Handbook on Oxygen Sources, Distribution and Need Estimation with Rational Use of Oxygen in COVID-19 Patient Management

O_2

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Contents

Abbreviations

LMIC	Low and middle income countries
LMO	Liquid medical oxygen
PSA	Pressure Swing adsorption
VSA	Vacuum Swing adsorption
DGHS	Director general of health services
CPAP	Continuous positive airway pressure
BiPAP	Bilevel positive airway pressure
NIPPV	Nasal intermittent positive pressure ventilation
N_2	Nitrogen
O_2	Oxygen
psig	Pound per square inch gauge
Nm^3	Normal Cubic meter
VPSA	Vacuum Pressure Swing adsorption
ICU	Intensive care unit
HFNOT/HFNO	High flow nasal oxygen therapy
ESFT	Essential supply forecast Tool
NIV	Noninvasive ventilation
HFNC	High flow nasal cannula
NRM	Non-rebreather mask
FiO_2	Fraction of inspired oxygen
SpO_2	Peripheral oxygen saturation
SOP	Standard operating procedure
ABG	Arterial blood gas analysis
CXR	Chest X ray
LPM	Liters per minute
VT	Ventricular tachycardia
BVM	Bag-valve-mask
MCH	Medical college hospital
PEEP	Positive end-expiratory pressure
SBT	Spontaneous breathing trials
CLT	Cuff leak test
ETT	Exercise tolerance testing
RASS	Richmond agitation sedation scale
ECHO	Echocardiogram
CBC	Complete blood count
RFT	Renal function test
LFT	Lung function test
ECG	Electrocardiogram
CTPA	Computed tomography pulmonary angiogram
CT	Computed tomography
ET	Endotracheal tube
CVC	Central venous catheter
LDH	Lactate dehydrogenase
CNS	Central nervous System
CDC	Communicable disease control
TV	Tricuspid valve
AC	Acute coronary syndrome

Introduction

Background

The second wave of COVID-19 pandemic has hit South-Asian countries hard. Bangladesh is not different from other South Asia countries, where COVID-19 cases increased at an unprecedented rate. Bangladesh has seen a surge of COVID-19 cases since the last week of May 2021 (1). As the number of cases continued to rise exponentially, scarce hospital resources ran thin, and critical care units were overburdened. As oxygen therapy is the cornerstone for management of patients with moderate and severe COVID-19, rational use of oxygen during the crisis cannot be overemphasized (2).

Oxygen therapy is essential component in COVID-19 pandemic situation which was never thought previously. Oxygen is an essential medicine that is used to treat hypoxia at all levels of the health care system. It is required for surgery and management of acute respiratory illnesses such as severe pneumonia, chronic pulmonary diseases, emergencies and cardiovascular diseases, among others. Yet in the 21st century many patients require oxygen and it is not available, especially in low-resource settings. The COVID-19 pandemic has highlighted the need for and gaps in oxygen globally. Severe pneumonia from COVID-19 has resulted in a surge in oxygen demand globally. However, even before the COVID-19 pandemic, there were reports that in the majority of LMIC, there was a struggle to access reliable medical oxygen. For example, across sub-Saharan Africa 31% of facilities have interrupted oxygen availability, and 25% have no availability at all. It was also reported that the availability of oxygen for medical use is the primary rate-limiting factor for treatment once a diagnosis has been made. Specific barriers to availability may include: high cost, lack of funding for long-term operations, lack of trained human resources, weak supply chains and non-continuous and unreliable power supply access. Medical oxygen has often been omitted in holistic planning efforts while strengthening health systems, and technical guidance related to installation and maintenance of oxygen systems is limited (3, 4).

In June-July 2020, Directorate General of Health Services (DGHS) of the Ministry of Health and Family Welfare (MOHFW) undertook a survey with support from different partners on Health Facility Preparedness and Readiness assessment for the COVID-19 response. It looked at 120 health facilities including specialized hospitals, medical college hospitals, district hospitals, upazilla health complexes, Non-government organizations (NGOs), and private health facilities across eight divisions of the country. This survey showed that in at least one hospital in the city have oxygen plant or liquid medical oxygen (LMO). It was found that there was no piped oxygen system in many district health facilities. Thus, the hospitals were not ready to receive any patients with COVID-19 who required oxygen for their better management. It was also revealed that around 70% of the facilities did not have adequate oxygen infrastructure including oxygen plant or liquified medical oxygen system, and other essential oxygen equipment such as oxygen concentrator and pulse oximeter (5).

To mitigate the impact of the pandemic on health outcomes, the DGHS of the MOHFW with support from different donors worked to strengthen the capacity of existing LMO system with extended pipeline and gas in specialized hospitals, medical college hospitals, and district hospitals. The Government is also expanding the capacity by installing Pressure Swing adsorption (PSA) plant and Vacuum Swing Adsorption plant system which are the latest technology of oxygen production system. The principal target of the government is not only to combat COVID-19 but also to improve the oxygen structure of several hospitals for better care of maternal and child health (5).

The government understood that installing only larger oxygen plant will not solve the problem of oxygen demand in coming future, a rational approach to use of oxygen is also imperative. During the surge of COVID-19, we have observed that people were running for oxygen cylinder, even those who did not need oxygen. On the other hand those who need oxygen could not get enough oxygen. Misconception and lack of knowledge regarding oxygen use existed across the health system during rise of COVID-19 cases in Bangladesh. Not only that, several fire outbreak occurred from mis-handling of Oxygen equipment in few government and private hospitals.

Improving the clinical outcomes of patients admitted to the hospital with COVID-19 requires a concerted effort by all stakeholders. As resources are limited and the case-load in hospitals tends to rise fast during COVID-19, this is an opportune time to focus on the basics of medical care, including oxygen therapy. It is important to do the fundamentals right as we do not have adequate resources for the widespread adoption of resource mapping protocols and expensive pharmacological agents. Considering that, DGHS, MOHFW felt the necessity to develop a guideline titled "Oxygen Sources, Distribution and Need Estimation with Rational Use of Oxygen in COVID-19 patient management".

The present publication has two sections, one for policy makers and hospital management; another for frontliners who directly mange the patient. The first describes the need for oxygen, introduces the technologies of oxygen sources, the different oxygen delivery devices and oxygen safety guideline. The second section illustrates a simple flow chart for oxygenation of COVID - 19 Patient, and it's detail description and the concept of oxygen toxicity.

Purpose of the guideline

The first section will help policy makers and hospital or clinic mangers to identify the types of technologies of oxygen sources available in the market, and based on need the hospital submit request or purchase the selected technologies of oxygen sources. This section will also support policy makers and health mangers can calculate the oxygen demand in their hospital and save their hospital by following the oxygen safety guideline.

The second section is for the healthcare worker who treat patients at their bedside. This section will guide them to provide oxygen in COVID-19 patients by following a simple flow chart. This section will also give them an understanding of different oxygen delivery devices and oxygen toxicity which is not discussed much, but an integral component of oxygen therapy.

Definitions

Oxygen therapy: Oxygen therapy or supplemental oxygen is the provision of medical oxygen as a health-care intervention.

Composition of Medical oxygen: Medical oxygen contains at least 82% pure oxygen extent 99%, is free from any contamination and is generated by an oil-free compressor. Only high quality, medical-grade oxygen should be given to patients.

Hospital Oxygen system: Hospital oxygen system must consist of an oxygen source, or production combined with storage and supply system.

