxygen Therapy; Long-Term Oxygen Therapy (LTOT); Oxygen Conservation Devices; Chronic Obstructive Pulmonary Diseases (COPD)

Introduction

Clinical application for the use of oxygen has extended beyond the hospital setting to homes. This is now widely used for selected patients with chronic pulmonary diseases and complications of hypoxemia. The benefits of long-term oxygen therapy (LTOT) have been well established and advocated.

There were two landmark studies in oxygen therapy that have given the recent concept of domiciliary oxygen therapy. In Nocturnal Oxygen Therapy Trial[1], patients in nocturnal oxygen therapy group received oxygen for 12 h a day during night from stationary sources using an oxygen concentrator. Patients in the continuous oxygen therapy group (24 h/day) received oxygen from liquid portable system or small cylinders while they were ambulatory. The percentage of patients surviving at 12, 24, and 36 months among those who received 24 h oxygen therapy was significantly higher ($p < 0.01$) than that among patients in nocturnal oxygen therapy group. In another study, the British Medical Research Council[2] evaluated the effects of therapy with oxygen for 15 h a day, including the hours of sleep in comparison to no oxygen in patients with chronic bronchitis, emphysema, and cor-pulmonale. In patients who received nocturnal oxygen therapy, the survival was notably higher, but the differences were not evident until after 500 days of oxygen therapy.

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There have been a lot of other small- and large-scale studies documenting different benefits from LTOT, thereby making the treating physician's job more responsible in carefully writing a "patient-specific prescription." Oxygen needs vary during rest, sleep[3–5], and physical activity.[6] Therefore, the prescription should clearly specify the oxygen administration settings during rest, sleep, and exertion. More so, home oxygen therapy in chronic obstructive pulmonary diseases (COPD) patients should be coupled with physical rehabilitation[7] and physiotherapy, aiming adequate mobility and exercise by the patient. This not only builds up strength and endurance but also gives a psychological boost to the patient.

Patient selection criteria for LTOT include all patients with chronic hypoxemic lung diseases with following guidelines in particular:

a) A definitive documented diagnosis responsible for chronic hypoxemia
b) An optimal medical treatment should be in effect
c) Patient in a stable condition
d) Oxygen administration should have been shown to improve hypoxemia and provide clinical benefit
e) Adequate physical rehabilitation should be coupled with home-based oxygen therapy and must be regularly supervised

Specific Indices Used While Prescribing LTOT

a) At rest, in nonrecumbent position the PaO_2 of 55 mm Hg or less.
b) Patients with PaO_2 of more than 55 mm Hg associated with one of the following:
   i. Associated evidence of cor-pulmonale, secondary pulmonary hypertension, and polycythemia or central nervous system dysfunction.
   ii. Demonstrable fall in PaO_2 below 55 mm Hg during sleep, associated disturb sleep pattern, cardiac arrhythmias. These patients may be benefited by nocturnal oxygen therapy.
   iii. Demonstrable PaO_2 fall and oxygen saturation during exercise. These patients have been shown to improve exercise performance, duration, and capacity.

It is important to note that not all those patients having PaO_2 of 55 mm Hg or less require oxygen as this oxygen tension may be seen in normal individuals at high altitude (at 10,000 feet). Only those patients having chronic hypoxemic pulmonary disease are suitable for oxygen therapy.

Benefits of LTOT, Especially in Combination with Physical Rehabilitation[2,8–10]

1. Increase in duration of survival.
2. Significant improvement in memory, motor coordination, mood, and other hypochondriac symptoms.
3. Decrease in pulmonary vasoconstriction and vascular resistance, thereby decreasing the severity of right heart failure.
4. There is decrease in red cell mass and hematocrit level, thereby reducing the complications of polycythemia.
5. Other potential benefits:
   a. Increase in exercise capability and endurance
   b. Improved quality of life
   c. Decrease in dyspnea
   d. Reduced hospitalization and exacerbation of respiratory failure
   e. Delayed development of cor-pulmonale

Oxygen Dosage

- Most of the patients are prescribed low-flow oxygen concentration of 1–2 L/min.
- PaO_2 should be maintained at 60 mm Hg, arterial oxygen Saturation (SaO_2) 85%–90%.
- During the exercise, sleep, or other activities, the flow rate may be increased by another 1–2 L/min.

