



## **SOP for Medical Oxygen Use and Fire Safety for Public and Private Hospitals of Madhya Pradesh**



**Directorate of Health Services  
Madhya Pradesh**

**Version 1.0  
May 2021**



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## Abbreviations

AGSS	Anaesthetic Gas Scavenging Systems
ARDS	Acute Respiratory Distress Syndrome
BMO	Block Medical Officer
BiPAP	Bilevel Positive Airway Pressure
BTS	British Thoracic Society
CCTL	Critical Care Team Leader
CH	Civil Hospital
CHAI	Clinton Health Access Initiative
CHC	Community Health Centre
CMHO	Chief Medical and Health Officer
COPD	Chronic Obstructive Pulmonary Disease
COVID-19	Coronavirus Disease 2019
CPAP	Continuous Positive Airway Pressure
CS	Civil Surgeon
DH	District Hospital
DHS	Directorate Health Services
DME	Directorate of Medical Education
DPG	Diphosphoglyceric Acid
ED	Emergency Department
GoMP	Government of Madhya Pradesh
HDU	High Dependency Unit
HFNC	High Flow Nasal Cannula
HFNP	High Flow Nasal Prong
HMEF	Heat Moisture Exchange Filter
ICU	Intensive Care Unit
IDSP	Integrated Disease Surveillance Programme
IMV	Invasive Mechanical Ventilation
ISO	International Organization for Standardization

LED	Light Emitting Diode
LIC	Low Income Country
LMIC	Low-to-Middle Income Country
LMO	Liquid Medical Oxygen
LPM	Litres Per Minute
MET	One Metabolic Equivalent
MGPS	Medical Gas Pipeline System
NCDC	National Centre for Disease Control
NICU	Neonatal Intensive Care Unit
NIV	Non-Invasive Ventilation
NGO	Non-governmental Organization
OT	Operation Theatre
PHC	Primary Health Centre
PICU	Paediatric Intensive Care Unit
PIFR	Peak Inspiratory Flow Rate
PRN	Prescription for Oxygen as required
PSA	Pressure Swing Adsorption
PSI	Pounds per square inch
ROP	Retinopathy of Prematurity
RR	Respiratory Rate
SCBA	Self-Contained Breathing Apparatus
T2RF	Type 2 Respiratory Failure
US	United States
WHO	World Health Organization

## Chemical Symbols

FiO <sub>2</sub>	Fraction of Inspired Oxygen
HbO <sub>2</sub>	Blood's Oxyhaemoglobin
PaCO <sub>2</sub>	Partial Pressure of CO <sub>2</sub> in arterial blood
PaO <sub>2</sub>	Partial Pressure of Oxygen in arterial blood
PCO <sub>2</sub>	Partial Pressure of CO <sub>2</sub>
PO <sub>2</sub>	Partial Pressure of Oxygen
SaO <sub>2</sub>	Oxygen Saturation as measured by blood analysis (e.g., a blood gas analysis)
SpO <sub>2</sub>	Oxygen Saturation as measured by pulse oximetry

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## Executive Summary

The Standard Operating Procedure on "**Medical Oxygen Use and Fire Safety in Public and Private Hospitals**" is the first of its kind in the country and lays the foundation for the improvement of health facilities in the State. The SOP aims to educate readers (medical professionals) on how to best use medical oxygen when caring for patients with medical emergencies and elective case management as well as to encourage best practice in the use of oxygen. The document holistically aims to raise the awareness level of healthcare workers for adherence to rational use of Oxygen and for adopting fire safety measures in health facilities.

Most living things need oxygen to survive and oxygen's importance in the field of healthcare cannot be underestimated. Oxygen was known to be the only element that supports respiration as early as 1800 and was first used in the medical field in 1810. However, it took about 150 years for the gas to be used throughout medicine. In the early to mid-20th century, oxygen therapy became rational and scientific, and today modern medicine cannot be practiced without the support of oxygen [2, 7].

Oxygen is an essential medicine that is used to treat hypoxaemia at all levels of the health care system. With applications from resuscitation to inhalation therapy, it is required for surgery, acute respiratory illnesses such as severe pneumonia, chronic pulmonary diseases, emergencies and cardiovascular diseases, among others. Many patients require oxygen; however, it is not available, especially in low-resource settings. Reliable access to quality assured medical oxygen can mean the difference between life and death for patients. Therefore, an enabling environment is required to streamline efforts to ensure that patients receive oxygen therapy when needed. These efforts would include safeguarding the quality of oxygen from manufacturer to patient, ensuring its appropriate administration to patient, and drastically improving the screening of hypoxemic patients [2,7].

Through a strategic collaboration to increase access to and utilization of oxygen therapy systems, CHAI and GoMP, with support from the BMGF - PATH, developed the present guidelines, which includes overview of the oxygen supply & delivery systems, pulse oximetry and medical oxygen therapy. It also includes guidelines to address the vulnerability of hospitals to fires. This document is in adherence with WHO-UNICEF's *Technical Specification and Guidance for Oxygen Therapy Devices* and WHO-Pan American Health Organization's *Hospital Fire Prevention and Evacuation Guide*.

The purpose of this document is to increase awareness about rational use of medical oxygen and hospital fire-safety measures, especially in low- and middle-income countries. This document is intended to be used by clinical staff, administrators, planners, managers, procurement officers, and biomedical engineers and technicians. Through information that is disseminated, the goal is to support hospitals in Madhya Pradesh to raise awareness on oxygen therapy and hospital fire safety measures, as well as the importance of appropriate selection, procurement, maintenance of oxygen therapy and hospital fire safety - related equipment and consumables.

The present publication has eight chapters. The first chapter describes the need for oxygen in respiratory care. The second chapter gives the overview of medical oxygen supply systems required across different health facilities. The third chapter describes the oxygen delivery systems which includes different oxygen sources (cylinders, concentrators, PSA plants, and LMO tanks), oxygen regulation, conditioning and monitoring devices (flowmeters, humidifiers, and analysers), and oxygen delivery devices (nasal cannula, nasal catheter, and venturi masks). The fourth

chapter discusses pulse oximetry and illustrates the comparison of different types of pulse oximeters (fingertip, handheld and tabletop). The fifth chapter talks about medical oxygen therapy including commencement, monitoring, weaning and discontinuation. The sixth chapter provides the summary of the oxygen therapy. The seventh & the eight chapter discuss the principles of electrical safety and fire-safety such as prevention, suppression, evacuation, training and evacuation drills.

This document provides the foundational principles for engaging stakeholders in medical oxygen (supply, distribution, administration, and equipment maintenance) and hospital fire-safety. Moreover, it reinforces the commitment of the Government of Madhya Pradesh (GoMP) towards providing systematic and coordinated improvements in supply of life-saving commodities, in this case, medical oxygen, to patients. Finally, the successful implementation of the guidelines on medical oxygen use and hospital fire-safety will require sustained involvement of and inputs from all stakeholders. Henceforth, all the stakeholders are urged to study the guidelines carefully and identify how they can contribute to achieving its aims and objectives.

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## **PART A: Medical Oxygen Use Guidelines**

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# 1. Introduction

## 1.1 Background

Oxygen is a life-saving therapeutic medical gas used for the management of hypoxaemia – an abnormally low level of oxygen in the blood that is caused by disease, trauma or other health conditions. In June 2017, the World Health Organization (WHO) included oxygen on the *WHO Model list of essential medicines* (EML) beyond use during anaesthesia, due to its proven life- saving properties, safety and cost-effectiveness. Oxygen is an essential element of basic emergency care and is required for anaesthesia, surgery and the treatment of several respiratory diseases, both chronic and acute. For adults and children alike, oxygen is an essential and cross-cutting resource for health delivery systems. Apart from oxygen, there are other medical gases that are used in healthcare settings (Table 1.1).

Table 1.1: Various types of medical gases and their uses [1]

Medical gas	Use
Oxygen	In treatment or prevention of hypoxemia or hypoxia
Nitrogen	For hypoxic challenge testing
Nitrous oxide	For analgesia and anaesthesia
Carbon dioxide	In laparoscopy, cryotherapy, extracorporeal membrane oxygenation therapy or respiratory stimulation
Helium	In treatment of upper airway obstruction or increased airway resistance
Medical air	To reduce the risk of hyperoxia during anaesthesia

Of the respiratory diseases treated with oxygen, lower respiratory tract infections, defined as pneumonia or bronchiolitis, are a leading cause of mortality and morbidity worldwide, causing an estimated 2.38 million deaths in people of all ages in 2016. In children under 5 years, pneumonia is the single largest infectious cause of death worldwide, killing around 880,000 children in 2016. About 13% of children hospitalized for pneumonia have hypoxaemia, which increases the risk of death by up to five times. It is estimated that every year about 1.5 million children admitted with severe pneumonia need oxygen treatment. Childhood deaths from pneumonia are largely preventable, making pneumonia-related deaths a profound inequity affecting the poorest populations around the globe [2].

In 2015 alone, there were a total of 1,29,643 under-5 child deaths in Madhya Pradesh and pneumonia was the leading cause in 14.2% of the deaths [27]. In 2019, Government of India launched SAANS campaign and the National guidelines for comprehensive management of childhood pneumonia. The same guidelines were launched in Madhya Pradesh in February 2021. Pulse oximetry is recommended in each case for early detection of hypoxemia ( $SpO_2$  is less than 90%) and for promoting evidence-based treatment. Oxygen therapy is recommended in cases of low  $SpO_2$  reading or clinical symptoms of hypoxemia such as wheezing, slow heart rate, stridor etc.

Having the ability to properly detect and diagnose hypoxaemia and having a reliable supply of oxygen to treat hypoxaemia are crucial elements of ending preventable deaths among adults and children globally. Achieving this requires a holistic and integrated system of technologies and measures in place that include everything from the oxygen source (either produced locally at a health facility or delivered and stored), devices (for flow regulation and conditioning), consumables (for oxygen delivery to the patient), to clinical guidance (related to oxygen therapy systems).

Moreover, on 11<sup>th</sup> March 2020, WHO declared Coronavirus Disease (COVID-19) outbreak as a pandemic and reiterated the call for countries to take immediate actions and scale up response to treat, detect and reduce transmission to save people's lives. COVID-19 is an acute respiratory tract disease caused by infection with SARS-CoV-2 virus that results primarily in single organ dysfunction including hypoxic respiratory failure and, in the most severe form, Acute Respiratory Distress Syndrome (ARDS). Published reports on COVID spread suggest that approximately 20% of confirmed cases require hospitalization, including 15% with severe disease ( $RR>30$ ,  $SpO_2<93\%$ ) and 5% with critical illness (requiring ICU admission), almost all of whom require oxygen therapy [26]. In the absence of a proven treatment protocol, the combination of therapeutic medical oxygen and supportive respiratory care is a critical lifesaving intervention. In addition, several studies have shown that improving oxygen systems can improve clinical outcomes for children suffering from severe pneumonia and other respiratory diseases. Because of this broad applicability and requirement of Oxygen across different wards and specialties in hospitals, CHAI has partnered with Directorate of Health Services, GoMP to help strengthen the oxygen delivery systems across healthcare providers in Madhya Pradesh. This publication is one element of this collaborative effort.

## **1.2 Purpose of the SOP**

This manual provides the foundational principles for engaging stakeholders in oxygen supply, distribution, administration, equipment maintenance and rational use of oxygen. Moreover, it reinforces the commitment of the Government of Madhya Pradesh (GoMP) towards providing systematic and coordinated improvements in supply of life-saving commodities, in this case, medical oxygen, to patients. Furthermore, this manual provides guidelines SOP on prevention, suppression and evacuation during fire outbreaks in hospitals while throwing light on the trainings that may be necessary to best handle the dire situation.

## **1.3 Target Audience**

The SOP is intended to support health facility administrators, clinical decision-makers, procurement officers, planning officers, biomedical engineers, infrastructure engineers and policymakers in the State to select, procure, use and maintain appropriate oxygen therapy system equipment. This document may also be of interest to health care workers, academics/researchers, development agencies, nongovernmental organizations (NGOs), device manufacturers, regulators and others involved in planning oxygen systems in LMICs.

## **1.4 Implementation of the SOP**

Copies of the SOP will be sent to all the Chief Medical and Health Officers (CMHOs), Civil Surgeons (CSs), Block Medical Officers (BMOs), Medical Officers (MOs), and nursing heads at all the District Hospitals (DHs), Civil hospitals (CHs), Community Health Centres (CHCs) and Primary Health Centres (PHCs), as well as to leads in Directorate of Medical Education (DME) medical and nursing colleges in the State of MP. The SOP shall also be disseminated to all registered Private Hospitals and Nursing Homes.

Local oxygen and fire-safety champions will be identified to review local oxygen and fire safety practices and arrange staff education. Lectures, teaching material and example documentation will be made available through the DHS website. Local oxygen champions shall ensure monitoring of oxygen prescription and use as well as be instrumental in the initial implementation of this SOP.

## 2. Overview of Medical Oxygen Supply System

Medical oxygen is required across many levels of the health system for various medical units and services ranging from primary health care, general wards, trauma management and emergency transport, to delivery rooms, operating theatres, intensive care units (ICUs) and specialized hospital and outpatient units (Table. 2.1). The oxygen systems required to meet needs at these different levels of the health system are varied [2].

**Table 2.1: Medical units at various levels of the health system where oxygen & pulse oximetry is needed [2]**

Primary level	Secondary level	Tertiary level
Home, Sub Centres, Primary Healthcare Centres (PHCs), Community Health Centres (CHCs)	Civil Hospitals (CHs)	District Hospitals (DHs), Medical Colleges
<ul style="list-style-type: none"> <li>• General ward</li> <li>• Labour unit</li> <li>• Neonatal resuscitation corner</li> <li>• Emergency triage</li> <li>• Referral transport</li> </ul>	<ul style="list-style-type: none"> <li>• Emergency triage</li> <li>• Labour and delivery room</li> <li>• Neonatal care</li> <li>• Paediatric and/or adult ward</li> <li>• ICU</li> <li>• Operating theatre</li> </ul>	<ul style="list-style-type: none"> <li>• Emergency triage</li> <li>• Labour and delivery room</li> <li>• ICU (neonatal, paediatric, adult)</li> <li>• Paediatric and adult wards</li> <li>• Surgery and recovery wards</li> <li>• Cardiopulmonary ward</li> <li>• Emergency ward</li> </ul>

First and foremost, oxygen systems must consist of an oxygen source, i.e., equipment for oxygen production or oxygen storage. Common sources of oxygen are compressed gas cylinders, oxygen concentrators, PSA plants and liquid oxygen in bulk storage tanks.

The appropriate choice of oxygen source is multifactorial; it is important to take into consideration the amount of oxygen needed at the health facility, available infrastructure, cost, capacity and supply chain for local production of medicinal gases, reliability of electricity, access to maintenance services and spare parts, etc.

In addition to the oxygen source, many other oxygen system components are required to deliver oxygen to patients who need it (Table 2.2). 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 ( $SpO_2$ ) to detect hypoxaemia, 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 (Table. 2.2) [2].

A complete oxygen system consists of elements from all categories shown in Table 2.2; however, not all products in each category are always necessary or appropriate in different contexts. As depicted in Table 2.3, the selection of many of these products depends on both the oxygen source used and the level of the health system where they are to be used.

Table 2.3 is a general guide to demonstrate how the components of oxygen systems can vary according to oxygen source and health system level. Depending on local capacity, this may not be representative of all settings.

Table 2.2: Oxygen systems components [2]

Oxygen Systems				
Oxygen source	Distribution	Regulation & conditioning	Delivery	Patient monitoring
<ul style="list-style-type: none"> <li>Concentrator</li> <li>Cylinder</li> <li>PSA plant</li> <li>Liquid oxygen</li> </ul>	<ul style="list-style-type: none"> <li>Central or sub-central piping</li> <li>Tubing</li> <li>Transport (for cylinders)</li> </ul>	<ul style="list-style-type: none"> <li>Regulator</li> <li>Flowmeter</li> <li>Flowmeter stand (flow splitter)</li> <li>Humidifier (heated and non-heated)</li> <li>Blender</li> <li>CPAP</li> <li>BiPAP</li> <li>Ventilator</li> </ul>	<ul style="list-style-type: none"> <li>Nasal cannula</li> <li>Nasal catheter</li> <li>Masks (venturi, re-breather masks, non-rebreather masks, etc.)</li> <li>Tubing</li> </ul>	<ul style="list-style-type: none"> <li>Pulse oximeter</li> <li>Multiparameter monitor</li> </ul>
<b>Power supply</b> Voltage stabilizers Surge suppressors Backup power supply				
<b>Maintenance</b> Oxygen analysers Tools and spare parts for maintenance of all devices				

Table 2.3: Devices required as part of a complete oxygen system, according to type of oxygen source (vertical) and level of the health system (horizontal) [2]

Oxygen sources			
Concentrators	Cylinders (stand alone or with manifold)	LMO tank and PSA plant	
<b>Devices for distribution</b>			
Primary level	Tubing	Tubing	(May not be suitable as primary level oxygen source) *
Secondary level and above (includes all primary level devices, plus...)		Central or sub-central piping	Central or sub-central piping
<b>Devices for oxygen regulation and conditioning</b>			
Primary level	Flowmeter stand (flow splitter)	<ul style="list-style-type: none"> <li>Flowmeter</li> <li>Humidifier (non-heated)</li> </ul>	(May not be suitable as primary level oxygen source) *
Secondary level and above (includes all primary level devices, plus...)		<ul style="list-style-type: none"> <li>Humidifier (heated)</li> <li>Blender</li> </ul>	<ul style="list-style-type: none"> <li>Flowmeter (wall-mounted)</li> <li>Humidifier (non-heated)</li> <li>Humidifier (heated)</li> <li>Blender</li> <li>CPAP</li> <li>Ventilator</li> </ul>
<b>Oxygen delivery devices</b>			
Primary level	<ul style="list-style-type: none"> <li>Nasal cannula</li> <li>Masks</li> <li>Tubing</li> </ul>	<ul style="list-style-type: none"> <li>Nasal cannula</li> <li>Masks</li> <li>Tubing</li> </ul>	(May not be suitable as primary level oxygen source) *
Secondary level and above (includes all primary level devices, plus...)	Nasal catheter	<ul style="list-style-type: none"> <li>Nasal catheter</li> <li>High Flow Nasal Cannula (HFNC)</li> </ul>	<ul style="list-style-type: none"> <li>Nasal cannula</li> <li>Masks</li> <li>Tubing</li> <li>Nasal catheter</li> <li>HFNC</li> </ul>
<b>Pulse oximeters and patient monitoring devices</b>			
Primary level	<ul style="list-style-type: none"> <li>Self-contained fingertip</li> <li>Handheld</li> </ul>	<ul style="list-style-type: none"> <li>Self-contained fingertip</li> <li>Handheld</li> </ul>	(May not be suitable as primary level oxygen source) *

Secondary level and above (includes all primary level devices, plus...)	Tabletop	Tabletop	<ul style="list-style-type: none"> <li>• Self-contained fingertip</li> <li>• Handheld</li> <li>• Tabletop</li> <li>• Multiparameter devices</li> </ul>
<b>Devices for quality power supply and oxygen analysis</b>			
Primary level	<ul style="list-style-type: none"> <li>• Voltage stabilizer</li> <li>• Surge suppressor</li> <li>• Oxygen analyser</li> <li>• Backup power supply</li> <li>• Tools and spare parts</li> </ul>	Oxygen analyser	(May not be suitable as primary level oxygen source) *
Secondary level and above (includes all primary level devices, plus...)			<ul style="list-style-type: none"> <li>• Voltage stabilizer</li> <li>• Surge suppressor</li> <li>• Backup power supply</li> <li>• Tools and spare parts</li> </ul>

*Notes:* Health system levels are as described in Table 2.1, which may not be applicable across all settings. All products listed at the primary level are also desirable at the secondary level and above.

\* Some primary level health facilities offer a wide variety of services and could benefit from an onsite plant or an LMO tank. However, such a plant or tank should only be considered if there is enough need for oxygen, and if there is appropriate capacity to use and maintain it.

Please find the list of equipment that are required to deliver oxygen therapy below (Table 2.4). Definitions for each of these will be provided in the chapters ahead. Please use the links below for more information:

[https://www.who.int/medical\\_devices/priority/Chapter\\_3\\_20167\\_WHO\\_Priority\\_medical\\_devices\\_list\\_for\\_COVID\\_19\\_response\\_3.pdf](https://www.who.int/medical_devices/priority/Chapter_3_20167_WHO_Priority_medical_devices_list_for_COVID_19_response_3.pdf)

[https://www.who.int/medical\\_devices/priority/Chapter\\_4\\_20167\\_WHO\\_Priority\\_medical\\_devices\\_list\\_for\\_COVID\\_19\\_response\\_4.pdf](https://www.who.int/medical_devices/priority/Chapter_4_20167_WHO_Priority_medical_devices_list_for_COVID_19_response_4.pdf)

**Table 2.4: Equipment required for delivering oxygen therapy**

Category of device	Device
Oxygen source devices	<ul style="list-style-type: none"> <li>• Concentrators</li> <li>• Cylinders</li> </ul>
Oxygen delivery devices	<ul style="list-style-type: none"> <li>• Nasal oxygen cannula with prongs</li> <li>• Mask with reservoir bag</li> <li>• Venturi mask</li> </ul>
Devices for oxygen regulation and conditioning	<ul style="list-style-type: none"> <li>• Flowmeter- Thorpe tube</li> <li>• Flow splitter</li> <li>• Non-heated bubble humidifier</li> <li>• Tubing (for medical gases)</li> </ul>
Ventilation devices	<ul style="list-style-type: none"> <li>• Ventilators</li> <li>• CPAP</li> <li>• BiPAP</li> </ul>
Manual ventilation devices	<ul style="list-style-type: none"> <li>• Self-inflating resuscitation bag with mask</li> <li>• Heat and moisture exchange filter (HMEF)</li> <li>• Colorimetric end-tidal CO<sub>2</sub> (EtCO<sub>2</sub>) detector</li> </ul>
Patient monitoring devices	<ul style="list-style-type: none"> <li>• Pulse oximeter (handheld, tabletop &amp; fingertip)</li> <li>• Patient monitor multiparametric (basic, intermediate and advanced)</li> </ul>



### 3. Oxygen Delivery Systems

#### 3.1 Overview of Different Oxygen Sources

Oxygen therapy, or supplemental oxygen, is the use of medical oxygen as a medicine in health care. Medical oxygen is oxygen that is (as a minimum) 82% pure oxygen and free from any contamination, generated by an oil-free compressor. The four most common sources of medical oxygen in health care facilities are: compressed gas cylinders, oxygen concentrators, PSA plants and LMO tanks (bulk-stored liquid oxygen) (Figure 3.1).

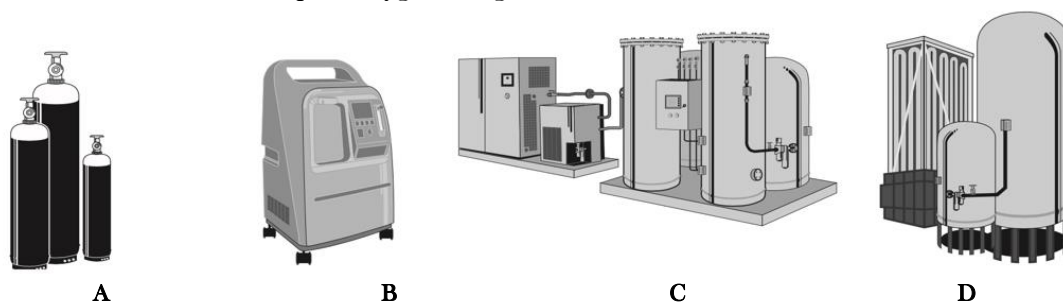


Figure 3.1: Sources of medical oxygen. (A) Cylinders. (B) Concentrators. (C) PSA Plant. (D) LMO tank.

Table 3.1: Type of medical oxygen cylinders

S. No.	Type of cylinder	How commonly used?
1	20 cubic feet (cu ft) (A type)	Used in ambulances
2	40 cu ft	Rare
3	60 cu ft (B type)	Common
4	80 cu ft	Rare
5	200 cu ft (D type, Jumbo)	Common



Figure 3.2: Types of medical oxygen cylinder

**Oxygen cylinders:** Oxygen gas can be compressed and stored in cylinders (Figure 3.2 and 3.3). These cylinders are filled at a gas manufacturing plant, either via a cryogenic distillation/ASUs or a process known as pressure swing adsorption (PSA) or by a LMO-based refiller 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 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.

**Table 3.2: Colour codes of medical gas cylinders [3]**

S. No.	Colour code	Medical gas
1	White shoulder and black body	Medical oxygen (O <sub>2</sub> )
2	Blue shoulder and blue body	Nitrous oxide (N <sub>2</sub> O)
5	Black shoulder and grey body	Nitrogen (N <sub>2</sub> )
<i>Only cylinders dedicated to medical grade oxygen are to be used.</i>		



**Figure 3.3: Colour codes of medical gas cylinders**

Cylinders (see Table 3.1) 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 [2, 5]. Please see the colour codes of medical gas cylinders in Table 3.2. Moreover, user care and preventative maintenance and troubleshooting recommendations for oxygen cylinders can be found in Table 3.3 and 3.4, respectively.

#### **When installing an oxygen cylinder:**

- Ensure the quality of the oxygen is assured, either by supplier quality certificate, PSA plant logbook or onsite analyser testing.
- Oxygen cylinders should be prepared for use and set up in a secure position; vigilance by the operator during preparation is of critical importance.
- Tighten all the connections (between the cylinder and the regulator and between the regulator and the flowmeter), so that oxygen does not leak out.
- Before assembling regulators and fittings, it is extremely important to ensure there are no particles of dirt in the cylinder outlet. Use clean compressed air or nitrogen to blow out any loose particles of dirt from the valve sockets.
- Where clean compressed air or nitrogen is not available, particles of dirt and residual moisture can be removed by quickly opening and immediately closing the valve (otherwise known as “sniffling”).
- No one should attempt to connect a regulator and/or accessory equipment using improvised hook-ups or adapters. Neither should plastic tape be used on a regulator.

#### **When using an oxygen cylinder:**

- All gas cylinders should be equipped with a functioning gas regulator while in use and a valve opening key should be kept nearby for timely opening/closing of the valve.

- Check the contents gauge on the cylinder before starting to be sure there is enough gas available. Open the regulator and check the amount of oxygen in the cylinder on the pressure gauge. If the needle is in the red zone, the cylinder is nearly empty and should not be used.
- Valve protection caps are required on all cylinders that are threaded to accommodate a cap unless the cylinder valve is connected for use to a regulator or manifold.
- When personnel have finished using a compressed gas cylinder, the cylinder valve should be closed and the pressure in the regulator and associated equipment released.