Section 1: For policy makers and hospital/clinic managers

Overview of oxygen therapy products

Common oxygen sources

1. Cylinder. Single time procurement and need to refill. The most common source of oxygen storage used in health-care settings is a cylinder.
2. Oxygen concentrators. 5 to 10 L/ minute; Single time procurement and need continuous electric supply
3. Liquid oxygen in bulk storage tanks; Need company supply channel
4. Oxygen generating plants; Need continues electrical supply

Common Oxygen delivery devices

1. Direct to patient

a) Cylinder with flowmeter: Low Flow system:1 to 15 l /min

b) Oxygen concentrator: Low Flow system: 1 to 10 l/min

c) Central Gas pipeline: Connect with Cylinder manifold or PSA or VSA and liquid oxygen tank: Uses with all devices

2. Oxygen devices in patient end:

a) Nasal canula: Flows 1-6 l/min, used with all oxygen supply or storage system

b) Face mask: Flows 4-10 l/min, used with all oxygen supply or storage system

c) Partial rebreathing mask: Flows 10-15 l/min, used with all oxygen supply or storage system except oxygen concentrator

d) Non rebreathing mask: Flows 10-15 l/min, used with all oxygen supply or storage system except oxygen concentrator

e) Venturi mask: Flows 6-15 l/min, used with all oxygen supply or storage system except oxygen concentrator

f) High flow nasal oxygen therapy: Flows up to 80 l/min, used with central gas line and electric supply

3. Artificial / Mechanical Ventilation

a) Noninvasive: Continuous positive airway pressure (CPAP), Bilevel positive airway pressure (BiPAP) and Nasal intermittent positive pressure ventilation (NIPPV): Need

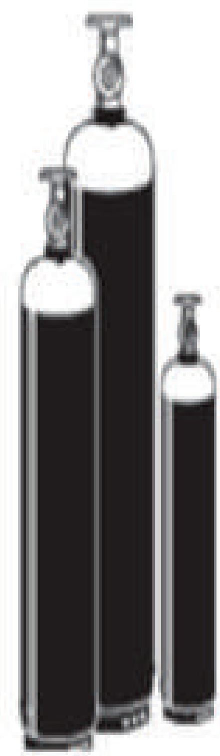
special mask; Flows 2-10l/min, used with all oxygen supply or storage system and electricity
b)nvasive ventilation: Endotracheal intubation: Flow 4-10 l/min, used with central gas line and electric supply

Oxygen Sources

The appropriate choice of oxygen source depends on many factors, including:
1.The amount of oxygen needed at the treatment center,
2.The available infrastructure,
3.Cost,
4.Capacity and supply chain for local production of medicinal gases,
5.Availability of electrical supply, and
6.Access to maintenance services and spare parts, etc.

Oxygen cylinders

Oxygen gas can be compressed and stored in cylinders. These cylinders are filled at a gas manufacturing plant, either via a cryogenic distillation or a process known as pressure swing adsorption (PSA), and transported to health facilities to be connected to manifold systems (groups of cylinders linked in parallel) that are piped to areas of the health facility; or to cylinders can be used directly within patient areas. The use of cylinders typically involves transport to and from the bulk supply depot for regular refilling, which could have logistical challenges and ongoing cost implications, often leading to unreliable supply in many settings. While less common, cylinders can also be filled by a PSA oxygen plant that is co-located with a health facility and that has a high-pressure compressor for cylinder filling purposes. Cylinders do not require electricity, but they do require several accessories and fittings to deliver oxygen, such as pressure gauges, regulators, flowmeters, and, in some cases, humidifiers. Cylinders also require periodic maintenance, commonly provided by gas suppliers at the point of refilling.



Cylinders can be used for all oxygen needs, including high pressure supply and in facilities where power supply is intermittent or unreliable. Cylinders are also used for ambulatory service for patient transport and used as a backup for other systems (4).

Oxygen concentrator

An oxygen concentrator is a self-contained, electrically powered medical device designed to concentrate oxygen from ambient air. Utilizing PSA technology, an oxygen concentrator draws in air from the environment, extracts the nitrogen, and can produce a continuous source of 95.5% concentrated oxygen. Oxygen concentrators are portable and can be moved between clinical areas, but they are also often set up to be stationary fixtures in patient areas. Concentrators designed for home care or bedside use are available in models that can deliver maximum flow rates between 5 and 10 L/min. When used with a flowmeter stand for splitting flow, concentrators can provide a continuous supply of oxygen to multiple patients at the same time. Concentrators can provide a safe and cost-efficient source of oxygen, but they do require a source of continuous and reliable power and regular preventive maintenance to ensure proper functioning. It is a best practice to also have cylinders as a backup supply.

Oxygen concentrators are used to deliver oxygen at the bedside or within proximity to patient areas. A single concentrator can serve several beds with the use of a flowmeter stand to split output flow (4).

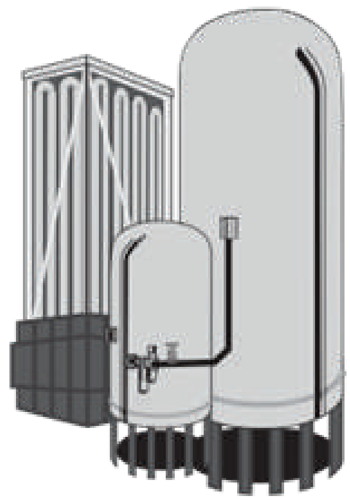
Oxygen Manifold Systems

A manifold is a fluid or gas distribution system or device that serves to bring many junctions into one place or a single channel into an area where many points meet. Manifold systems range from simple supply chambers with several outlets to multi-chambered flow control units including integral valves and interfaces to electronic networks. Complex pneumatic and hydraulic circuits can utilize manifolds and manifold systems with interfaces to sophisticated electronic networks.

Cylinders are often arranged into two groups; a primary and secondary group. In a hospital, size J cylinders are commonly used, which are capable of holding 6800 liters of oxygen each or 13,600 of nitrous oxide. Initially, the gas is used up from the primary group first, with gas being expended equally from all cylinders, as they are connected in parallel through a common outlet. Once the levels in the cylinders are sufficiently low, a pressure transducer switches to the secondary manifold; allowing the primary manifold to be replenished. Manifolds are used to supply nitrous oxide, Entonox, air or oxygen; although a vacuum insulated evaporator is more commonly used to store oxygen. Gas manifolds should be stored in an area separate from the main building. It should not be exposed to the environment and should be well ventilated (6).

Liquid oxygen in bulk storage tanks

Cryogenically produced liquid oxygen is always generated off-site (not at a medical facility). Medical facilities can be equipped with large bulk liquid oxygen tanks that are refilled periodically by a truck from a supplier. The liquid oxygen tank supplies a centrally piped system throughout the health facility by self-vaporization and for which a power supply is not required. Although an economical option in some settings, the use of liquid oxygen relies on external supply chain mechanisms and needs a bit more caution with respect to transport and storage due to the risks associated with higher pressures. Extra care should be taken in more extreme environments. It is best practice to also have cylinders as a backup supply.

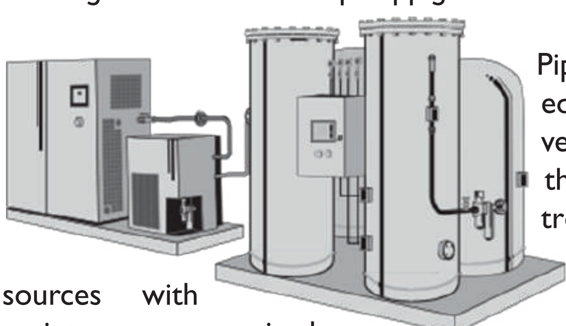


A typical storage system consists of a cryogenic storage tank, one or more vaporizers and a pressure control system. The cryogenic tank is constructed, in principle, like a vacuum bottle. There is an inner vessel surrounded by an outer vessel. Between the vessels is an annular space that contains an insulating medium from which all the air has been removed. This space keeps heat away from the liquid oxygen held in the inner vessel. Vaporizers convert the liquid oxygen into a gaseous state. A pressure control manifold then controls the gas pressure that is fed to the process or application These cryogenic storage tanks are equipped with pressure-relief valves and rupture disks to protect the cylinders from pressure buildup. Liquid containers operate at pressures up to 350 psig and have capacities between 80 and 450 liters of liquid.