Available Modalities for Home-Based Oxygen Therapy

Home-based oxygen therapy devices must be adequate to replace the needs of patient outside hospital and be adaptable to suit their daily needs and requirement. The therapy must be properly prescribed and regularly monitored by the treating physician in terms of therapeutic dosing with respect to change in improvement or deterioration of respiratory condition. Selection of device is equally essential, and the doctor must know his/her patient as much as he/she understands the device to suitably match them both. A physically active patient may require a more portable and light device in addition to a stationary source. Cost and affordability may become a crucial factor in a developing countries like India where a large chunk of population belong to low socioeconomic band. The available modalities for home-based oxygen therapy are the following:

○ Compressed gas cylinders
○ Liquid oxygen system (LOX)
○ Oxygen concentrator

Compressed Gas Cylinder. This is the most widely available source of LTOT. It provides oxygen of up to 99% hospital-grade purity. There are various types of cylinders containing compressed oxygen, depending on the size and capacity. The commonly used cylinders are H or K type (diameter 22.5 cm, height 137.5 cm, capacity 6900 L). Although the filling pressure of these cylinders is 2200 psig, the gas flow to the patient is at 50 psi. When held at a rate of 2 L/min continuous flow, they last for 2½ days, so approximately three refills are required per week.

Advantages. Low cost, widespread availability, and good backup facility make them more popular. The gas can be stored for long time. Nowadays, portable (D&E) cylinders and light-weighted aluminum cylinders are also available. Portable cylinders can be refilled at home from a liquid oxygen source by using a special valve.

Disadvantage. Bulky, heavy, regular refill, portability issue, and high-pressure system raise safety issues.

Liquid Oxygen System. The LOX system for home use is a smaller version of the bulk liquid system used in the hospitals

Figure 1: Portable liquid oxygen canisters of different capacities. Image Courtesy: nbnrespiratory.com (The NBN group)

Figure 2: Everflo® standard stationary oxygen concentrator (courtesy: Phillips Respironics).

Figure 3: SimplyGo® portable oxygen concentrator (courtesy: Phillips Respironics).

and provides approximately 99% pure oxygen. The first LOX system for home-based use was developed in 1965 as a stationary and portable source.[11] The reservoir unit contains approximately 70–90 pounds of oxygen in the liquid state at -273 °F. One liter of liquid oxygen can produce approximately 860 L of gaseous oxygen. It lasts for 4½–10 days at a continuous flow rate of 2 L/min, thus 3–7 refills per month are required. The vessel is approximately 3–4 feet tall and approximately 18 inches in diameter. The internal pressure is approximately 22–50 psig, which can generate a flow rate of 0.25–15 L/min. Nowadays, light-weighted portable units are also available [Figure 1]. These are more practical but expensive and not easily available. More so, there is a minor loss of gaseous oxygen from the liquid units at a rate of approximately 1 lb/day.

Some small-scale studies did show benefits of LOX over gaseous oxygen in terms of patients' acceptability, hours of therapy received per week, lasting duration, and portability of canister.[12] Home-based use of LOX has become more practical with introduction of commercially available home liquefier. It uses concentrator gas and refrigerates it to a liquid state. It can produce 3 L liquid oxygen, which can then be transfilled to a portable LOX system.

Oxygen Concentrator. Introduced as large devices to be run in hospital-based settings in early the 1970s,[13] these are electrically powered systems that provide oxygen from atmospheric air. Back then, these used to be heavy equipment, as much as 50 kg. A series of improvements and modifications have made them lighter (less than 20 kg) and less noisy in the present date [Figure 2]. These are of two fundamental variants:

a. Molecular sieve (MS) type: It contains columns of synthetic aluminum silicate that filters out the nitrogen molecules, water vapor, and other trace gases. It can deliver $90 \pm 5\%$ oxygen at flow rate of up to 4 L/min. As the flow rate increases, a greater volume of gas passes through the membrane sieve and the time spent in contact with aluminum silicate is less, absorption of nitrogen is less complete, and oxygen concentration of inspired gas falls.
b. Molecular oxygen enricher: Also called polymeric membrane, this uses a semi-permeable membrane that permits selective diffusion of oxygen and water, which produces gas of high humidity enriched to approximately 40% oxygen. It relies on a high flow rate to achieve adequate oxygenation of the patient. It can deliver 30%–40% oxygen at a flow rate of 1–10 L/min.