#### **Safety considerations during general handling of a cylinder:**

- Personal protective equipment, such as eye and hand protection, should be worn when handling oxygen cylinders.
- All compressed medical oxygen gas cylinders (regardless of size) should be secured to racks, walls, work benches or hand trolleys by a strong chain or strap, capable of preventing the cylinder from falling or being knocked over.
- Cylinder should be securely placed in a cylinder trolley in an upright position by the patient bedside to prevent it from accidental falling. Note that small cylinders, when used for patient transport, may be laid flat, but still need to be firmly secured.
- Do not drop cylinders or allow sharp impacts on cylinders.
- Cover the top of the oxygen cylinder with the cap when it is not in use or when being transported for delivery.
- Set up the cylinder for patient use a safe distance from the patient.
- After connecting the appropriate equipment, turn the flow control off; carefully open the main valve, then turn up the flow slowly to the desired rate.
- Do not place the cylinder on a patient's bed.
- Before moving cylinders, they must be disconnected from any regulators or manifolds, applying any protective valve caps before the cylinders are released.
- Cylinders should be moved only on a hand truck or other cart designed for handling gas cylinders.
- No more than one cylinder should be handled at a time except on carts designed to transport more than one cylinder.
- All medical gas cylinders should be clearly labelled to identify the contents. A cylinder without a readable product label should not be used and should be returned to the supplier.
- All defective gas cylinders or equipment should be reported immediately to the supplier for correction or replacement.

#### **Storage of a cylinder:**

- Always physically separate full and empty medical gas cylinders. Ambulatory organizations can do this by using separate racks, physical barriers or by colour coding the storage rack.
- Label the cylinders clearly (open/empty or full/unopened), to avoid confusion and delay selecting between full, partial, and empty cylinders.
- Store in well-ventilated, clean, dry conditions, not exposed to extremes of heat or cold.
- Protect cylinder and all other fittings from contamination by oil and grease.
- Never use a single-use and/or re-use an industrial gas cylinder for refilling medical oxygen.

### **Fire safety considerations during cylinder use:**

- Ensure appropriate fire extinguishers are kept nearby and are regularly inspected.
- Keep oxygen cylinders at least several metres from a heat source, open flames, electrical devices, or other possible sources of ignition.
- Put a “no smoking” sign near oxygen sources in the hospital.
- Check that all nearby electrical circuit breakers and devices are in safe working condition and free from sparking to prevent a serious fire occurrence.

### **When and how to change a cylinder:**

#### **When to change a cylinder**

- Check your pressure gauge on the regulator unit (Figure 3.4) (or control panel in case of jumbo cylinders connected to manifold) often to make sure you do not run out of oxygen. Please be aware that some manifold systems may have a sound based-alarm system to alert low supply of oxygen in the cylinder.
- Always check the gauge (or control panel) when the valve is turned on.
- When the needle gets closer to 0 on the gauge (or the pressure reading is low on control panel), it is time to change the cylinder.
- Be sure to change the cylinder before the needle gets below 56 psi (4 bar).
- If the pressure gauge is broken, please note the weight of an empty and a full cylinder. Regularly note the weight of a cylinder to ensure it is empty before changing it.

#### **How to change a cylinder**

- Turn off the oxygen flow.
  - Using the cylinder wrench (spanner/key), turn the cylinder on/off valve clockwise to close it.
  - Bleed off the pressure in the valve by opening the flow regulator knob.
  - When the gauge reads zero on the regulator, turn the flow regulator knob to zero.
- Change the cylinder.
  - Remove the regulator unit (including pressure gauge and flowmeter) from the empty cylinder and attach it to a filled cylinder.
- Turn on the oxygen flow.
  - Place the cylinder wrench on the cylinder’s on/off valve, located at the top of the cylinder.
  - Open the valve by turning it anti clockwise one full turn. As the valve opens, the gauge on the regulator will show the amount of pressure in the cylinder. Pressure in a full cylinder will read about 1680-2100 psi (120-150 bar).
  - Adjust the flow knob on the regulator until the gauge reaches the flow rate your doctor prescribed.

Oxygen cylinders should have a labelling tag stating its status – Full or Empty or In-use. Moreover, the “date of service” should also be mentioned on the cylinder. Ideally, the cylinders should be periodically checked once every 5 years and the “date of test” should be stamped on the cylinders.



Figure 3.4: Regulator unit for oxygen cylinder comprising of pressure gauge, regulator knob and flowmeter

Table 3.3: User care and preventive maintenance recommendations for oxygen cylinders (and associated accessories) [2]

Scheduled period	Activities	Check
Daily	Cleaning	<ul style="list-style-type: none"> <li>Ensure delivery tubes and masks are decontaminated.</li> <li>If humidifier bottle is used, disinfect and refill with clean water.</li> </ul>
	Visual checks	<ul style="list-style-type: none"> <li>Check cylinder is correct type and correctly labelled.</li> <li>Check all parts are fitted tightly and correctly.</li> </ul>
	Function	<ul style="list-style-type: none"> <li>Before use, ensure cylinder has sufficient pressure.</li> <li>Ensure flow is sufficient for intended use.</li> <li>Close cylinder valve after each use.</li> </ul>
Weekly	Cleaning	<ul style="list-style-type: none"> <li>Clean cylinder, valve and flowmeter with damp cloth.</li> </ul>
	Visual checks	<ul style="list-style-type: none"> <li>Check for leakage: hissing sound or reduction in pressure or water bubbles observed when soapy water poured on nozzle</li> </ul>
	Function	<ul style="list-style-type: none"> <li>Remove valve dust with brief, fast oxygen flow checks.</li> <li>Check flow can be varied using flow control.</li> </ul>
Every 6 months	Biomedical technician check required.	

Table 3.4: Troubleshooting for oxygen cylinders (and associated accessories) [2]

Problem or fault	Possible cause	Solution
No oxygen is flowing	Empty cylinder.	Replace cylinder.
	Flowmeter knob or cylinder flow valve is closed.	Open valves, and then check meter registers pressure.
	Faulty regulator.	Close all valves and replace regulator.
Leakage from cylinder or flowmeter	Cylinder is not connected to pressure regulator properly.	Tighten all fittings.
	Faulty or missing washer between regulator and cylinder.	Replace washer.
	Flowmeter seal damaged or loose.	Replace sealing washer and realign flowmeter.
	Cylinder spindle faulty.	Label faulty and take appropriate action, tighten gland nut
Leakage cannot be located	Leakage too small to be heard.	<ul style="list-style-type: none"> <li>Apply soap solution (NOT oily soap) to joints. Bubbles will show at leak point.</li> <li>Clean/replace washer and tighten at that joint.</li> </ul>
Flowmeter ball not moving, yet oxygen is flowing	Faulty flowmeter.	<ul style="list-style-type: none"> <li>Close all valves, disconnect flowmeter and clean inside. Reconnect and test.</li> <li>If problem persists, replace flowmeter.</li> </ul>
Pressure gauge does not show pressure, yet oxygen is flowing	Faulty pressure gauge.	Replace pressure gauge by contacting biomedical technician.

**Oxygen Concentrators:** 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% concentrated oxygen. It processes the air through an internal filtration system (e.g. a molecular sieve [zeolite granules or membranes]), which has a large total surface area to separate N<sub>2</sub> from the air. It typically consists of an air compressor, filters, dual chambers, a reservoir, and controls. The oxygen concentration is variable depending on the flow rate utilized.

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 LPM. When used with a flowmeter stand for splitting flow, concentrators can provide a continuous supply of oxygen to two patients at the same time. The filter of a concentrator should be cleaned once every 7 days and the membrane should be replaced once every 3 years. The estimated life span of concentrators are about 7 years, and this can vary between brands.

Concentrators can provide a safe and cost-efficient source of oxygen, but they do require a source of continuous and reliable electricity and regular preventive maintenance to ensure proper functioning. They should be kept in well ventilated rooms and about a yard (3 feet) from the wall. It is best practice to also have cylinders as a backup supply [2, 6]. User care, preventive maintenance, and troubleshooting recommendations and technical specifications for oxygen concentrators can be found in Table 3.5, 3.6 and 3.7, respectively.

**Table 3.5: User care and preventive maintenance recommendations for oxygen concentrators [2]**

Scheduled period	Activities	Check
Daily	Cleaning	<ul style="list-style-type: none"> <li>Remove any dust/dirt with damp cloth and dry it off.</li> <li>Ensure delivery tubes and masks are decontaminated.</li> <li>If humidifier bottle is used, disinfect and refill with clean water.</li> </ul>
	Visual checks	<ul style="list-style-type: none"> <li>Check all parts (screws, connectors, tubes, etc.) are fitted tightly and correctly.</li> </ul>
	Function	<ul style="list-style-type: none"> <li>Ensure flow is sufficient before intended clinical use.</li> </ul>
Weekly	Cleaning	<ul style="list-style-type: none"> <li>Wash filter in warm water and dry. Replace the filter if damaged.</li> <li>Clean the humidifier bottle thoroughly and dry it off.</li> </ul>
	Visual checks	<ul style="list-style-type: none"> <li>Replace the humidifier bottle if covered with limescale.</li> <li>Replace mains plug, cable or socket if damaged.</li> </ul>
	Function	<ul style="list-style-type: none"> <li>Run the machine for 2 minutes and ensure no alarm sounds.</li> <li>Check (see bubbles) that flow can be varied using flow control.</li> </ul>
Every 6 months	Biomedical technician check required.	

**Table 3.6: Troubleshooting for oxygen concentrators [2]**

Problem or fault	Possible cause	Solution
Unit not operating, power failure alarm sounds	No power from mains socket.	<ul style="list-style-type: none"> <li>Check if mains switch is on and cable correctly connected.</li> <li>Replace fuse with correct voltage/current if compromised.</li> <li>Check mains power is present at socket using equipment known to be functional.</li> <li>Contact electrician for repair if required.</li> </ul>

	Concentrator circuit breaker has been set off.	Press reset button if present
	Electrical cable fault	Try cable on another piece of equipment. Contact electrician for repair if required.
<b>Unit not operating, no power failure alarm</b>	Alarm- battery dead	Replace battery and test as above
<b>No Oxygen flow</b>	Flow not visible	Place tube under water and look for bubbles. If bubbles emerge steadily, gas is indeed flowing
	Tubes not connected tightly	Check tubing and connectors are fitted tightly
	Water or matter blocking the Oxygen tubing	Remove tubing, flush through, and dry out before replacing
	Blocked flow meter or humidifier	Replace meter / bottle or refer to biomedical technician
<b>Temperature light or low oxygen alarm sound</b>	Unit overheated or obstructed	<ul style="list-style-type: none"> <li>Remove any obstruction caused by drapes, bedsheets, wall, etc.</li> <li>Clean filters.</li> <li>Turn unit off, using standby oxygen system. Restart unit after 30 minutes.</li> <li>Call biomedical technician if required.</li> </ul>
<b>Electrical shocks</b>	Wiring fault	Refer to electrician

**Table 3.7: Technical Specifications for Oxygen concentrators [2]**

These technical specifications are generic and are according to the latest available commercial products. They should be adapted to the setting where the product will be used.













<b>Purpose of Use</b>		
1	Clinical or other purpose	Delivery of low-flow, continuous, clean and concentrated oxygen (> 82%) from room air (21%). With appropriate accessories, two or more hypoxaemic patients can be treated with one concentrator.
2	Clinical department/ Ward (if relevant)	Wards, surgical operating theatre.
3	Overview of functional requirements	1. Provides a continuous flow of concentrated oxygen (> 82%) from room air through one or more oxygen outlets; commonly between 5 and 10 L/min in total. 2. Contains oxygen monitor to verify concentration. 3. Delivers oxygen through a nasal prongs or nasal catheter. 4. Flow from one concentrator can be divided for at least two paediatric patients with (built-in or add-on) flowmeters that allow continuous flow rate control. 5. Requires continuous AC power source to operate, such as solar power, battery or mains electricity ± backup (e.g. generator, UPS or battery). (Maximum flow is chosen based on the expected patient load at any given time. Oxygen needs vary per patient and application. In general, up to 2 L/min per patient under 5 years of age is needed).
<b>Technical Characteristics</b>		
4	Displayed parameters	<ul style="list-style-type: none"> <li>Oxygen flow rate (on flowmeter).</li> <li>Cumulative hours of operation.</li> </ul>
5	User adjustable settings	Oxygen flow rate
<b>Physical/Chemical Characteristics</b>		
6	Components (if relevant)	<ul style="list-style-type: none"> <li>Case to be hard, cleanable with standard hospital cleaning materials.</li> <li>Oxygen outlet to be securely mounted and sheltered to reduce risk of being broken or bent.</li> </ul>
7	Mobility, portability	<ul style="list-style-type: none"> <li>Whole unit to be movable with wheels on at least two feet.</li> <li>Unit weight to be &lt; 27 kg</li> </ul>

	(if relevant)	
8	Raw materials (if relevant)	Water, detergent and/or mild cleaning solution to clean device exterior and gross particle filter (if applicable).
<b>Utility Requirements</b>		
9	Electrical, water and/or gas supply (if relevant)	<ul style="list-style-type: none"> <li>Electrical source requirements to be locally compatible (voltage and plug type need to be specified).</li> <li>Capacity for safe operation on at least <math>\pm 10\%</math> of local rated voltage.</li> <li>Mains power cable to have length <math>\geq 2.5</math> m.</li> <li>Electrical protection by resettable circuit breakers or replaceable fuses, fitted in both neutral and live lines.</li> </ul>
<b>Accessories, Consumables, Spare Parts, Other Components</b>		
10	Accessories (if relevant)	<ul style="list-style-type: none"> <li>The unit shall include internally and externally mounted filters for cleaning the air intake.</li> <li>All user-removable filters shall be cleanable. Cleaning instructions for filters shall be included in the instructions for use.</li> <li>For two or more simultaneous paediatric patients: 1 x flowmeter stand with minimum range from 0 to 2 L/min.</li> <li>Kink-resistant oxygen tubing with standard connectors (15 m each).</li> <li>2 x adult cannula with 2 m kink-resistant oxygen tubing with standard connectors.</li> <li>4 x infant cannula with 2 m kink-resistant oxygen tubing with standard connectors.</li> <li>4 x neonatal cannula with 2 m kink-resistant oxygen tubing with standard connectors.</li> </ul>
11	Sterilization/disinfection process for accessories	Disinfection for nasal prongs.
12	Consumables	<ul style="list-style-type: none"> <li>5-year supply recommended.</li> <li>1-year supply (adjust quantities per patient load and usage frequency): <ul style="list-style-type: none"> <li>- nasal prongs or nasal catheters (each size for adult, child, infant);</li> <li>- child nasal prongs: distal diameter: 1–2 mm;</li> <li>- child/infant catheters: 6 or 8 French gauge</li> </ul> </li> </ul>
13	Spare parts	<ul style="list-style-type: none"> <li>Internal and external filters and spare parts for user fitting (as described in user manual), including: <ul style="list-style-type: none"> <li>- parts supply, including all necessary filters, for 2 years' operation at 15 hours per day.</li> <li>- 1 x spare battery set for alarm system (if applicable).</li> <li>- 1 x spare mains power cable, length <math>\geq 2.5</math> m.</li> <li>- 2 x replacement sets of spare fuses (if non-resettable fuses are used).</li> <li>- DISS to 6 mm barbed adaptor for each outlet (if relevant).</li> <li>- Bidder must give a complete list of the specific spare parts included in their bid.</li> <li>- Other spares that may be needed: circuit breaker, printed circuit board, sieve beds, compressor service kit, valves, wheels, motor capacitor, flowmeters, and fan.</li> </ul> </li> </ul> <p>(Spare parts are not interchangeable between devices of different brands and models and can vary in their design and lifetime. Medical units to select spare parts ensuring compatibility with the brand and model of the equipment.)</p>
<b>Training, Installation and Utilisation</b>		
14	Pre-installation requirements	<ul style="list-style-type: none"> <li>Verify plug electrical requirements with socket to be used.</li> <li>Clinical and staff training on device use.</li> <li>System for procuring spare parts.</li> </ul>
15	Requirements for commissioning	<ul style="list-style-type: none"> <li>Note and report any signs of external or internal damage upon device delivery.</li> <li>Record the number of hours on the hour meter.</li> <li>Verify oxygen concentration level is within specifications when device is operated with all tubing and flowmeters installed.</li> <li>Verify operation of oxygen concentration, battery, and power failure alarms.</li> </ul>

		<ul style="list-style-type: none"> <li>Spare parts for 1 year or 5000 hours (5 years or 15 000 hours ideally) of use are arranged.</li> </ul>
16	Training of users	<ul style="list-style-type: none"> <li>Clinical staff training in oxygen therapy guidelines, device use and multiple-patient use.</li> <li>Technical staff training in device operation, safety and maintenance provided by manufacturer, supplier or experienced users.</li> <li>Advanced maintenance tasks required shall be documented.</li> </ul>
17	User care	<ul style="list-style-type: none"> <li>Device exterior to be wiped effectively with a mild solution of detergent or cleaning agent (weekly), without connection to mains power.</li> <li>Gross particle filter to be cleaned effectively when removed and washed with soap and water (weekly).</li> <li>Do not clean with alcohol.</li> </ul> <p>(User care needed more often in very dusty environments.)</p>
18	Maintenance tasks	<ul style="list-style-type: none"> <li>Test power failure alarms.</li> <li>Measure operating pressure with pressure test gauge.</li> <li>Measure oxygen concentration with a calibrated oxygen analyser.</li> <li>Repair internal components as needed.</li> <li>Maintain spare-parts inventory.</li> </ul>

**PSA plant (central oxygen supply system):** A PSA plant is a large, onsite, central source of oxygen that is piped directly to terminal units within patient areas. Plants can generate oxygen using PSA technology (like concentrators). They should have an automated system to activate alarm when the pressure is low, and the plant should be always attended by a trained and dedicated staff. The plant should be in a no smoking zone and should have the signage and smoke detectors. Plants 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 neighbouring health facilities. Manifold room should be preferably located on the ground floor and it should have easy access to delivery vehicles. Note that oxygen plants require a reliable source of power. It is best practice to also have cylinders as a backup supply.

Table 3.8: Colour codes for medical gas pipeline systems [29]

Gas	US	Pressure	HTM/ ISO	Pressure
Oxygen		50-59 psi		4 Bar (400 kPa)
Nitrous oxide		50-59 psi		4 Bar (400 kPa)
Medical air		50-59 psi		4 Bar (400 kPa)
Surgical air		100-120 psi		7 Bar (700 kPa)
Medical Vacuum		-650 to -450 mmHg		-650 to -450 mmHg
Carbon dioxide		50-59 psi		4 Bar (400 kPa)
<i>Outlet shall be equipped with a primary and secondary check valve and the secondary check valve shall be rated at minimum pressure of 200 psi.</i>				

US, United States; psi, pounds per square inch; HTM, Health Technical Memorandum; ISO, International Organization for Standardization

Medical gas pipeline system (MGPS) (Figure 3.5) is installed to provide a safe, convenient, and cost-effective system for the provision of medical gases to the clinical and nursing staff at the point-of-use. It reduces the problems associated with the use of gas cylinders such as safety, portage, storage, and noise. Patient safety is paramount in the design, installation, commissioning, and operation of medical gas pipeline systems. The basic principles of safety are achieved by ensuring quantity of supply, identity of supply, continuity of supply and quality of 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 may make these systems of oxygen delivery unsuitable for many hospitals [2].

For different central gas pipeline outlets and pipeline colour codes, and medical gas points per bed, please see Table 3.8 and 3.9, respectively.

Please note that due to auto settings on the MGPS or manifold systems, cylinders on reaching 25% of their total oxygen capacity switch to the other cylinders that are 100% full. To avoid wastage of Oxygen, these cylinders that are 25% full should be disconnected from the manifold and should be used at patient bedside until empty (< 5% full).

Fire detection system such as smoke or heat detector heads should be installed in the plantrooms, medical gases manifold rooms and (when internal) medical gases cylinder stores in any hospital. An automatic shutdown system, linked to local smoke detectors, can be installed. If such a system is planned, it is essential that an automatic emergency supply manifold system is sited well away from the fire-risk area and is arranged to come on-line automatically in the event of plant shutdown [29].

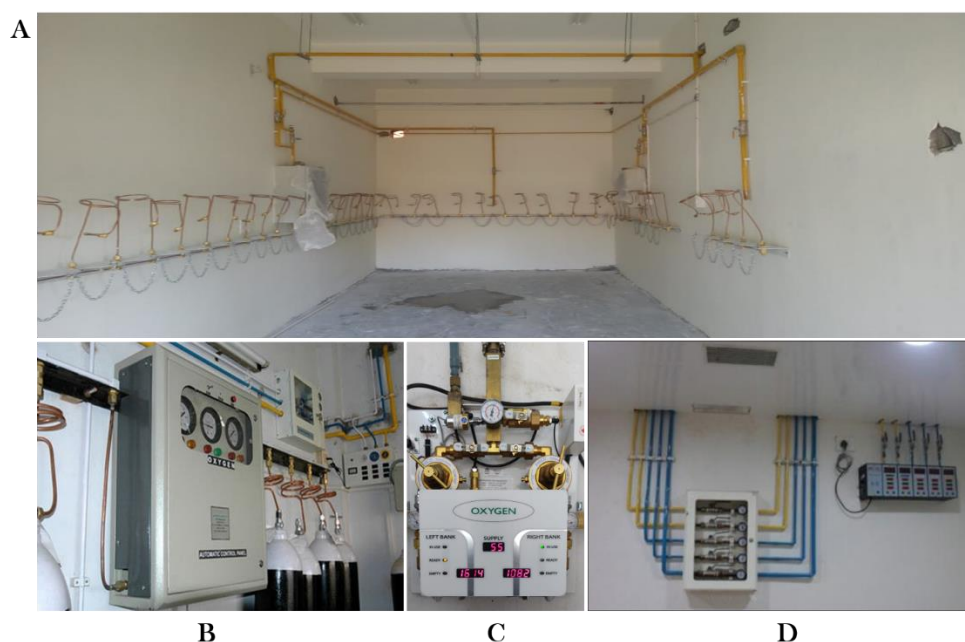


Figure 3.5: (A) Manifold room. (B) Oxygen manifold control panel (analog). (C) Oxygen manifold control panel (digital). (D) Manifold alarm system and isolation valves

Table 3.9: Number of medical gas and air points per bed [3]

Specialities/Wards	Number of outlet points per bed		
	Oxygen	Suction	Air
ICU	2	2	1
PICU/NICU	3	3	3
HDU	2	2	1
Wards	1	1	1
OT	2	2	1
Labour Room	2	2	1
Cardiac ICU	2	2	1
<i>In general wards at least 20% of the beds should have an oxygen outlet.</i>			

**Liquid oxygen (LMO tanks):** Oxygen liquefies at  $-183^{\circ}\text{C}$ . Facilities can be equipped with large bulk liquid oxygen tanks that are refilled periodically by a LMO tanker from a supplier. The liquid oxygen tank supplies a centrally piped system throughout the health facility by self-vaporization, meaning that a power supply is not required. Although currently an economical option in some locations, liquid oxygen requires high technical knowledge and large, well-

ventilated spaces, and can introduce risks in settings with extreme temperature and humidity. It is best practice to also have cylinders as a backup supply [2]. Please find below the comparison of different oxygen sources in Table 3.10.

**Micro cylinders:** In addition to the above listed sources of oxygen, micro cylinders are portable cryogenic liquid cylinders with a capacity of 150 - 450 L. They have ergonomically placed valves for ease of access, operation, and maintenance, and can be conveniently handled by trolleys. They are ideal for “temporary user point” applications with built in vaporiser coils with option of external vaporiser (Figure 3.6).



Figure 3.6: Micro cylinders [28]

## 3.2 Oxygen Regulation, Conditioning, and Monitoring Devices

**Flowmeters:** In oxygen therapy systems, flowmeters are needed to measure and control the rate of oxygen flow to a patient (see Table 3.11 for typical flow ranges), either from a concentrator, a high-pressure cylinder, or a terminal unit of a piped system. Concentrators have built-in flowmeters so there is no need to purchase them separately.

Table 3.10: Description and comparison of oxygen sources [2]

	Cylinders	Concentrators	PSA Plants	LMO Tanks
<b>General Characteristics</b>				
<b>Description</b>	A refillable cylindrical storage vessel used to store and transport oxygen in compressed gas form. Cylinders are refilled at a gas generating plant and thus require transportation to and from the plant.	A self-contained, electrically powered medical device designed to concentrate oxygen from ambient air, using PSA technology.	An onsite oxygen generating system using PSA technology, which supplies high-pressure oxygen throughout a facility via a central pipeline system, or via cylinders refilled by the plant.	Bulk liquid oxygen generated off-site and stored in a large tank and supplied throughout a health facility via a central pipeline system. Tank requires refilling by liquid oxygen supplier.
<b>Clinical application and/or use case</b>	Can be used for all oxygen needs, including high- pressure supply and in facilities where power supply is intermittent or unreliable. Also used for ambulatory service or patient transport. Used as a backup for other systems.	Used to deliver oxygen at the bedside or within close proximity to patient areas. A single concentrator can service several beds with the use of a flowmeter stand to split output flow.	Can be used for all oxygen needs, including high-pressure supply.	Can be used for all oxygen needs, including high- pressure supply and in facilities where power supply is intermittent or unreliable.
<b>Appropriate level of health system</b>	Primary, secondary, possibly tertiary (any medical unit requiring oxygen).	Primary, secondary, possibly tertiary (any medical unit requiring oxygen).	Secondary and tertiary.	Secondary and tertiary.

