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Oxygen Devices for Long-Term Oxygen Therapy and Comparison for Use in Low-Resource Settings

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Abstract - *Chronic Obstructive Pulmonary Disease (COPD) is a leading cause of death worldwide and mainly in low-resource settings where there is unavailability of sufficient medical facilities due to the high cost of medical devices and expensive treatment. Long-Term Oxygen Therapy (LTOT) is carried out for the treatment of COPD patients, since it has shown improve survival, high life-expectancy and life-style in COPD patients but also comes under the category of expensive treatment, making it difficult to use in low-resource settings. This article focuses on different devices (Liquid Oxygen, Compressed Gas Cylinder, and Oxygen Concentrators) used for LTOT and helps in the appropriate selection of the device. Comparison between these devices is provided on the basis of cost (capital cost as well as operational cost) and performance of the device. The article also gives a note on the monitoring of oxygen during the treatment and the use of delivery systems.*

Key Words: **Chronic Obstructive Pulmonary Disease (COPD), Long-Term Oxygen Therapy (LTOT), Oxygen Concentrator (OC), Liquid Oxygen, Portable Oxygen Concentrator (POC).**

1. INTRODUCTION

Human respiratory system plays a very important role in functioning of the body as it is responsible for supplying adequate oxygen to maintain the arterial blood gases levels and oxygen levels in body tissues. Many of the biochemical reactions in the body depends on the proper supply of oxygen [1]. Due to COPD the respiratory system is not able to provide adequate oxygen levels naturally and thus patients are prescribed for Long-Term Oxygen Therapy. This review focuses on different type of devices for Long-Term Oxygen Therapy (LTOT) and suitable ways for LTOT in Low Resource Setting (LRS).

2. Long-Term Oxygen Therapy (LTOT)

Chronic Respiratory Diseases comes under 4 major categories of Non-communicable diseases (NCDs). According to World Health Organization (WHO), NCDs caused about 41 million deaths i.e. 71% out of the overall total 57 million deaths in 2016. Chronic Respiratory Diseases that comes under NCDs caused about 3.8 million deaths i.e. 9% [2]. COPD comes under Chronic Respiratory Diseases and Global Initiative for Obstructive Lung Disease (GOLD) indicated that COPD is treatable and preventable. COPD has disease burden about 210 million people globally. In 2004, COPD was fourth leading cause of death (5.1%) globally and its estimated rise will be 8.6% in 2030[3].

In the late 1970s, British Medical Research Council (MRC) and Nocturnal Oxygen Therapy Trial (NOTT) has proven that using Long-Term Oxygen Therapy (LTOT) for more than 15hours per day improves the survival rate of the patients having COPD with resting hypoxaemia. Thus, LTOT is proven to be a therapeutic modality for the treatment of COPD [4]. Pavlov et al. also mentioned that COPD is a leading cause of death globally and has projected that there will be a continuous rise in mortality in the future. It has been found that the overall mortality can be reduced by LTOT. This treatment is also improving the emotional status and cognitive functions of the COPD patients [5].

2.1 Prescription for LTOT

Long-Term Oxygen Therapy is prescribed when the patient is facing hypoxaemia and COPD. It is generally recommended that for a COPD patient LTOT use should be greater than 15 hours per day. Improvement can be expected if adherence to LTOT is maximum or as per prescription and should always be used upon a written order from licensed physician. Patients with hypoxaemia and COPD are prescribed LTOT when PaO2 is less than 55 mmHg and in some cases if they are having moderate hypoxaemia where PaO2 lies between 55-60 mmHg. A proper monitoring of the treatment is to be done on daily duration of LTOT [4-6]. M. J. Kampelmacher and team has mentioned that European Respiratory Society and American Thoracic Society has given the recommendation to prescribe LTOT for the patients having hypoxaemia with COPD, as LTOT has shown improvement in survival of COPD patients. Here also, it is recommended that the oxygen therapy is to be prescribed for 15 hr per day [7].

3. Type of Devices For LTOT

Long-Term Oxygen Therapy (LTOT) at home is basically carried out by following type of sources- Liquid Oxygen, Pressurized gas cylinders and oxygen concentrators [8].

(a) (b) (c)

Figure -1: (a) Oxygen cylinders, Figure 1(b) oxygen concentrator, Figure 1(c) liquid oxygen system. Sources of Oxygen at home for LTOT [8].

