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#### Potential conflicts of interest

None declared.

# PORTABLE/AMBULATORY OXYGEN

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## INTRODUCTION AND GENERAL CONSIDERATIONS

Supplemental use of oxygen (O<sub>2</sub>) for at least 16–18 h·day<sup>-1</sup> has been shown to improve blood arterial oxygen tension and to reduce the risk of secondary correlated events (*i.e.* pulmonary hypertension or cardiac failure) in the population of patients with resting hypoxaemic chronic respiratory failure (CRF) due to chronic obstructive pulmonary disease (COPD). So far, this pharmacological intervention has been shown to be one of the most effective in reducing mortality in these patients when applied on a long-term basis [1, 2]. This particular approach has been defined as long-term oxygen therapy (LTOT).

Notwithstanding, many more respiratory patients may develop hypoxaemia during exercise or activities of daily living, which an appropriate ambulatory oxygen (AO) regimen could correct. AO can be delivered by portable devices and specific equipment carried by patients themselves [3, 4]: the main goal with this approach is to enable the patient to leave their home for a longer period of time, thus improving the perceived health status and daily self-activities.

Overall, prescription of AO is generally applied to patients on LTOT, who show a higher grade of independence; at least the ability to walk and to leave their home. The British Thoracic Society (BTS) recommend determining the individual's level of outdoor activities before prescribing AO, in order to fulfil both clinical as well as economical criteria for selection [4]. Therefore, the whole population of patients receiving LTOT will not be suitable for AO: in housebound

individuals (which stands for a significant proportion of CRF patients [5]) and in those patients unable to leave their home (if unassisted) due to major physical disabilities (*e.g.* osteoarthritis and/or neuromuscular diseases), domiciliary or occasional use of oxygen therapy is generally provided [4].

Finally, AO may also be prescribed in those respiratory patients who do not fulfil the criteria for LTOT prescription and may show an exercise-induced oxygen desaturation (a fall in arterial oxygen saturation (Sa,O<sub>2</sub>) of 4% below 90%) which is remarkably reversed with supplemental oxygen [4, 6]. At least theoretically, this latter group of patients needs a formal assessment of Sa,O<sub>2</sub> during an ambulation test, in order to set the minimum supplied O<sub>2</sub> flow, from portable systems, that is able to compensate the failure.

## Benefit of AO therapy

Even if the clinical benefits still remain uncertain and concordance with therapy is poor, there are several scientific studies (short- or long-term studies) investigating the effect of AO therapy (also during exercise) in patients with chronic respiratory disease (especially those suffering from underlying COPD).

Many studies regarding the short-term efficacy of AO [7–11], as reported in a systematic review by BRADLEY *et al.* [12], have found clinical benefits when using portable oxygen systems. These clinical benefits consist both in improved quality of life, amelioration in exercise performance (endurance and/or maximal exercise capacity) and

reduction of correlated symptoms (*i.e.* breathlessness). However, as BRADLEY *et al.* [12] made clear, the clinical importance of the size of improvement is unclear; thus, future research is still required in order to establish the real effect of AO prescription, in particular in COPD patients with different grades of hypoxaemia or with exercise-induced oxygen desaturations.

Furthermore, little is known about the effectiveness of AO therapy when used for longer periods; in a recent Cochrane review [3] only one study, of nine CRF patients with severe hypoxia at rest, has shown significant physiological effects (reduction in minute ventilation at maximal exercise and increase in arterial oxygen tension ( $P_{a,O_2}$ ) at rest). The available evidence does not allow any firm conclusions about the adoption of an AO regimen in COPD patients. Indeed, in future studies, it would be interesting to separately evaluate the effect of AO in patients who are “desaturators” and “non-desaturators”.

The BTS Working Group on Home Oxygen Services has developed the practical document on the patient’s assessment to guide different options for oxygen and AO prescription [4, 13].

#### Grade 1: LTOT patients with low activity

These patients are mainly housebound or do not leave their home unless assisted. They will only need an occasional portable cylinder during external ambulation; oxygen flow-rate will be set at the same level as during sedentary use. The average time of use will be approximately 1 h·day<sup>-1</sup> but may vary.