Product-specific characteristics				
<b>Distribution mechanism</b>	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.
<b>Electricity requirement</b>	No	Yes	Yes	No
<b>Initial costs</b>	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.
<b>Ongoing operating costs</b>	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.
<b>Maintenance requirement</b>	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.
<b>User care</b>	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.
<b>Merits</b>	No power source needed.	<ul style="list-style-type: none"> <li>Continuous oxygen supply (if power available) at low running cost.</li> <li>Output flow can be split among multiple patients.</li> </ul>	<ul style="list-style-type: none"> <li>Can be cost-effective for large facilities.</li> <li>Continuous oxygen supply – no dependence on external vendor for oxygen supply.</li> </ul>	<ul style="list-style-type: none"> <li>99% oxygen obtained.</li> <li>High oxygen output for small space requirement.</li> </ul>
<b>Drawbacks</b>	<ul style="list-style-type: none"> <li>Requires transport/ supply chain.</li> <li>Exhaustible supply.</li> <li>Highly reliant upon supplier.</li> <li>Risk of gas leakage.</li> <li>Risk of unwanted relocation.</li> </ul>	<ul style="list-style-type: none"> <li>Low pressure output, usually not suitable for CPAP or ventilators.</li> <li>Requires uninterrupted power.</li> <li>Requires backup cylinder supply.</li> <li>Requires maintenance.</li> </ul>	<ul style="list-style-type: none"> <li>High capital investments.</li> <li>Requires uninterrupted power.</li> <li>Needs adequate infrastructure.</li> <li>High maintenance for piping.</li> <li>Requires backup cylinder supply.</li> <li>Risk of gas leakage from piping system.</li> </ul>	<ul style="list-style-type: none"> <li>Requires transport/ supply chain.</li> <li>Exhaustible supply.</li> <li>High maintenance for piping.</li> <li>High total cost.</li> <li>Needs adequate infrastructure.</li> <li>Requires backup cylinder supply.</li> <li>Risk of gas leakage from piping system.</li> </ul>

When using oxygen sources with varying pressures (e.g., oxygen cylinders or terminal units), it is important that flowmeters are placed on the low-pressure side, downstream of a pressure-reducing valve. **Thorpe tube flowmeter** (please see Figure 3.7), also known as a rotameter, is a

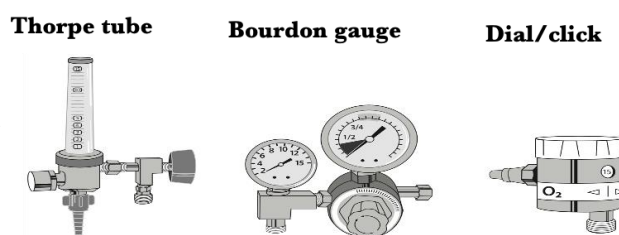
variable orifice flowmeter that consists of a connection to a gas source, a distal valve to control gas flow rate, an upright clear tube containing a float (which rises and falls in relation to gas flow) and an outlet port. The valve is opened and closed by turning an attached dial. This type of flowmeter must be used in a vertical position. The two other types of flowmeters are Bourdon gauge and dial/click flowmeter [2].

Table 3.11: Typical flow ranges available and their clinical applications [2]

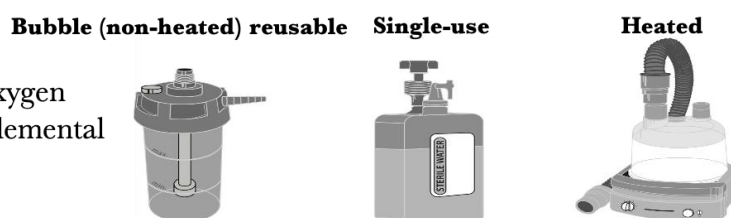
Flow ranges	Graduations	Clinical application
0 - 200 mL/min or 0 - 1 L/min	20 mL/min or less 0.1 L/min or less	Ultra-low flow applications; appropriate for neonatal care.
0 - 3 L/min	0.25 L/min or less	Low-flow applications; appropriate for neonatal and paediatric care.
0 - 5 L/min	0.5 L/min or less	Low to medium flow; appropriate for paediatric oxygen therapy.
0 - 15 L/min	1 L/min or less	Versatile, for low- to high-flow applications.

**Flow-splitting devices:** A flow-splitting device can provide an effective and efficient means of economically administering medical oxygen to multiple patients from a single source, when supply permits. Flow-splitting devices may be used with concentrators, cylinders and centralized systems for both paediatric and adult patients. The two main devices for splitting oxygen flow are the flowmeter stand and the dual flowmeter.

**Flowmeters-** to measure and control the rate of oxygen flow to a patient either from a concentrator, a high-pressure cylinder or a terminal unit of a piped system.



**Humidifiers-** integrated into oxygen delivery systems to humidify supplemental oxygen.



**Oxygen analyzers-** measure and display the concentration of oxygen in patient breathing circuits, medical gas supply lines, compressed gas cylinders and oxygen concentrators



Figure 3.7: Different regulation, conditioning & monitoring devices

**Oxygen humidifiers:** These are medical devices that can be integrated into oxygen delivery systems to humidify supplemental oxygen. Humidification is generally not necessary when oxygen is delivered at relatively low flow rates through nasal prongs or nasal catheters. When oxygen is delivered at higher-than-standard flow rates, or when methods of oxygen delivery bypass the nose, such as when nasopharyngeal catheters are used, humidification is needed – especially when cold oxygen is delivered from a cylinder. They are mainly of two types: non-

heated bubble humidifiers and heated humidifiers (Figure 3.7). Water in the humidifiers should be replaced daily.

**Oxygen analysers:** Oxygen analysers, also referred to as oxygen monitors, are devices that measure and display the concentration of oxygen in patient breathing circuits, medical gas supply lines, compressed gas cylinders and oxygen concentrators (Figure 3.7). They are also used to check and adjust devices used to administer oxygen to patients [2].

### 3.3 Oxygen Delivery Devices

Devices for oxygen delivery differ in cost, efficiency of oxygen use, and ability to provide the requisite fraction of inspired oxygen ( $\text{FiO}_2$ ) (i.e., the percentage or concentration of oxygen that a patient inhales). The choice of appropriate delivery device will thus depend on clinical needs and device capabilities (Figure 3.8)

**Nasal cannula:** Nasal cannulae, also called nasal prongs, are the preferred method for delivering oxygen to infants and children under 5 years of age with hypoxaemia, according to the WHO. Nasal cannulae consist of plastic tubes that end in two short, tapered prongs that are placed in the nostrils. When delivering standard flow rates with this delivery method, the flow of oxygen typically does not meet the patient's full inspiratory demand so ambient air mixes with the delivered oxygen.

**Nasal catheter:** This is a thin, flexible tube that is passed into the nose and ends with its tip in the nasal cavity. Nasal catheters are less costly than nasal cannulae and are recommended as an alternative where nasal cannulae are not available. Nasal catheters are usually well tolerated, and they are unlikely to be dislodged.

Both nasal cannulae and nasal catheters provide an optimal balance between safety, efficacy, and efficiency.

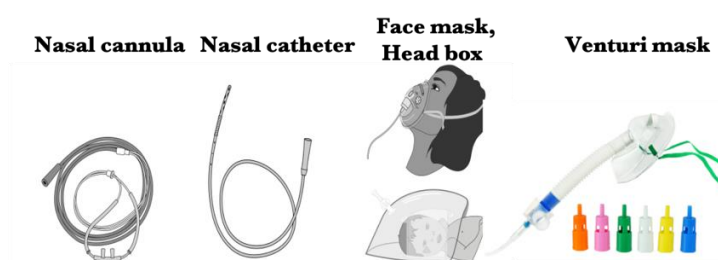


Figure 3.8: Different delivery devices

**Non-invasive methods:** Non-invasive methods of oxygen delivery include head boxes, face masks (simple, partial rebreathing and non-rebreathing), incubators and tents. With these methods, the  $\text{FiO}_2$  can be determined more precisely by an oxygen analyser placed near the patient's mouth. For neonates, infants, and children, however, the use of head boxes, face masks, incubators, and tents to deliver oxygen is generally discouraged, as they are wasteful of oxygen and potentially harmful due to the risk of carbon dioxide accumulation [2]. Please see Table 3.12 for various flow rates that are delivered by different masks. Please ensure proper decontamination of face masks and head box after use. Single-use items should be disposed as per biomedical waste management rules of 2016 [33].

### 3.4 Primary vs Secondary vs Reserve Oxygen Supply

#### Primary supply

- Shall be permanently available and shall be the main source of supply
- As a minimum, the primary supply should have usable quantity of product to meet expected usage between scheduled product deliveries
- Can be from LMO tanks, oxygen cylinders, PSA plants, concentrators (Figure 3.9)



Figure 3.9: Primary vs secondary vs reserve supply

#### Secondary supply

- Shall also be permanently available and shall be the source of supply in the event of primary supply failure
- As a minimum, the secondary supply should have usable quantity of product to meet expected usage between a request for product delivery and the delivery of the product
- Can be from gaseous oxygen cylinders

#### Reserve supply

- It is the final source of supply and is capable of meeting the required demand in the event of failure of the primary and secondary supply
- As a minimum, the reserve supply should have usable quantity of product to meet critical patient care between a request for product delivery and the delivery of the product
- Can be from gaseous oxygen cylinders [8]

Table 3.12: Types of masks and their oxygen delivery flow rates [7]

S. No.	Mask type	Flow rate
1	Venturi mask	24% (Blue)
		28% (White)
		35% (Yellow)
		40% (Red)
		60% (Green)
2	Nasal cannulae	1-4 l/min
3	Simple face mask	5-10 l/min
4	Reservoir mask	15 l/min

### 3.5 Storage Requirements

- The selection of location should comply with national regulations.

- Avoid installing liquid storage vessel in indoor environment or near drains or pits.
- The control equipment should be protected from the weather and the area fenced.
- Weighing scale should be available at the storage area to weigh the oxygen received from the vendor at the time of delivery. A reference chart for weight should also be displayed.
- For medical oxygen cylinders:
  - Storage should be separated from vacuum and medical air compressor plant to avoid possible oil contamination.
  - Appropriate undercover storage facilities for cylinders should be provided to ensure that the cylinders are maintained in a safe, secure and clean condition.
  - Storage under cover in a well-ventilated area, kept dry and clean and not subjected to extremes of heat or cold.
  - Not stored near stocks of combustible materials or near sources of heat.
  - Stored separately from industrial and other non-medical cylinders.
  - Stored to maintain separation between full and empty cylinders.
  - Used in strict rotation so that cylinders with the earliest filling date are used first.
  - Stored separately from other medical cylinders within the store [8, 9].

### 3.6 Capacity Requirements

The capacity of any supply system shall be based on the estimated usage and frequency of delivery. The location and the capacity of the primary, secondary and reserve sources of supply, of all supply systems and the number of full cylinders held in storage, as defined by the management of the health care facility in consultation with the gas supplier, using risk management principles, shall be taken into account by the system manufacturer.

Refer to ISO 7396 -1 for the recommended risk management procedure and typical risk assessment checklist used to identify the associated risks with the medical oxygen supply system.

### 3.7 Review of Demand

A system should be in place to regularly review healthcare facility demand patterns and for ensuring that the bulk medical supply can reliably meet this demand. This review should involve the gas supplier and healthcare facility management.

### 3.8 Alarm Systems

Alarm systems and their management should be considered as part of the risk management procedure in identifying the associated risks involved and with the medical oxygen supply system.

#### Alarm systems requirements:

- Both visual and audible alarm are required.
- If an audible alarm can be silenced by the operator, the silencing shall not prevent the audible alarm from being activated by a new alarm condition.
- Alarm system shall be tested periodically as recommended by equipment manufacturer.
- Master alarm shall be located in an area where 24 hours attendance is provided.

#### The following alarm signals should be fitted:

- Liquid level in any cryogenic vessel below the minimum specified by the management of the healthcare facility in consultation with the gas supplier

- Changeover from primary to secondary supplies
- Secondary or reserve supply below minimum pressure
- Deviation of pipeline pressure by more than  $\pm 20\%$  from the nominal distribution pressure [8]

### 3.9 Operational Management System

Operational management system should be in place to include regulatory requirements, functional responsibilities, operational procedures, training and communications, cylinder and sources of supply management, preventive maintenance, repair and risk assessment, giving definitions and working practices throughout [8].

### 3.10 Fire Safety

- Ensure appropriate fire extinguishers are kept nearby and are regularly inspected.
- Keep oxygen cylinders at least several metres from a heat source, open flames, electrical devices, or other possible sources of ignition.
- Put a “no smoking” sign near oxygen sources in the hospital.
- Check that all nearby electrical circuit breakers and devices are in safe working condition and free from sparking to prevent a serious fire occurrence.

#### In case of fire:

- If it is safe to move the cylinders,
  - close cylinder valve to stop the flow of product
  - move cylinders away from source of heat
  - if it is not safe to move the cylinders,
  - cool with water from a protected position.
- All types of fire extinguishers may be used when dealing with a fire involving medical oxygen cylinders.
- If the fire and rescue service attend it is vital, they are informed that medical oxygen cylinders are inside the building and where they will be located [8, 10].

Technical specifications for cylinders and concentrators can be found at the link below:

[https://www.who.int/medical\\_devices/publications/tech\\_specs\\_oxygen\\_therapy\\_devices/en/](https://www.who.int/medical_devices/publications/tech_specs_oxygen_therapy_devices/en/)



## 4. Pulse Oximetry

Pulse oximetry is a simple and non-invasive method to indirectly measure the blood oxygen saturation ( $\text{SpO}_2$ ) which is a measurement of the amount of oxygen attached to haemoglobin (Hb) in the blood. Pulse oximeters (see Table 4.1) are the accepted global standard for detecting and monitoring hypoxaemia, which is an abnormally low level of oxygen in the blood. Hypoxaemia can occur with conditions primarily affecting the lungs, such as pneumonia, bronchiolitis, asthma and neonatal respiratory distress, but also systemic illnesses such as sepsis and trauma. Pulse oximetry is also used during anaesthesia in surgery and for monitoring patient response to oxygen therapy. Together with an appropriate oxygen supply, pulse oximetry is necessary for the efficient and safe use of oxygen.

Pulse oximeters use the principle of differential light absorption to determine  $\text{SpO}_2$ . A sensor (also called a probe) is applied to an area of the body (e.g., a finger, toe, earlobe or forehead) and transmits different wavelengths of light from light-emitting diodes (LEDs) through the skin and into the tissue. These wavelengths are differentially absorbed by the blood's oxyhaemoglobin ( $\text{HbO}_2$ ), which is red, and deoxyhaemoglobin, which is blue. A photodetector in the sensor (opposite to the LED) converts the transmitted light into electrical signals proportional to the absorbance. The pulse oximeter's microprocessor processes these signals and derives a  $\text{SpO}_2$  reading.

Although pulse oximetry is an important medical technology that has existed for over 30 years, it is often not available or functional in many LICs. Challenges related to the availability of pulse oximetry include low prioritization by countries and governments regarding its utility due to competing needs and limited health care spending. Where it is available, lack of functionality is common due to inadequate procurement and maintenance systems for the replacement of probes and batteries, and for repairs. Adoption into routine clinical practice may also be a challenge for widespread use. Moreover, due to lack of pulse oximetry, the recognised evidence-based diagnosis, many go undiagnosed and untreated for hypoxemia, leading to complications and mortality.

On the other hand, the Tools for Integrated Management of Childhood Illness (TIMCI) project is a global effort led by PATH to accelerate the availability, adoption, and scale-up of tools to identify severe illness and decrease mortality in children in LMICs. Among several objectives, TIMCI aims to improve access to pulse oximeters as well as to accelerate the development and market entry of non-invasive multimodal devices – specifically a handheld device that expands the features of standard pulse oximeters with respiratory rate (RR) measurement – to manage severe illness at the primary care level in low resource settings [36].

A pulse oximeter can serve as either a spot-checking device or can be used for continuous monitoring:

- A **spot check** is a single  $\text{SpO}_2$  reading that is taken in order to detect if a patient is hypoxemic and therefore qualifies for oxygen therapy.
- For **continuous monitoring** (required during surgery and intensive care), the probe remains fixed to the patient and a continuous reading of  $\text{SpO}_2$  is provided by the device.

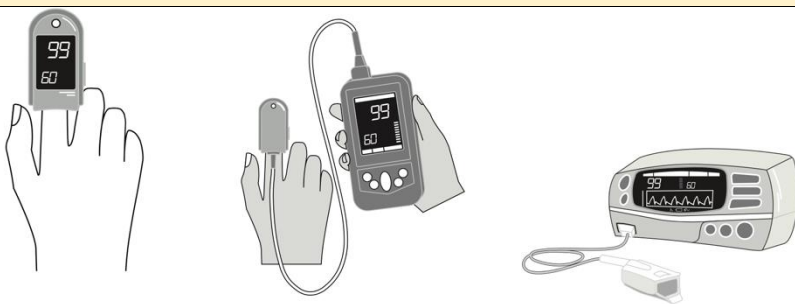
Continuous monitoring is required during surgery as the condition of the patient could shift rapidly, particularly under anaesthesia. When oxygen therapy is given, particularly during intensive or emergency care, a pulse oximeter is beneficial for measuring the ongoing success of

the therapy and can be used as a screening or warning to predict arterial haemoglobin oxygen desaturation. In premature neonates, continuous monitoring helps avoid hyperoxaemia, which is a risk factor for retinopathy of prematurity, a developmental disorder of the retina that may result in blindness. Pulse oximetry is also essential during attempts to wean oxygen therapy to determine whether a patient can maintain SpO<sub>2</sub> within the target range. Because pulse oximeters detect pulsatile blood flow, most devices will also display pulse rate. Since pulse oximeters provide a non-invasive and continuous means of monitoring SpO<sub>2</sub>, they reduce the need for arterial puncture and laboratory blood gas analysis [2, 6].

## 4.1 Types of Pulse Oximeters

Please see the description and comparison of different types of pulse oximeters in Table 4.1.

Table 4.1: Description and comparison of pulse oximeters [2]

	Self-contained fingertip	Portable handheld	Tabletop
<b>General characteristics</b>			
<b>Illustration/image</b>			
<b>Description</b>	Portable device that has the sensor, analyser and display contained in a single unit.	Handheld portable device with display screen and attached sensor probe and cable.	Stationary device for continuous operation/monitoring. Some can be wall- or pole-mounted.
<b>Clinical application and/or use case</b>	<p>Measurement of pulse rate and SpO<sub>2</sub> to detect hypoxaemia, supporting the diagnosis of respiratory disorders. Almost always designed for adults. Some paediatric models can be used on children (check weight range for device) but are not appropriate for use in neonates.</p> <p>Suitable for spot checks only.</p>	<p>Measurement and/or ongoing monitoring of pulse rate and SpO<sub>2</sub> to detect hypoxaemia, supporting the diagnosis of respiratory disorders. Most, but not all, will display a saturation index plethysmography waveform.</p> <p>Suitable for spot checks, or for continuous monitoring (if used for continuous monitoring, alarm feature must be available and activated, and device must be regulatory approved for continuous monitoring).</p>	<p>Monitoring of pulse rate, SpO<sub>2</sub> and plethysmography waveform to detect hypoxaemia, supporting the diagnosis of respiratory disorders.</p> <p>Suitable for longer term continuous monitoring.</p> <p>Suitable for spot checks, or for continuous monitoring (if used for continuous monitoring, alarm feature must be available and activated, and device must be regulatory approved for continuous monitoring).</p>
<b>Appropriate level of health system (and areas of use)</b>	Primary, secondary and tertiary level, but application dependent, i.e. where spot checking on adults (or children, if a paediatric model for an appropriate weight range is used) is the desired function.	Primary, secondary, tertiary, e.g., health centres, general medical and outpatient areas, operating room, ICU, neonatal intensive care unit (NICU), recovery.	Secondary and tertiary, health centres e.g., general medical and outpatient areas, operating room, ICU, NICU, recovery.

Product-specific characteristics			
Parameters monitored	SpO <sub>2</sub> . Pulse rate.	SpO <sub>2</sub> . Pulse rate (some may have additional features such as respiratory rate).	SpO <sub>2</sub> . Pulse rate (some may have additional features).
Accessories required	<ul style="list-style-type: none"> <li>Replacement batteries.</li> <li>May have USB cable for charging.</li> </ul>	<ul style="list-style-type: none"> <li>Probes; size specific to the patient – adult, child, infant and neonate (reusable probes typically need replacing at least once per year).</li> <li>Replacement batteries.</li> <li>Charging/power cable.</li> </ul>	<ul style="list-style-type: none"> <li>Probes; size specific to the patient – adult, child, infant and neonate (reusable probes typically need replacing at least once per a year).</li> <li>Replacement batteries.</li> <li>Charging/power cable.</li> </ul>
Merits	<ul style="list-style-type: none"> <li>Low upfront cost.</li> <li>Portable.</li> <li>Self-contained unit; no external probes/ cables.</li> </ul>	<ul style="list-style-type: none"> <li>Multiple use-case options.</li> <li>Portable.</li> <li>More alarms and internal memory than fingertip devices.</li> <li>Typically, have ≥ 12 hours' operational capacity on rechargeable built-in battery and take ≤ 4 hours to charge.</li> <li>Ideally have a port (or Wi-Fi) for downloading and/or printing data.</li> </ul>	<ul style="list-style-type: none"> <li>Multiple use-case options.</li> <li>May be pole mounted.</li> <li>Large internal memory to store patient IDs and records.</li> <li>Typically, have ≥ 12 hours' operational capacity on rechargeable built-in battery and take ≤ 4 hours to charge.</li> <li>Ideally have a port (or Wi-Fi) for downloading and/or printing data.</li> <li>Most accurate, in general.</li> </ul>
Drawbacks	<ul style="list-style-type: none"> <li>Not recommended for use in neonates.</li> <li>No internal memory.</li> <li>Can be sensitive to wear and tear.</li> <li>Device failure likely requires complete replacement.</li> <li>Can get lost easily.</li> <li>Least accurate, in general.</li> </ul>	<ul style="list-style-type: none"> <li>If single-use probes are used, it can be expensive and difficult to maintain supply, especially in remote areas.</li> <li>Reusable probes can be sensitive to wear and tear.</li> </ul>	<ul style="list-style-type: none"> <li>Highest upfront cost.</li> <li>Less portable than the other units.</li> <li>If single-use probes are used, can be expensive and difficult to maintain supply, especially in remote areas.</li> <li>Reusable probes can be sensitive to wear and tear.</li> </ul>
Power requirement	Usually single-use batteries, some devices may work with rechargeable batteries.	Battery (single-use or rechargeable) and/or electrical power.	Rechargeable battery and/or electrical power.

## 4.2 Cost Considerations for Pulse Oximeters

It is worth noting that an initial upfront cost can vary considerably between pulse oximeter types and a lower initial device cost does not necessarily mean lower lifetime cost. Moreover, following ongoing costs throughout the life of the device must also be considered:

- reusable probes (require replacement every 6–12 months) versus single-use probes
- some reusable probes will require replacement sensor wraps or adhesives
- rechargeable versus single use batteries
- expected life of device and replacement costs
- shipping and local distribution costs
- training costs
- maintenance (parts and labour) costs
- energy costs

**Pulse oximeter probes** represent a significant ongoing cost. Their cables and connectors are fragile and susceptible to wear and tear, requiring frequent replacement. Both disposable (single patient) and reusable probes are available; however, the annual cost of disposable probes is likely to far exceed the cost of the instrument itself. On the other hand, disposable probes may be essential for proper fit with small involving life-threatening pathogens. Thus, when purchasing a consider the types and ongoing life cycle costs of appropriate cables and probes, and other supplies such as sensor wraps and adhesives for non-clip-on probes. There are two categories of probe sensor design: **reflection sensors** and **transmission sensors**. With reflection sensors, both the emitter and detector are on the same side. This can result in limited signal strength. With transmission sensors, the emitter and detector are on opposite sides. This is the more common design used in almost all pulse oximetry [2].

## 4.3 Pulse Oximetry for Neonates

Pulse oximeter probes may be attached to the finger, nose, earlobe or forehead; the skin in these areas has a much higher vascular density than other areas (e.g. chest wall). Some models may also have multisite probes (for ear, finger or toe). If important for the desired application, make sure probes are available in adult, child, infant and/or neonatal sizes (Figure 4.1).

Neonatal probes are often flexible bands designed for use on the forefoot, palm or wrist. Sizes for paediatrics are often based on weight ranges and are not standardized across manufacturers. Probes should be specified and procured according to clinical needs. It is important that the probe is a good fit for the patient and well positioned, so that it is not too tight (constricting circulation) or too loose (letting in too much light or falling off altogether). Please find considerations for neonates below:

- Continuous monitoring of neonates on oxygen and/or receiving respiratory therapies (e.g. CPAP) is essential (when possible), particularly for premature neonates.
- In premature neonates, continuous monitoring helps avoid hyperoxaemia, which is a risk factor for retinopathy of prematurity.
- Neonatal probes are often flexible bands, or sensors held on by a small wrap, designed for use preferably on the palm or outer fleshy aspect of the foot.
- Disposable probes may offer better fit with small preterm infants, but they incur high recurring costs and introduce the risk of infection if reused.
- The probe site should be repositioned every four hours, to check skin and avoid skin trauma and/ or burns [2].

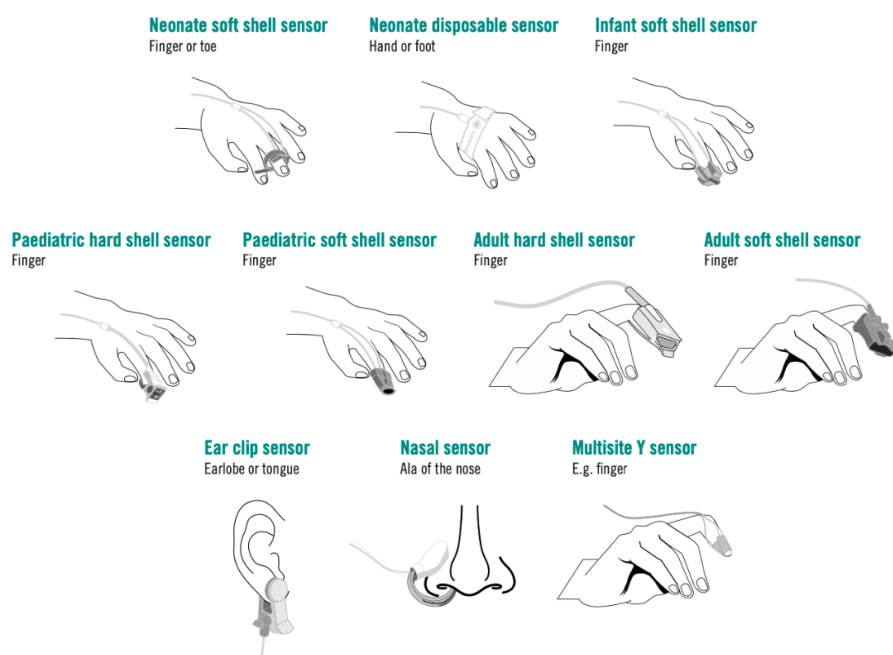


Figure 4.1: Different types of pulse oximeter probes [2]

#### 4.4 Technical Specifications, Maintenance and Trouble- Shooting of Pulse Oximeters

Please see the technical specifications, maintenance and troubleshooting for different types of pulse oximeters in Table 4.2.