Portable oxygen concentrators (POCs), shown in Figure 3, are now readily available, being first introduced in the mid 1990s. They can work on both direct and alternating electricity sources. Not all POCs are same. Their working algorithm and oxygen-producing capabilities may differ among different makes and models from different manufacturers.[14] This has to be kept in mind when prescribing POCs to a patient and warrants thorough clinical evaluation including patient's compliance, potential complications, and hazards.[15]

POCs have now added a new dimension to the home-based oxygen therapy as a part of *non-delivery LTOT technology*[16]

Table 1: Various Oxygen delivery patient interfaces

Device	Flow* LPM	FIO2 range (%)	Appropriate use
Nasal cannula	1/4–8	22–45	Long-term oxygen therapy (LTOT) patients
Transtracheal catheter	1/4–4	22–45	Patients who do not accept cannulae, high-flow requirements
Reservoir cannula	1/4–4	22–35	LTOT patients
Simple mask	6–12	35–50	Acute short-term therapy requiring moderate FIO2
Reservoir mask	6–10	35–60	Emergencies, acute hypoxemia, moderate FIO2
Non-rebreather mask	10–15	80–100	Emergencies, respiratory failure

Source: Guide to Prescribing Home Oxygen by Thomas L. Petty, National Lung Health Education program[17].
*Liter flow and FIO^ are reflective of continuous flow only.
+ Device yields arterial oxygen saturation equivalent to an inhalant in this FIO2 range.

where concentrators are used to provide for both stationary and ambulatory sources of oxygen. Other ways for non-delivery LTOT[15] are to refill small portable cylinders using standard stationary concentrators to achieve ample ambulation and by using a liquefier to compress oxygen produced from standard stationary concentrators.

The POCs are available in three operating modalities; intermittent pulsed-dosing system, continuous-flow system, and dual mode. The intermittent pulsed-dosing system though originally aimed to conserve oxygen by reducing wastage in home-based setting serves here an additional purpose of saving battery life of POCs.

Advantage of oxygen concentrators. It is ideal for home use as the running cost is negligible and it obviates the need for regular refilling.

Disadvantage. The initial cost is high and proper maintenance of equipment and replacement of filters is required. The cost of electricity is another factor. Portability does not seem to be an issue now owing to availability of POCs, though noise production, heat, and requirement of backup source of oxygen in case of prolonged electricity failure are other concerns.

Delivery Devices. Various delivery devices that can be used for home/LTOT include nasal cannulae, nasal prongs, and masks, as described in Table 1.

Nowadays there has been cosmetic improvement in delivery devices; example includes *Oxyspecs*, which conceal the oxygen tubing by applying it to ordinary thick rimmed frames of eye glasses. There is no difference in the type of delivery devices used with different types of oxygen sources. Humidification is not necessary at flow rates of less than 4 L/min, unless the patient complains of the dryness of nose or mouth, nasal irritation, or crusting.

Oxygen Conservation

Administration of LTOT incurs considerable cost. Mainly, patients tend to conserve by reducing the flow as well as the duration of administration but that does not serve the purpose. The standard oxygen supply devices allow the flow of oxygen during both inspiration and expiration.

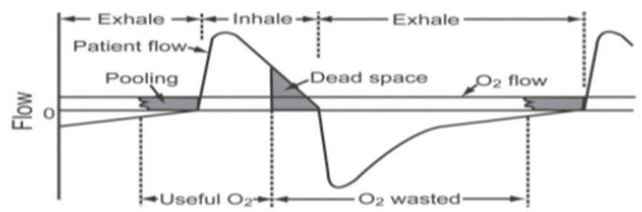

Figure 4: Diagram of a respiratory flow cycle in relationship to continuous-flow supplemental oxygen, indicating the sections of the breathing pattern that useful oxygen is delivered (courtesy: McCoy RW[18]).

In fact, it is only 15%–20% part of the respiratory cycle during inspiration that delivers the oxygen to the alveoli effectively, as oxygen flowing exhalation is 60%–70% and the last 30% of inhalation fills the anatomical dead space [Figure 4]. A lot of oxygen delivered to the patient is therefore wasted.

Oxygen Conservation Devices. There are three types of devices commercially available to reduce the oxygen wastage that occurs during patient's exhalation and mainly used in the home care setting.