3.1. Liquid Oxygen

The use of liquid oxygen for oxygen therapy at home was started in 1965 when the first home-based system of liquid oxygen was developed. The liquid oxygen system consisted of a stationary sub-system which was large in size and can be used at home and a refillable liquid oxygen portable sub-system that can be used outside the house. Figure 1(c), represents a liquid oxygen system. The liquid oxygen system provides 100% O2 and is stored in cryogenic tanks and maintained at a very low temperature of -183°C [8-9]. In a study done by J. Schaanning and team, 117 patients were prescribed Liquid Oxygen treatment where the mean flow rate was 1.9 l/min and 20.5 hours per day which satisfies condition for LTOT [10].

3.1.1. Advantages of Liquid Oxygen

A major advantage of portable liquid oxygen equipment is that it weighs very less and are available in weight of even 2.5 kg. Another recognizable advantage is that by using oxygen saving devices it can be used up to 15 to 20 hours [10]. Due to less weight, it is more suitable for portable applications and can be used by a wide range of people depending on age and strength. Patients are able to go outdoor when using liquid oxygen system and the filling and use of the system is also easy. Certain studies have shown that patients use liquid oxygen more than gaseous oxygen, thus, is more effective oxygen therapy and study performed by Neri et al. confirms that portable liquid oxygen decreases the breathlessness and is useful for hypoxaemia patients [11].

3.1.2. Disadvantages of Liquid Oxygen

Liquid oxygen therapy is more expensive as compared to other forms of oxygen therapy that are listed in this article. According to a Sweden study it was revealed that Liquid oxygen therapy is 4 times costlier than oxygen therapy by gas cylinder and oxygen concentrator [12]. Additional precautions are to be taken for liquid oxygen therapy. As liquid oxygen therapy provides minimum 99.5% purity, it should be controlled in case of neonates since they require concentration below 40% and also for elderly patients with chronic bronchitis were inspired oxygen should be 30% concentrated. Liquid oxygen is vaporized and converted into compressed gas and heated to ambient temperature before giving to patient [13].

3.2. Compressed Gas Cylinder

Oxygen and other gases used for medical applications are stored in metal containers know as gas cylinders. These cylinders are mainly made from various steel alloys or aluminum and on the top consists of different type of valves such as pin index valve, hand wheel valve, integral valve and bull nose valve to control the flow. Oxygen cylinders are available in wide range of sizes and capacities as shown in **Table 1**. Thus, allowing the patient to choose the cylinder as per their requirement and application at home or outside [14]. With the help of trolleys, backpack and other equipment, cylinders can be used for portable applications but are generally less preferred because they possess comparatively less capacity compared to liquid oxygen and portable oxygen concentrators. Major advantage of compressed cylinder is that they can be used as emergency oxygen source when oxygen concentrator lacks due to power cuts, mostly in low-resource settings. Frequent filling, maintenance and additional precautions are to be followed to avoid any hazards [9]. Figure 1(a) represents the gas cylinders.

Table-1: Size and specification of commonly used oxygen cylinders [14].

Size	Capacity (L)	Pressure (psi)	Tare Wt. (kg)	Valve type
B	200	1900	2.27	Pin index
D	400	1900	3.4	Pin index
E	660	1900	5.4	Pin index
F	1360	1900	14.5	Bull Nose
G	3400	1900	34.5	Bull Nose
H	6900	2200	53.2	Bull Nose
M	3450	2200	29.0	Bull Nose

3.3. Oxygen Concentrator

Oxygen Concentrator (OC) draw air from surrounding and concentrates the oxygen in the surrounding air to therapeutic levels by passing it to various filters or zeolite sieve beds. These oxygen concentrators require minimum maintenance and can work up to 5 years when connected to power supply [15]. They are available as 3, 5, 8 and 10 l/min unit and produces up to 95.5% concentrated oxygen. For LTOT in low-resource setting oxygen concentrators are the most cost-effective solutions [15]. Figure 1(b) shows an oxygen concentrator.