Table 4.2: Technical specifications of pulse oximeters [2]

	Self-contained fingertip	Portable handheld	Tabletop
<b>Operational characteristics</b>			
<b>Functions</b>	SpO <sub>2</sub> & Pulse rate monitor	SpO <sub>2</sub> & Pulse rate monitor, with plethysmography waveform	Continuously monitors SpO <sub>2</sub> , plethysmography waveform and pulse rate
<b>Patient types</b>	Adults and children, for all skin pigmentations	Adults, children, infants & neonates, for all skin pigmentations	Adults, children, infants and neonates, for all skin pigmentations
<b>Spot checking</b>	Yes	No	No
<b>SpO<sub>2</sub> detection range</b>	70-99%	70-100%	70-100%
<b>SpO<sub>2</sub> resolution</b>	1% or less	1% or less	1% or less
<b>SpO<sub>2</sub> accuracy</b>	Within $\pm 3\%$	Within $\pm 2-3\%$	Within $\pm 2-3\%$
<b>Pulse rate detection range</b>	30-240 beats per minute (bpm)	30-240 beats per minute (bpm)	30-240 beats per minute (bpm)
<b>Pulse rate resolution</b>	1 bmp or less	1 bmp or less	1 bmp or less
<b>Pulse rate accuracy</b>	Within $\pm 3$ bpm	Within $\pm 3$ bpm	Within $\pm 3$ bpm
<b>Display</b>	SpO <sub>2</sub> pulse rate, signal quality, sensor error or disconnect and low battery status	SpO <sub>2</sub> pulse rate, plethysmographic waveform, signal quality, alarm messages, battery status	SpO <sub>2</sub> pulse rate, plethysmographic waveform, signal quality, alarm messages, battery status
<b>Suitable for low perfusion conditions</b>	Yes	Yes	Yes

Use in demanding environment (shock, vibration & free fall tests)	Yes	Yes	Yes
Available sizes (finger/toe thickness)	8-25 mm	Capable of working with adult, child, infant and neonatal reusable probes	Capable of working with adult, child, infant and neonatal reusable probes
Automatic correction for movement and ambient light artefacts	Yes	Yes	Yes
Suitable for cleaning & disinfection	Yes	Yes	Yes
Operation range of temperature	5-40 °C	5-40 °C	5-40 °C
Operation range of humidity (non-condensing)	10-90%	10-90%	10-90%
<b>Electrical characteristics</b>			
Operated by	Battery (2500 spot checks)	Battery or mains supply	Mains supply & internal rechargeable battery backup
Battery types	Single use or rechargeable	Single use or rechargeable	Rechargeable
Protection against defibrillator discharges or electrical surgical units	Not applicable	Yes	Yes
Installation	Not required	Required (probes and cables are connected correctly, functional checks)	Required (probes and cables are connected correctly, functional checks)
Safety & handling	When not in use, the device should always be stored, within its storage case, in a secure and clean location with controlled temperature and humidity and protected from dust and exposure to insects.		

Please see maintenance for different types of pulse oximeters in Table 4.3.

**Table 4.3: Maintenance of pulse oximeters [2]**

Self-contained fingertip		Portable handheld & Tabletop	
User maintenance			
Daily	<ul style="list-style-type: none"><li>• Run functionality tests before applying to the patient, e.g. displays and probe lights are illuminated.</li><li>• Clean and disinfect the fingertip oximeter after each patient tested, according to the manufacturer’s instructions and IPC protocol specific to the setting.</li><li>• When it is not used, store in appropriate place (well ventilated and secured in storage case).</li><li>• Do not use expired or short life span batteries</li><li>• Refer to user and service manuals for more guidance</li></ul>	Cleaning	<ul style="list-style-type: none"><li>• Clean and disinfect exterior surfaces of the pulse oximeter according to the manufacturer’s instructions.</li><li>• Clean and disinfect the probe after each patient tested, according to the manufacturer’s instructions.</li><li>• Discard single-use probes after each use.</li></ul>
		Visual checks	<ul style="list-style-type: none"><li>• Check all parts are present and connected.</li><li>• Ensure that probes which are not in use are not left hanging or lying about where they can be damaged.</li><li>• Check cables are not twisted and remove from service if any damage is visible.</li></ul>
		Function	<ul style="list-style-type: none"><li>• Check operation on healthy subject if in doubt of function.</li></ul>

Weekly	<div>Cleaning <ul style="list-style-type: none"> <li>Unplug, remove equipment cover (if applicable), clean and disinfect exterior surfaces of the pulse oximeter according to the manufacturer's instructions. Replace cover.</li> </ul> </div> <div>Visual checks <ul style="list-style-type: none"> <li>Tighten any loose screws and check parts are fitted tightly.</li> <li>If plug, cable or socket are damaged, replace.</li> </ul> </div> <div>Function <ul style="list-style-type: none"> <li>Check operation of all lights, indicators and visual displays. Check probe disconnection alarm.</li> </ul> </div>
Every 6 months	<ul style="list-style-type: none"> <li>Biomedical engineering unit preventive maintenance check required (refer to service manual).</li> </ul>

Please see troubleshooting for self-contained fingertip pulse oximeters in Table 4.4.

**Table 4.4: Troubleshooting for self-contained fingertip pulse oximeters [2]**

Problem or fault	Possible cause	Solution
Display suddenly turns off	The oximeter is automatically powered off when no signal is detected (time to shut off may differ by model; consult user manual).	Relocate the probe on another finger or restart the oximeter and be sure the signal strength is strong enough for stable display.
	The power of the battery is too low.	Replace the battery.
Display lockup	Display does not appear to change (you should see a change to the pleth wave or pulse indicator if the device is on the finger).	Reposition finger or relocate on another finger. Remove and replace battery. If the problem persists, contact technical service of the provider.
SpO <sub>2</sub> or pulse rate does not display	Oximeter is not placed correctly on the finger.	Reposition the device.
	Patient's SpO <sub>2</sub> value is too low to be measured.	<ul style="list-style-type: none"> <li>Shield the probe from excessive ambient light.</li> <li>Try device on another patient for comparison to ensure it is not a faulty device.</li> </ul>
Unstable SpO <sub>2</sub> or pulse rate	Finger might not be placed deep enough into the clamp probe.	Retry by inserting the finger to the end.
	Excessive movement.	Prevent movement of the finger, hand or body.
No readings	Low pulse quality (no reading).	<ul style="list-style-type: none"> <li>Reposition finger.</li> <li>Warm finger by rubbing.</li> <li>Select another finger.</li> </ul>
Oximeter does not turn on or blank display	No battery or low power of battery.	Replace battery.
	Battery installed incorrectly.	Reinstall the battery or check the polarity / direction of the battery.
	The display might be damaged.	Replace with new device.
	Dirty/corroded contact.	Decontaminate the contact.
	Finger positioned incorrectly.	Shift finger to activate the device.
	Device may be too cold.	Allow device to sit at room temperature for at least 30 minutes.

Please see troubleshooting for portable handheld and tabletop pulse oximeters in Table 4.5.

**Table 4.5: Troubleshooting for portable handheld and tabletop pulse oximeters [2]**

Problem or fault	Possible cause	Solution
Equipment is not running	No power from mains socket.	<ul style="list-style-type: none"> <li>Check power switch is on.</li> <li>Replace fuse with correct voltage and current if blown.</li> <li>Check mains power is present at socket using equipment known to be working.</li> </ul>

		<ul style="list-style-type: none"> <li>Contact electrician for rewiring if power not present.</li> </ul>
	Battery (if present) is discharged.	Recharge or replace the battery.
	Power supply cable fault.	<ul style="list-style-type: none"> <li>Try cable on another piece of equipment to determine the power cable or the device is faulty.</li> <li>Contact biomedical engineering unit for repair if required.</li> </ul>
<b>SpO<sub>2</sub> or pulse rate not displayed or unstable</b>	Probe is not mounted correctly	Connect probe and cable properly.
	Probe is dirty.	Remove grease, dirt, nail polish, etc. and clean probe.
	Patient movement.	<ul style="list-style-type: none"> <li>Request patient to remain still.</li> <li>For paediatric patients, try employing distraction/engagement of the apprehensive child or breastfeed (if still breastfeeding).</li> <li>For neonates and infants, try locating the sensor on the foot.</li> </ul>
	Patient's SpO <sub>2</sub> value is too low to be measured.	Re-site probe if necessary. Further clinical examination of patient.
	Internal malfunction.	Device may require replacement. Contact biomedical engineering unit.
<b>"Probe off" displayed on screen</b>	Probe is not connected properly	<ul style="list-style-type: none"> <li>Connect the probe properly.</li> <li>Check the extension cable and probe.</li> </ul>
	Connection between the probe and oximeter is loose	Tighten the connection or refer to biomedical engineering unit for repair.
<b>"Error" displayed on screen</b>	Faulty probe.	Replace the probe.
	Faulty control circuit.	Refer to biomedical engineering unit to replace control board if possible or contact supplier.
<b>Continuous alarm sounds</b>	Alarm limits set too low or high.	Set appropriate alarm limits.
	Power disconnected.	Connect power cable.
	Internal malfunction.	Refer to biomedical engineering unit to replace the control board.
<b>Electrical shocks</b>	Wiring fault.	Remove from clinical use immediately. Re-wire the connection based on the manufacturer's schematic and circuit diagram.

## 5. Medical Oxygen Therapy

### 5.1 Aims of Medical Oxygen Therapy

The aim of the guidelines is also to describe the indications and procedure for the use of oxygen therapy, and its modes of delivery. The goal of oxygen delivery is to maintain targeted  $\text{SpO}_2$  levels in patients through the provision of supplemental oxygen in a safe and effective way which is tolerated by the patients to (Figure 5.1):

- Relieve hypoxaemia and maintain adequate oxygenation of tissues and vital organs, as assessed by  $\text{SpO}_2/\text{SaO}_2$  monitoring and clinical signs
- Give oxygen therapy in a way which prevents excessive  $\text{CO}_2$  accumulation - i.e., selection of the appropriate flow rate and delivery device
- Reduce the work of breathing
- Ensure adequate clearance of secretions and limit the adverse events of hypothermia and insensible water loss by use of optimal humidification (dependent on mode of oxygen delivery)
- Maintain efficient and economical use of oxygen [11]

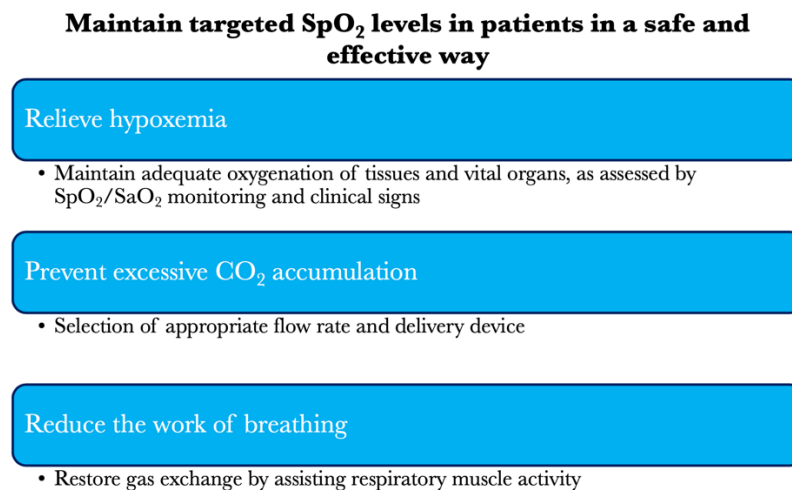


Figure 5.1: Aims of medical oxygen therapy

Please see Table 5.1 for the physiological effects of acute hypoxia and hyperoxia.

### 5.2 Basic Definitions

- $\text{FiO}_2$ : Fraction of inspired oxygen (%).
- $\text{PaCO}_2$ : The partial pressure of  $\text{CO}_2$  in arterial blood. It is used to assess the adequacy of ventilation.
- $\text{PaO}_2$ : The partial pressure of oxygen in arterial blood. It is used to assess the adequacy of oxygenation.
- $\text{SaO}_2$ : Arterial oxygen saturation measured from blood specimen.
- $\text{SpO}_2$ : Arterial oxygen saturation measured via pulse oximetry.
- *Heat Moisture Exchange Filter (HMEF)*: They are devices that retain heat and moisture minimizing moisture loss to the patient airway.
- *High flow*: High flow systems are specific devices that deliver the patient's entire ventilatory demand, meeting, or exceeding the patients Peak Inspiratory Flow Rate

(PIFR), thereby providing an accurate  $\text{FiO}_2$ . Where the total flow delivered to the patient meets or exceeds their Peak Inspiratory Flow Rate, the  $\text{FiO}_2$  delivered to the patient will be accurate. High flow to be used in approved cases only such as when more consumption of oxygen is required.

- *Humidification* is the addition of heat and moisture to a gas. The amount of water vapour that a gas can carry increases with temperature.
- *Hypercapnia*: Increased amounts of carbon dioxide in the blood.
- *Hypoxaemia*: Low arterial oxygen tension (in the blood.)
- *Hypoxia*: Low oxygen level at the tissues.
- *Low flow*: Low flow systems are specific devices that do not provide the patient's entire ventilatory requirements, room air is entrained with the oxygen, diluting the  $\text{FiO}_2$ .
- *Minute ventilation*: The total amount of gas moving into and out of the lungs per minute. The minute ventilation (volume) is calculated by multiplying the tidal volume by the respiration rate, measured in litres per minute (LPM).
- *Arterial blood gas (ABG) analysis*: An arterial-blood gas test measures the amounts of arterial gases, such as oxygen and carbon dioxide.
- *Peak inspiratory flow rate (PIFR)*: The fastest flow rate of air during inspiration, measured in litres per second.
- *Tidal volume*: The amount of gas that moves in, and out, of the lungs with each breath, measured in millilitres (6-10 ml/kg).
- *Ventilation - perfusion (VQ) mismatch*: An imbalance between alveolar ventilation and pulmonary capillary blood flow [12].

Table 5.1: Physiological effects of acute hypoxia and hyperoxia [7]

	Hypoxia		Hyperoxia	
	Effects	Risks	Effects	Risks
Respiratory system	<ul style="list-style-type: none"> <li>• Increased ventilation</li> <li>• Pulmonary vasoconstriction</li> </ul>	Pulmonary hypertension	Decreased ventilation (minimal)	<ul style="list-style-type: none"> <li>• Worsened ventilation/perfusion matching</li> <li>• Absorption atelectasis</li> </ul>
Cardiovascular system	<ul style="list-style-type: none"> <li>• Coronary vasodilation</li> <li>• Decreased systemic vascular resistance (transient)</li> <li>• Increased cardiac output</li> <li>• Tachycardia</li> </ul>	<ul style="list-style-type: none"> <li>• Myocardial ischaemia/ infarction</li> <li>• Ischaemia/infarction of other critically perfused organs</li> <li>• Hypotension</li> <li>• Arrhythmias</li> </ul>		<ul style="list-style-type: none"> <li>• Myocardial ischaemia (in context of decreased haematocrit)</li> <li>• Reduced cardiac output</li> <li>• Reduced coronary blood flow</li> <li>• Increased blood pressure</li> <li>• Increased peripheral resistance</li> </ul>
Metabolic system	<ul style="list-style-type: none"> <li>• Increased 2,3-DPG</li> <li>• Increased <math>\text{CO}_2</math> carriage (Haldane effect)</li> </ul>	Lactic acidosis	<ul style="list-style-type: none"> <li>• Decreased 2,3-DPG</li> <li>• Decreased <math>\text{CO}_2</math> carriage</li> </ul>	Increased reactive (harmful) oxygen species

		(Haldane effect)
Neurological system	Increased cerebral blood flow due to vasodilation <ul style="list-style-type: none"> <li>• Confusion</li> <li>• Delirium</li> <li>• Coma</li> </ul>	Decreased cerebral blood flow
Renal system	<ul style="list-style-type: none"> <li>• Renin-angiotensin axis activation</li> <li>• Increased erythropoietin production</li> </ul> Acute tubular necrosis	Reduced renal blood flow

### 5.3 Normal Values and SpO<sub>2</sub> Targets

Partial pressure of arterial oxygen (PaO <sub>2</sub> )	<ul style="list-style-type: none"> <li>• 80 -100 mmHg - children/adults</li> <li>• 50 - 80 mmHg - neonates</li> </ul>
Partial pressure of arterial CO <sub>2</sub> (PaCO <sub>2</sub> )	<ul style="list-style-type: none"> <li>• 35 - 45 mmHg children/adults</li> </ul>
pH	<ul style="list-style-type: none"> <li>• 7.35 -7.45</li> </ul>
General SpO <sub>2</sub> targets	<ul style="list-style-type: none"> <li>• 94% - 98% (PaO<sub>2</sub> between 80 and 100 mmHg) in patients without cyanotic congenital heart disease or chronic lung disease</li> <li>• &gt; 70% (PaO<sub>2</sub> 37 mmHg) in patients who have had cardiac surgery of their congenital cyanotic heart disease</li> <li>• &gt; 60% (PaO<sub>2</sub> 32mmHg) in unrepaired congenital cyanotic heart disease</li> <li>• 91 - 95% for premature and term neonates</li> <li>• ≥ 90% for infants with bronchiolitis</li> </ul>
The above values are expected target ranges and are generalized to the paediatric population, for age/patient specific ranges please consult the treating medical team.	

### 5.4 Indications for Oxygen Therapy

When considering the application of oxygen therapy (see Table 5.2 for recommendations on oxygen therapy), it is essential to perform a thorough clinical assessment of the patient.

- Transient, self-correcting desaturations that have no other physiological correlates (e.g., Tachycardia, cyanosis) may not routinely require oxygen therapy in most cases.
- The threshold for oxygen therapy can vary with the patient's general state and point in the illness.
- There is no physiological basis for the application of low flow oxygen therapy to a patient with normal SpO<sub>2</sub> and increase work of breathing.
- The treatment of documented hypoxia/hypoxaemia as determined by SpO<sub>2</sub> or inadequate blood oxygen tensions (PaO<sub>2</sub>).
- Achieving targeted percentage of oxygen saturation (as per normal values unless a different target range is specified on the observation chart).
- The treatment of an acute or emergency situation where hypoxaemia or hypoxia is suspected, and if the patient is in respiratory distress manifested by:

- dyspnoea, tachypnoea, bradypnoea, apnoea
- pallor, cyanosis
- lethargy or restlessness
- use of accessory muscles: nasal flaring, intercostal or sternal recession, tracheal tug
- Short term therapy e.g., post anaesthetic or surgical procedure
- Palliative care - for comfort [6, 12]

*Any patient who develops or has an increase in their oxygen requirement should be medically reviewed within 30 minutes after start of the oxygen therapy.*

## 5.5 Initiation of Oxygen Therapy

### 5.5.1 Commencing Oxygen Therapy

- SpO<sub>2</sub> is less than 92% (PaO<sub>2</sub> less than 80mmHg) in patients without cyanotic heart disease
- SpO<sub>2</sub> is less than 70% (PaO<sub>2</sub> less than 37mmHg) in patients with cyanotic heart disease who have had cardiac surgery
- SpO<sub>2</sub> is less than 60% (PaO<sub>2</sub> less than 32mmHg) in patients with cyanotic heart disease who are waiting for cardiac surgery
- <91% in premature and new-born neonates
- Persistently < 90% for infants with bronchiolitis

**Table 5.2: Illnesses requiring oxygen therapy [7, 13]**

Illness type	Conditions	Comments
Critical	<ul style="list-style-type: none"> <li>● Cardiac arrest or resuscitation</li> <li>● Shock, sepsis, major trauma, drowning, anaphylaxis, major pulmonary haemorrhage, status epilepticus</li> <li>● Major head injury</li> <li>● Carbon monoxide poisoning</li> </ul>	<ul style="list-style-type: none"> <li>● The initial oxygen therapy is a reservoir mask at 15 l/min pending the availability of reliable oximetry readings.</li> <li>● For patients with spontaneous circulation and a reliable oximetry reading, it may quickly become possible to reduce the oxygen dose whilst maintaining a target saturation range of 94–98%.</li> <li>● If oximetry is unavailable, continue to use a reservoir mask until definitive treatment is available.</li> <li>● Patients with COPD and other risk factors for hypercapnia who develop critical illness should have the same initial target saturations as other critically ill patients pending the results of blood gas results after which these patients may need controlled oxygen therapy with target range 88–92% or supported non-invasive ventilation if there is severe hypoxaemia and/or hypercapnia with respiratory acidosis.</li> </ul>
Serious	<ul style="list-style-type: none"> <li>● Acute hypoxaemia (cause not yet diagnosed)</li> <li>● Acute asthma</li> <li>● Pneumonia</li> <li>● Lung cancer</li> <li>● Deterioration of lung fibrosis or other interstitial lung diseases</li> <li>● Pneumothorax</li> <li>● Pleural effusions</li> <li>● Pulmonary embolism</li> </ul>	<ul style="list-style-type: none"> <li>● The initial oxygen therapy is nasal cannulae at 2–6 L/min (preferably) or simple face mask at 5–10 L/min unless stated otherwise.</li> <li>● For patients not at risk of hypercapnic respiratory failure who have saturation below 85%, treatment should be started with a reservoir mask at 15 L/min and the recommended initial oxygen saturation target range is 94–98%. If oximetry is not available, give oxygen as above until oximetry or blood gas results are available. Change to reservoir mask if the desired saturation range cannot be maintained with nasal</li> </ul>

	<ul style="list-style-type: none"> <li>• Acute heart failure</li> <li>• Severe anaemia</li> <li>• Postoperative breathlessness</li> </ul>	<ul style="list-style-type: none"> <li>• cannulae or simple face mask (and ensure that the patient is assessed by senior medical staff).</li> <li>• If these patients have coexisting COPD or other risk factors for hypercapnic respiratory failure, aim at a saturation of 88–92% pending blood gas results but adjust to 94–98% if the <math>PCO_2</math> is normal (unless there is a history of previous hypercapnic respiratory failure requiring NIV or IMV) and recheck blood gases after 30–60 min.</li> </ul>
Close monitoring but $O_2$ therapy is not required unless patient is hypoxaemic	<ul style="list-style-type: none"> <li>• Myocardial infarction and acute coronary syndromes</li> <li>• Stroke</li> <li>• Hyperventilation or dysfunctional breathing</li> <li>• Most poisonings and drug overdoses</li> <li>• Metabolic and renal disorders</li> <li>• Acute and subacute neurological and muscular conditions producing muscle weakness</li> <li>• Pregnancy and obstetric emergencies</li> </ul>	<ul style="list-style-type: none"> <li>• If hypoxaemic, the initial oxygen therapy is nasal cannulae at 2–6 L/min or simple face mask at 5–10 L/min unless saturation is below 85% (use reservoir mask) or if at risk from hypercapnia (see below).</li> <li>• The recommended initial target saturation range, unless stated otherwise, is 94–98%.</li> <li>• If oximetry is not available, give oxygen as above until oximetry or blood gas results are available.</li> <li>• If patients have COPD or other risk factors for hypercapnic respiratory failure, aim at a saturation of 88–92% pending blood gas results but adjust to 94–98% if the <math>PCO_2</math> is normal (unless there is a history of respiratory failure requiring NIV or IMV) and recheck blood gases after 30–60 min.</li> </ul>
COPD and other conditions requiring controlled or low-dose $O_2$ therapy	<ul style="list-style-type: none"> <li>• COPD and other conditions causing fixed airflow obstruction (eg bronchiectasis)</li> <li>• Exacerbation of cystic fibrosis</li> <li>• Neuromuscular disease, neurological condition and chest wall deformity</li> <li>• Morbid obesity</li> </ul>	<ul style="list-style-type: none"> <li>• Prior to availability of blood gases, use a 24% Venturi mask at 2–3 L/min or 28% Venturi mask at 4 L/min or nasal cannulae at 1–2 L/min and aim for an oxygen saturation of 88–92% for patients with risk factors for hypercapnia but no prior history of respiratory acidosis. Adjust target range to 94–98% if the <math>PCO_2</math> is normal (unless there is a history of previous NIV or IMV) and recheck blood gases after 30–60 min.</li> </ul>

COPD, chronic obstructive pulmonary disease; IMV, invasive mechanical ventilation; NIV, non-invasive ventilation;  $PCO_2$ , arterial or arteriolised carbon dioxide tension

### 5.5.2 Monitoring During the First Hour of Oxygen Therapy

- All patients should have their oxygen saturation observed for at least five minutes after starting oxygen therapy.
- If the oxygen saturation should fall below the target saturation and the patient is unstable, medical advice should be sought.
- If the oxygen saturation is above the target saturation range and the patient is stable, the delivery system and oxygen flow rate should be reduced accordingly.
- Patients who have a target saturation of 88–92% should have their blood gases measured within 30– 60 min. This is to ensure that the carbon dioxide level is not rising. This recommendation also applies to those who are at risk of developing hypercapnic respiratory failure but who have a normal  $PaCO_2$  on the initial blood gas measurement.
- Stable patients whose oxygen saturation is within their target saturation range of 94–98% do not need repeat blood gas measurements within 30– 60 min if there is no risk of hypercapnia and acidosis and may not need any further blood gas measurements (Figure 5.2) [7].

### 5.5.3 Increasing Oxygen Therapy

- If a patient's oxygen saturation is lower than the prescribed target range, first check all aspects of the oxygen delivery system for faults or errors.
- If a patient's oxygen saturation is consistently lower than the prescribed target range, there should usually be a medical review and the oxygen therapy should be increased according to an agreed written protocol.
- The patient should be observed for 5 min after oxygen therapy has been increased.
- If the oxygen saturation fails to rise following 5–10 min of increased oxygen therapy or if there is clinical concern following medical review, then blood gas measurements should be repeated.
- If the target saturation is in the 88–92% range, blood gas measurements should be repeated at 30–60 min after any increase in oxygen therapy to ensure that the carbon dioxide level is not rising.