It can be used for all oxygen needs, including high pressure supply and in facilities where power supply is intermittent or un-reliable (4).

Oxygen generator

An oxygen generator is a large, onsite, central source of oxygen that is piped directly to terminal units within patient areas. Generators can generate oxygen using PSA technology (similar to concentrators) or by cryogenic distillation. Generators can also be set up to refill cylinders for oxygen distribution or backup oxygen supply; these cylinders can be connected to sub-central manifold systems at the health facility or transported to neighboring health facilities. Note that oxygen plants require a reliable source of power. It is best practice to also have cylinders as a backup supply.



Pipeline systems supply oxygen at high pressure to equipment such as anaesthetic machines and ventilators. A key advantage of pipeline systems is that they obviate the need for handling and transporting heavy cylinders between hospital wards. The high cost of installing centralized oxygen sources with copper pipelines and the high level of specialized maintenance required currently make these systems of oxygen delivery unsuitable for many district-level hospitals in low resource setting. Pipeline systems can be used for all oxygen needs, including high-pressure supply (4).

PSA generator

Pressure swing adsorption (PSA) is the process by which ambient air passes through an internal filtration system (e.g. a molecular sieve [zeolite granules or membranes]), which has a large enough total surface area to separate nitrogen (N2) from the air, concentrating the remaining oxygen (O2) to a known purity. It typically consists of an air compressor, dryer, filters, dual separation chambers, a reservoir, and controls.

PSA oxygen generator is a unit designed to concentrate oxygen from ambient air at scale, with output capacity varying according to calculated oxygen demand, typically ranging from 2 Nm3/hr to 200 Nm3/hr. For distribution of oxygen produced from PSA plants, oxygen can either be piped directly from the oxygen tank to wards, or further compressed to fill cylinders via a supplemental booster compressor and a cylinder filling ramp/manifold.

All medical PSA oxygen generator are sources of oxygen that can produce medical-grade oxygen, at scale, 24 hours a day, 7 days a week.

PSA plants themselves can be turn-key units complete with all the necessary equipment and supplies; however, the staff operating and maintaining them require specialized training. Strict maintenance schedules are needed to prevent malfunctions. Adequate supplies and spare parts are needed to allow operations for 5 years in resource-limited settings. A reliable supply chain is needed to meet any additional needs. Should repairs be required, these are often carried out by manufacturer or distributor staff (7).

VSA generator

Vacuum Swing Adsorption (VSA) is a non-cryogenic gas separation technology. Using special solids, or adsorbents, VSA segregates certain gases from a gaseous mixture under minimal pressure according to the species' molecular characteristics and affinity for the adsorbents. These adsorbents (e.g., zeolites) form a molecular sieve and preferentially adsorb the target gas species at near ambient pressure. The process then swings to a vacuum to regenerate the adsorbent material.

VSA differs from cryogenic distillation techniques of gas separation as well as pressure swing adsorption (PSA) techniques due to the fact that it operates at near-ambient temperatures and pressures.

Advantages of VSA over PSA

1.Energy efficiency is the key for VSA systems which is not found in PSA. VSA systems showed their energy efficiency when same product flow, pressure as well as purity conditions are there.
2.VSA systems are said to be much more inexpensive than PSA systems, if production rate is found to be more than 20 tons per day which can be 60 tons per day too or more (8).

Comparison of oxygen sources

	Cylinders	**Concentrators**	**Oxygen generator**	**Liquid oxygen**
Distribution mechanism	Connected to manifold of central/sub-central pipeline distribution system, or directly connected to patient with flowmeter and tubing.	Direct to patient with tubing or through a flowmeter stand.	Central/ sub-central pipeline distribution system, or can be used to refill cylinders that can be connected to manifold systems in the facility.	Central pipeline distribution system.
Electricity requirement	No	Yes	Yes	No
Initial costs	Moderate; cylinder, regulator, flowmeter, installation, training.	Moderate; concentrator, spares, installation, training.	High; plant and pipeline distribution system, installation, training.	Can be high; tank, pipeline installation, training.
Ongoing operating costs	High; cylinder deposit and leasing fees, refill costs, transportation from refilling station to health facility.	Low; electricity and maintenance (spare parts and labour).	Low/moderate; electricity and maintenance (spare parts and labour). May require additional staff to operate/manage if not operated by third party.	Moderate (can be high if tank is leased); refill costs, maintenance.
Maintenance requirement	Limited maintenance required by trained technicians.	Moderate maintenance required by trained technicians (1), who could be in-house.	Significant maintenance of system and piping required by highly trained technicians and engineers, can be provided as part of contract.	Significant maintenance of system and piping required by highly trained technicians and engineers, can be provided as part of contract.
User care	Moderate; regular checks of fittings and connections, regular checks of oxygen levels, cleaning exterior.	Moderate; cleaning of filters and device exterior.	Minimal; at terminal unit only.	Minimal; at terminal unit only.

Merits	No power source needed.	• Continuous oxygen supply (if power available) at low running cost. • Output flow can be split among multiple patients.	• Can be cost-effective for large facilities. • Continuous oxygen supply.	• 99% oxygen obtained. • High oxygen output for small space requirement.
Drawbacks	• Requires transport/ supply chain. • Exhaustible supply. • Highly reliant upon supplier. • Risk of gas leakage. • Risk of unwanted relocation.	• Low pressure output, usually not suitable for CPAP or ventilators. • Requires uninterrupted power. • Requires backup cylinder supply. • Requires maintenance.	• High capital investments. • Requires uninterrupted power. • Needs adequate infrastructure. • High maintenance for piping. • Requires backup cylinder supply. • Risk of gas leakage from piping system.	• Requires transport/ supply chain. • Exhaustible supply. • High maintenance for piping. • High total cost. • Needs adequate infrastructure. • Requires backup cylinder supply. • Risk of gas leakage from piping system (4).

Pipeline Intra-Hospital Distribution

These networks are helpful to supply oxygen at high pressure to equipment such as anesthesia machines, ICU ventilators and HFNOT. A key advantage of pipeline systems is that they obviate the need for handling and transporting heavy cylinders between hospital wards. However, the high cost and complexity of installing centralized oxygen sources with copper pipelines and the associated specialized maintenance required for this make pipeline systems less accessible for turn-key installations (9).