- Reservoir oxygen delivery devices
- Demand oxygen delivery (DOD) device or electromechanical pulsing device
- Transtracheal oxygen delivery devices

Reservoir Oxygen Delivery. In this method, oxygen, which is stored during exhalation in a reservoir bag (approximately 20 ml), becomes available at the beginning of inhalation. Depending on the types of reservoir cannulae, it is of two types:

Mustache-configured oxymizer: This device consists of a nasal prongs and a closely coupled a 20 ml reservoir with collapsible membrane and oxygen supply conduit at the distal lateral ends of the reservoir [Figure 6]. The cannula with its reservoir is situated under the nose, covering the mustache area of the face. The membrane is highly compliant and responds to minimal change in nasal airflow for its operation as an oxygen-conserving device.

During early exhalation, the dead space gas phases the membrane forward, forming a reservoir chamber between the membrane and the back wall of the reservoir. As exhalation

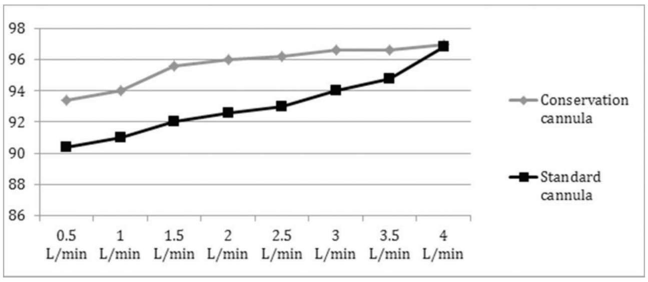

Figure 5: Mean oxygen saturation (in % on *Y*-axis) for conservation and standard cannulae at different oxygen flow rate (on *X*-axis) with saturation below 90% on room air.

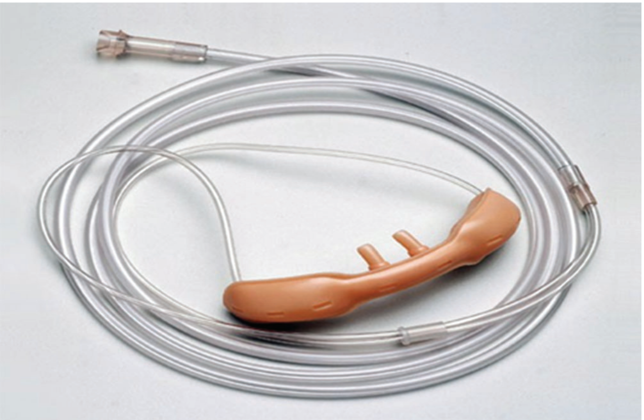

Figure 6: Mustache Oxymizer® (image courtesy: www.myrespiratorysupply.com).

A standard oxygen face mask with reservoir bag and one-way valve.

continues, oxygen entering from the lateral end of reservoir forces the dead space gas medially, venting it through the nasal prongs. Hence, at the end of exhalation, the reservoir is filled with oxygen. Thus, when the patient is ready to inhale, he/she receives a 20 ml bolus of oxygen-enriched gas in addition to the steady flow oxygen.

Oxymizer pendant: This was first described by Tiep et al.[19] in their study published in 1985. The reservoir coupled to the nasal prongs consists of a collapsing chamber that hangs at the chest. It saves oxygen between 2:1 and 4:1 over continuous-flow oxygen therapy [Figure 7].

Figure 7: Oxymizer® pendant (image courtesy: www.medline.com).

Table 2: Average Oxygen savings at different flow rates: Standard nasal cannula versus Oxymizer Devices

Oxygen requirements with standard nasal cannula (lpm)	Oxygen requirements with Oxymizer® devices (lpm)	Resulting oxygen savings** (%)
2.0	0.5	75.00
3.0	1.0	66.60
3.5	1.5	57.14
4.0	2.0	50.00
5.0	2.5	50.00
5.5	3.0	45.45
6.0	3.5	41.67
7.0	4.5	35.71
7.5	5.0	33.33

**Average savings. Your patient's actual oxygen level may vary.
ATS-ERS COPD Guidelines recommend titrating using the prescribed delivery device.

The principle of operation of the pendant, although similar to the oxymizer, has important differences, as shown in Table 2.

During early exhalation, the dead space gas moves from nasal prongs toward reservoir. During ensuing larger portion of exhalation, and once the reservoir chamber is filled to capacity, oxygen that enters the conduit near the junction of reservoir chamber fills the conduit. When the patient is ready to inhale, he/she receives 20 ml oxygen-enriched gas.

