ONEHEALTH TRUST

GUIDE ON MEDICAL OXYGEN USE IN LOW- AND MIDDLE-INCOME COUNTRIES

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Related research and additional information on health systems capacity-building and India's National Medical Oxygen Grid are available at https://www.onehealthtrust.org.

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Dedication

This work is dedicated to the many who suffer without access to medical oxygen every day and to the tens of thousands of kind individuals who generously supported India's fight for oxygen during the COVID-19 pandemic.

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List of Abbreviations

Number	Abbreviation	Expansion
1	ABG	arterial blood gas
2	ARDS	acute respiratory distress syndrome
3	ASU	air separation unit
4	BiPAP	bilevel positive airway pressure
5	CAP	community-acquired pneumonia
6	CO	carbon monoxide
7	CO_2	carbon dioxide
8	COPD	chronic obstructive pulmonary disease
9	CPAP	continuous positive airway pressure
10	COVID-19	Coronavirus Disease 2019
11	CPR	cardiopulmonary resuscitation
12	CVD	cardiovascular disease
13	DALY	disability-adjusted life year
14	ECLS	extracorporeal life support
15	FiO_2	fraction of inspired oxygen
16	HAP	hospital-acquired pneumonia
17	HBOT	hyperbaric oxygen therapy
18	HFNC	high-flow nasal cannula
19	HIV	human immunodeficiency virus
20	ICMR	Indian Council of Medical Research
21	IPC	Indian Pharmacopoeia Commission
22	IHD	ischemic heart disease
23	kL	kiloliter
24	LMO	liquid medical oxygen
25	LRTI	lower respiratory tract infection
26	LTOT	long-term oxygen therapy
27	LPM	liters per minute
28	MI	myocardial infarction
29	MT	metric ton

List of Abbreviations (continued)

Number	Abbreviation	Full Form
30	mmHG	millimeters of mercury
31	MT/day	metric tons per day
32	NIV	non-invasive ventilation
33	OC	oxygen concentrator
34	PaO_2	partial pressure of arterial oxygen
35	PHC	primary health center
36	PO_2	partial pressure of oxygen in lungs
37	PSA	pressure swing adsorption
38	qSOFA	quick sequential organ failure assessment
39	RDS	respiratory distress syndrome
40	SOFA	sequential organ failure assessment
41	SpO_2	partial pressure of oxygen as measured by pulse oximetry
42	WHO	World Health Organization

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Executive Summary

Access to a timely supply of medical oxygen plays a critical role in managing respiratory distress associated with various conditions, including birth asphyxia, chronic obstructive pulmonary disease, pneumonia, myocardial infarction, trauma, carbon monoxide toxicity, and hemorrhage. Although an inexpensive and essential tool in patient care, medical oxygen has been largely neglected in health systems. The recent experience with oxygen shortages during the Coronavirus Disease 2019 (COVID-19) pandemic sharply highlighted its need beyond tertiary hospitals in large cities in many countries.

The oxygen ecosystem is riddled with issues of access, quality, pricing, safety, and regulatory compliance on the supply side and challenges with knowledge and recognition of when and how to use medical oxygen on the demand side (WHO 2023). Supply side challenges have been addressed in previous reports including by the 2024 Lancet Commission on Medical Oxygen. In brief, liquid medical oxygen has a natural monopoly, and the prices are kept artificially high by a small number of players who have little incentive to serve patient populations outside profitable urban centers. In contrast, the demand side has received much less attention. Insufficient knowledge of or ability to use pulse oximetry and oxygen for routine medical care outside of tertiary settings means that oxygen is not prioritized or is used unsafely, wastefully, or ineffectively.

Supply follows demand. If there is no demand for medical oxygen during normal times in non-urban settings, it follows that there is no reliable supply either. This is a problem both during non-pandemic times and also when there are pandemic-associated emergencies. In essence, oxygen shortages during the second wave of COVID-19 was due in part to a lack of supply outside of tertiary care settings, but a major underlying cause was that frontline healthcare providers outside these settings were neither trained in the use of medical oxygen nor were they authorized to do so.