#### Grade 2: LTOT patients in active group.

These patients are mobile and need to leave their home on a

regular basis. They will require referral to a specialist for full assessment for AO. This will involve the determination of the least oxygen flow-rate required to abolish desaturations ( $\leq 90\%$ ) during ambulation. At present there is not a reliable tool to predict which patients will be compliant to AO. Thus, the working group suggested that patients are first provided with AO, sufficient for 2 h·day<sup>-1</sup> use, and asked to monitor their daily usage. All patients should be then re-assessed 2 months later and the oxygen prescription adjusted, if necessary.

#### Grade 3: non-LTOT patients with exercise desaturations.

They will require referral to specialist for more detailed assessment as to whether they meet the criteria for AO.

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### PORTABLE OXYGEN SYSTEMS AND THEIR USE DURING DAILY LIFE

Supplemental oxygen by means of portable systems is mandatory for active patients who leave their home and are able to perform several daily activities. Since the early beginnings of LTOT, most technical advances on portable device have been steadily focused on improving the facilities for AO.

Oxygen administration, which is usually delivered by easy to use, well-tolerated tubing and nasal cannulae, while performing activities (*e.g.* eating, drinking or walking), can be generally provided by three main types of commercially available sources: compressed gas cylinders, oxygen concentrators, and liquid oxygen containers (table 1 and fig. 1). These three systems don’t have significant difference ►

in the quality of oxygen delivered in the clinical practice and, even if with different technical characteristics, they both have the goal of allowing the patients to achieve their highest level of independence during activities; unfortunately, oxygen concentrators and portable gas cylinders have a more specific indication in patients requiring domiciliary oxygen or able to perform short-term outdoor activities, due to their technical limitations for use compared with liquid oxygen containers.

Alternatively, a new generation of portable liquid, lightweight (down to 3 kg) containers can nowadays be provided by several suppliers to facilitate the patients' mobility (also when travelling).

The choice of the most appropriate oxygen system (concentrator or liquid) does not match specific individual's characteristics other than the patient's adherence (e.g. the ability to overcome an individual's disability by using that specific device) and correlated costs. At present, AO is provided using small portable oxygen cylinders in the UK, whereas liquid oxygen canister systems are widely used in other countries across the world (e.g. USA or Italy). Notwithstanding, both these

systems are used without any adequate and fully proved evidence of their effectiveness.

**Gas cylinders**

Compressed oxygen cylinders (the first system was delivered in the 1888 in the USA) are widely used in almost every country, with an industry code letter that defines one of four different sizes. The letter "E" designates the largest and heaviest cylinder that patients usually pull around on a wheel-cart (empty weight of ~7 kg if in aluminium and >14 kg if in steel) [14]. Other smaller cylinders are denominated as "D", "C" and "B" (the smallest) size. The D, C, and B cylinders are often used with a carry case that has a shoulder strap.

A pressure manometer with a valve system and a flow meter are required to adjust the amount of gas delivered to the patient; for correct use, the valve system must be opened slowly with caution, by anticlockwise turning, and flow-rate regulated to that prescribed.

At present, due to the costs and the relatively easier availability (even in small towns) compared with other systems, compressed oxygen cylinders are most widely prescribed for domiciliary or ►



Figure 1. Sources of oxygen systems. a) Liquid oxygen with refillable base ("liberator") and portable canister ("stroller"). b) Oxygen portable concentrator. c) Compressed gas cylinders.

Table 1. Advantages and disadvantages of oxygen sources

	Advantages	Disadvantages
<b>Gas O<sub>2</sub></b>	Consolidated circuits of capillary distribution Good quality of O <sub>2</sub> Wide availability	Cumbersome and heavy weight Difficulty on transport and refilling High cost
<b>Liquid O<sub>2</sub></b>	Light weight High capacity of containers Easy to refill Excellent portability during physical exercise	Evaporation with O <sub>2</sub> loss Need for moderate maintenance High cost
<b>O<sub>2</sub> Concentrator</b>	Does not requires distribution circuits Easy to use	Heavy weight Loss of efficacy with high O <sub>2</sub> flows Not easily portable Noisy Requires mains electricity supply

hospital use; their use for AO is really limited.