The pendant and oxymizer provide equivalent oxygen savings at flows of 0.5 L/min. However, due to its tubular storage, it is possible to operate the pendant at 0.25 L/min using a steady-flow delivery system. The pendant maintains its saving benefits during exercise.

Demand Oxygen Delivery Devices or Electromechanical Pulsing Device. These devices deliver oxygen only during the inhalation rather than using a reservoir to conserve oxygen

Figure 8: Evolution®: a pulsed dose oxygen delivery regulator (image courtesy: Chad Therapeutics).

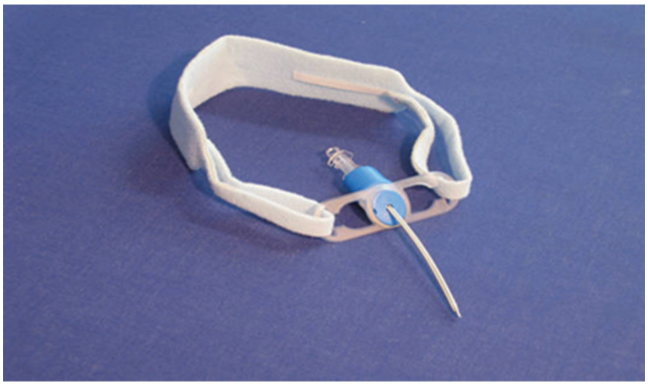

Figure 9: Transtracheal catheter (image courtesy: www.airwayeducation.homestead.com).

during exhalation, a demand flow or pulsed oxygen delivery (POD) device uses a sensor and valve system to eliminate expiratory flow altogether.

It consists of a box-shaped unit attached to the outlet of the oxygen source and a solenoid valve that opens on sensing the decrease in pressure as the patient inhales. A pulsed volume of 15–35 ml oxygen is delivered each time. It reduces the amount of oxygen usage by 35%–75%, producing a saving of approximately 7:1 compared with continuous-flow system. There are various types of devices, depending on the sensors that could be electronic, fluidic, or combined.

Intermittent flow rate regulators have been developed by several manufacturers. They can be attached to the oxygen source and regulate the flow of oxygen by delivering only during inspiratory phase of respiration. There are two variants available. *The fixed-dose intermittent flow regulators* [Figure 8], which deliver a fixed volume of oxygen with each breath taken. This gives a clear advantage over continuous-flow oxygen regulators as apart from saving the otherwise wasted oxygen during expiratory phase, the total dose of oxygen delivered per minute increases with increase in respiratory rate. *The minute volume delivery device/regulators* in contrast use a different principle. Here, the volume of oxygen to be delivered per minute can be set, thus the per dose volume decreases as the respiratory rate rises, proving particularly useful in chronic hypercapnic respiratory failure where the intention is to keep the saturation at suboptimal level to maintain the patient's respiratory drive.

Encouraged by successes witnessed in the early studies, DOD or POD devices have since then gained wide approval and acceptance. Arterial oxygen saturation (SaO_2) progressively increases as the delay between inspiratory signal and delivery of pulse is shortened. In contrast, delay up to 164 ms does not seem to affect SaO_2 with transtracheal oxygen delivery.[20] In another study, pulsed dose oxygen delivery showed improvement in exercise tolerance and oxygen saturation similar to continuous oxygen therapy in patients with severe COPD with added benefit of oxygen conservation.[21]

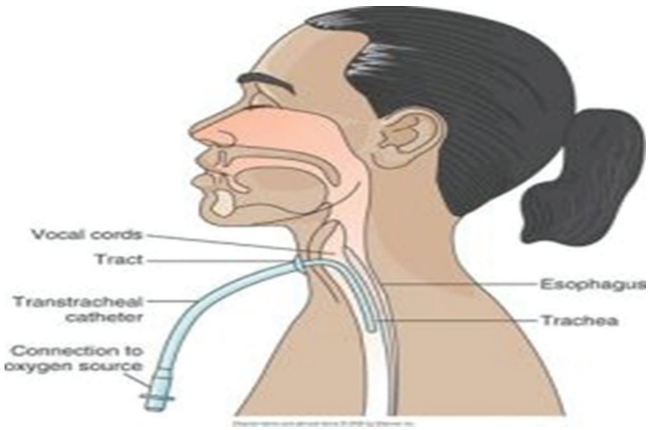

Figure 10: A transtracheal catheter *in situ* (image courtesy: www.cram.com).