In 2022, the One Health Trust, in partnership with PricewaterhouseCoopers (PwC) and with the support of USAID-RISE, Gates Foundation, and Swasth Alliance, developed a blueprint for India's national medical oxygen grid to highlight the importance of information technology for tracking oxygen assets and safeguarding against oxygen crises and kickstart an effort to solve the supply side of the equation (Aggarwal et al. 2022). Guidance documents are available from international bodies and organizations on how to maintain a functioning oxygen ecosystem (Department of Public Health Government of Maharashtra 2021; WHO and UNICEF 2019; O'Driscoll et al. 2017; IMA 2020).

This guidance document aims to address the demand side. To the best of our knowledge, there are no guidelines that address how medical oxygen should be used in community health facilities outside urban settings. Without clear guidelines on how, when, and why oxygen should be used in medical care, demand will remain underrecognized and oxygen underused. This document is intended to encourage the judicious use of medical oxygen and its recognition as an essential component of any modern health care system. The guidance was developed in consultation with Indian pulmonologists and experts and is meant for use by policymakers, health care administrators, procurement officers, biomedical engineers, and technicians.

Overview

During the peak of the second wave of the COVID-19 pandemic in May 2021, the demand for medical oxygen increased sharply in India as in many countries (IMA 2020). This sudden increase, for which the country was unprepared, posed a serious challenge to the health system in ensuring timely oxygen supplies. Although India had an oxygen production capacity of approximately 7,200 metric tons (MT), only eight states—Gujarat, Jharkhand, Karnataka, Kerala, Maharashtra, Odisha, Tamil Nadu, and West Bengal—accounted for nearly 80 percent of the total production capacity (IMA 2020). Moreover, places in which patients were dying due to lack of medical oxygen were far away from these production facilities and tertiary hospitals where healthcare providers were trained in how to administer oxygen. Transporting liquid medical oxygen (LMO) over long distances in a short time was not feasible—and training medical providers in rural areas on how to use it to deal with acute respiratory distress in a short time was impractical.

In response, the government and partners in philanthropic and nongovernmental organizations embarked on an ambitious project to import oxygen cylinders, concentrators, and pressure swing adsorption (PSA) plants. These resources improved the health system's ability to respond to future emergencies in instances where the capacity has been maintained, but this also depends on providers' technical expertise on how to best use medical oxygen. Although partners in the development community, including Program for Appropriate Technology in Health (PATH), Clinton Health Access Initiative (CHAI) and Jhpiego, have invested in training providers, efforts must grow. As of May 2022, the World Health Organization (WHO) has included medical oxygen in the Model List of Essential Medicines and List of Essential Medicines for Children (WHO 2022).

The Guide on medical oxygen use in low- and middle-income countries aims to inform healthcare providers about the broad spectrum of clinical conditions that may require oxygen therapy and the importance of ensuring reliable oxygen supplies at all levels of health systems. It reinforces the commitment of the Indian government to strengthen the oxygen ecosystem. It was developed by researchers at the One Health Trust based on information available in the public domain and extensively reviewed by pulmonologists and other medical experts. The authors referred to various resources, including technical specifications on oxygen therapy devices (Department of Public Health Government of Maharashtra 2021; WHO and UNICEF 2019; Indian IMA 2020) and recommendations on oxygen use in health care (O'Driscoll et al. 2017). The scope of the guidance entails oxygen therapy for common clinical conditions, key concepts and good clinical practices, and a summary of the oxygen supply systems.

Global Disease Burden

Management of various diseases may warrant oxygen therapy. It is important to understand the burden of such diseases and ensure that oxygen supplies are available at health facilities and staff are trained to administer oxygen. Failure to recognize the importance of strengthening the oxygen ecosystem can impact patient care and result in increased disabilities and often avoidable loss of lives.