### Oxygen concentrators

Oxygen portable concentrator appeared in the early 1970s. This is an electrical device that provides oxygen from the atmospheric air, concentrating and separating it from nitrogen through a series of molecular filters, and delivering it directly to the patient's airways through a control-flow device. The performance of oxygen concentrators progressively reduces with the increase of the delivered flow-rate [15, 16]. For this reason, it is not recommended for use in patients with a severe chronic hypoxaemia, who may often require an oxygen flow  $>4 \text{ L}\cdot\text{min}^{-1}$ .

The most important advantage of an oxygen concentrator is that it can operate independently of base systems (oxygen cylinders need to be refilled periodically from a base unit). However, this portable system needs to be connected to the main electricity supply, a major drawback that limits the patient's mobility.

### Liquid oxygen containers

This system allows the storage of oxygen in liquid form and delivered through coils where it vaporises; this system represents an economic and easy oxygen source in ambulatory patients, widely accepted and used in clinical practice. In particular, two aspects are important with this mode of oxygen delivery: 1) a large storage volume (the liquid oxygen occupies a volume 862-fold less compared with the same amount in gas form [17]) which practically allows the use of relatively small oxygen liquid volume to supply high oxygen flows to patients; and 2) a portable unit (namely "stroller") with a capacity of 0.5–1.2 L and a weight of 3 kg (when full), that can be refilled from the base unit container ("liberator") for ambulatory use.

Even if this lightweight portable unit can be carried by the patient on the shoulder for outdoor actions, it has limited capacity and time-limited usage, linked to the flow-rate prescribed (especially at flow-rates  $>6 \text{ L}\cdot\text{min}^{-1}$ ). This particular limitation can be only partly resolved by adding conserving devices such as flow-economisers.

### Advice for portable liquid oxygen use

With the purpose of avoiding fires or dangerous outbreaks (oxygen is a highly flammable gas) when using liquid oxygen, it is important that patients are formally "educated" on the specific use of these devices. In particular:

- to fill the stroller from liberator in a well aerated area, far from any electric power supply;
- to eliminate any trace of humidity from the extremities of the containers before connecting stroller and liberator, in order to avoid frosting, which would otherwise make detaching the stroller from the liberator impossible;
- to refill the stroller just before using, thus avoiding unnecessary gas loss (patients often refill the stroller in the evening but use it the following morning).

### Portable Oxygen during daily living

To encourage outdoor AO, new technologies on portable oxygen systems, which can be used during daily physical activities, have been developed (fig. 2). Use of these portable devices has been shown to improve the perceived quality of life in COPD patients [11].

However, very few patients taking AO therapy spend time outside their home [9, 18, 19] and only 50% may use AO more than five times a week or regularly. A recent trial in Canada [20] aimed at determining the long-term efficacy (1 yr) of AO

in COPD patients but was stopped prematurely after a 3-month interim analysis due to the low rate of usage. Therefore, little is known on how COPD patients use AO outdoor and/or during their domestic activities. Regarding this unknown aspect, a recent placebo-controlled 8-week trial (cylinder oxygen *versus* cylinder air) on 20 stable COPD patients, was not able to show any significant change in the amount of domestic activities, health-related quality of life or time spent outdoor, although the overall duration with portable oxygen was increased over time in the portable oxygen group compared with portable air [21].

The literature has suggested so far that oxygen administered during walking can improve physical performance of COPD patients as well as decrease breathlessness [22, 23]. Data in non-hypoxaemic COPD patients, who received oxygen during exercise training, included in a pulmonary rehabilitation programme, also supported an additional clinical benefit as compared with standard training breathing room air [24].

The adoption of a portable  $\text{O}_2$  device (canister) pulled on a small wheeled cart (aid modality; fig. 3a) in COPD patients has been associated with better change of exercise performance (both in terms of metres walked and speed achieved) and perceived symptoms compared with the same canister carried on the patient's shoulder, particularly in those individuals with lower residual exercise capacity at baseline [25]. Although only 60% of these patients provided with a portable oxygen device use it outdoors for walking [19], this very simple aid [25] is likely to be helpful in severe COPD. Indeed, walking speed frequently represents a practical issue in elderly pedestrians who are at risk of being struck by cars when crossing the street [26]; therefore, in respiratory and disabled patients, strategies for any functional and/or walking



Figure 2. Use of oxygen portable systems during common activities of daily life. a) Stairs climbing. b and c) In-house activities. d) Car driving.

improvement should be considered of particular interest. Similar effects on the functional exercise capacity can be achieved when using a rollator (fig. 3b) [27].