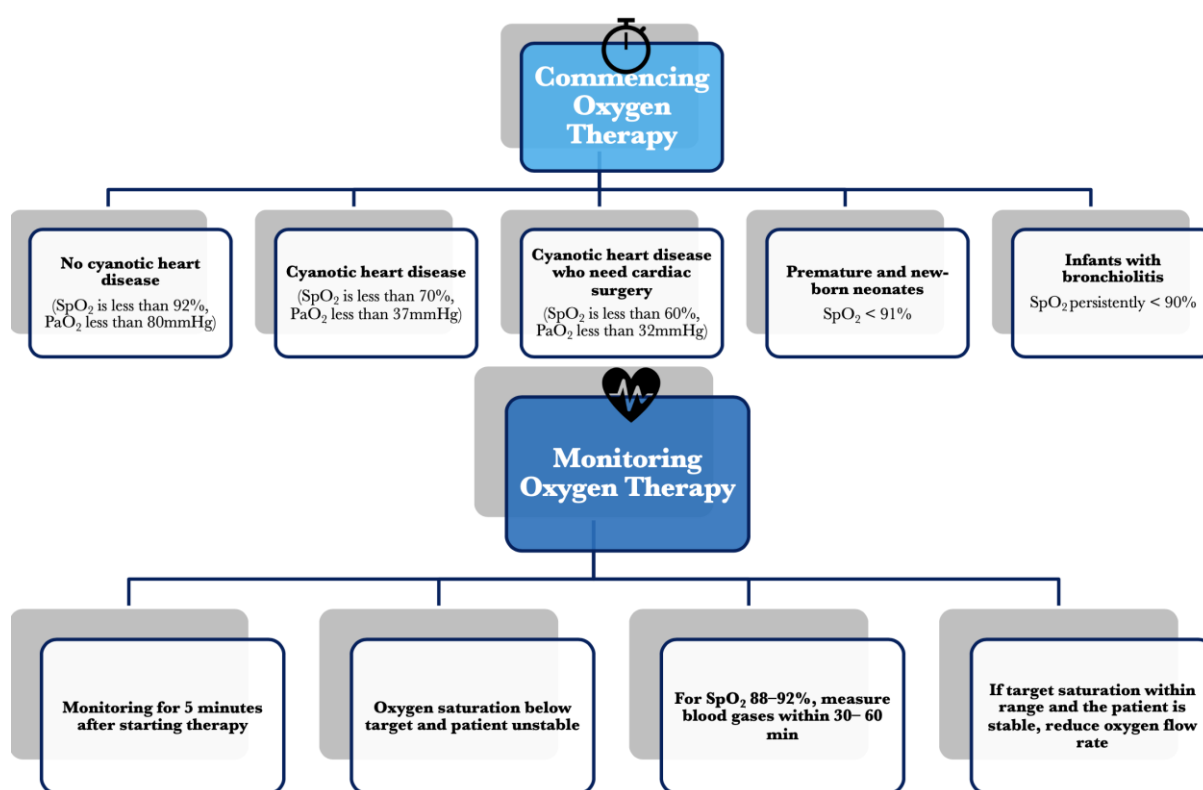


Figure 5.2: Commencing and monitoring oxygen therapy

### 5.5.4 Lowering Oxygen Therapy

- Lower the oxygen dose if the target saturation is higher than the prescribed range.
- Lower the oxygen dose if the patient is clinically stable and the oxygen saturation has been in the upper zone of the target range for some time (usually 4–8 h).
- Saturations should be observed for 5 min following a change of oxygen therapy or rechecked after 5 min on the lower dose of oxygen.
- If the target saturation is maintained, the new delivery system and flow should be continued. Repeat blood gas measurements are not required. If the patient is stable the process can be repeated, and the patient can eventually be weaned off oxygen (Figure 5.3).

Please see Figure 5.4 for guidance for oxygen prescription guidance for acutely hypoxaemic patients in hospital.

*Oxygen treatment is usually not necessary unless the  $SpO_2$  is less than 92%.  
That is, do not give oxygen if the  $SpO_2$  is  $\geq 92\%$ .*

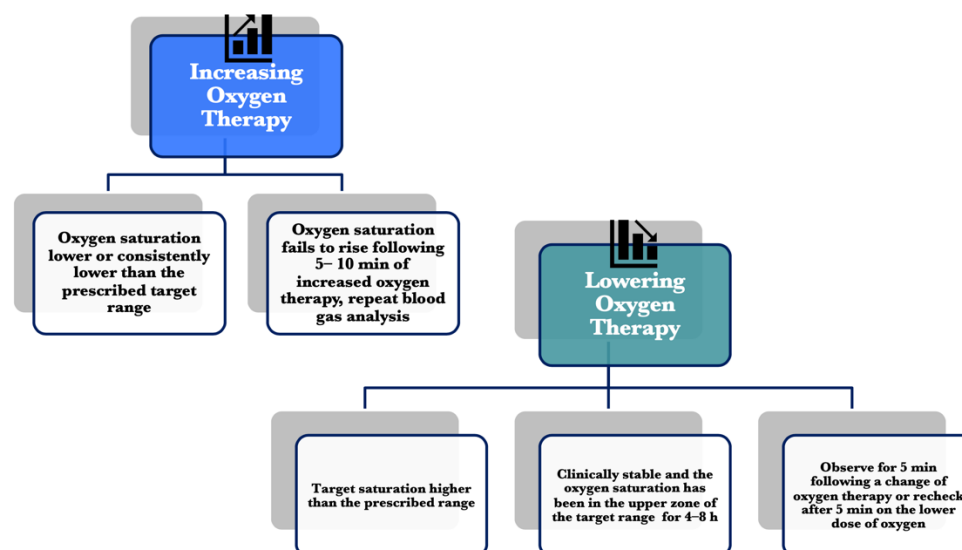
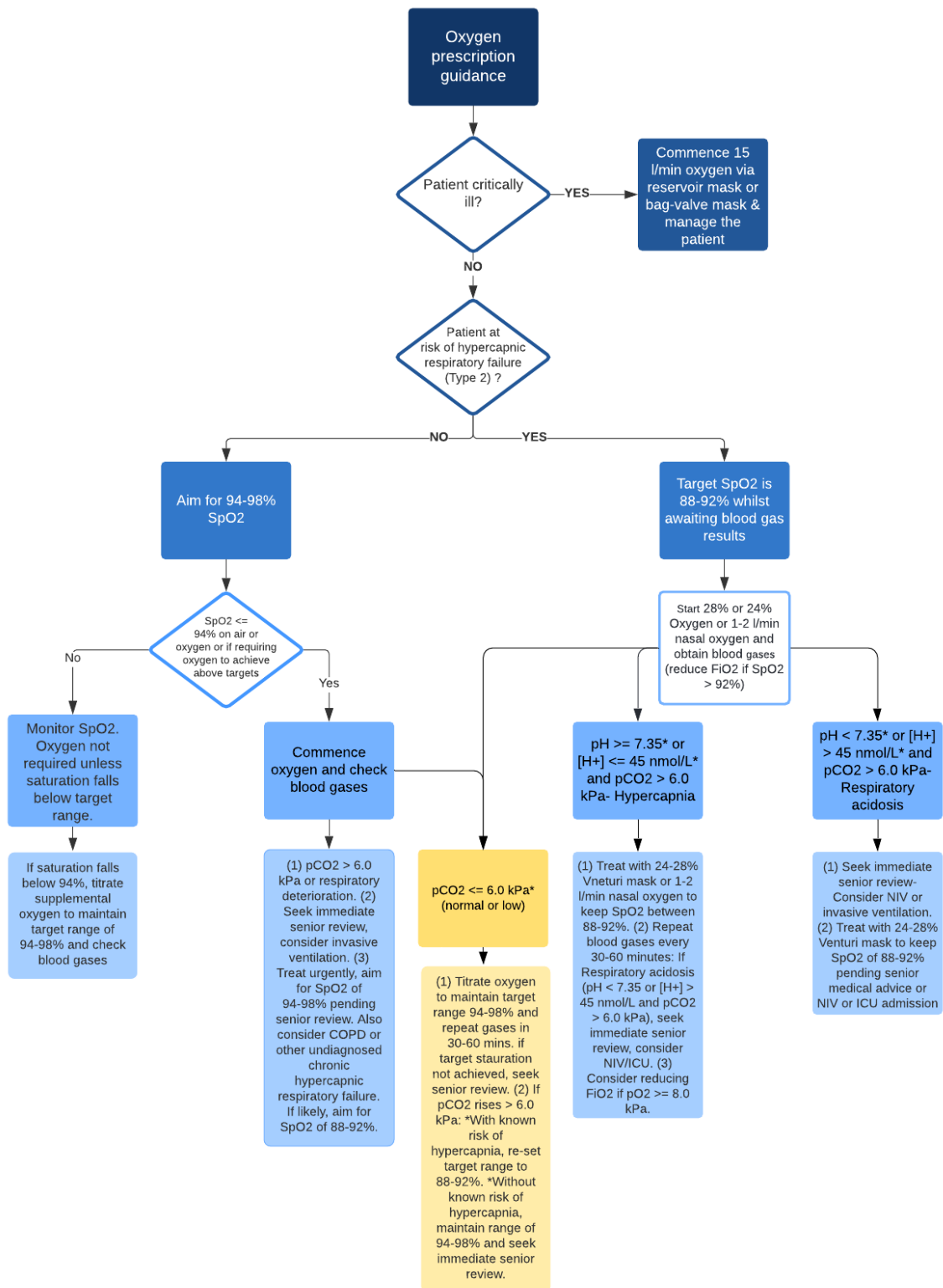


Figure 5.3: Increasing and lowering oxygen therapy

## 5.6 Patient Assessment and Documentation

- Assess the airway and optimise airway position (e.g., head tilt, chin lift) as necessary
- Conduct and document clinical assessment including but not limited to of cardiovascular, respiratory and neurological systems at the commencement of each shift and with any change in patient condition
- Check and document oxygen equipment set up at the commencement of each shift and with any change in patient condition
- Hourly checks should be made for the following:
  - Oxygen flow rate
  - Patency of tubing
  - Humidifier settings (if being used)
- Hourly checks should be made and recorded on the patient observation chart for the following (unless otherwise directed by the treating medical team):
  - heart rate
  - respiratory rate
  - respiratory distress (descriptive assessment - i.e., use of accessory muscles/nasal flaring)
  - oxygen saturation
    - continuous pulse oximetry is recommended for the patients who are severely unwell, and who are likely to have rapid and clinically significant drop in oxygen saturations when the oxygen therapy is disconnected.
    - continuous pulse oximetry may not be necessary in the stable patient receiving oxygen therapy.



Any increase in FiO<sub>2</sub> must be followed by repeat blood gases in 1 hour (or sooner if conscious level deteriorates)

\* If pH is < 7.35 ([H<sup>+</sup>] > 45 nmol/L) with normal or low PCO<sub>2</sub>, investigate and treat for metabolic acidosis and keep SpO<sub>2</sub> 94-98%

**Figure 5.4:** Oxygen prescription guidance for acutely hypoxaemic patients in hospital. COPD, chronic obstructive pulmonary disease; ICU, intensive care unit; NIV, non-invasive ventilation; PO<sub>2</sub>, oxygen tension; PCO<sub>2</sub>, carbon dioxide tension; SpO<sub>2</sub>, arterial oxygen saturation measured by pulse oximetry [7].

- Ensure the individual MET criteria are observed regardless of oxygen requirements. One metabolic equivalent (MET) is defined as the amount of oxygen consumed while sitting at rest and is equal to 3.5 ml O<sub>2</sub> per kg body weight x min [12].

## 5.7 Weaning and Discontinuation of Oxygen Therapy

*Unless clinically contraindicated, an attempt to wean oxygen therapy should be attempted at least once per shift.*

### How to discontinue oxygen therapy for stable patients

- Most stable convalescent patients will eventually be stepped down to 2 l/min via nasal cannulae prior to cessation of oxygen therapy. Patients at risk of hypercapnic respiratory failure may be stepped down to 1 l/min via nasal cannulae or a 24% Venturi mask at 2 l/min as the lowest oxygen dose prior to cessation of oxygen therapy.
- Oxygen therapy should be stopped once a patient is clinically stable on low-dose oxygen and the oxygen saturation is within the desired range on two consecutive observations. Oxygen should also be stopped if the patient is on a written protocol of timed oxygen (eg, postoperatively).
- Oxygen saturation on room air should be monitored for 5 min after stopping oxygen therapy. If it remains in the desired range it should be rechecked at 1 h.
- If the oxygen saturation and physiological tracking is satisfactory at 1 h, the patient has safely discontinued oxygen therapy, but saturation and physiology should continue to be monitored on a regular basis according to the patient's underlying clinical condition.
- If the saturation falls on stopping oxygen therapy, recommence the lowest dose that maintained the patient in the target range and monitor for 5 min. If this restores the saturation into the target range, continue oxygen therapy at this level and attempt discontinuation of oxygen therapy again at a later date provided the patient remains clinically stable.
- If a patient requires oxygen therapy to be restarted at a higher dose than before to maintain the same target saturation range, the patient should have a clinical review to establish the cause for this deterioration.
- Some patients may have episodic hyoxaemia (eg, after minor exertion) after they have safely discontinued continuous oxygen therapy. If these patients require intermittent oxygen therapy, they should have a prescription for oxygen as required (PRN) but PRN oxygen should not be routinely prescribed for those who have stopped continuous oxygen therapy.
- Cross oxygen off the drug chart when oxygen discontinued (and sign to confirm discontinuation) (Figure 5.5) [7].

## 5.8 Selecting the Delivery Method

- A range of flow meters are available such as 0-1 LPM, 0-2.5 LPM, 0-15 LPM.
- Also 0-50 LPM in paediatric intensive care unit (PICU) only.
- Oxygen delivery method selected depends on:
  - age of the patient
  - oxygen requirements/therapeutic goals
  - patient tolerance to selected interface
  - humidification needs

## Weaning & Discontinuation

- **Most stable convalescent patients** - step down to 2 l/min via nasal cannulae prior to cessation of oxygen therapy
- **Patients at risk of hypercapnic respiratory failure** - step down to 1 l/min via nasal cannulae or a 24% Venturi mask at 2 l/min as the lowest oxygen dose prior to cessation of oxygen therapy
- **Clinically stable patients** - Stop once a patient is clinically stable on low-dose oxygen and the oxygen saturation is within the desired range on two consecutive observations
- **After stopping** - Monitor saturation for 5 min after stopping & if it remains in the desired range it should be rechecked at 1 h
- **If the saturation falls on stopping oxygen therapy**, recommence the lowest dose that maintained the patient in the target range and monitor for 5 min. If this restores the saturation into the target range, continue oxygen therapy at this level and attempt discontinuation of oxygen therapy again at a later date provided the patient remains clinically stable.
- **Clinical review** - If a patient requires oxygen therapy to be restarted at a higher dose than before to maintain the same target saturation range
- **If the oxygen saturation and physiological tracking is satisfactory at 1 h**, oxygen therapy safely discontinued, but saturation and physiology should continue to be monitored if needed

Where oxygen weaning is successful, continuous pulse oximetry monitoring may be discontinued

Figure 5.5: Weaning and discontinuation of oxygen

### 5.8.1 Low Flow Delivery Method

Low-flow systems include:

- Simple face mask
- Non re-breather face mask (mask with oxygen reservoir bag and one-way valves which aims to prevent/reduce room air entrainment)
- Nasal prongs (low flow)
- Tracheostomy mask
- Tracheostomy HME connector
- Isolette - neonates (usually for use in the Neonatal Intensive Care Unit only)

*In most low flow systems, the flow is usually titrated (on the oxygen flow meter) and recorded in litres per minute (LPM).*

*Some flow meters may deliver greater than the maximum flow indicated on the flow meter if the ball is set above the highest amount. Use caution when adjusting the flow meter.*

### 5.8.2 High Flow Delivery Method

High flow systems include (Figure 5.6):

- Ventilators
- BiPAP/CPAP
- High Flow Nasal Prong (HFNP) therapy

*Oxygen therapy should not be delayed in the treatment of life-threatening hypoxia.*

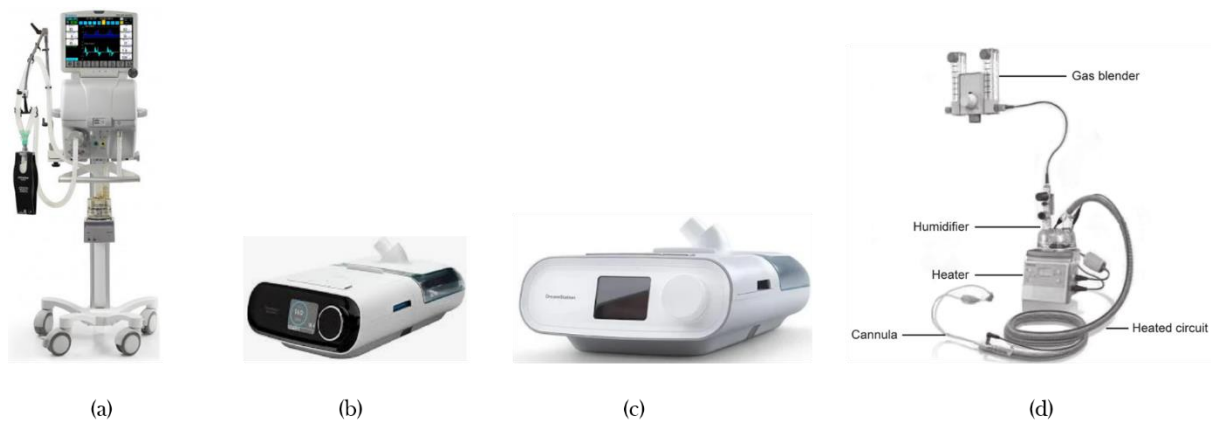


Figure 5.6: High flow delivery devices (a) Mechanical ventilator. (b) BiPAP. (c) CPAP. (d) HFNC system

## 5.9 Humidification

Oxygen therapy can be delivered using a low flow or high flow system. All high flow systems require humidification. The type of humidification device selected will depend on the oxygen delivery system in use, and the patient's requirements. The humidifier should always be placed at a level below the patient's head.

- **Rationale:**
  - Cold, dry air increases heat and fluid loss
  - Medical gases, including air and oxygen, have a drying effect on mucous membranes resulting in airway damage.
  - Secretions can become thick & difficult to clear or cause airway obstruction
  - In some conditions e.g., asthma, the hyperventilation of dry gases can compound bronchoconstriction.
- **Indications:**
  - Patients with thick copious secretions
  - Non-invasive and invasive ventilation
  - Nasal prong flow rates of greater than 2 LPM (under 2 years of age) or 4 LPM (over 2 years of age)
  - Nasal prong flow rates of greater than 1 LPM in neonates
  - Facial mask flow rates of greater than 5 LPM
  - Patients with tracheostomy

## 5.10 Delivery Mode

- **Simple Nasal Prongs**
  - Nasal prongs without humidification

For nasal prong oxygen without humidification a maximum flow of:

- 2 LPM in infants/children under 2 years of age
- 4 LPM for children over 2 years of age.
- 1 LPM for neonates

Care and considerations of child with simple nasal prongs:

- Position the nasal prongs along the patient's cheek and secure the nasal prongs on the patient's face with adhesive tape.
  - Position the tubing over the ears and secure behind the patient's head. Ensure straps and tubing are away from the patient's neck to prevent risk of airway obstruction.
  - Check nasal prong and tubing for patency, kinks or twists at any point in the tubing and clear or change prongs if necessary.
  - Check nares for patency - clear with suction as required.
  - Change the adhesive tape weekly or more frequently as required
- Nasal prongs with humidification system
 

For nasal prong oxygen with humidification a maximum flow of:

  - 4 LPM in infants/children under 2 years of age
  - 6 LPM for children over 2 years of age
  - 10 LPM for adolescents  $\geq 30\text{kg}$
- **High flow (in approved cases only)**
  - Flow of 2 L/kg/min up to 12kg, plus 0.5 L/kg/min for each kg above 12kg (to a maximum of 50 LPM)
  - FiO<sub>2</sub> 21-50% (blender must be used)
  - FiO<sub>2</sub> above 50% requires PICU review (except if patient is in NICU)
- **Face Mask**
  - Simple face mask
  - Nebuliser mask / Tracheostomy mask / Tracheostomy direct connection
  - Non-rebreathing face mask

Considerations when using a non-rebreathing face mask:

  - To ensure the highest concentration of oxygen is delivered to the patient the reservoir bag needs to be inflated prior to placing on the patients face.
  - Ensure the flow rate from the wall to the mask is adequate to maintain a fully inflated reservoir bag during the whole respiratory cycle (i.e., inspiration and expiration).
  - Non-rebreathing face mask are not designed to allow added humidification.
  - Not routinely used outside of ED and PICU and should only be used in consultation with the medical team.
- **Tracheostomy (Figure 5.7)**

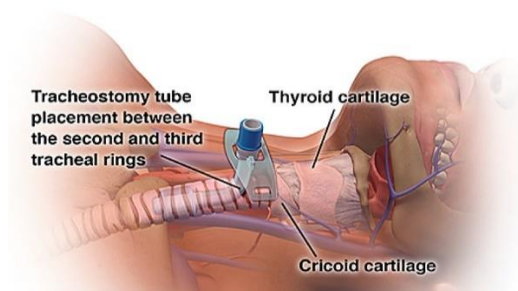


Figure 5.7: Tracheostomy [32]

- **Incubator** (Figure 5.8)



Figure 5.8: Oxygen incubator

### 5.11 Important Considerations for Oxygen Therapy

- Supplemental oxygen relieves hypoxaemia but does not improve ventilation or treat the underlying cause of the hypoxaemia. Monitoring of  $\text{SpO}_2$  indicates oxygenation not ventilation. Therefore, beware the use of high  $\text{FiO}_2$  in the presence of reduced minute ventilation.
- Many children in the recovery phase of acute respiratory illnesses are characterised by ventilation/perfusion mismatch (e.g., asthma, bronchiolitis, and pneumonia) and can be managed with  $\text{SpO}_2$  in the low 90's as long as they are clinically improving, feeding well and don't have obvious respiratory distress.
- Normal  $\text{SpO}_2$  values may be found despite rising blood carbon dioxide levels (hypercapnia). High oxygen concentrations have the potential to mask signs and symptoms of hypercapnia.
- Oxygen therapy should be closely monitored & assessed at regular intervals. Therapeutic procedures & handling may increase the child's oxygen consumption & lead to worsening hypoxaemia.
- Children with cyanotic congenital heart disease normally have  $\text{SpO}_2$  between 60%- 90% in room air. Increasing  $\text{SpO}_2 > 90\%$  with supplemental oxygen is not recommended due to risk of over circulation to the pulmonary system while adversely decreasing systemic circulation. However, in emergency situations with increasing cyanosis supplemental oxygen should be administered to maintain their normal level of  $\text{SpO}_2$ .

### 5.12 Potential Complications of Oxygen Use

- **$\text{CO}_2$  Narcosis** - This occurs in patients who have chronic respiratory obstruction or respiratory insufficiency which results in hypercapnia (i.e., raised  $\text{PaCO}_2$ ). In these patients the respiratory centre relies on hypoxaemia to maintain adequate ventilation. If these patients are given oxygen this can reduce their respiratory drive, causing respiratory depression and a further rise in  $\text{PaCO}_2$ .
- **Pulmonary Atelectasis** - Complete or partial collapse of the entire lung or area (lobe) of the lung

- **Pulmonary oxygen toxicity** - High concentrations of oxygen (>60%) may damage the alveolar membrane when inhaled for more than 48 hours resulting in pathological lung changes.
- **Retinopathy of Prematurity (ROP)** - An alteration of the normal retinal vascular development, mainly affecting premature neonates (<32-week gestation or 1250g birthweight), which can lead to visual impairment and blindness.
- **Substernal pain-due** - characterised by difficulty in breathing and pain within the chest, occurring when breathing elevated pressures of oxygen for extended periods.

Monitoring of SpO<sub>2</sub> or SaO<sub>2</sub> informs of oxygenation only. Therefore, beware of the use of high FiO<sub>2</sub> in the presence of reduced minute ventilation.

### 5.13 Oxygen Safety

Oxygen is not a flammable gas, but it does support combustion (rapid burning). Due to this the following rules should be followed:

- Do not smoke in the vicinity of oxygen equipment.
- Do not use aerosol sprays in the same room as the oxygen equipment.
- Turn off oxygen immediately when not in use. Oxygen is heavier than air and will pool in fabric making the material more flammable. Therefore, never leave the nasal prongs or mask under or on bed coverings or cushions whilst the oxygen is being supplied.
- Oxygen cylinders should be secured safely to avoid injury.
- Do not store oxygen cylinders in hot places.
- Keep the oxygen equipment out of reach of children.
- Do not use any petroleum products or petroleum by-products e.g., petroleum jelly/Vaseline whilst using oxygen [12].

Please find below additional requirements for warnings and safety notices:

- “**WARNING:** There is a risk of fire associated with oxygen enrichment during oxygen therapy. Do not use the oxygen concentrator or accessories near sparks or open flames.”
- “**WARNING:** Use only water-based lotions or salves that are oxygen-compatible before and during oxygen therapy. Never use petroleum or oil-based lotions or salves to avoid the risk of fire and burns”.
- “**WARNING:** Do not lubricate fittings, connections, tubing, or other accessories of the oxygen concentrator to avoid the risk of fire and burns.”
- “**WARNING:** Use only spare parts recommended by the manufacturer to ensure proper function and to avoid the risk of fire and burns.”
- “**WARNING:** Oxygen makes it easier for a fire to start and spread. Do not leave the nasal cannula or mask on bed coverings or chair cushions, if the oxygen concentrator is turned on, but not in use; the oxygen will make the materials flammable. Turn the oxygen concentrator off when not in use to prevent oxygen enrichment.”
- “**WARNING:** Smoking during oxygen therapy is dangerous and is likely to result in facial burns or death. Do not allow smoking within the same room where the oxygen concentrator or any oxygen carrying accessories are located.
- If you intend to smoke, you must always turn the oxygen concentrator off, remove the cannula and leave the room where either the cannula or mask or the oxygen concentrator

is located. If unable to leave the room, you must wait 10 minutes after you have turned the oxygen concentrator off and thoroughly ventilate the room before smoking.”

- “No smoking” signs wherever oxygen is used and not to allow an open flame or a cigarette anywhere within 3 m of an oxygen source.

### **5.14 Further Readings**

More information on use of oxygen in acute COPD, acute asthma, pneumonia, pulmonary embolus, trauma, heart failure, myocardial infarction and unstable coronary artery syndrome can be found in the UK BTS guideline for oxygen use in adults in healthcare and emergency settings [7]. Moreover, the use of oxygen in COVID-19 can be found at National Centre for Disease Control (NCDC) guidelines on clinical management of severe acute respiratory illness (SARI) in suspect/confirmed novel coronavirus (nCoV) cases [30].



## 6. Summary of Oxygen Therapy

Oxygen is a drug and hence should be prescribed, administered (rational use) and monitored by trained staff. In life-threatening situations, high-flow oxygen via a reservoir (non-rebreather) bag should be given immediately, without a prescription, but subsequent documentation should take place. In all other situations, oxygen should be prescribed by a doctor, on a designated document (usually the drug chart) and signed for at each drug round by trained staff.

Guidelines advocate that oxygen is prescribed with a target saturation range, initial delivery device and flow rate and is regularly reviewed by oximetry. Increasing oxygen requirement, decreasing saturation or increasing respiratory rate may herald patient deterioration and should prompt rapid medical assessment. As oxygen requirements decrease, supplemental oxygen can be titrated downwards and eventually discontinued, but the prescription for an oxygen target range should remain active in case the patient deteriorates again. In conditions where there is risk of T2RF, Venturi masks are the delivery device of choice as constant or known oxygen concentrations are administered, regardless of flow [11,12].

Evidence and guidelines exist for case management but are not always followed by health care workers. Electronic clinical decision support algorithms (CDSAs) can help organize patient information and symptoms through digital applications and connect that information to the relevant Integrated Management of Childhood Illness guidelines. CDSAs can promote adherence to guidelines, strengthen their implementation, and help enhance health care workers' ability to accurately manage sick children. PATH, with support from Unitaids, and in partnership with the Swiss Tropical and Public Health Institute, is implementing a new initiative to improve accurate screening and diagnosis of illness in children under five LMICs [36].