Oxygen Needs Estimation

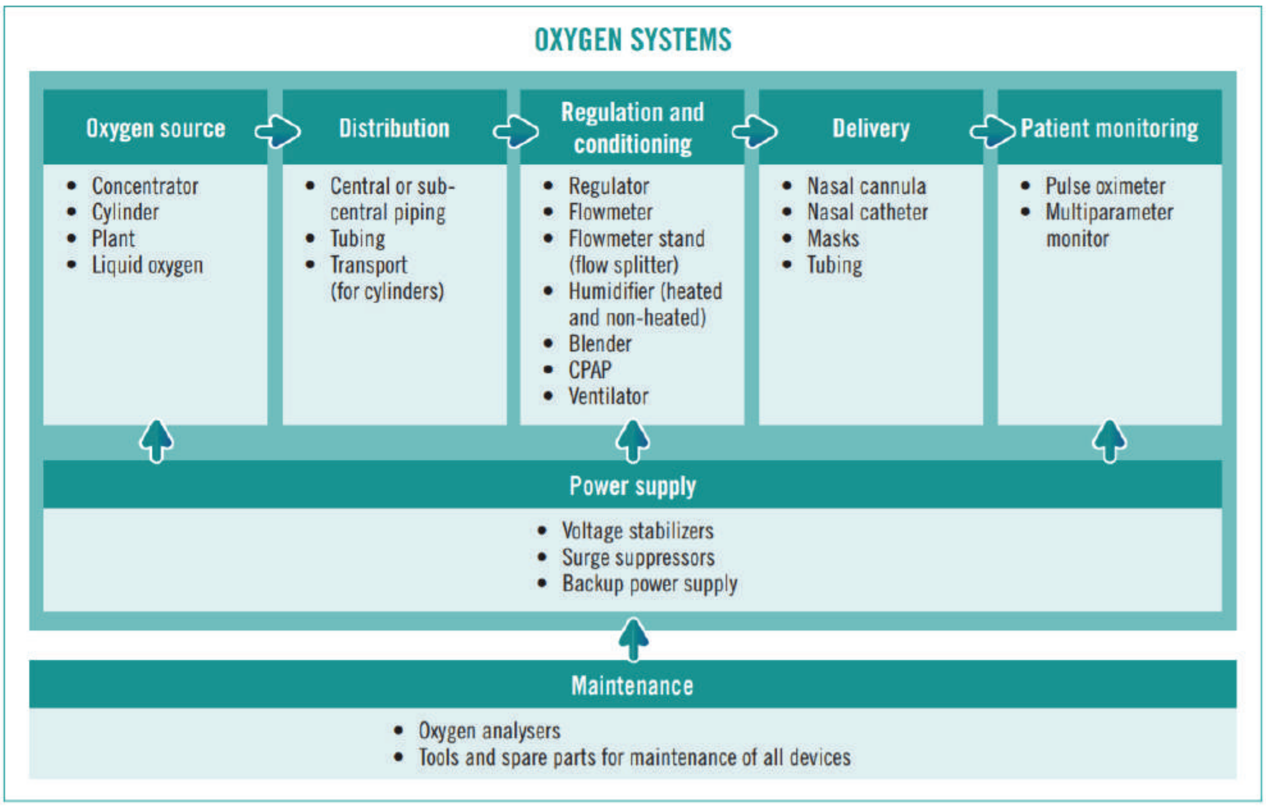
Another aspect of selecting the most appropriate source of oxygen is taking into consideration the gross flows of oxygen that will be needed for treatment. To determine the total flow needs, the anticipated case load has to be estimated. This can be done using the WHO COVID-19 Essential Supply Forecast Tool (ESFT). From the total patients expected, the ratio of patient severity can be ascribed as outlined: mild, moderate, severe, or critical. Thus, the required flows can be estimated to meet the oxygen therapy needs for the hospitalized severe and critical patients, representing 20% of the total. Our national guideline about 85% of the COVID-19 patients requiring hospitalization will be classified as “severe”, and 15% as “critical”. Thus, the recommended flow rates for each patient severity category using different oxygen delivery device, shown in the table below (9).

Table: Sample oxygen flow planning per 100 bed (Hypothetical) facility

Disease Severity	**Total Number of patient**	**Oxygen therapy device**	**Per patients Average O_2 flow rate**	**Amount of O_2 required**	**Preferred cost-effective source**	**Alternative source**
Moderate to severe	50	Nasal cannula, simple facemask, NRM, Venturi mask	2-15 L/min	(50 x 10 x60) = 30000 L/hr	Oxygen cylinder, manifold, concentrator	Oxygen generator (PSA/VSA)
Severe to Critical	40	NIV / HFNC	15-70 L/ min	(40 x 45 x 60) = 108000 L/hr	Liquid O_2 tank	VSA / PSA, O_2 generating plant
Critical	10	Artificial ventilation	5-15 liter/min	(10 x 10 x 60) = 6000 L/Hr	Liquid O_2 tank	VSA/ PSA, O_2 generating plan
Total	144,000 L/Hr 24 Hours = 3,456,000 liter per day					

Oxygen systems components

In addition to the oxygen source and oxygen delivery devices, many other oxygen system components are required to get oxygen to patients who need it. This includes mechanisms for oxygen distribution, apparatuses to control pressure, flow, humidity and concentration, and devices for delivering oxygen to patients. Pulse oximetry is also required for measuring a patient's oxygen saturation level (SpO2) to detect hypoxia, and for monitoring their oxygen status while receiving oxygen therapy. For those devices that are electrically powered, devices are needed to protect equipment from poor-quality mains electricity or provide continuity of power during mains power interruptions. Underpinning all of this is the need for maintenance, which, in addition to available expertise, requires tools to test the functionality of the oxygen therapy equipment as well as spare parts to keep it functioning (4).



Risks and hazards from gas cylinders

Gas cylinders can be hazardous due to both their physical (size and weight) and chemical characteristics. Hazards from gases are also subject to the chemical properties of each gas. These may be one or more of the following:

- Fire or explosion from the release of flammable gases near ignition sources.
- Spontaneous combustion from oxidizing gases (e.g. oxygen or nitrous oxide)
- Exposure limits for all gases, especially toxic or corrosive gases (e.g. anhydrous ammonia);
- Asphyxiation from non-toxic, non-flammable gases by displacement of oxygen (e.g. nitrogen, carbon dioxide or argon)
- Incorrect storage
- Leaks
- Faulty equipment/connections
- Storage and Handling of Gas Cylinders Guidelines
- Physical risks
- Manual handling
- Sudden release of gas if cylinder is damaged (torpedo effect).
- Pressure – compressed gas cylinders are filled to a pressure of 200-300 atmospheres
- Gas Density (10)

Cautions with oxygen therapy

Oxygen therapy supports life and supports combustion. While there are many benefits to inhaled oxygen, there are also hazards and side effects. Anyone involved in the administration of oxygen should be aware of potential hazards and side effects of this medication.

What are oxygen use precautions?

Oxygen is a safe gas as long as it is used properly. Contrary to what most people believe, oxygen will not explode.

Oxygen does, however, support combustion. Therefore, any material that is already burning will burn much faster and hotter in an oxygen-enriched atmosphere.

It is very important to follow these precautions so that you and your family are safe when you are using your oxygen.

The following list includes at-home oxygen therapy safety DON'Ts:

- Do not go near open flames – Stay at least 10 feet away from open flames while using an oxygen concentrator or oxygen tank. Keep away from cigarettes, candles, gas stoves, etc.
- Do not use an electric razor while using oxygen therapy. They are known to put off sparks.
- Do not put on or take off clothing that is prone to static electricity while wearing supplemental oxygen.
- Do not use oil or petroleum-based products on your face while using oxygen, since they are inflammable

The following list contains at-home oxygen therapy safety DOs:

• Keep oxygen tanks and cylinders secure at all times. If they fall over, the valve can come loose, and the pressurized oxygen may turn the tank into a dangerous missile.
• Place a non-smoking sign in your home or one in each room.
• Keep the service number for your oxygen equipment nearby, in case something breaks. A good idea would be to put a sticker with the customer care number on the equipment and your first-aid box.
• Have a quick escape plan in case of a house fire, so you immediately know what to do to prevent panic and confusion.
• When not in use, store your oxygen equipment in an area of your house that is far from any sources of heat (11).

Using your cylinders safely

While handling cylinders

• Do no smoke or use naked flame near a cylinder usage or storage area.
• Never use oil, grease based products on the cylinder or any accessories.
• Wear appropriate personal protective equipment (glasses, boots, gloves), particular for large cylinders.
• Always have the SOPs on hand for reference and follow recommended handling instructions

During cylinder transportation

• Detach regulators and other accessories from the cylinder.
• Secure cylinders against movement.
• Use open or well ventilated vehicles or trailers in preference to enclosed ones. Limit the number of cylinders to be transported.