Transtracheal Oxygen Delivery. Transtracheal catheters [Figures 9 and 10] were introduced as a modality for LTOT in 1982 with publication of Heimlich's studies[22] on dogs. Later, he developed a percutaneous catheter for clinical use, which showed promising results over conventional oxygen delivery methods.[23] Oxygen is delivered directly into the trachea through a thin Teflon catheter inserted by a guide wire between the second and the third tracheal rings. Oxygen is delivered through tubing attached to a small fitting at the neck. It is a more effective method of oxygen conservation as:

a) The oxygen delivery is ahead of the nasopharynx, therefore bypassing the dead space.
b) Additionally, the upper airways serve as reservoir toward the end of exhalation.
c) More so, the delivered oxygen is not diluted with atmospheric air before entering the respiratory tract.
d) Exercise capacity and dyspnea show improvement independent of oxygen saturation by some less understood mechanism.[24]

e) Oxygen requirement is reduced considerably, by approximately half, both at rest and during exercise.[25–27]

This device besides conserving oxygen has other benefits such as it:

a) Increases patient mobility
b) Avoids nasal and ear irritation
c) Improves compliance with therapy
d) Enhances personal image and allows a better sense of taste, smell, and appetite.

It is indicated when a patient cannot be adequately oxygenated with standard approaches, does not comply with other devices, exhibits complications with nasal cannula use, or prefers it for cosmetic reasons with increased mobility.

Transtracheal catheter is useful for patients receiving very high flow rates. It saves oxygen by an efficiency factor of 2:1–3:1. Its efficiency can be enhanced by combining it with pulsed oxygen delivery. Some of transtracheal catheters commercially available are Heimlich Microtrach®, The Oxycath® (Laboratoire Cometh, Lyon, France), The Scoop® Catheter (Trans-tracheal Systems, Denver, CA), and The Intratracheal Oxygen Catheter; ITOC (Cook, Critical Care, Bloomington, WI).[28,29] ITOC, a silicon-based catheter, is of more permanent nature as it is implanted through a subcutaneous tunnel from the chest wall to the trachea.

Complications of this technique include hemoptysis, subcutaneous emphysema, cellulitis, and clogging of catheter. It can get plugged with mucus and thick secretions. It should therefore be cleaned on daily basis. More so, studies have shown that transtracheal catheter for LTOT is more effective and safe alternative to conventional oxygen delivery devices provided a stringent patient selection is done with expert and competent physicians.[30]

Conclusion

The variety of oxygen sources for home therapy in present-day scenario is large. The selection of the type of source for a given patient becomes a more tricky decision to make. Here, it is to be understood first that oxygen is not just a gas but a “drug”, and just like any other drug it has to be cautiously prescribed, mentioning each minute detail and following up for stringent monitoring of the therapy. To adequately achieve this, physicians must familiarize themselves with the devices available as much as they understand their patients. It is to always be kept in mind that not all devices are similar. They differ in oxygen-producing capacity, working algorithm, dose delivery, operating time, and so on. Device should be prescribed at discharge from hospital only after analyzing the patient requirement beforehand by assessing his/her oxygen requirement at rest and during exercise. This is now possible with help of Clinical Oxygen Dose Recorder device for monitoring both the oxygen source and the patient. When connected between the oxygen source and the patient, it can record and store several hour’s information of patient’s oxygen saturation and the oxygen flow rate. This data can be used by the physicians for interpreting patients’ needs at different hours of day. AccuO2 (OptiSat Medical, Minneapolis, MN) is a new oximetry-driven oxygen delivery and conservation device that auto-adjusts patient’s oxygen supply to maintain the target arterial oxygen saturation. A recent study[31] has shown this to method to achieve oxygen saturation closer to the target and achieve higher conservation ratio than other standard conservation devices or continuous-flow oxygen delivery. The cost being an issue with most portable devices and POCs, especially in developing countries, this needs to be taken care of by proper counseling of the patients and their attendants. It can be explained that the cost of treatment incurred due to recurrent exacerbations and hospital re-admissions add up to much more than the one time purchase cost of the device. Besides, the agony to the patient due to frequent exacerbations is only an add-on to the cost.

With the advances in technology, we can expect newer modalities and devices of higher oxygen-producing capacity at a more affordable cost. Meanwhile, it is for the physicians and specialists to devise proper and individualized patient-based protocols for oxygen therapy to make most out of the available resources.

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