Please find the summary points below:

- Oxygen therapy does not relieve breathlessness in the absence of hypoxaemia. For example, there is no clinical benefit with short burst oxygen therapy in COPD patients with breathlessness, or with the use of oxygen over room air via nasal cannulae for patients with COPD who do not have severe resting hypoxaemia. Similarly, there is no additional symptomatic benefit in the use of daily oxygen over room air via nasal cannulae for refractory breathlessness in the palliative setting.

In the absence of hypoxaemia, oxygen therapy is not indicated in the treatment of acute coronary syndrome or stroke, conditions associated with reversible ischaemia. In myocardial infarction, high concentration oxygen therapy is associated with greater infarct size, when compared with room air or titrated oxygen therapy if required to avoid hypoxaemia. In stroke, routine administration of continuous or nocturnal oxygen therapy does not improve outcomes.

- Hypoxaemia is both a marker of risk of a poor outcome due to the severity of the underlying disease(s) that has caused hypoxaemia, and an independent risk factor of poor outcome. The clinical impact depends on the underlying cause(s), the speed of onset and severity of hypoxaemia, the age of the patient, and associated comorbidities. It has been proposed that a  $\text{PaO}_2$  of 50mmHg (6.6 kPa) can be considered as the safe lower limit of hypoxaemia in patients with COPD, and that oxygen therapy which achieves a  $\text{PaO}_2$  of at least 50 mmHg would prevent immediate death from hypoxaemia.

- The potential risks due to hyperoxaemia with high concentration oxygen therapy include respiratory (increased  $\text{PaCO}_2$ , absorption atelectasis and direct pulmonary toxicity), cardiovascular (increased systemic vascular resistance and blood pressure, reduced coronary artery blood flow, reduced cardiac output), cerebrovascular (reduced cerebral blood flow) effects, and increased reperfusion injury due to increased reactive oxygen species.
- The physiological response of an increase in  $\text{PaCO}_2$  due to high concentration oxygen therapy has been demonstrated not only in stable and acute exacerbations of COPD, but also in severe asthma, community-acquired pneumonia and obesity hypoventilation syndrome. Proposed mechanisms for oxygen induced hypercapnia include increased ventilation perfusion mismatch due to reduced hypoxic pulmonary vasoconstriction, reduced ventilatory drive, atelectasis and the Haldane effect, with the contribution of each likely to depend on the clinical situation.
- There is variable accuracy of pulse oximetry to predict  $\text{SaO}_2$  in acutely ill patients, with  $\text{SpO}_2$  measurements both over and under estimating  $\text{SaO}_2$ , with wide limits of agreement. Clinicians need to be aware of the variable accuracy of  $\text{SpO}_2$  in the utilisation of pulse oximetry in clinical practice. Factors that might affect the accuracy of pulse oximetry include severe hypoxaemia, carboxyhaemoglobin and methaemoglobin levels, anaemia, dark skin, low perfusion, excessive ambient light and nail polish.
- The use of high flow oxygen in an attempt to protect against subsequent hypoxaemia in the event of deterioration has the potential to delay the recognition of such a deterioration. This may provide a false reassurance that the patient is stable. There is likely to be no major change in vital signs or a marked decrease in  $\text{SpO}_2$  as assessed by pulse oximetry until a potentially life-threatening situation has developed. At this stage there is limited opportunity to further increase the oxygen therapy while medical review and an intervention such as transfer to an HDU or ICU is undertaken.

Similarly, if a patient who requires a high  $\text{FiO}_2$  to maintain adequate  $\text{SpO}_2$  deteriorates there is limited capacity to increase  $\text{FiO}_2$  to avoid life threatening hypoxaemia. For this reason, it is recommended that patients who need an  $\text{FiO}_2 > 0.40$ , such as  $> 6$  LPM via a simple face mask, to maintain an adequate  $\text{SpO}_2$ , should receive senior clinician review and may require transfer to a ward area, such as an HDU. Likewise, patients who need an  $\text{FiO}_2 > 0.50$ , such as  $> 8$  LPM via a simple face mask, to maintain an adequate  $\text{SpO}_2$ , should receive ICU review as most will require ICU transfer.

- Peripheral venous blood gas analysis is a less invasive test than an ABG, however it does not provide an accurate estimate of  $\text{PaCO}_2$  or  $\text{PaO}_2$ . It does, however, provide rapid clinically important information to assess acutely unwell patients, including pH, lactate, glucose, haemoglobin, sodium and potassium. In addition, it provides a  $\text{PCO}_2$  which, if less than  $< 40\text{mmHg}$ , essentially rules out hypercapnia.
- A target  $\text{SpO}_2$  range of 88-92% is recommended in the treatment of COPD and other conditions associated with chronic respiratory failure due to demonstration of:
  - A greater than two-fold reduction in mortality with pre-hospital oxygen therapy titrated to this target, compared with high concentration oxygen therapy in patients with an acute exacerbation of COPD.

- An increase in  $\text{PaCO}_2$  with 100% oxygen therapy in patients with chronic respiratory failure due to obesity hypoventilation syndrome.
- A general target  $\text{SpO}_2$  range of 92-96% in acute medical conditions has been recommended, incorporating a lower range than that recommended in the BTS guidelines (94-98%). This lower target recognises that:
  - An  $\text{SpO}_2$  of >92% is a practical lower threshold to rule out hypoxaemia, defined as an  $\text{SaO}_2$  <90% or a  $\text{PaO}_2$  <60mmHg (8 kPa).
  - There is no known risk of hypoxic tissue injury at an  $\text{SaO}_2$  of 90%.
  - Older healthy subjects have  $\text{SaO}_2$  levels to this lower level of 90%.
  - Healthy subjects have a mean nadir  $\text{SpO}_2$  of around 90% during sleep.
  - Subjects with sleep disordered breathing commonly tolerate  $\text{SpO}_2$  levels between 80 and 90% for prolonged periods.
  - Adults with comorbidities tolerate  $\text{SpO}_2$  levels between 80 and 90% during long distance travel.
  - Guidelines for acute coronary syndrome and heart failure recommend administration of oxygen if the  $\text{SpO}_2$  is <93% and <90%, respectively.
  - In adults with coronary artery disease, anaerobic metabolism indicative of myocardial ischaemia is observed in some patients with  $\text{SaO}_2$  between 70 and 85%, suggesting a 'safe' lower limit of oxygen saturation of 90%.
  - There is an evidence-base for titration of oxygen therapy to a target  $\text{SpO}_2$  range of 93 to 95% in acute severe asthma and community-acquired pneumonia.
  - There is an evidence-base for the safety of oxygen therapy to a target  $\text{SpO}_2$  range of 88 to 92% in acute exacerbations of COPD.
  - This recommendation is likely to reduce excessive use of high concentration oxygen therapy.
  - An upper level of 96% avoids the potential risks of hyperoxia and allows for patient improvement to be recognised earlier during monitoring, so that oxygen can be down titrated.
- A target  $\text{SpO}_2$  range of 85% is recommended in patients with prior exposure to bleomycin or in paraquat poisoning is due to the demonstration of:
  - Potentiation of lung injury by oxygen
  - Lack of harm from hypoxaemia with saturations around 85% in these clinical situations
- The potential advantages of nasal cannulae as an initial method of delivering oxygen therapy are:
  - Ability to give nebulised bronchodilator at the same time as oxygen is administered.
  - Oxygen can be prescribed by variable flows to achieve a target saturation range rather than a fixed  $\text{FiO}_2$ , although oxygenation may be maintained better with Venturi mask.
  - Comfort, ease of use and low cost.
  - Less likely to be taken off to eat or speak, and less likely to fall off.
  - No risk of rebreathing of carbon dioxide.
- Humidified High Flow Nasal Cannulae are an alternative to standard low flow nasal cannulae or high flow masks for oxygen delivery. There are no established evidence-based recommendations to guide appropriate clinical use in adults, however currently

some centres recommend HFNC only in the ED, HDU or ICU. The potential benefits, demonstrated mostly from observational studies, of this delivery system include:

- Greater comfort and tolerance via delivery of warmed and humidified nasal oxygen, compared with delivery via a face mask
- Better titration of  $\text{FiO}_2$  across a wider range of  $\text{FiO}_2$ s
- Preservation of upper airways function, such as speech, swallowing and cough

Potential disadvantages of HFNC include:

- Risk of complacency if a high  $\text{FiO}_2$  requirement is not recognised to represent life-threatening illness requiring more than correction of hypoxaemia
- Role in severe exacerbations of COPD and asthma has not been investigated [14]

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## **PART B: Hospital Fire-Safety Guidelines**

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## 7. Basics of Electrical Safety

Electrical equipment if misused or poorly maintained, can be the cause of injury, death, or fire. If they are well maintained, electrical equipment can save lives, improve the quality of lives, and reduce capital expenditure. Electrical equipment and the electrical connections that supply power to it should always therefore be treated with care.

Careful consideration should always be given to the placing of equipment. Damp conditions should be avoided, and equipment should be positioned in a dry, clean, well ventilated area on a solid, level base. Equipment should be as near as possible to the electrical supply and the use of extension leads should be discouraged.

Since most fires occur with the plugs, sockets and cables supplying electrical power, this chapter mainly focuses on safe use and maintenance of these [34].

### 7.1 Socket Outlets and Plugs

- A convenient and safe socket outlet should be available (Figure 7.1).
- Socket outlets should be at least 2 m from a sink or wash basin.
- The socket outlet should be adequate for the electrical capacity for the equipment.
- There should be proper grounding in the sockets.
- Plugs should match the socket outlets [34].



Figure 7.1: Socket outlets and plugs [34]

### 7.2 Wiring of Sockets and Plugs

The wiring of a plug is colour coded to help guard against electrical accidents. The colour codes in India as per Indian Electricity Rules are as follows:

- Phase (or Live) Red, Blue or Yellow  
This carries the electrical drive current from the supplier to the equipment. It is the most dangerous line. Only qualified staff should work with this.
- Neutral - Black  
This returns the current to the supplier. It should not be connected to Earth.
- Earth (or Ground) - Green OR Green with Yellow lines  
This is used for safety and protection. If equipment is housed in a metal case, the earth line will generally be connected to the case. The earth line in a socket is connected to a pipe or plate buried in the ground.

Notes on earthing:

- The earthing will depend upon the type of equipment being used:
  - If there are only two wires in the power cable, no earth connection is required.
  - If the cable fitted has three conductors then equipment needs to be earthed properly.
- Always make sure that the earth wire is longer than the other two so that if the cable is accidentally pulled out of the plug, the earth wire is the last wire to become disconnected [34].

### 7.3 Sizes and Types of Sockets and Plugs

The current rating (i.e. the amount and size of equipment they can supply) is measured in Amperes, written 'A'. The rating and size of normally found plugs and sockets are:

- For low power operations - 5 Amperes - small size
- For large power applications - 15 Amperes - large size

Mains electricity comes at a specified voltage and is measured in Volts, written 'V'. The voltage in India is 220 - 240 V for single phase and 440 V for three phase operations. It also is delivered at a specific frequency, measured in Hertz, written 'Hz'. Mains electricity in India is at 50 Hz.

A variety of electrical plugs are found throughout India, so an adaptor plug set is recommended. Type D is most common (Figure 7.2), which is also known as the Old British Plug. It has three large round pins in a triangular configuration.



Figure 7.2: Type D plug and socket (left) and Type C plug and socket (right) [34]

The type C European 2-pin plug and electrical outlet is also very popular connector for common medical equipment which does not require earthing. Popularly known as the Europlug, it is used throughout continental Europe, parts of the Middle East, much of Africa, South America, central Asia, and the former Soviet republics [34].

### 7.4 Mains Cables

Electricity is carried to the equipment through the mains cable. Points to be aware of are:

- No bare metal or internal coloured wire should be visible - the plastic insulation is there for safety.
- Cable should not be repaired with insulating tape - water can still get inside.
- Long flexible leads are dangerous - leads should be as short as possible.

- The cable, plug and socket should never be allowed to get wet water can conduct electricity [34].

## 7.5 Fuses

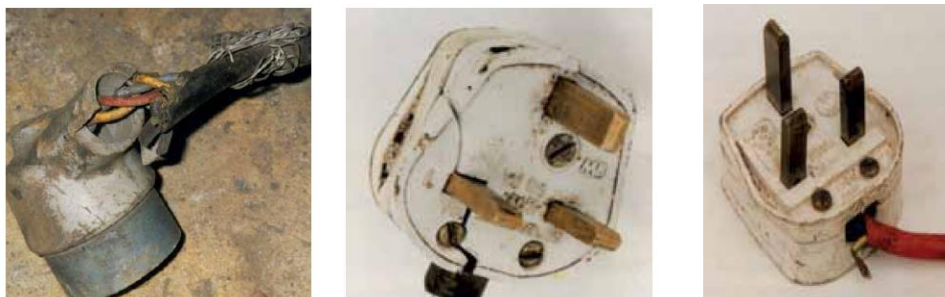
Fuses are used as protection. If the current through them is greater than their specified rating, they blow. This breaks the circuit and stops the current, making the equipment safe. Points of safety regarding fuses are:

- Always use the correct rating of fuse voltage V (volts) and current A (amperes).
- Always use the correct size of fuse - keep the old one to check against.
- NEVER replace the fuse with bare wire - it will not be safe.
- Circuit breakers are fuses that have buttons or switches for reset - they do not normally need replacing [34].

**Table 7.1: Trouble Shooting - Electrical Safety [34]**

Fault	Possible Cause	Solution
Equipment is not running	No power from mains socket	Check power switch is on. Replace fuse with correct voltage and current rating if blown. Check mains power is present at socket using equipment known to be working. Contact electrician for rewiring if power not present.
	Electrical cable fault	Try cable on another piece of equipment. Contact electrician for repair if required.
	Internal problem	Refer to biomedical technician
Fuse or circuit breaker blows a second time after replacement	Internal equipment fault	Refer to electrician or biomedical technician
Coloured or metal wire visible in cable, socket or plug	Insulation damaged	Remove item and refer to electrician for repair. DO NOT cover with tape.
Cracks visible in socket or plug	Damaged cover	Remove item and refer to electrician for repair. DO NOT cover with tape.
Electrical shocks	Wiring fault	Refer to electrician

## 7.6 Electrical Safety Issues



**Figure 7.3: Electrical safety issues. Damaged cable grip (left), cracked casing (centre) and damaged cable sheath (right) [34]**

## 7.7 Electrical Safety Weekly Checklist

Table 7.2: Electrical Safety Weekly Checklist [34]

Weekly Checklist	
Cleaning	<ul style="list-style-type: none"><li>• Clean dust and liquid off with a DRY cloth.</li><li>• Remove tape, oil and dirt from all cables, plugs and sockets.</li></ul>
Visual checks	<ul style="list-style-type: none"><li>• Remove any cracked connectors or cables from service.</li><li>• Check for and report any damaged room wiring or fittings.</li><li>• Check for and report any signs of burning, melting or sparks.</li><li>• Untangle all cables and store carefully.</li></ul>
Function checks	<ul style="list-style-type: none"><li>• Report any sockets that are loosely fitted or not working.</li><li>• Check for and report and broken fans or lights</li></ul>

## 7.8 Socket Testing

- Plug the Socket Tester (Figure 7.4) into a live socket and switch the socket on.
- Indicator lamps across the front of the unit provide a clear indication of a correctly wired socket.
- Fault indications are quickly identified using the label:
  - Line Neutral Reverse
  - No Earth
  - Neutral Fault
  - Live Earth Reverse
  - These devices will not detect Earth Neutral Reverse [34]



Figure 7.4: Socket tester [34]

## 8. Fire Safety in Hospitals

This section aims to address the vulnerability of hospitals to fires. All possible steps should be taken to minimize the hazard of fires in hospitals and to stress the need for evacuation. This chapter is divided into four main sections (Figure 8.1):

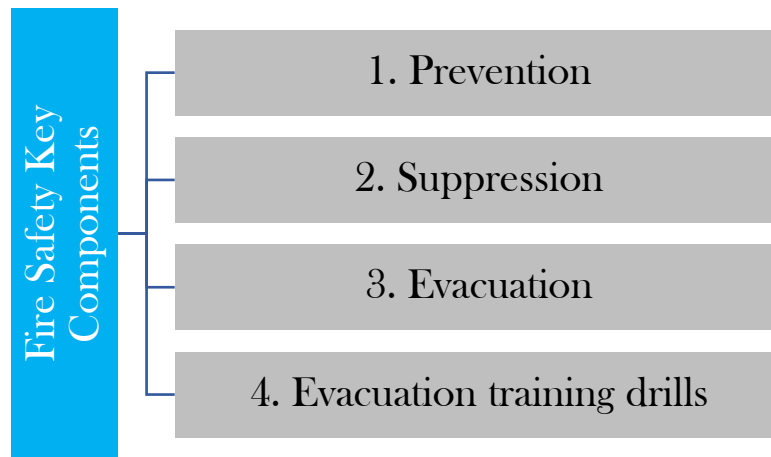


Figure 8.1: Key components of fire safety

The primary aim of a hospital facility should **not** be to evacuate patients unless absolutely necessary. Hence, special attention should be focused on proper prevention and suppression techniques to avoid this worst-case scenario. That being said, evacuation training and preparedness is of paramount importance to avoid and/or minimize loss of life. Please see the main causes of hospital fires in Figure 8.2.

One of the most critical considerations in fire safety is the prevention of fire. However, in the event of either accidental or malicious fires, suppression equipment needs to be readily accessible to combat these fires. Staff members of the health facility need to have working knowledge of how to use the equipment and to avoid panic.

The last resort, failing the ability to completely suppress the fire, is to evacuate the facility. Moving all patients, visitors, and staff out of dangerous and/or damaged facilities as safely as possible is always the goal of an evacuation. It is important to recognize that people's attention to detail and processes will not be optimal in an evacuation scenario. To that end, understanding key principles will help staff members make good decisions during a chaotic event.

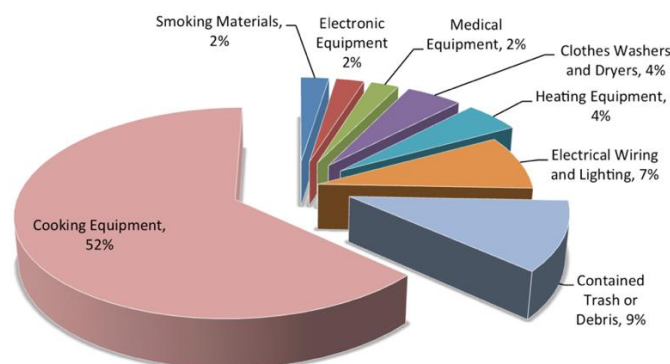


Figure 8.2: Main causes of hospital fires [16]

# In Case of Fire, Call 101 (it is toll free)!

*The initial steps to protect hospitals against fires are prevention and suppression.  
Complete evacuation of patients should be avoided unless absolutely necessary.*

## 8.1 Prevention

Fire can be prevented by using materials that are resistant to combustion or burning and avoiding materials that are highly flammable which require special care if they are to be used in a hospital. Using the right materials can limit the occurrence and magnitude of fires and also delay their spread in medical facilities.

The three main ingredients that constitute a fire: heat, fuel, and oxygen (Figure 8.3). Fires can be classified into 5 types:

- **Class A:** Fires that involve ordinary combustible materials such as wood, cloth, paper, rubber, and many plastics.
- **Class B:** Fires that involve flammable liquids, combustible liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols, and flammable gases.
- **Class C:** Fires that involve energized electrical equipment, such as power tools, wiring, fuse boxes, appliances, TVs, computers, and electrical motors.
- **Class D:** Fires that involve combustible metals such as magnesium, potassium, titanium, zirconium, lithium, and sodium.
- **Class K:** Fires that involve combustible cooking oils and fats used in commercial cooking equipment [16, 19, 20].



Figure 8.3: Ingredients of a fire [16]

## 8.2 Suppression

Fire suppression is critical to circumvent/minimize damage or the loss of property and life. The ability to quickly detect and extinguish fires is a key factor in avoiding the worst-case scenario, which is evacuation of the hospital.

### 8.2.1 Fire Alarms Systems

There are several ways in which fires can be detected. The traditional and obvious method of detection is a person seeing the fire and/or smelling smoke, at which point a fire alarm should be activated or a notification issued. In some cases, a designated “runner” relays the notification to others through word of mouth. In other instances, manual fire alarm pulls or manually

activated alarm-initiating devices are used to sound the fire alarm. Manual pull boxes should be located so that they are conspicuous, unobstructed, and accessible.

A variety of smoke and heat sensors can be installed as part of a fire alarm system to detect fires that begin in low-traffic areas away from personnel/staff. These sensors should ideally trigger an automatic alert system with visible (flashing lights/strobe lights) and audible bells or voice alerts to indicate that a fire was detected. Smoke detectors will generally detect a fire faster than heat detectors. There are three types of smoke detectors: ionized, photoelectric, and combined ionized/photoelectric. Ionized smoke detectors are relatively inexpensive, while photoelectric detectors tend to cost more [16, 20, 21, 22].

*A fire alarm system is established to (i) enhance the safety of building occupants and (ii) to minimise damage to the property.*

### 8.2.2 Fire Extinguishers



Fire extinguishers are labelled with standard symbols and letters representing the classes of fires that they are equipped to fight. Please find the types of fire extinguishers in Table 8.1. Adequate number of fire extinguishers should be available at key areas. They should be placed at appropriate height (4-5 feet) from floor level for easy access. Moreover, a list of fire extinguishers with location should be displayed in prominent places. They should also be labelled with the filling date and the next due date of re-filling.




#### How to use fire extinguishers:

The following are important considerations before you attempt to fight a fire:

- Make sure that everyone else is leaving the area, someone has sounded the alarm, and someone has called the fire department.
- Ensure that you have an unobstructed escape route at your back.
- Verify that the fire is small, confined, and not spreading.

Table 8.1: Types of fire extinguishers [16, 23]

Image	Type of fire extinguisher	Type of fire
	ABC Dry Chemical- monoammonium phosphate as an extinguishing agent	Class A, B, and C fires
	Carbon Dioxide (CO <sub>2</sub> )	Fires caused by flammable liquid or electrical fires

	Halon- uses a bromochlorodifluoromethane (halon 1211) as their extinguishing agent	Class B and C fires but are also effective in fighting Class A fires
	Dry Powder- a copper-based or sodium chloride-based powder.	Class D (metal) fires
	Class K Extinguisher- uses a wet-potassium-acetate-based, low-pH agent	Class K (grease) fires

- Make sure that you know what is burning and that you have the appropriate type of extinguisher to fight the fire.
- You are knowledgeable regarding the use of the extinguisher.
- Make sure that you keep your back to a clear exit and stand 2 to 3 meters (6 to 8 feet) away from the fire.
- Your safety is paramount; if the fire is out of control, leave the area immediately.

Fire wardens (or health and safety officers) and hospital staff should be trained on how to use fire suppression devices. Regular training sessions should be undertaken as part of the medical facility's scheduled safety and evacuation simulations.

The four steps in using a fire extinguisher can be remembered through a simple acronym: **PASS** (see Figure 8.4).

1. P - Pull the pin.
2. A - Aim the extinguisher at the base of the fire.
3. S - Squeeze the handle of the fire extinguisher.
4. S - Sweep from side-to-side at the base of the flame.



Figure 8.4: Using fire extinguishers - PASS [16, 23]

The minimum requirement, and the least expensive option, for a firefighting system is a fire alarm system with smoke detectors and a fire suppression system with fire extinguishers. There are other fire suppression devices that can be installed in a hospital to improve the facility's resilience to fire hazards. These include water sprinkler and mist sprinkler systems, water hose reels, and smoke extractors. However, all these systems need to resist earthquakes [16, 20, 22, 23, 24].

### 8.3 Evacuation

This is a crucial component of the aim to save lives in emergency situations in hospitals. A comprehensive evacuation plan needs to be in place that all staff members are aware of and are experienced in carrying out. This section presents the basic steps involved in the evacuation of a medical facility. It is important to note that there is no fixed methodology for evacuations; the procedure will vary for each individual health care facility.

**Code red alert system in hospital:** Code red is an emergency code which is used to alert employee and fire-fighting team in case a fire or possibility of fire is detected within the hospital premise. Unexpected fire is considered as an emergency and code red system is used to urgently activate a set of action intended to control the fire and prevent any major mishap. The system may slightly vary from hospital to hospital, depending upon how the hospital is structured and organized.

All employees are expected to know the 'Code Red' system and must adhere to the action plan and guidelines to be followed under this system. Employees are also expected to know the location of the nearby fire-extinguisher and emergency exit route to be used for the area where they work. A new employee in the hospital must be oriented to the code red system on first day of the work. Following system shall be used for Code Red.

**a. Code red alert activation:** Code red shall be activated by any employee of the hospital who detects or is informed about unexpected fire flames, smoke, smell of smoke, unusual heat, or any other indication of fire. The fire or fire like situation could be observed in any part of the hospital, including hospital's exteriors and terrace. Code red should be activated even if it is uncertain if the situation is caused because of fire or not.

For activating code red, the designated intercom number should be called from the nearest intercom device and 'Code Red' followed by the location details shall be spoken. For example, if the fire is observed in the hospital's main kitchen, the employee should call the intercom

number and say, 'Code Red alert - Hospital's main kitchen'. This should be repeated thrice in clear voice so that the receiver at the other end understands the code and location. The intercom line should be manned by a telephone operator round the clock, who has access to public announcement system. As soon as code red alert call is received, he/she immediately should use public announcement system to announce 'May I have your attention please. Code Red at .... area'. This activates code red system in hospital. The announcement shall be repeated 3 times initially in clear voice and then shall be repeated intermittently after that.

In-charge of central oxygen supply shall wait for instruction on whether Oxygen supply shall be closed to the area where fire is detected and do according to the instruction. He/she shall be available for any further instruction.

**b. Code red - All clear:** The fire-fighting team in-charge has the authority to declare if the situation has been tackled and is safe from fire. For this the in-charge should call back intercom number and say, 'Code Red - All Clear'. On getting this information, the operator then should announce the same on public announcement system. Employee on listening 'Code Red - All Clear' can assume that the fire emergency has been taken care of and they can resume back to their normal work.

The employees, patient, and visitors of the area where fire occurred shall be instructed, if the area can be used or not. Also, any patient or employee if injured during the incident shall immediately be taken to hospital's emergency for treatment.

**Fire exit routes:** A facility should have a minimum of two fire exit/exit routes on every floor. Each of the exit routes should be clearly marked and should be located as far away from each other as possible so that if one exit route is blocked with smoke or fire, the alternate route can be used. The fire exit routes signage should illuminate (radium coated) and be clearly visible at night and during power cuts. Moreover, evacuation maps should be posted at the hospital's main access points to clearly identify fire exit/exit routes. It is important to note that the evacuation may not necessarily involve patients and personnel exiting the building; they may be required to move to an upper floor [16].