Storing your cylinders

• Always display a "NO SMOKING OR OPEN FLAMES" sign.
• Storage areas should be kept 3m from heat sources or combustible materials.
• Store cylinders away from oils or grease.
• Never store flammable gas near oxidising gases.
• Never store objects on top of the cylinder.
• Always rotate cylinders - first come, first used.
• Store gases in well ventilated areas.
• If something is wrong with a cylinder,
• Label as "suspect"
• Put in quarantine. (10)

Prepare a register and check the line, cylinder, and whole system daily, monthly and quarterly and write down the information in register

Nutshell of OXYGEN SAFETY GUIDELINES FOR HOSPITAL	
Guideline	**Additional Information**
Oxygen is a medication.	Remind patient that oxygen is a medication and should not be adjusted without consultation with a physician or respiratory therapist.
Storage of oxygen cylinders	When using oxygen cylinders, store them upright, chained, or in appropriate holders so that they will not fall over.
No smoking	Oxygen supports combustion. No smoking is permitted around any oxygen delivery devices in the hospital or home environment.
Keep oxygen cylinders away from heat sources.	Keep oxygen delivery systems at least 1.5 metres from any heat source.
Check for electrical hazards in the home or hospital prior to use.	Determine that electrical equipment in the room or home is in safe working condition. A small electrical spark in the presence of oxygen will result in a serious fire. The use of a gas stove, kerosene space heater, or smoker is unsafe in the presence of oxygen. Avoid items that may create a spark (e.g., electrical razor, hair dryer, synthetic fabrics that cause static electricity, or mechanical toys) with nasal cannula in use.
Check levels of oxygen in portable tanks.	Check oxygen levels of portable tanks before transporting a patient to ensure that there is enough oxygen in the tank.
Arterial blood gas analysis (ABGs) should be ordered for all critically ill patients on oxygen therapy.	High concentrations of oxygen therapy should be closely monitored with formal assessments (pulse oximetry and ABGs) (12).

Section 2: For healthcare workers

Important consideration

• The essence of this guideline can be summarized simply as a requirement for oxygen to be prescribed according to a target saturation range and for those who administer oxygen therapy to monitor the patient and keep within the target saturation range.

• The guideline recommends aiming to achieve normal or near-normal oxygen saturation for COVID-19 patients.

Oxygen Surge Plan

The ability to boost capacity to deliver oxygen therapy is the cornerstone of the overall approach to managing the COVID-19 outbreak and it has implications for the functioning of the entire system. The principles, set out here, of building surge capacity should be integrated into a heath care system, either centrally or at facility level. The oxygen surge plan should be integrated into the overall COVID-19 response plan. For instance, if a new COVID-19 treatment center is planned, the location and layout of the construction site will be a key factor for the oxygen surge planning.

Protocol for oxygenation of covid 19

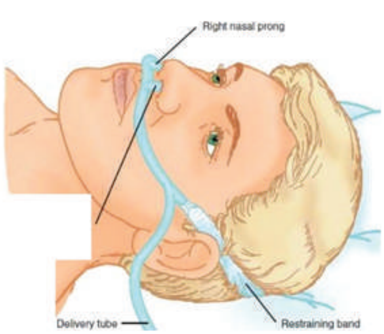
1. Oxygen therapy is most important for managing the covid 19 hypoxic patient.
2. When oxygen use is more than 21 % then it is a drug, need proper prescription.

Oxygen delivery devices

1. Low-flow oxygen delivery systems

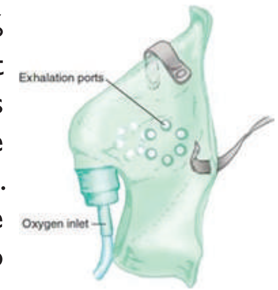
a) Nasal cannula

A nasal cannula is the most common oxygen delivery system, used for mild hypoxia. It delivers oxygen into the nasopharyngeal space and can be set to deliver between 1 and 6 LPM (24–40% FIO2). FIO2 increases by approximately 4% with each litre of oxygen per minute. Nasal cannulae are widely used in domiciliary oxygen devices. An oxygen flow >6 LPM should be avoided as it can dry the nasal mucosa and can disturb sleeping patterns. A nasal cannula is convenient as the patient can talk and eat while receiving oxygen, and it is easy to use. However, it can be easily dislodged and is not as effective in patients with deviated septum or polyps (13).



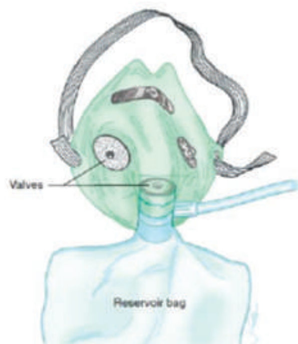
b) Simple face mask

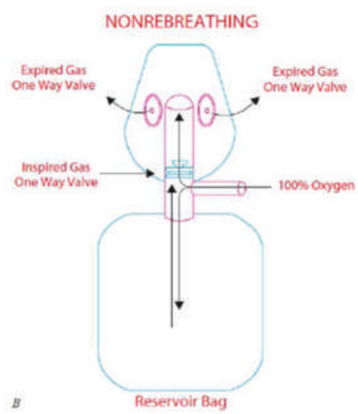
A simple face mask can be set to deliver between 5 and 10 LPM (35–55% FIO2) and is indicated when a moderate amount of oxygen is needed. It fits over the patient's mouth and nose and has side exhalation ports through which the patient exhales carbon dioxide. Humidified air may be added if the oxygen concentrations are causing nasal mucosa dryness. The mask's efficiency relies on how well it fits. Eating and drinking can be difficult with the mask on, and it can be confining for some patients, who may feel claustrophobic with the mask on (13).

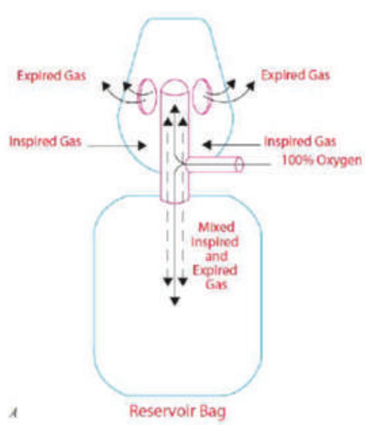


c) Non-rebreather mask

A non-rebreather mask is a low-flow device with high FIO2. It uses a reservoir bag (1000 mL) to deliver a higher concentration of oxygen. A one-way valve between the mask and the reservoir bag prevents the patient from inhaling expired air. It can be set to deliver between 10 and 15 LPM (80–95% oxygen). Oxygen flow <10 LPM can cause the bag to completely collapse during inspiration. FIO2 depends on the patient's pattern of breathing. This mask is useful in severely hypoxic patients who are ventilating well, but it carries the risk of carbon dioxide retention and aspiration in case of vomiting (13).







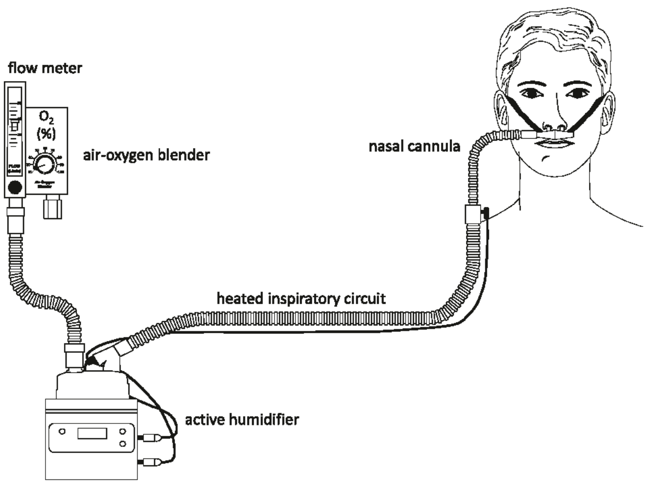
2. High-flow oxygen delivery systems

a) Partial rebreather mask

Unlike the non-rebreather mask, there is no one-way valve between the rebreather mask and the reservoir bag and the inspired oxygen and expired air are collected in the reservoir bag (13).