A recent trial of NASIŁOWSKI *et al.* [28] carried out in patients with CRF due to severe COPD, comparing two different portable oxygen systems (concentrators and liquid unit) with placebo (cylinder with compressed air), demonstrated similar effectiveness (in terms of metres achieved in the 6 min walking distance test) during both sources of oxygen supplementation with no relevant difference even when compared with compressed air [28].

In conclusion, it's still not possible to establish whether patients on LTOT should be effectively provided with AO during exercise or daily activities. Nevertheless,

experience from clinical practice in LTOT patients suggests that clinicians should consider this option in very disabled individuals and they may need to adequately

titrate oxygen flow during walking (or exercise) by adding  $1 \text{ L} \cdot \text{min}^{-1}$  to the resting flow or by monitoring the arterial oxygen desaturation on exercise [18]. Indeed, the current guidelines recommend an oxygen flow titration able to bring about an arterial oxygen saturation  $>90\text{--}92\%$  during effort; the appropriate oxygen flow should be finally set by repeated exercise tests on a level equal to, or slightly higher than, that normally experienced during the individual's regular daily living.

### Travel with portable oxygen

Among the daily activities of CRF patients, travel might represent a further application for AO. Since the oxygen container is transportable, it may be used in the patient's car or on public transport, such as bus, train or airliner. When travelling, the device should remain in an upright position (*i.e.* standing up on the back seat with a rear seat belt to hold it in place). Concentrators may also be stowed on buses for interstate journeys; some airlines are able to carry oxygen concentrators free of charge. Nowadays, airlines might provide such equipments and arrange it in order to encourage the lung disease sufferer to travel in any part of the aircraft. In the ►



Figure 3. Walking aids for portable liquid oxygen canisters. Oxygen is transported using a small wheeled cart (a) or a rollator (b).

future, it is hoped that airlines will be able to provide an oxygen concentrator which may fit under the aircraft seat and be set at the required flow rate.

Local oxygen suppliers, public authorities or private airlines may generally provide all the information needed for this scope. However, safety regulations forbid the use of patients' own compressed oxygen equipment, during flight.

### METHODS OF OXYGEN ADMINISTRATION IN CLINICAL PRACTICE

Oxygen administration in CRF patients needing AO can be delivered through several systems (fig. 4) mixing additional oxygen at different inspired fractions ( $FI,O_2$ ) to ambient air. Schematically, these methods could be distinguished into "low flows" or "high flows" systems. In tracheotomised patients, oxygen administration is warranted by the direct connection of the oxygen source to the tracheal cannula through a so-called

"artificial nose" and/or "speaking valve".

The low flows systems do not completely satisfy the patient's inspiratory demand:  $FI,O_2$  can vary remarkably because it depends on both the oxygen flow supplied and the respiratory pattern of the patients. Such methods include nasal cannulae, masks and masks with a reservoir (with partial re-respiration).

The nasal cannulae (widely use with  $O_2$  portable systems and for  $O_2$  administration of  $1-6 \text{ L}\cdot\text{min}^{-1}$ ) are small tubes inserted in the patient's nostrils. They represent the most simple and economic system to administrate oxygen, while being very well tolerated by the patient and are often useful to achieve an  $FI,O_2$  able to adequately correct hypoxaemia on exercise. This method does not interfere with any daily actions, such as eating, speaking or coughing. The main side effects in the long-term use of nasal cannulae (especially with elevated flow rates) include nasal mucosa irritation, nasal bleeding and alteration of taste and smell senses.

The mask and the mask with reservoir (with capacity to accumulate  $O_2$  until a  $FI,O_2$  of 90% is achieved) are plastic dispositive that can guarantee higher  $FI,O_2$  compared with the nasal cannulae. However, a minimal flow of  $5-6 \text{ L}\cdot\text{min}^{-1}$  is needed in order to prevent the accumulation of carbon dioxide ( $CO_2$ ) inside the mask (in the simple model) or the bag collapse (in the reservoir model).