Recall that evacuation procedures are undertaken only as a final resort action for the hospital. In the case of a fire, evacuation is performed once the preventative and suppression measures described earlier have failed to contain the fire and lives are under immediate threat. Evacuation of a health care facility may be required in a range of disasters, not only in the event of fires. Some of these disasters are natural (earthquakes, floods, fires, tsunamis), manmade (explosions, biological threats, chemical threats, radiological dispersions) and technological (oil spills, gas leaks) [16, 22, 25].

**Self-Contained Breathing Apparatus (SCBA):** A self-contained breathing apparatus (SCBA) is a device worn to provide breathable air in environments with oxygen deficiency, smoke, dangerous gases, and other airborne contaminants that may be otherwise dangerous to breathe. Workers handling hazardous materials or operating in contaminated zones are typically required to wear a self-contained breathing apparatus. Only positive-pressure SCBAs are recommended for entry into atmospheres that are immediately dangerous to life and health. It is essential for modern firefighting and today's complex fire grounds. An SCBA typically consists of a facemask with a hose that connects to an air source worn by the user. The air source can be a tank of compressed air, compressed oxygen, or an oxygen-generating chemical (Figure 8.5).

They are of two types:

- **Air Breathing Apparatus (Open-circuit):** It supplies the compressed air from the air cylinder to the wearer through cylinder valve, pressure reducer, pressure demand valve or demand valve. Exhaled air goes to the atmosphere through exhalation valve.
- **Oxygen Breathing Apparatus (Closed-circuit):** It supplies the compressed oxygen from the oxygen cylinder to the wearer through cylinder valve, pressure reducer, demand valve, etc. Carbon dioxide in exhaled air is absorbed by the absorbing canister, and oxygen is re-supplied through breathing bag. This mechanism enables for long time use.



Figure 8.5: Self-Contained Breathing Apparatus (SCBA)

### 8.3.1 At the Sound of the Fire Alarm

Once the fire alarm is triggered,

- Designated personnel to investigate the reason for the alarm and to identify the level of the threat (suppression or evacuation)
- Designated personnel to communicate with other hospital staff (through the hospital telephone operator or using any other means) and inform the sequence of events (if necessary)
- If there is a fire threat and the decision to evacuate is made, the designated personnel should notify the entire facility of the evacuation order using appropriate systems such as text messages, emails, loudspeakers, etc.
- Designated personnel should also notify external agencies such as the fire department, police department, etc. [16, 20].

### 8.3.2 Types of Evacuation

Time frames for evacuation may differ depending on the nature of the threat and the amount of time that can be taken to prepare for moving patients. Specific types of evacuations can be found in Figure 8.6.

The following actions may be needed when the “**prepare only**” instruction is issued:

- Ensure that fire exit doors are clear to allow movement of patients and equipment.
- Locate and secure patients’ medical records and medical supplies.
- Ready evacuation transport equipment such as wheelchairs, blankets, and gurneys
- Set in motion a system to move people to designated assembly points.
- Await further instructions; do not evacuate unless given the authorization to do so.

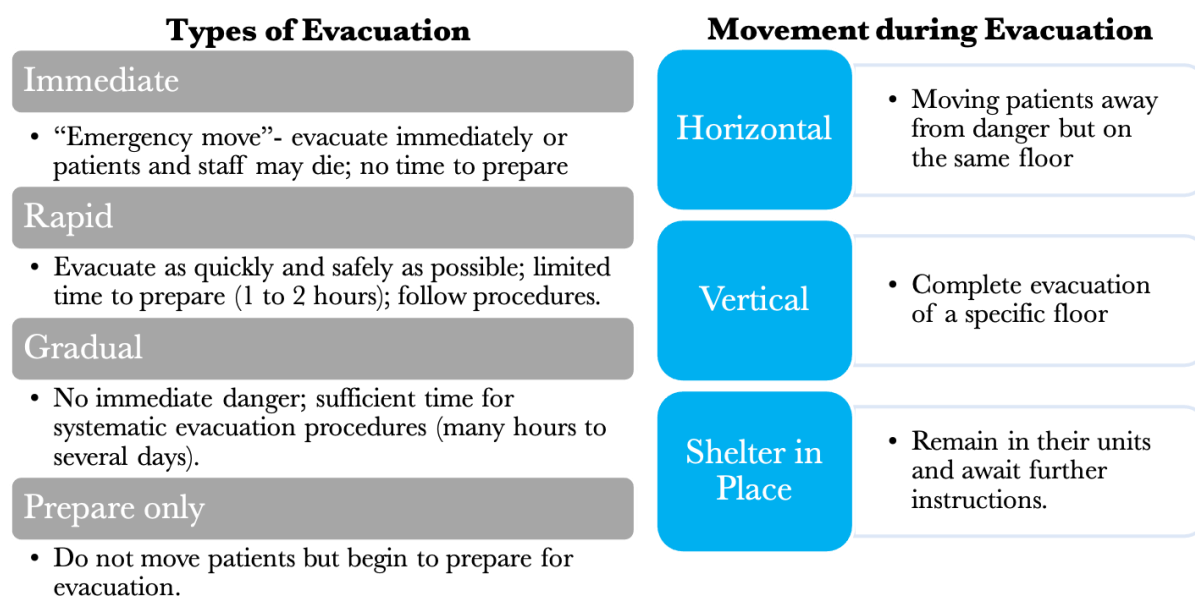


Figure 8.6: Types of evacuations and movement during evacuation [16]

Based on reports from the persons who detected and/or reported the fire situation, what type of evacuation is required should be determined: **Horizontal, Vertical or Shelter in Place**. See Figure 8.6 for more details.

The type of movement is dependent on the type of hazard; for instance, the fire may be on the floor below or the threat may be a tsunami, in which case the evacuation sequence will be to move upward. Moreover, the evacuation routes should be clearly established, and all hospital staff should have working knowledge of the evacuation routes and which one to take, based on the type of evacuation and as instructed by the designated personnel [16, 20].

### 8.3.3 Level of Evacuation

The level of evacuation can be one of the following:

- Complete evacuation
- Partial evacuation

In most emergencies, a full evacuation will **not** be required. Due to the complex needs and unstable condition of many hospital patients, evacuation is generally considered as a last resort. Evacuation should be ordered only when absolutely necessary and when there is an imminent or potential unmitigated threat to patient/staff safety.

### 8.3.4 Special Needs of Patients

It is important to identify the special needs of patients, some of whom may require additional attention:

- **Needs of Patients with Disabilities:** Patients who cannot hear or see or are under anaesthetics (unconscious) at the time of the evacuation may require special accommodations.
- **Medical Care and Equipment Needs:** Patients may require specific life support equipment (e.g., ventilators) that should accompany them when they evacuate. Specific

medications that patients need for treatment should also accompany them when they evacuate.

- **Emotional Support Needs:** Patients may require psychological support as a result of the stress of the disaster situation.

### 8.3.5 Patient Prioritization During Evacuation

Prioritizing patients with respect to the limited physical resources available for evacuation (e.g., personnel, elevators, stairwells, transport sleds) is among the most logistically and ethically challenging tasks involved in the evacuation of a hospital [16].

Table 8.2: Patient prioritisation (from high (top) to low (bottom)) [16]

1	1. Patients in immediate danger
2	2. Ambulatory patients
3	3. Patients in general care units requiring transport assistance
4	4. Patients in ICUs
5	5. Patients in the operating room (It is important to note that surgical procedures that have been initiated should be completed to a point of safety before the patient is moved. In the case of immediate danger, evacuate horizontally to a safe area to complete the surgery to a point of safety. Operating beds are movable).

#### Evacuation of patients on ventilator support or critical care patients

- Formation of Hospital and Transport agreements
  - Mutual-aid agreements should be established with other appropriately staffed and resourced hospitals to transport and redistribute critically ill and injured patients from an evacuating hospital(s), and these agreements should be integrated within the framework of disaster preparedness plans.
- Prepare for and Simulate Critical Care Evacuation
  - Staffing requirements and existing resources should be taken into both safely move patients and to provide continuous care for patients remaining in the ICU.
  - A detailed vertical evacuation plan using stair should be developed for critically ill and injured patients.
  - Regular simulation of mass critical care event which should include vertical evacuation that evaluates (1) patient movement using specialized evacuation equipment and (2) the ability to maintain effective respiratory and hemodynamic support while moving downstairs.
- Prepare for and Simulate Critical Care Transport
  - Pre-identify unique transport resources that are required for movement of specific populations, such as critically ill neonates, children, and technology-dependent patients, at a regional level. This information can then be used in real time to match allocated resources to patients.
  - Conduct detailed and realistic exercises that require ICU evacuation with local and regional ground and transport agencies.
- Designate a Critical Care Team Leader
  - A designated Critical Care Team Leader (CCTL) during an impending evacuation will provide close coordination and support of ICU evacuation preparations.

- When preparing for and during an ICU evacuation, a primary role of the CCTL should be to categorize each candidate ICU patient evacuee by (1) ICU resources required and (2) skill set of transport staff required.
  - CCTLs and staff should receive special training, education, and practice on patient categorization and transport requirements.
- Initiate Pre-Event ICU Evacuation Plan
  - If pre-event hospital evacuation of critically ill patients might be required, then we suggest planning for patient evacuation or shelter in place using an Incident Command System should begin as early as possible.
- Requesting Assistance for Evacuation
  - CCTL should be aware of the process for requesting evacuation assistance and the resources available at a regional and national level.
- Ensure Adequate Power and Transport Ventilation Equipment
  - Surge ventilators with flexible electrical power and oxygen requirements should be available to support patients with respiratory failure that can maintain function while either (1) sheltering in place or (2) evacuating to an outside facility. These ventilators should be portable, run on alternating current power with battery backup, and with the ability to run on low-flow oxygen without a high-pressure gas source. They should be safe (disconnect alarm) and relatively easy for staff to operate.
- Prioritizing Critical Care Patients for Evacuation
  - In a time-limited evacuation, less critical patients can be evacuated faster and with fewer resources per patient and, thus, may be moved first to evacuate the most patients in the fastest time.
  - When there is adequate time for evacuation, then more critically ill patients may be moved first and in parallel with less ill patients.
  - The most critically ill patients dependent on mechanical devices for life support may, in some conditions, be safely cared for with a shelter-in-place strategy if it is deemed the risk of evacuation is too high.
- Critical Care Patient Distribution
  - During ICU evacuations, CCTLs should coordinate with Hospital Incident Command and identify receiving hospitals for patient evacuation via the usual practice of provider-to-provider communication.
- Preparing the Critical Care Patient for Evacuation
  - Standardized preparation of critically ill patients should be performed prior to hospital-to-hospital transfer, including initial stabilization, diagnostic procedures, damage control procedures, and medical interventions, to address anticipated physiologic changes during transport.
- Sending Critical Care Patient Information with Patient
  - A paper (or electronic) medical record should be required to travel with the patient and should include basic patient identification, problem lists, and medications.
- Transporting Critical Care Patients to Receiving Hospitals
  - Transportation methods should prioritize moving the greatest number of patients as rapidly and safely as possible to locations with adequate capacity and expertise where definitive care can be provided.
  - Alteration in the usual standards for modes of transport may be required.
- Tracking Critical Care Patients and Equipment
  - Both evacuating and receiving hospitals should track patients and equipment [31].

### 8.3.6 Special hazards or concerns during fire outbreak

Several types of hazards may contribute to risks to the lives of staff and patients, as well as to property risks, in a hospital fire. A health care facility's evacuation procedure will be incomplete without due care and consideration given to these impediments.

Table 8.3: Special hazards and concerns associated with hospital fires [16]

Special hazards/concerns	Description
Oxygen	Procedures must be in place for turning off oxygen and other medical gases and equipment, which may contribute as fuel to the fire. Each operating room has a manifold to turn off medical gases. Staff should be aware of the location of this manifold and should turn it off once an evacuation is ordered.
Smoke/fumes	Fumes and smoke pose a high risk to life safety, and the evacuation procedure should incorporate a strategy to move people away from areas where these hazards are present.
Electrical equipment Lighting	Unplug electrical equipment. Ensure that there is adequate emergency lighting to perform the evacuation, as the electricity is normally switched off in a fire. Emergency lighting systems with capacitors that are activated when the power is switched off are commonly used.
Water	Medical equipment should be protected from water, which may damage essential machines. Also, exposed patients will become wet and cold and possibly quite sick; consider having plastic sheeting available to cover patients during an evacuation.

### 8.3.7 Evacuation transport equipment

In the event of an evacuation, it is essential to have enough transportation equipment available for patients which is easily accessible at all times. This equipment may include the following:

- Blankets
- Wheelchairs
- Beds
- Stretchers

### 8.3.8 Evacuation orders

Often, the decision of whether to evacuate is not immediately obvious and may require input from a variety of individuals. Therefore, a facility should have a team or an individual who can quickly weigh the risks of evacuation against the risks of sheltering in place. The authority to order a partial or full evacuation of the facility generally rests with the hospital's top administrator such as Civil Surgeons, BMOs, CMHOs, MOs or the designated incident commander.

Please find below some of the key decisions that must be quickly made and communicated:

- Level of evacuation: partial, complete
- Type of evacuation: immediate, rapid, gradual, prepare only
- Elevator or stairwell use
- Patient prioritization
- Activation of pre-planned evacuation components/personnel:
  - Assembly point and discharge site Locations
  - Evacuation/operations coordinator
  - Staff assignments

- Patient destination team(s)

It is imperative that the incident commander continuously assess the situation, as plans and activities may need to adapt to changes in the circumstances surrounding the evacuation [16].

### 8.3.9 Hospital incident command system structure

Please find below an example of the structure of incident command system in a hospital in Figure 8.7.

### 8.3.10 Patient tracking and medical records

There should be designated “patient tracking” staff who are responsible for tracking and reporting on the location of patients throughout the evacuation process to provide continuous accountability. These staff members (and their roles) include the following:

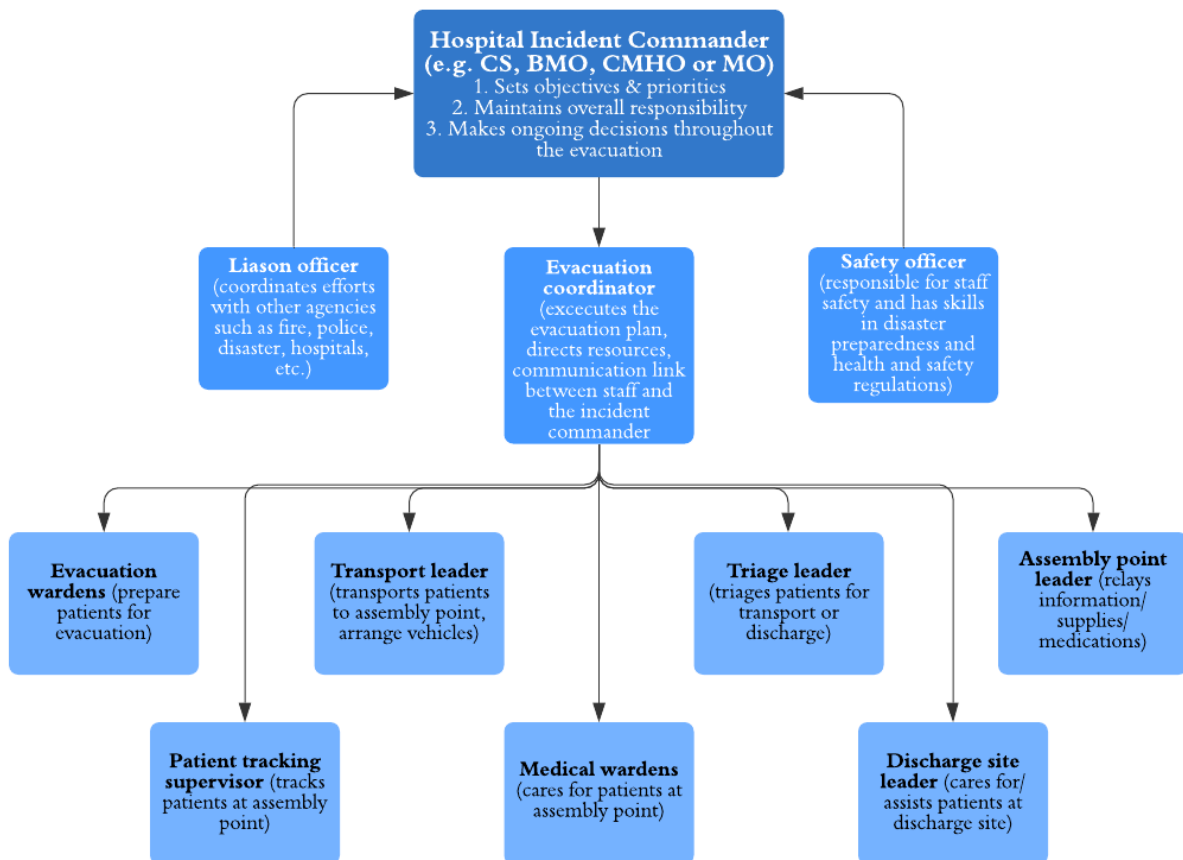


Figure 8.7: Structure of incident command system in a hospital [16]

- To perform head counts at the assembly points.
- To check rooms and floors to ensure that they have been vacated.
- To address special hazards or concerns (e.g., turning off medical gases).

If possible, ensure that medical records accompany patients when they evacuate the facility. Medical records are usually located on the wards with the patients. Medications and critical equipment for patients should be taken as well.

Designated personnel should also attempt to notify family members and other responsible parties about the patient's transfer destination. They should also answer calls and respond to questions from family members about the patient's welfare and location [16].

### 8.3.11 Assembly points and discharge site locations

The hospital should identify several locations surrounding the building that could be used as assembly points, holding areas, and/or discharge sites.

**Assembly Point/ Holding Area:** A place or set of places where patient care units gather (outside the main clinical buildings of the hospital) to receive basic care and await transfer or re-entry back into the hospital. Assembly points are not intended to be comprehensive field hospitals; rather, they should be designed as holding areas where only essential care resources are available.

**Discharge Site:** The place where patients who are being discharged home wait for family or friends to pick them up. Discharge sites should be located some distance away from assembly points to minimize traffic congestion and competition for roadways.

## 8.4 Evacuation Training Drills

Upon the sound of the fire alarm, it is expected that hospital staff will activate a practiced system or sequence of activities in response. Each health facility should have a unique system that has been tailored to meet its needs.

An evacuation/response plan should be discussed and developed by the hospital administration and the engineering and medical teams. The plan should include regularly scheduled training for all staff [16].

### 8.4.1 Training of staff

**General training** of all staff should include, but not be limited to, the following:

- Training on how to lift and move patients.
- Training on how to use fire extinguishers.
- Training on what to do if they see a fire. For example, the RACE (see Figure 8.8) acronym specifies actions to be taken in a fire:
  - R - remove anyone endangered by the fire to a safe area
  - A - activate the alarm
  - C - close all windows and doors; contain the fire
  - E - evacuate
- Training on what to do if they hear the alarm and see the flashing lights.

**Specific training** defines the roles and responsibilities of each staff member. For example, in the case of a fire alarm, who notifies the fire service and the rest of the hospital? [16, 23].

### 8.4.2 Fire drills

Fire drills are designed to ensure that, through regular training and simulations, staff members will:

- Have knowledge and understanding of the fire safety plan so that they can act swiftly, safely, and in an orderly manner.

- Be knowledgeable regarding fire protection. Frightened individuals cannot act sensibly and intelligently, and they may do things to harm themselves or those around them.
- Have increased self-confidence and power to fulfil their responsibilities in the event of a fire [16, 19, 21, 24, 25].

*It is important to note that all training simulations and fire drills need to be scheduled and performed regularly, and performance evaluations need to be completed and used to improve subsequent training drills.*



Figure 8.8: Steps to be taken in case of a fire – RACE [16]

## 8.5 Important Considerations for Fire Safety

- Statutory Compliance – Fire NOC should be obtained.
- Steps on how to operate fire extinguishers (section 7.2.2.) should be translated in local language and pasted close to the fire extinguishers in bold and easily readable text.
- Fire safety officer's designation at the facility level should be made mandatory.
- Periodic trainings and drills should be conducted on fire safety at least once a year and their record should be maintained.
- Any old electrical wirings and any loose hanging wirings should be replaced.
- Regular and timely audits should be conducted by fire safety officers and other experts in the field.
- Full evacuation of a hospital should generally be considered as a last resort when mitigation or other emergency response efforts are not expected to maintain a safe care environment.
- Safety is always the primary concern.
- Simplicity is key; the staff will need a simple plan to follow in an emergency.
- Flexibility is vital because the procedures must be adaptable to a variety of situations.
- Self-sufficiency at the unit level is important because timely communication from hospital leaders may be difficult or even impossible; employees at every level must know immediately what to do in their area.
- It may be necessary to evacuate patients to holding sites before transportation resources and/or receiving destinations are available. If the medical facility cannot accommodate a *horizontal safe site* (a location on the same floor safe from danger), then *assembly points* located away from the main clinical areas should be identified and designated.
- Individual patient care units should stay together at the assembly points whenever possible (instead of the patients in these units being divided into separate groups).

according to their ambulatory status). This is because the unit teams familiar with their patients will be better able to manage them in a chaotic situation away from the care unit.

- External patient transporters should generally not be asked to come into the hospital to evacuate patients because of the risks, time delays, and inefficiency associated with this process when large numbers of patients are involved.
- Fire detection system such as smoke or heat detector heads should be installed in the plantrooms, medical gases manifold rooms and (when internal) medical gases cylinder stores in any hospital. An automatic shutdown system, linked to local smoke detectors, can be installed. If such a system is planned, it is essential that an automatic emergency supply manifold system is sited well away from the fire-risk area and is arranged to come on-line automatically in the event of plant shutdown.
- When difficult choices must be made, leaders and staff must focus on the “greatest good for the greatest number” [16, 17, 18].

## 8.6 Potential High Fire Risk Departments

Table 8.4: Potential high fire risk department

S. No.	Name of the Department / Unit / Area in Hospital	Required Fire Fighting Equipment
1	X- ray	Smoke detector + Sprinkler + Fire Alarm
2	Kitchen	Smoke detector + Sprinkler + Fire Extinguisher + Fire Alarm
3	OT	Smoke detector + Sprinkler + Fire Alarm
4	Blood bank	Smoke detector + Fire Extinguisher + Fire Alarm
5	Labour room / ward	Smoke detector + Sprinkler + Fire Extinguisher + Fire Alarm
6	SNCU	Smoke detector + Sprinkler + Fire Alarm
7	Store + Pharmacy	Smoke detector + Sprinkler + Fire Extinguisher + Fire Alarm + Water hydrant

## 8.7 Important Fire Safety Warning Signs



Figure 8.9: Fire safety warning signs



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## Appendix A: Different conversion metrics for Oxygen [15]

### 1. To convert Oxygen (gaseous) from m<sup>3</sup> to Metric Ton (MT)

Oxygen's density in gaseous form has to be taken into consideration

$$\begin{aligned} 1 \text{ m}^3 \text{ of Oxygen} &= 1.429 \text{ kg} \\ &= 1.429/1000 \text{ MT} \\ &= 0.001429 \text{ MT} \end{aligned}$$

Therefore, to obtain the value in MT, multiply the m<sup>3</sup> value with 0.001429

### 2. To convert kL (Liquid Oxygen) to MT

#### a. Directly from Liquid Oxygen to MT

$$\begin{aligned} 1 \text{ Litre of Liquid Oxygen} &= 1.1417 \text{ kg} \\ 1 \text{ kilo Litre (kL)} &= 1141.7 \text{ kg} \end{aligned}$$

Therefore, 1 kilo Litre (kL) = 1.1417 MT

#### b. Liquid Oxygen to Gaseous Oxygen to MT

$$\begin{aligned} 1 \text{ Litre of Liquid Oxygen} &= 875 \text{ litres (gas)} \\ 1 \text{ kL} &= 875 \times 1000 = 8,75,000 \text{ L} \\ 1 \text{ litre} &= 0.001 \text{ m}^3 \\ 8,75,000 \text{ litres} &= 875 \text{ m}^3 \\ 1 \text{ m}^3 &= 1.429 \text{ kg} \\ 875 \text{ m}^3 &= 875 \times 1.429 = 1250.375 \text{ kg} = 1.25 \text{ MT} \end{aligned}$$

Therefore, 1 kL of liquid oxygen = 1.25 MT

### 3. Gas oxygen LPM to MT/day

$$\begin{aligned} 1 \text{ LPM to } 1 \text{ L/day} \\ 1 \text{ LPM} &= 1440 \text{ L/day} \\ 1 \text{ L of gas} &= 0.001429 \text{ kg} \\ \text{Weight (kg) per day} &= 1440 \times 0.001429 = 2.05 \text{ kg/day} = 0.00205 \text{ MT/day} \end{aligned}$$

Therefore, 1 LPM = 0.00205 MT/day

### 4. 1 cu ft of Oxygen = 0.03756 kg = 0.02628 m<sup>3</sup>

### 5. Conversion reference

Capacity (in m <sup>3</sup> /h)	Capacity (m <sup>3</sup> /day)	Capacity (MT/day)	Capacity (Jumbo cylinders/day)	Capacity (LPM)
5	120	0.17	17.14	83.74
15	360	0.52	51.43	251.23
30	720	1.03	102.86	502.45
60	1440	2.06	205.71	1004.91
100	2400	3.43	342.86	1674.85

Conversions to Jumbo Cylinders (JC)/ day	
1 m <sup>3</sup> /hour	3.43 JC/day
1 MT/day	101 JC/day
1 Litre per Minute (LPM)	0.20 JC/day

## **Appendix B:** Calculating oxygen consumption in a hospital.

This calculation methodology is in-line with the prevalent government of India guidelines on clinical treatment of hypoxemia cases in COVID-19. Treatment guidelines are evolved depending upon the clinical evidence. Hence, the oxygen flowrates should be updated based on the latest directives from MoHFW, India.

### **Mild patients**

(No. of Oxygen supported beds occupied x 10 LPM x 60 x 24)/7000 = jumbo cylinders per day

### **Severe patients**

(No. of ICU supported beds occupied x 24 LPM x 60 x 24)/7000 = jumbo cylinders per day

Please note that the % of beds may vary. For instance, to calculate oxygen consumption, only 50% of oxygen supported beds may be taken into account.

Please note that the flow rates that were used for mild and severe patients in the past were 7.14 LPM and 11.9 LPM, respectively.