b) Venturi mask

A Venturi mask is a high-flow device that allows precise measurement of FIO2 delivered. It consists of a bottle of sterile water, corrugated tubing, air/oxygen ratio nebuliser system, a drainage bag, and a mask (e.g. aerosol face mask, tracheostomy mask, T-piece, a face tent). The oxygen flow exceeds the patient's peak expiratory flow. Therefore, it is unlikely for the patient to breathe in air from the room. A Venturi mask utilises different sized ports to change the FIO2 delivered (24–50%). The FIO2 and oxygen flow are clearly stated on the bottom of each port. It does not dry mucous membranes, but it is confining for some patients, and it interferes with talking and eating. It is particularly useful in COPD patients, where precise oxygen delivery is crucial (13).



c) High-flow nasal cannula

A high-flow nasal cannula consists of a flow generator, an air-oxygen blender, a humidifier and a nasal cannula. The flow generator can provide gas flow up to 70 LPM, and the blender escalates FIO2 up to 100% while the humidifier saturates the gas mixture (at 31–37°C). The heated humidified oxygen is delivered to a wide-bore nasal prong. The flow rate and FIO2 can be independently titrated based on the patient's flow and FIO2 requirements. Overall, high flows and humidification improve functional residual capacity and mucociliary clearance of secretions, and thereby they reduce the work of breathing (13).

Comparison of different oxygen delivery devices

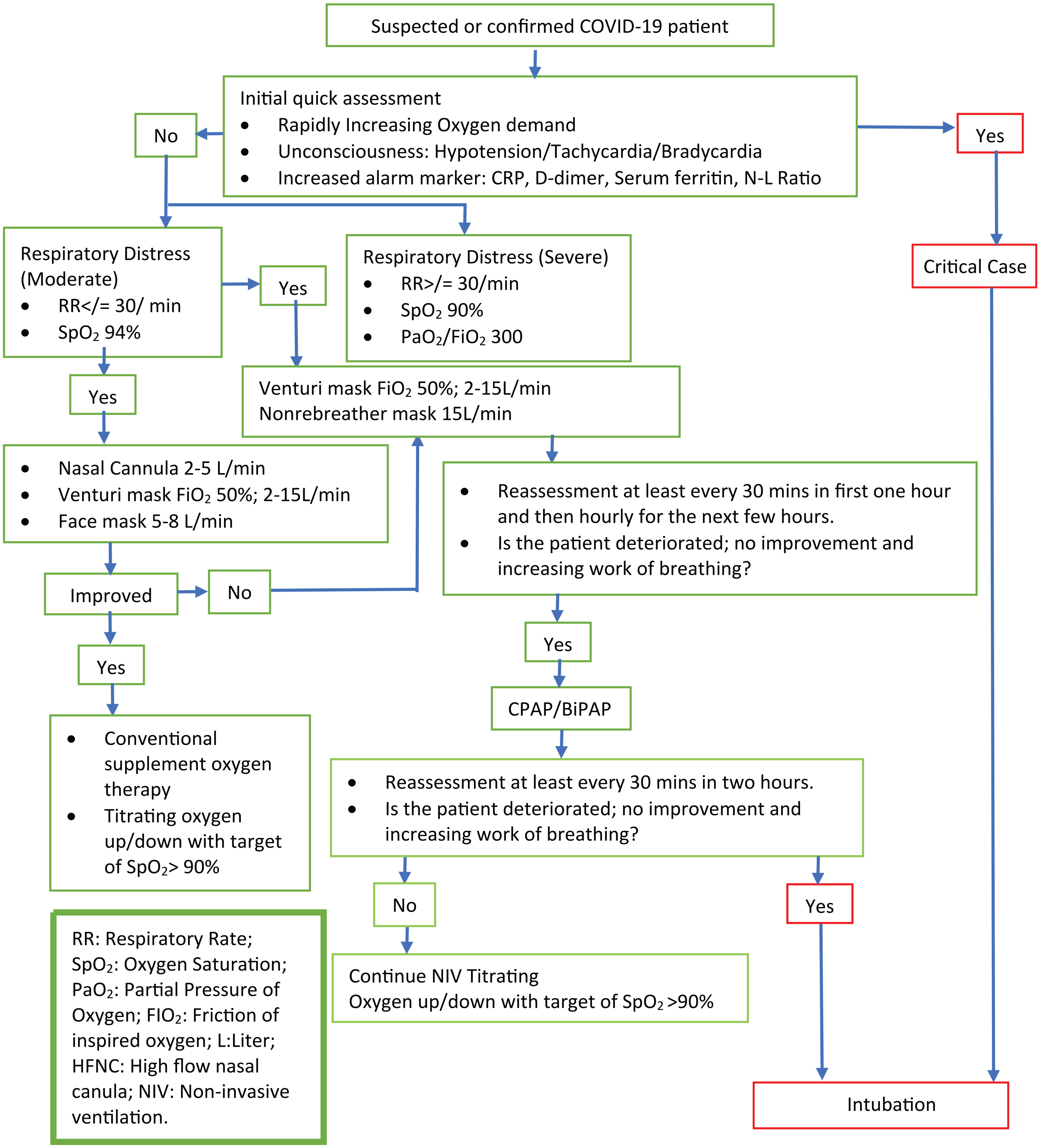
Name of devices	Amount of oxygen can be delivered	Achievable FiO_2
Nasal Canula	1 – 6 LPM	24 – 40%
Simple Face mask	5 – 10 LPM	35 – 55%
Non-rebreather mask	10 – 15 LPM	95 - 100%
Partial rebreather mask	10 – 15 LPM	80%
Venturi mask	5 – 15 LPM	28 – 100%
High-flow nasal cannula	5 – 15 LPM	100%
Non-invasive Ventilation (BiPAP and CPAP)	5 – 15 LPM	90%
Artificial ventilation	5-15 LPM	90 – 100%

Demand and Supply

All assisted ventilation implies a mix of medical air and oxygen. Flows for critical patients indicated here represent only the oxygen portion of the total gas flow required to achieve target therapeutic fraction of inspired oxygen (FiO2), which is the total % oxygen in the lungs available for gas exchange. FiO2 will change over the course of a treatment and vary from one patient to the next. The oxygen flow rate indicated here represents an average of the proportion of oxygen flows over the course of a patient's time on assisted ventilation. A simple equation to determine flow proportion at any time is as follows (9):

$$\text{Target Fi0}_2 = \frac{\text{O}_2 \text{ L /min} + (\text{air L /min} \times 21\%)}{\text{Total flow, L /min}}$$

Flow chart for oxygenation of COVID 19 Patient



Details of Oxygenation of COVID-19 patients with examples

Step 1: Quick clinical assessment

- Disorientation
- Hemodynamic stability
- Any sign of airway obstruction
- And Check SpO_2
- Optional ABG and CXR

Step 2: Resuscitation based on A B C

- ‘A’ stands for airway – look for airway patency
- ‘B’ stands for breathing – look for breathing pattern
- ‘C’ stands for circulation – look for pulse and blood pressure

Step 3: Start Oxygen

It is assumed that patient with

mild disease ($SPO_2 \geq 94$) may be treated at home;

moderate disease (SPO_2 90 to 92) may require non-ICU oxygen supported bed; and severe disease ($SPO_2 < 90$) may need ICU for noninvasive/invasive ventilation.