3.3.1. Use of Oxygen Concentrators in low-resource settings

Many research and study show that although concentrator produce concentrated oxygen at the instant, it is

as much efficient as other sources of oxygen and is prescribed to many patients with respiratory failure. A test was performed in which 14 concentrators were given to patients for a period of 12 months and maintenance and questionnaire were carried on regular basis. It concluded that the test was successful with good mechanical performance of device. And the study also mentioned that the running cost of oxygen concentrators is very less than compressed gas cylinders and liquid oxygen [16]. Jackson has mentioned that for a month on a supply of 2 l/min, oxygen concentrator is equivalent to 21 cylinders. The study gives a relation between the **Cost vs Oxygen treatment for number of hours per day**, for treatment with cylinder and oxygen concentrators as shown in **Chart-1,** concluding that treatment using oxygen concentrators are always cheaper than treatment using cylinders when used even for more than 14 hours per day [17].

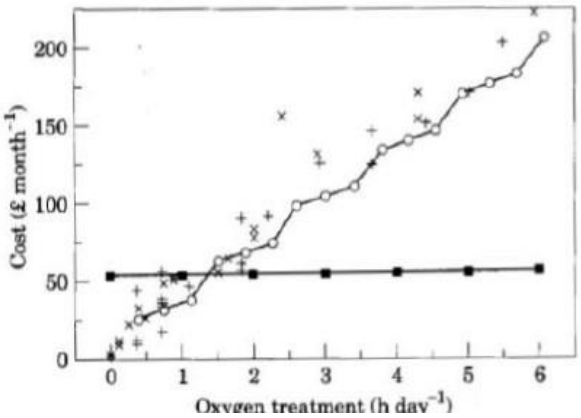

Chart-1: The concentrator cost (■) and the theoretical and actual costs of cylinder supply of oxygen. [(o)- theoretical minimum cylinder cost; (+)- cylinder costs 3 months prior to study; (x)- cylinder costs within study] [17].

A difficulty that arises to use an oxygen concentrator in low resource settings is that it requires **continuous** power supply to run, whereas many developing countries have **intermittent** power supply. Thus, Bradley and team has highlighted and developed oxygen system that works on battery and can be charged by intermittent electric supply. Oxygen Concentrators still remains better since in developing countries there are lacks of roads and transport system, intermittent electricity and less funds for heath thus making it difficult to provide a continuous supply of cylinders, since it requires regular refilling that makes the treatment too costly [18]. Wilson et al. also reported that oxygen concentrators are more suitable in developing countries where there are shortages of compressed gases and results in financial saving by avoiding cylinder hiring and transportation cost [19]. A study performed in Solukhumbu District, Nepal at altitude of 3900m also proved that oxygen concentrators are reliable and effective in high-altitude remote regions. They provide cheaper oxygen therapy as compared to cylinders, since in such remote areas refilling facilities for cylinders are not available and thus avoid the frequent transportation cost for refilling cylinders [20]. **Table-2** gives a comparison between oxygen cylinders; oxygen concentrators and also central oxygen i.e. pipeline system. It can be seen that even though oxygen concentrators have high capital cost than cylinders, the operational cost is very less and thus resulting in overall cost saving and hence useful in low-resource settings for LTOT.

3.3.2. Portable Oxygen Concentrators And Its Efficacy

Oxygen Concentrators are most economic for LTOT but restrict the outdoor activities of the patients. Hence, a patient who has to travel or do outdoor activities was forced to use the liquid oxygen portable unit, leading to costlier treatment. But this problem is now solved due to the invention of Portable Oxygen Concentrator (POC). A study of 6-minute walk test was performed by Nasilowski et al. that concluded POC did not differ from portable Liquid Oxygen units [21]. POCs weigh as less as 5 pounds. POCs work on both AC and DC supply from chargeable batteries and vehicle DC outlets. Thus, highly efficient for outdoor use. POCs deliver oxygen at Continuous Flow (CF) or Intermittent flow (IF). Combined CF and IF devices are also available. CF POCs are similar to stationary OC (flow is measured in l/min), whereas IF POCs provides flow in mL/breath, known as Fixed Bolus Volume (FBV) or in mL/minute know as Fixed Minute Volume (FMV) [22]. POC is a type of oxygen concentrator and is similar to stationary concentrator possessing high capital cost but the operational cost is comparatively low, therefore is useful in low resource settings. Every POC that is available in market differs in certain specifications and shows different results in different working condition of the user. Therefore, a proper POC is to be selected for the patient depending in which conditions and activities they will use it. This can be seen in a test performed by Chatburn and Williams [23].

4. Comparison in LTOT Categories

Table-2 shows the comparison between available types of Long-Term Oxygen Therapies (Central Oxygen pipeline system, Oxygen Cylinders and Oxygen Concentrators) with respect to power supply requirement, transportation need, exhaustible supply, initial and operational cost, user care and need of maintenance [15].