## **Appendix C:** Checklist for monitoring of oxygen supply system in health care facilities

To ensure safe and reliable MGPSs and their efficient operation and use as per standards, responsible operational management and maintenance of following systems must be considered:

- Medical Oxygen System - Liquid oxygen system, manifold, and control panels
- Nitrous Oxide System - Manifold and control panel
- Medical and Surgical Air System - Compressor systems, control panel, dryers, reservoirs, filters, etc.
- Medical Vacuum System- Vacuum pumps, control panel, reservoir, filters, etc.
- Waste Anaesthetic Gas Scavenging Systems (AGSS)
- Carbon dioxide Manifold System
- Nitrogen Manifold System
- Copper pipelines
- Area Valve Service Units
- Isolation Valves
- Area Alarm panels and Master alarm panels
- Gas Outlets
- Bed Head Panels
- Pendants

Staff responsible for plant operation should be aware of the activities necessary to ensure the continued safe operation of the system and what action should be taken in an emergency. The authorised person should take a lead in explaining to users the function of the system and will have to be adequately trained and informed about the system. Operator will be responsible for safe cylinder handling, storage, and transportation. Any work involving alterations, extensions or maintenance work on the system should be subject to the permit-to-work procedure as per standards.

### **Operation of Medical Gas**

Manpower should be provided to operate the oxygen system 365 days in a year. The duty of the worker should be limited to 8 hours per day. The operators should ensure a trouble-free supply at the outlets at the required pressure. They should monitor the consumption of O<sub>2</sub> & N<sub>2</sub>O on hourly basis and submit a consolidated report weekly. Timely intimation of cylinder refills due date, timely intimation of oxygen LMO tank refill due date based on consumption, and other service maintenance must be done by the operator.

The operator should be fully aware of the safety regulation applied to medical gas system. It is the mandatory responsibility of the facility to conduct training sessions of adequate level to the workforce to keep them fit for handling the oxygen systems. All tests to be conducted by authorized persons, competent persons, quality controller etc. must be arranged additionally as required.

S. No.	Designation	Shift 1 (6am-2pm)	Shift 2 (2-10pm)	Shift 3 (10pm-6am)	General shift (8am-4pm)	Leave Substitutes	Total
1	Supervisor (Diploma in Mechanical/ Electrical) with 5-year experience in installation maintenance & operation of MGPS				1		1
2	Medical Gas (Technicians (ITI)) with 2-year experience in installation maintenance & operation of MGPS	1	1	1		1	3
3	Helpers (8th Standard or more) with minimum 6-year experience in installation, maintenance & operation of MGPS	2	2	2			6

Daily Checklist			
S. No.	System	Activity	Performed (Yes/No)
1	Oxygen Plant/Tank	Inspected oxygen pressure and liquid level	
		Entered details in the log	
		Inspected for leakages	
		Inspected at the change over	
		Intimated the preventive maintenance one week ahead of the schedule	
		Supervised maintenance jobs and checking reports	
2	Manifold (Oxygen and Nitrous oxide)	Inspected operation	
		Inspected for leakages	
		Inspected inlet and outlet pressure	
		Inspected at the change over	
		Loaded the cylinders as required	
		Replaced defective parts	
		Notified breakdown	
		Logged details	
3	Compressed Air	Inspected at the change over	
		Inspected pressure	
		Inspected dryer	
		Inspected receiver	
		Inspected filter	
4	Medical Vacuum System	Inspected vacuum pump	
		Inspected vacuum level	
		Inspected controls	
		Inspected at change over	
		Inspected for drop in vacuum level	
		Inspected filters	
5	Medical Gas Pipelines	Inspected for leakages	
		Inspected isolation valves	
		Inspected vacuum lines for any blockages	
		Inspected alarms	
		Replaced leaking lines	
6	Bed head panels, gas outlets, pendants	Inspected for leakages	
		Inspected for defective valves	
		Replaced defective valves	

## **Appendix D: Safety considerations for liquid oxygen [35]**

### **Oxygen Storage Tanks in Hospitals:**

- Oxygen Storage Tanks should be installed away from public places such as hotels/residential areas/ other ignition sources, etc. where there is the presence of naked flames, which might lead to an explosion in case of a gas leak.
- There should be safe barricading for oxygen storage plants as prescribed by the SMPV (U) rules [Static and Mobile Pressure Vessels (Unfired) rules].
- There should be no unauthorized entries into the plant premises and smoking should be prohibited in its vicinity.
- The necessary hydro-testing to be done as prescribed legally and certificates to be available at site.
- Use of Pressure Vessels of a capacity beyond one kilolitre should be with appropriate license issued by the authority competent (PESO).

### **Hazards Associated with Liquid Oxygen:**

- Exposure to cold temperature of the cryogenic liquid that can cause severe burns.
- Oxygen enrichment of the surrounding atmosphere; and the possibility of a combustion reaction if the oxygen is permitted to contact a non-compatible material.
- It can cause many materials of construction to lose their strength and become brittle enough to shatter.
- It is important to note that fire chemistry starts to change when the concentration of oxygen increases. Materials easily ignited in air not only become more susceptible to ignition but also burn with added violence / strength / vigour in the presence of Oxygen.
- Elevated oxygen levels can be reached very quickly, and all personnel must be aware of the hazard.
- Any clothing that has been splashed or soaked with liquid oxygen or exposed to high oxygen concentrations should be removed immediately and aired for at least an hour. Personnel should stay in a well-ventilated area and avoid any source of ignition until their clothing is completely free of any excess oxygen. Clothing saturated with oxygen is readily ignitable and will burn vigorously.
- Do not permit smoking or open flames in any areas where liquid oxygen is stored or handled.
- Do not permit liquid oxygen or oxygen-enriched air to come in contact with organic materials or flammable or combustible substances of any kind. Some of the organic materials that can react violently with oxygen when ignited by a spark or even a mechanical shock are oil, grease, asphalt, kerosene, cloth, tar, and dirt that may contain oil or grease. Sanitizers (especially alcohol based), surgical spirit, etc. can also add fuel to fire in a hospital setting where the atmosphere is Oxygen rich.
- If liquid oxygen spills on asphalt or other surfaces contaminated with combustibles, do not walk on or roll equipment over the area of the spill. Keep sources of ignition away for 30 minutes after all frost or fog has disappeared.
- Systems used in oxygen service must meet stringent cleaning requirements to eliminate any incompatible contaminants.

### **Storage of Liquid Oxygen:**

- Store and use liquid containers with adequate ventilation. Do not store containers in a confined area or in an area unprotected from the extremes of weather.

- Cryogenic containers are equipped with pressure relief devices designed to control the internal pressure. Under normal conditions these containers will periodically vent product. Do not plug, remove or tamper with any pressure relief device.
- Oxygen must be separated from flammables and combustibles by at least 20 feet or a half-hour fire wall. Post “No Smoking” and “No Open Flames” signs.

#### **Handling of Liquid Oxygen:**

- Cryogenic containers must be stored, handled and transported in the upright position. When moving, never tip, slide or roll containers on their side. Use a suitable hand truck for moving smaller containers. Move larger containers by pushing, not pulling. Avoid mechanical and thermal shocks.
- Never allow any unprotected part of the body to come in contact with uninsulated pipes or equipment containing cryogenic product. The extreme cold will cause flesh to stick fast and potentially tear on withdrawal.
- Use only oxygen-compatible materials and lubricants.
- If there is any difficulty in operating the container valve or container connections, discontinue use and contact the vendor. Do not remove or interchange connections. Use only the properly assigned connections.
- Use only transfer lines and equipment designed for use with cryogenic liquids. Some elastomers and metals, such as carbon steel, may become brittle at extremely low temperatures and may easily fracture. These materials must be avoided in cryogenic service.
- It is recommended that all vents be piped to the exterior of the building.
- When liquid oxygen is held in any closed vessel or space, there must be an appropriate pressure relief device because of the very large pressure increase that can occur as the liquid oxygen vaporizes. Liquid oxygen must also be handled with all the precautions required for safety with any cryogenic fluids. Keep out of reach of children.

#### **Personal Protective Equipment (PPE):**

- Medical Oxygen handling personnel must be thoroughly familiar with properties and safety considerations before being allowed to handle liquid oxygen and its associated equipment. The eyes are the most susceptible to the extreme cold of the liquid and vapours of liquid oxygen.
- The recommended PPE is a full-face shield over safety goggles; clean, loose-fitting thermal-insulated or leather gloves; long-sleeved shirts; and pants without cuffs. Wear this PPE when handling or using liquid oxygen, or whenever the possibility of exposure due to a spill exists.
- In addition, safety shoes are recommended for those involved with the handling of containers. In emergency situations, self-contained breathing apparatus (SCBA) must be used.
- Clothing that is fire resistant in air may be readily ignitable in oxygen-enriched atmospheres.
- Only trained and certified emergency responders should respond to emergency situations.

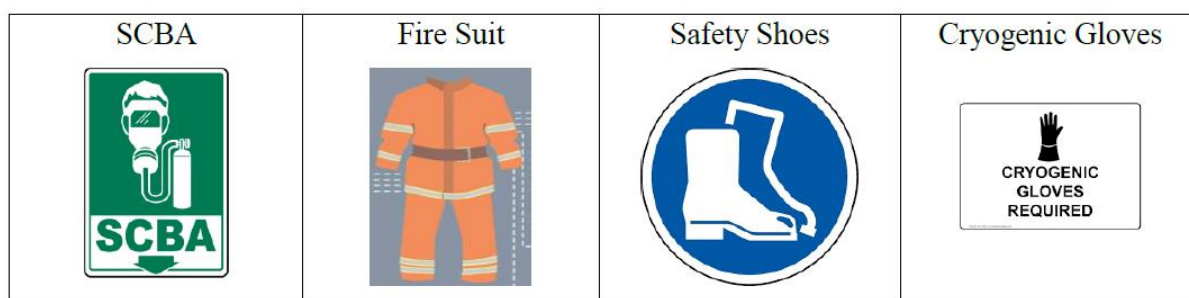


Figure D.1: PPE equipment

#### First Aid:

- For skin contact with liquid oxygen, remove any clothing that may restrict circulation to the frozen area. Do not rub frozen parts, as tissue damage may result. As soon as practical, place the affected area in a warm water bath with a temperature not exceeding 105°F (40°C). Never use dry heat. Call a physician as soon as possible.
- Frozen tissue is painless and appears waxy with a possible yellow colour. It will become swollen, painful, and prone to infection when thawed. If the frozen part of the body has been thawed, cover the area with a dry sterile dressing with a large bulky protective covering, pending medical care.
- In case of massive exposure, remove clothing while showering the victim with warm water. Call a physician immediately.
- If the eyes are exposed to the extreme cold of the liquid or vapours, immediately warm the frostbite area with warm water not exceeding 105°F (40°C) and seek medical attention.

#### Fire Fighting:

- Since oxygen is non-flammable but supports combustion, fire-fighting actions require shutting off the source of oxygen, if possible, then fighting the fire according to the material involved.
- Do not direct water streams toward venting oxygen. The water will freeze and plug the pressure-relief vent, which may result in container failure.
- Oxygen vigorously accelerates combustion. Materials that would not normally burn in air could combust vigorously in atmospheres having high concentrations of oxygen.

#### Emergency Actions:

- If possible, shut off source of escaping oxygen. Evacuate area. Prevent liquid oxygen from entering sewer, basements and work-pits.
- Do not absorb in sawdust or any other combustible material. Keep the bulk tank, PCC (Portable Cryogenic Container) or tanker cool by spraying with water if exposed to a fire. If tanker has overturned, do not attempt to upright or move it.

#### Accidental Release Measures:

- Personal Precautions-Clothing saturated by cold gas should be removed immediately. Clothes and other materials will burn fiercely in presence of high concentrations of oxygen.
- Environmental Precautions- Oxygen itself does not pose a hazard to the environment. However, because of extreme cold of the liquid, damage to ecology can occur in the immediate environs of the spill. Beware of oxygen-enriched atmospheres coming into contact with readily combustible materials.
- Small Spills - Shut off the source of escaping oxygen. Ventilate the area.

- Large Spills - Evacuate the area. Shut off the source of the spill if this can be done without risk. Restrict access to the area until completion of the clean-up procedure. Ventilate the area using forced draught if necessary.

#### **Exposure Controls/Personal Protection:**

- Occupational Exposure Hazards - Avoid exposure to oxygen-enriched atmospheres, as this could result in clothing becoming saturated by oxygen. On ignition the clothing could burn fiercely resulting in serious burns.
- Engineering Control Measures - Engineering control measures are preferred to reduce exposure to oxygen-enriched atmospheres. General methods include forced draught ventilation, separate from other exhaust ventilation systems.
- Personal Protection - Safety goggles or glasses, plus face shield, loose-fitting insulated gloves and safety shoes, or boots. Skin Wear loose-fitting overalls preferably without pockets.
- Conditions to avoid - Oxygen-enriched atmospheres will react with all of the elements, excepting the rare gases, especially at elevated temperatures. These reactions could sometimes be violent, as those when high concentrations of oxygen come into contact with highly combustible materials such as oil and grease.
- Incompatible Materials- At the temperature of liquid oxygen, ordinary carbon steels and most alloy steels, lose their ductility and are therefore considered to be unsatisfactory. Metals and alloys that have satisfactory ductility include austenitic stainless steel (i.e. types 204 and 216), and nickel chromium alloys, nickel, Monel 400, copper, brasses, bronze and aluminium alloys.

#### **Disposal Methods:**

- Small amounts may be allowed to evaporate into the atmosphere. In case of large spills consult an expert and allow evaporation. Large amounts should only be handled by gas supplier.
- Disposal of Packaging: The disposal of containers must only be handled by the gas supplier.

#### **Response Strategy:**

The moment liquid oxygen leaks into open air it vaporizes or becomes a dense mist. So, it cannot be contained effectively in case of a leak and the only solution is to eliminate the risk of fire and to arrest the leak by finding its source. In case of an accident which results in oxygen leak, the following information is critical:

- The primary objective is to stop the leak at the source.
- For attempting to close the leak, firefighters need to approach the container. The following Personal Protective Equipment (PPE) must be used:
  1. Pyro protected full body coverall/fire suits.
  2. Self-contained breathing apparatus (SCBA)
  3. Cryogenic gloves
  4. Safety shoes
  5. In addition, a tools box with spark proof tools, to arrest the leak
- Protection equipment are essential because when there is an accident, the atmosphere around the container becomes oxygen-rich due to leakage. To stop it, the valve through which leakage is occurring needs to be isolated. The atmosphere around the valve will have almost 75% oxygen, and firefighters can't stay in such environment for a long time.

- The container should be cooled and it should not be allowed to heat up. This is because of the fact that majority of the liquid oxygen will still be inside the container.
- All sources of ignition from the surrounding area should be eliminated. Due to the huge amount of oxygen leak, a fire can easily lead to an explosion.
- There should be adequate ventilation around the container so that the leaked oxygen doesn't get accumulated anywhere (such as in drainages) because this might cause an explosion later.
- Firefighters must stay up-wind from the container when working on it so that the leaked oxygen poses comparatively less threat to them.
- In case of fire, water spray or water fog should be used to extinguish the fire and cool down the container. Water jets should not be used under any circumstances. Water spray and water fog helps in reducing the excess oxygen level in the atmosphere and thus, decrease the risk of explosion.
- If there is only leakage of oxygen and no fire, water spray and water fog must be used only to decrease the oxygen level in the atmosphere. It should not be sprayed directly on the container.
- If the gas leak cannot be arrested, the area in danger must be evacuated.
- All traffic moment in the area must be stopped to decrease the risk of a fire and explosion.
- Electricity to the area must be disconnected to reduce the risk of a spark and thus, an explosion.
- Leakage Arrester Kits are used in case of breakage of main valves.

## Appendix E: Handling of Oxygen Cylinders [35]

They are usually found in hospitals and must be handled with care.

- It is observed that oxygen cylinders are transported by rolling them on the ground. This procedure is wrong and compressed gas cylinders should always stay upright.
- Oxygen cylinders should be chained to prevent it from falling in storage areas.
- All gas cylinders must have caps over their valves. The valves should be capped (even if the cylinder is empty) when the cylinders are not in use to protect it from damage which might cause leakage. The valve is the most fragile part of a cylinder.
- Empty cylinders should be kept separated from filled ones.
- Cylinders must always be kept away from combustible materials.
- Cylinders should be stored in well ventilated areas.
- Smoking should be strictly prohibited near cylinder storage areas and 'No-Smoking' signs should be clearly placed.
- Cylinders should be transported with care as a broken valve will result in the cylinder shooting away like a rocket, which might cause injuries or even death. Trolley should be used for manoeuvring.
- Proper Handling of Compressed Gas Cylinders must be known to all hospital personnel. Regular trainings are to be imparted to hospital staff.

## Appendix F: Medical Oxygen – Basic Do’s and Don’ts for rational use of Oxygen [35]

Do’s* (*Indicative only; Medical advice to be followed)	Don’ts
Target SpO <sub>2</sub> : 92-94%	Don’t use HFNC with high Oxygen flow
Target PaO <sub>2</sub> : Around 60 mm Hg	Don’t allow leakages from NIV mask
Never exceed oxygen flow (litres per minute – LPM) of - 14 LPM on NRBM 8 LPM on simple mask 6 LPM on nasal prongs	Don’t keep central oxygen pipeline connected when ventilator is not in use
Titrate use of IPAP to achieve Tidal Volume of 6-7 ml/kg only	Don’t keep flow meter connected when not in use
Use only EPAP/CPAP for better oxygenation	Don’t keep ventilator SWITCHED ON when not in use
Encourage awake proning for all. Lateral position is favoured for those who do not tolerate prone position, in obese and pregnant patients.	Don’t use leaky or faulty flow meters
Use Oxygen concentrator (with different capacity and dual flowmeter)	Don’t keep humidifier bottle full of water in flow meter

## Appendix G: Emergency plan for hospitals during leakages [35]

### Scenario 1 – Leakage from Cryogenic Liquid Oxygen tank

- The leakage usually occurs during refilling of Oxygen. The staffs of refilling agencies shall be trained to control the leakage using non-sparking equipment.
- Flowmeter check could be done daily for leakage or valve complaint.

No.	Task	Responsibility
1	Inform the Medical Superintendent.	By Hospital staff in Central Supply Oxygen Room
2	Inform Fire and Rescue Department 101, Police 100, PRO, Deputy Superintendent.	By Medical Superintendent
3	Change the valve of Oxygen supply from Liquid Oxygen to Bulk Cylinder Oxygen to ensure continuous supply of Oxygen.	By Central Supply Oxygen Room staffs
4	Using a SCBA and PPE kit for fire, the leakage from the cryogenic tankers could be checked.	Fire Fighters
5	Inform the bulk cylinder refilling agency and ask to provide additional supply of oxygen on war foot basis.	By Medical Superintendent
6	Shift the patients to other hospitals or other wards if needed or procure additional bulk Oxygen cylinders from nearby hospitals.	By Medical Superintendent

### Scenario 2 – Leakage in Central Supply Oxygen Room

No.	Task	Responsibility
1	Inform the Medical Superintendent.	By Hospital staff in Central Supply Oxygen Room
2	Inform Fire and Rescue Department 101, Police 100, PRO, Deputy Superintendent.	By Medical Superintendent
3	Arrange Type B cylinders as per the number of patients who need Oxygen supply in the hospital.	By Deputy Superintendent
4	Inform the bulk cylinder refilling agency and ask to provide additional supply of oxygen on war foot basis.	By Medical Superintendent
5	Shift the patients to other hospitals if needed or procure additional bulk Oxygen cylinders from nearby hospitals.	By Medical Superintendent

### Scenario 3- Leakage or fire in Natural Oxygen Plant

No.	Task	Responsibility
1	Inform the Medical Superintendent.	By Hospital staff who witness/ check/ monitor the leakage
2	Inform Fire and Rescue Department 101, Police 100, PRO, Deputy Superintendent.	By Medical Superintendent
3	Inform the staffs in Central Supply Oxygen Room to change the valve and provide Oxygen from Automatic Gas Manifold (Centralized supply) to the hospital areas necessary.	By Deputy Superintendent
4	Change the supply to additional areas by Bulk cylinders which were covered earlier by Natural Oxygen Plant.	By staffs in Central Supply oxygen room
5	Turn off the supply of Oxygen from Natural Oxygen Plant until the production is restored.	By Natural Oxygen Supply room
6	Inform the bulk cylinder refilling agency and ask to provide additional supply of oxygen on war foot basis.	By Medical Superintendent

## **Appendix H:** Hazards from Oxygen enrichment [35]

### **Fire Hazards from Oxygen Enrichment:**

Oxygen reacts with most elements. The initiation, speed, vigour and extent of these reactions depend in particular upon:

- The concentration, temperature and pressure of the reactants
- Ignition energy and mode of ignition.

### **Reaction Mechanism:**

The mechanism of these reactions is complicated and depends, among other things, upon the nature of the substances concerned, their physical state, geometric configuration, concentration, and manner of ignition. This, too, influences the speed of reaction, which can vary from slow combustion to an explosion.

### **Combustibility of Materials:**

Oxygen enrichment of the atmosphere, even by a few percent, considerably increases the risk of fire. Materials, which do not burn in air, including fireproofing materials, may burn vigorously or even spontaneously in enriched air.

### **Hydrocarbon Oils and Grease:**

Oil and grease are particularly hazardous in the presence of oxygen as they ignite spontaneously and burn with explosive violence. They should **NEVER** be used to lubricate oxygen or enriched air equipment. Special lubricants, with which oxygen can be used under certain conditions, are available.

### **Smoking:**

Burning accidents, which occur, are normally triggered by the lighting of a cigarette. Therefore, it is impossible to over-emphasize the danger of smoking in oxygen-enriched atmospheres or where oxygen enrichment can occur. In such areas smoking shall be forbidden.

## Appendix I: Hospital fire safety inspection report [16]

Hospital Fire Safety Inspection Report		
Hospital name, address & contact number:		
1	<b>Means of escape</b>	<b>Yes/No</b>
	Are there any fire exits?	
	Are all exits clear of obstructions?	
	Are exit signs adequate?	
	Are exit routes clear?	
	<b>Comments:</b>	
2	<b>Fire alarm system</b>	<b>Yes/No</b>
	Is there a fire alarm system?	
	Is the fire alarm system functional?	
	Is the fire alarm system regularly serviced?	
	Is there any smoke or heat detector?	
	Is the smoke or heat detector functional?	
	Is the smoke or heat detector regularly serviced?	
	<b>Comments:</b>	
3	<b>Firefighting equipment</b>	<b>Yes/No</b>
	Is there any fire extinguisher?	
	Is the fire extinguisher functional?	
	Is the fire extinguisher regularly serviced?	
	Is there any hose reel?	
	Is the hose reel functional?	
	Is the hose reel regularly serviced?	
	<b>Comments:</b>	
4	<b>Training</b>	<b>Yes/No</b>
	Is there a staff training program on fire-safety?	
	Are fire evacuation mock drills scheduled and performed regularly?	
	<b>Comments:</b>	
5	<b>Fire safety leadership</b>	<b>Yes/No</b>
	Are there any designated personnel for fire-safety management in the facility?	
	<b>Comments:</b>	
6	<b>Fire prevention standards (official use only)</b>	
	Name of the Inspecting officer:	
	Date of inspection:	
	Date of next inspection:	
	<b>Comments:</b>	

## Appendix J: Hospital fire safety baseline assessment checklist

S. No.	Assessment	Mark Y/N or as desired
<b>Hospital Profile</b>		
1	Name of the Hospital	
2	No. of functional beds	
3	Monthly bed occupancy	
4	How many fire outbreaks in the past 5 years?	
<b>Infrastructure</b>		
5	Is the hospital situated on the dead end of the street or in the middle of the street?	
6	Any residential area near the hospital?	
7	Any commercial setup/shop near the hospital?	
8	Level of hospital- L1/L2/L3?	
9	Height of the building?	
10	Type of construction- Ground floor, G+1, G+2?	
11	What is the floor area ratio of the hospital building?	
12	Availability of staff quarters/ hostel/ any abandoned building in the premise?	
13	Availability of open area in the premise to assemble the public in situation of emergence?	
14	Availability of the main gate entry from the street?	
15	Type of Gate - Double leaf gate, Sliding gate?	
16	Width of the gate?	
17	Firefighting vehicle can easily enter the hospital through the main gate?	
18	No. of entry points (gates) to the hospital (within the premise)?	
19	Type of gates- Channel gate, sliding or double leaf?	
20	Width of the gate of the main hospital building (entry point)?	
21	Any electricity control point like transformer available within the hospital premise? If yes, mention the number.	
22	Availability of lights in the premise?	
23	Availability of separate parking space within the hospital premise and away from the main entry point to the hospital building?	
<b>Fire Safety Points (Prevention Aspect)</b>		
24	Availability of underground water reservoir? If yes, mention the number.	
25	Availability of overhead water reservoir? If yes, mention the number.	
26	Any point or gate identified in the hospital building as emergency exit?	
27	Display of fire evacuation plan if it exists?	
28	Constituted hospital disaster management committee?	
<b>Availability of Emergency Response Plan for Fire, Evacuation, etc.</b>		
29	Functional public-address system (assigned intercom number)?	
30	Availability of emergency hooter?	
31	Availability of emergency power backup system?	
32	Availability of material safety data sheet of hazardous chemicals in the hospital store?	
33	Total number of fire extinguishers installed?	
	Type of extinguisher installed- A, B, C, etc.?	
	Size of extinguishers?	

	5 kg (if installed, mention the number)?	
	10 kg (if installed, mention the number)?	
	4.5 kg (if installed, mention the number)?	
	500 gram-Foam (if installed, mention the number)?	
	Availability of sand buckets?	
34	Availability of smoke detectors in key areas (if yes, mention the department)?	
	ICU	
	SNCU	
	Paediatrics wards	
	Isolation ward	
	Store	
	Kitchen	
	Record room	
	Other	
35	Water hydrants (if the building is G+2 and plot area more than 1000 m <sup>2</sup> but less than 1500 m <sup>2</sup> )	
	No. of hydrants installed (if in compliance with the above criteria)?	
36	Availability of automatic sprinkler system as per IS 15105 (if basement area exceeds 200 m <sup>2</sup> )	
	Area/department where sprinklers are installed (if in compliance with the above criteria)?	
37	Availability of dedicated fire water tank (if basement area is more than 200 m <sup>2</sup> )?	
	Availability of diesel fire water pump which can discharge water 1620 litres/minute (if in compliance with the above criteria)?	
	Electrical fire water pump which can discharge water 180 litres/minute (if in compliance with the above criteria)?	
38	Availability of hose reel (if G+1 construction)?	
	Area where hose reels are installed and no. of hose reels available (if in compliance with the above criteria)?	
<b>Statutory Compliance</b>		
39	NOC of the building from the municipality	
40	NOC for fire safety of the building	
41	AMC of firefighting equipment	
<b>Training</b>		
42	Training of all the staff to operate firefighting equipment	
43	Availability of SOP for fire emergency?	
44	Provision for periodic mock drills (if yes, no. of mock drills conducted in a year)	
45	Are staff members familiar with their role and responsibility in the event of a fire?	
Remarks:		