Condition of patient	**Oxygenation procedure**	**Target**	**Preferred source**	**Preferred device**
SpO_2 is persistently lower than 94%	Start supplemental oxygen up to 1-6 LPM and provide up to 40% FiO_2 **Consider awake proning** Monitor SpO_2, Consciousness, Respiratory rate, Pulse and Blood pressure	SpO_2 92% to 96% with the minimum FiO_2.	Oxygen cylinder or oxygen concentr ator	Nasal cannula or face mask

Step 4: If no improvement in oxygenation

Condition of patient	Oxygenation procedure	Target	Preferred source	Preferred device
Mild to moderate $SPO_2 \leq 90\%$ to 92% room air.	Give higher oxygen 5- 10 LPM which provide up to 60% FiO_2. **Consider awake proning** Monitor SpO_2, Consciousness, Respiratory rate, Pulse and Blood pressure	SpO_2 92% to 96% with the minimum FiO_2.	Oxygen cylinder or oxygen concentrator	Nasal cannula or face mask

Step 5: If no improvement in oxygenation, plan to transfer to any appropriate health facility where higher oxygen storage system is available

1. Calculate oxygen requirement during transfer and keep extra cylinder and pulse oximeter in the ambulance.
2. It is recommended that the following delivery devices should be available in ambulance settings where oxygen is administered.
    - High concentration reservoir mask (non-rebreathe mask) for high-dose oxygen therapy.
    - Nasal cannulae (preferably) or simple face mask for medium dose oxygen therapy.
3. This Guideline suggests aiming to achieve a normal or near-normal oxygen saturation for all acutely ill patients apart from those at risk of hypercapnic respiratory failure. The suggested target saturation range for most patients is 94-98%. Patients at risk of hypercapnic respiratory failure have a lower target saturation range, usually 88-92%.
4. In ambulance, if SpO_2 is 85 – 91%, Titrate O_2 flow to SpO_2 of 92 – 96%
    - Initial dose of 2 – 6 L/min via nasal cannulae
    - Consider simple face mask 5 – 10 L/m
5. In ambulance, if $SpO_2 < 85\%$
    - Initial dose nonrebreather mask 10-15 L/min
    - If inadequate VT, consider BVM ventilation with 100% Oxygen
6. Once Patient haemodynamically stable and has reliable oximetry reading
    - Titrate O_2 flow to SpO_2 of 92 – 96%

Calculation of oxygen requirement with transport time (considering Type D Oxygen Cylinder-1500 Liter)			
Type of device	Oxygen delivered by device (per minute)	Oxygen delivered by device (per hour)	Support time
Nasal cannulae	5 Litre	300 Litre	Five hours
Face mask	10 Litre	600 Litre	Two and half hours
NRB mask	15 Litre	900 Litre	Around One and half hours

Step 6: Referred to in any appropriate health facility where higher oxygen storage system is available

Condition of patient	**Oxygenation procedure**	**Target**	**Preferred source**	**Preferred device**
Referred to District Hospital/ MCH and condition is deteriorating	Venturi Mask: up to 15 LPM and provide up to 60% FiO_2 or Partial rebreather mask: up to 15 LPM and provide up to 70% FiO_2 or Nonrebreather mask: up to 15 LPM and provide up to 95% FiO_2 Monitor SpO_2, Consciousness, Respiratory rate, Pulse and Blood pressure	SpO_2 92% to 96% with the minimum FiO_2.	Central gas line Or Large cylinder at District Hospital/ MCH/ in any appropriate health facility	Venturi Mask or Partial rebreather mask or Nonrebreather mask

Step 7: If no improvement in oxygenation

Condition of patient	Oxygenation procedure	Target	Preferred source	Preferred device
Severe disease SPO_2 < 90	1. HFNC should be preferable in ICU settings and should only be used in the presence of trained person. HFNC can provide up to 100% FiO2 with 60L/min flow. Increased risk of aerosolization. Need frequent adjustment. Can not be used for prolonged time and improve filtration must be followed. Indicated for hypoxic respiratory failure, COPD exacerbation and acute cardiogenic pulmonary edema. Or CPAP/BiPAP via oronasal mask. CPAP can reduce work of breathing and improve oxygenation, while bilevel positive airway pressure (BiPAP) generally improves ventilation and can improve tidal volumes. CPAP/BiPAP should be considered in patients who have failed by high-flow nasal cannula or if high-flow nasal cannula is not available and those who don't prefer to intubate. 2. Patients who remain hypoxemic despite use of oxygen, HFNO, or NIV, and who do not exhibit clear signs of respiratory distress; this however requires close monitoring and clear failure and escalation criteria. Prone positioning for 12–16 hours in case of refractory hypoxemia (PaO_2/FiO_2 < 150 mmHg, FiO2 ^{3} 0.6, PEEP ^{3} 10 cmH_2O). 3. Monitor SpO_2, Consciousness, Respiratory rate, Pulse and Blood pressure	SpO_2 92% to 96% with the minimum FiO2.	1. For HFNC need central oxygen line with 4 bar pressures 2. PSA or VSA Oxygen Plant Noninvasive ventilation (BiPAP and CPAP) can be used with any oxygen source with backup battery	High flow nasal cannula/non invasive ventilation

Step 8: If no improvement in oxygenation

Condition of patient	Oxygenation procedure	Target	Preferred source	Preferred device
Indications of tracheal intubation and mechanical ventilation ➢ Signs of impending respiratory failure ➢ Rapid progression of disease over hours ➢ Lack of improvement on >40L/min of high flow oxygen and FiO_2 >.6 ➢ Increasing work of breathing ➢ Worsening mental status ➢ Arterial pH < 7.3 with $PaCO_2$ >50 ➢ Hemodynamic instability ➢ Multiorgan organ failure	Ventilator setup for COVID 19 patients with ARDS Low tidal volume ventilation strategy: ➢ AC with TV target 6 ml/kg BW (range 4 to 8 ml/kg BW) ➢ RR 12 to 25 breaths/min ➢ PEEP: PEEP 5 to 20 cm H_2O. ➢ FiO_2: titrate oxygen to target PaO_2 55 to 80 mmHg, SpO_2 90 to 96 for most patients ➢ Plateau pressure < 30 cm H_2O Monitor SpO_2, Consciousness, Respiratory rate, Pulse and Blood pressure	SpO2 92% to 96% with the minimum FiO_2.	1. For HFNC need central oxygen line with 4 bar pressures 2. PSA or VSA Oxygen Plant 3. Non invasive ventilation (BiPAP and CPAP) can be used with any oxygen source with backup battery	High flow nasal cannula/ \noninvasive ventilation

Extubation and weaning

• Patients are often ready for extubation while they remain infectious. As extubation is frequently associated with some coughing, it is considered an aerosol-generating procedure.

• For weaning use closed systems rather using a T-piece trial for spontaneous breathing trials (SBT).

• To reduce the risk of reintubation following extubation due to respiratory failure, cuff leak test (CLT) should be performed if clinical suspicion for upper airway edema is high (eg,\fluid overload) or the presence of risk factors for post extubation stridor (eg, prolonged intubation ≥6 days, age >80 years, large endotracheal tube, traumatic intubation).

• As there is potential risk of aerosolization during cuff leak test, it should be preferentially done in an airborne isolation room. Administer glucocorticoids (eg,methylprednisolone20 mg intravenously every four hours for a total of four doses) to most patients with COVID-19 before extubation and only extubate those in whom the CLT is positive after glucocorticoids.

• Perform extubation in an airborne isolation room.

• Respiratory therapists and others in the room during extubation should adhere to airborne precautions including N95 masks with eye protection or equivalent. Some experts use medications to decrease coughing (eg, lidocaine via ETT, low-dose opioid bolus, dexmedetomidine, remifentanil if available), although data to support the routine use of anti-tussive are limited.

• Drape the patient's chest and face with a plastic cover to provide barrier protection between the patient and the operator.

• After balloon deflation, extra care should be taken during extubation to keep the inline suction catheter engaged during cuff deletion and to have another handheld suction catheter available for the removal of pharyngeal and oral sections.