Table-2: Comparison in different oxygen sources. [15]

System	Central oxygen (pipeline system)	Oxygen cylinders	Oxygen concentrators
Power source required	No	No	Yes, continuously (100 to 600 W, depending on model)
Transport requirement	Those associated with cylinders	Regularly; heavy and costly to transport	Only at time of installation
Exhaustible	Yes, if pipes are refilled from an offsite supply	Yes, depending on the size,	No, continuous supply as long

supply	facility	storage pressure and patient needs	as power remains uninterrupted
Initial costs	Significant: generator and cylinders (US$20000), piping system (US$10000+), installation, commissioning and training	Moderate: cylinder, oxygen flow meter and regulator per cylinder (~US$ 200) b	Moderate: concentrator (US$ 300–3400) b, spares, installation, commissioning and training
Operational costs	Small to moderate: maintenance, continuous refill of pipeline by bank or tanks	High: cylinder refills and transport from refilling station to hospital	Small: electricity and maintenance
User care	Minimal	Minimal: regular checking, minimizes fire hazard (no grease or flammables)	Moderate: cleaning of filters and device exterior, and minimizes fire hazard
Maintenance	Moderate: check for pressure leaks with manometer Maintenance of oxygen pipelines to prevent leaks and oxygen wastage Significant: if supply facility is onsite.	Moderate: check for pressure leaks with gauge	Moderate: check for low oxygen output with analyzer
Cost per 1000 liters oxygen	Data not available	US$ 10–30/kilolite r varying with estimated oxygen requireme nt and power availability	US$ 2–8/kiloliter (greater depending on cost of power source), varying with estimated oxygen requirement and power availability

5. Monitoring of Oxygen Saturation

Patients with hypoxaemia and COPD have reduced oxygen saturation in their blood, thus, are prescribed with oxygen therapy. But it is also very important to monitor the oxygen saturation in blood regularly along with LTOT to see whether the therapy is satisfying the oxygen need or need changes in modifications in the prescribed values. Therefore, frequent monitoring of oxygen saturation is necessary in patients with LTOT, also it should be cheap and affordable so can be available in low resource settings. Pulse oximeter can be used to measure the oxygen saturation in hemoglobin in arterial blood and pulse rate and give instant results using digital screen and audible beep. It is a cheap and accurate device and is easily readable [24,25].

6. Delivery Systems

Various oxygen delivery systems are available and should be selected considering the flow they provide. Oxygen delivery systems are developed as low flow oxygen delivery systems (which include nasal cannula, simple face mask, non-rebreather mask and partial rebreathing mask) and high flow delivery systems (This category includes venturi mask). **Table-3** shows these delivery systems along with the flow rate and approximate fraction of inspired oxygen (FiO2) that are provided by these devices, guiding in the appropriate selection [26]. For developing countries, the focus is always to provide systems that are cheap and reliable. Thus, World Health Organization (WHO) has recommended the use of nasal prongs and nasopharyngeal catheters for low flow rates [27].

Table-3: Flow rate and approximate FiO2 by oxygen delivery systems.[26]

Oxygen delivery devices	Flow rate (liter/min)	Approximate FiO2
Nasal cannula	1-6	0.24-0.44
Simple face mask	5-8	0.40-0.60
Partial rebreathing mask	6-10	0.60-0.80
Non rebreathing mask	10-15	0.90-1.00
Venturi mask	2-15	0.24-0.60

3. CONCLUSIONS

Long-Term Oxygen Therapy (LTOT) is been as effective and efficient solution for the treatment of hypoxaemia and Chronic Obstructive Pulmonary Diseases (COPD). We

studied various types of technologies involved in LTOT and also compared them on basis of various factors and conclude that oxygen concentrators are well suitable devices for use in low resource settings. Considering the available variety and need for selecting the most suitable treatment, the choosing and performing should be done as per the prescription of the respiratory physician. Appropriate selection of the oxygen system and oxygen delivery system is to be done depending on the medical condition of the patient. The physician must have knowledge about the devices and their types including the monitoring and should select the device as per the preference of the patient. With developing technology, new devices are getting available in the market, the health and government agencies should focus on the availability of these devices to the patients in low resource settings. Also, the manufacturers must focus on the development of devices with less capital cost and less maintenance and operational cost.

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