Finally, the Venturi mask represents the most useful method to best ensure the high flow oxygen delivery; its functioning is linked to the principle of "jet mixing" through a narrow duct hole which increases gas velocity; with a variation of the duct calibre (proportional to the gas velocity), it is then possible to obtain (and deliver) different oxygen concentrations.

Overall, nasal cannulae are best suited to provide LTOT and AO; alternatively, masks have a more specific indication of use in hospital during acute care of patients with CRF.

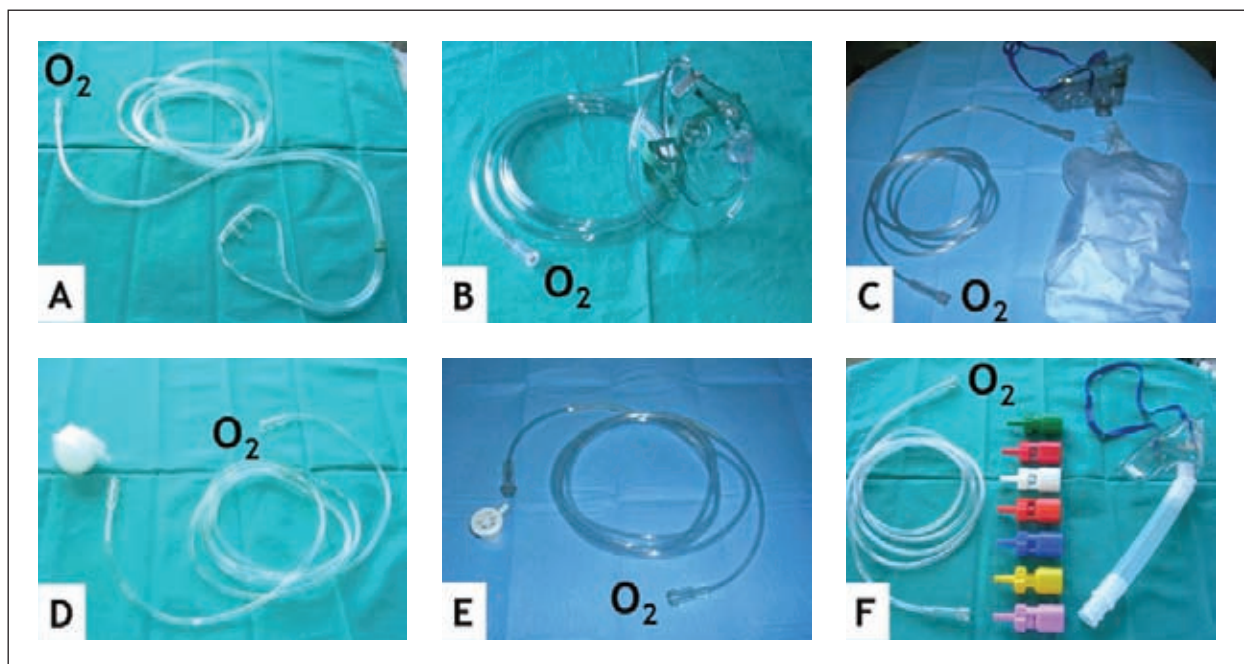


Figure 4. Methods of oxygen administration. a) Nasal cannula, b) simple mask, c) mask with reservoir, d) artificial nose, e) speaking valve and f) Venturi mask.

## CONCLUSION AND FUTURE PERSPECTIVE

In many respiratory patients, the presence of oxygen desaturation during exercise or activities of daily living can be corrected with the use of AO regimen. AO can be provided by portable devices (concentrators, compressed or liquid portables) and specific equipment carried by the patients. Even if the clinical benefits

of AO still remain uncertain, a common consensus exists among the respiratory specialists for implementing this regimen with the final aim of improving the patient's level of independence, perceived health status and functionality, especially in the most sick and disabled individuals.

Future research is then need to answer any unresolved questions.

In particular, clinical studies aimed at clarifying the long-term impact of AO in CRF individuals are welcomed. Finally, technological developments of portable oxygen systems, such as the new hybrid concentrators, might enlarge the product market with "on demand", more easily refillable, higher flow, lighter and less expensive devices to compete with the classical liquid or gas cylinders. ■

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