• The endotracheal tube should be removed as smoothly as is feasible during inspiration and disposed of into a biohazard plastic bag bundled together with the ventilator tubing, the plastic drape, and tape/ETT holders, and inline suction catheter. The bag is sealed and disposed of immediately

Discontinuation of oxygen therapy

1. Oxygen should be reduced in stable patients with satisfactory oxygen saturation.
2. Plan of reducing FIO2 to at least 40%.
3. Gradually change the device.

Awake prone positioning

Awake prone positioning in non-intubated patients with COVID-19 pneumonia:

• Improves oxygenation
• Lowers intubation rate.

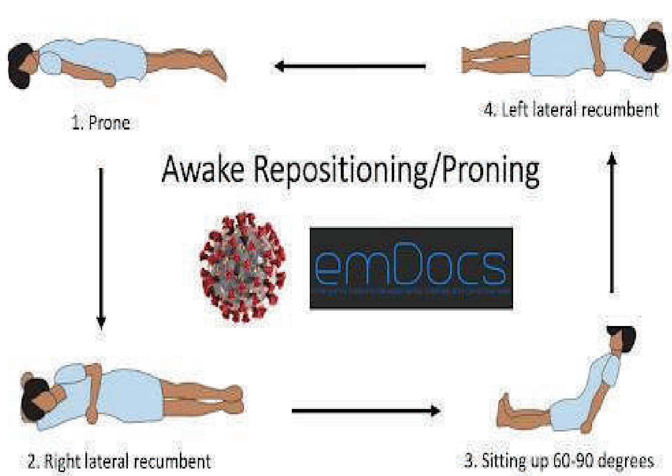
Appropriate candidates for awake prone positioning: Those who are able to adjust their position independently and tolerate lying prone.

Contraindications

• Who are in respiratory distress
• Who require immediate intubation
• Hemodynamically unstable patients
• Patients who recently had abdominal surgery
• Who have an unstable spine

Steps of Awake prone positioning:

Patient will maintain each step for 30 minutes to 2 hours and this cycle will continue. Monitor pulse oximeter 15 minutes after each step to make sure that oxygen saturation.



Other

General Management

Sedation and analgesia

• Requirements for sedation and analgesia appear high in mechanically ventilated patients with COVID-19 and that heavy use of sedatives and analgesic medication is required for ventilator synchrony.
• Target a Richmond Agitation-Sedation Scale (RASS) of -1 to -2 and in patients with ventilator desynchrony, a RASS of -2 to -3.
• RASS of -4 to -5 are targeted in those with severe desynchrony and those requiring neuromuscular blockade.

Monitoring in ICU (Daily management of COVID-19 patient)

• Check vital signs and SpO2 regularly
• Do routine investigations like CBC, CXR, RFT, LFT, ECG regularly
• ECHO if cardiac involvement is suspected
• CT chest and CTPA if needed
• Ensure adequate sedation if patient is on mechanical ventilator: use Fentanyl / propofol /midazolam for sedation
• Use neuromuscular blocking agents if needed if patient is on mechanical ventilator
• Monitor ET displacement or ETCO2 monitoring & CVC in place during prone ventilation
• Check special laboratory markers like D-dimer, LDH, Ferritin, Procalcitonin, Lactate, Troponin I & Pro-BNP regularly

Oxygen toxicity or oxygen poisoning

Oxygen is vital to sustain life. However, breathing oxygen at higher-than-normal partial pressure leads to hyperoxia and can cause oxygen toxicity or oxygen poisoning. The clinical settings in which oxygen toxicity occurs is predominantly divided into two groups; one in which the patient is exposed to very high concentrations of oxygen for a short duration, and the second where the patient is exposed to lower concentrations of oxygen but for a longer duration. These two cases can result in acute and chronic oxygen toxicity, respectively. The acute toxicity manifests generally with central nervous system (CNS) effects, while chronic toxicity has mainly pulmonary effects. Severe cases of oxygen toxicity can lead to cell damage and death. Those at particular risk for oxygen toxicity include hyperbaric oxygen therapy patients, patients exposed to prolonged high levels of oxygen, premature infants, and underwater divers (14).

Oxygen therapy for children

Fewer children than adults have been affected by the COVID-19 pandemic, and the clinical manifestations are distinct from those of adults. Some children particularly those with acute or chronic co-morbidities are likely to develop critical illness.

Indications

Any child with a SPO_2 < 90% should receive oxygen (15)

Oxygen delivery methods in children and infants

Method	Maximum O_2flow (LPM)	Actual inspired fraction (%) from 1LPM by a 5 kg infant	PEEP	Humidification	Risk for hypercapnoea	Risk for airway obstruction	Equipment required	Nursing demand
Nasal prongs	Neonates: 0.5 - 1							
	Infants: 2							
	Preschool: 4							
	School: 6	45	Minimal	Not required	No	Minimal	Nasal prongs	+
Nasal catheter	Neonates: 0.5							
	Infants: 1	50	+	Not required	No	+	8-F catheter	++
Nasopharyngeal catheter	Neonates: 0.5					++		
	Infants: 1	55	++	Required	No		8-F catheter, humidifier	+++
Head box, facemask, incubator, tent Not recommended, as oxygen is used inefficiently	Head box: 2–3 LPM		Nil	Not required	Yes	No	Head box, facemask	+++

F, French; PEEP, positive end expiratory pressure

Higher flow rates without effective humidification may cause drying of nasal mucosa, with associated bleeding and airway obstruction (16).

Monitoring oxygen therapy

Pulse oximetry should be available to all healthcare staff managing patients receiving oxygen therapy and they should be trained in their use. Clinicians should be aware that pulse oximetry gives no information about the PCO2 or pH and most pulse oximeters are unreliable when a patient's SpO2 falls below about 85%. Pulse oximetry is dependent on pulsatile flow, and it may not be possible to achieve a satisfactory oximeter reading in patients with cold hands, especially those with severe Raynaud's phenomenon due to collagen vascular diseases (which may also cause hypoxic lung disease). The readings may also be affected by shock, skin pigmentation, nail varnish, etc. It is essential to record the oxygen delivery system alongside the oximetry result. All measurements of oxygen saturation should be recorded in the observation chart along with the code for the oxygen delivery system that is being used.

Respiratory rate, oxygen saturation and oxygen therapy

Clinical review required if saturation is outside target range. Observation frequency______

Continuous oxygen / PRN / Not on oxygen therapy Target range: 88–92% 94–98% Other____

Date	Example																					Date
Time	08.00																					Time
Respiratory rate	20																					Respiratory rate
Oxygen saturation %	94%																					Oxygen saturation %
Oxygen device or air	N																					Oxygen device or air
Oxygen flow rate l/min	4																					Oxygen flow rate l/min
Your initials*	LW																					Your initials*

*All changes to oxygen delivery systems must be initialled by a registered nurse or equivalent.

If the patient is medically stable and in the target range on two consecutive rounds, report to a registered nurse to consider weaning off oxygen.

*Codes for recording oxygen delivery on observation chart	
A Air (not requiring oxygen, or weaning or on "PRN" oxygen)	H28 Humidified oxygen at 28% (also H35, H40, H60 for humidified oxygen at 35%, 40%, 60%)
N Nasal cannulae	RM Reservoir mask
	TM Tracheostomy mask
SM Simple mask	CP Patient on CPAP system
	NIV Patient on NIV system
V24 Venturi 24% V28 Ventri 28% V35 Venturi 35%	OTH Other device:______
V40 Venturi 40% V60 Venturi 60%	(specify which)

Retrieved from British Thoracic Society guideline for emergency oxygen use in adult patients (17)

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সহযোগিতায়: ইউএসএআইডি'র 'মামনি' মাতৃ ও নবজাতক স্বাস্থ্যসেবা উন্নয়ন প্রকল্প: ইমার্জেন্সি রেসপন্স টু কোভিড-১৯ প্যান্ডেমিক, ২০২২

USAID
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Save the Children