Table 1 summarizes the burden of the more frequent disorders/health conditions, many of which may require oxygen administration for patient survival (and hence are a proxy for oxygen demand) (Vos et al. 2020).

Table 1. Global Disease Burden for Common Health Conditions

Health condition	Measure	Value
Ischemic heart disease	Prevalence	197,219,449 cases 2,548.89 cases per 100,000 2.65% of total cases
	Incidence	21,203,479 new cases 274.04 new cases per 100,000 0.05% of total new cases
	Deaths	9,137,791 deaths 118.1 deaths per 100,000 16.17% of total deaths
	Disability-adjusted life years (DALYs)	182,030,144 DALYs 2,352.58 DALYs per 100,000 7.19% of total DALYs
Stroke	Prevalence	101,474,558 cases 1,311.47 cases per 100,000 1.36% of total cases
	Incidence	12,224,551 new cases 157.99 new cases per 100,000 0.03% of total new cases
	Deaths	6,552,724 deaths 84.69 deaths per 100,000 11.59% of total deaths
	DALYs	143,232,184 DALYs 1,851.15 DALYs per 100,000 5.65% of total DALYs

(continued)

Health condition	Measure	Value
Lower respiratory infections	Prevalence	10,969,729 cases 141.77 cases per 100,000 0.15% of total cases
	Incidence	488,902,504 new cases 6,318.64 new cases per 100,000 1.22% of total new cases
	Deaths	2,493,199 deaths 32.22 deaths per 100,000 4.41% of total deaths
	DALYs	97,189,707 DALYs 1,256.09 DALYs per 100,000 3.83% of total DALYs
Chronic obstructive pulmonary disease	Prevalence	212,335,951 cases 2,744.26 cases per 100,000 2.85% of total cases
	Incidence	16,214,828 new cases 209.56 new cases per 100,000 0.04% of total new cases
	Deaths	3,280,636 deaths 42.4 deaths per 100,000 5.80% of total deaths
	DALYs	74,432,366 DALYs 961.97 DALYs per 100,000 2.94% of total DALYs
Neonatal disorders	Prevalence	92,519,486 cases 1,195.73 cases per 100,000 1.24% of total cases
	Incidence	23,532,231 new cases 304.13 new cases per 100,000 0.06% of total new cases
	Deaths	1,882,438 deaths 24.33 deaths per 100,000 3.33% of total deaths
	DALYs	185,886,390 DALYs 2,402.24 DALYs per 100,000 7.33% of total DALYs

(continued)

Health condition	Measure	Value
Congenital birth defects	Prevalence	50,862,393 cases 657.35 cases per 100,000 0.68% of total cases
	Incidence	8,518,013 new cases 110.09 new cases per 100,000 0.02% of total new cases
	Deaths	549,304 deaths 7.1 deaths per 100,000 0.97% of total deaths
	DALYs	52,784,936 DALYs 682.2 DALYs per 100,000 2.08% of total DALYs

Source: Vos et al. 2020

Basics of Oxygen Therapy

Oxygen constitutes 21 percent of atmospheric gases; under normal conditions, this is sufficient to fulfill the respiratory needs of the human body. However, certain health conditions can lead to oxygen deficiencies in the blood (hypoxemia) and tissues (hypoxia). This can be detrimental to vital organs and thus calls for timely administration of oxygen (Sood 2023).

Oxygen saturation can be quantified as either oxygen saturation levels (SpO_2) or arterial oxygen tension (PaO_2). Although SpO_2 is more convenient to measure, PaO_2 is considered the gold standard for assessing hypoxemia. Commonly, SpO_2 is measured by a pulse oximeter and PaO_2 by the invasive arterial blood gas (ABG) analysis. A PaO_2 value less than 60 mmHg (usually corresponding to SpO_2 of 90 percent) indicates hypoxemia.

For most patients, the aim of oxygen therapy is to achieve the target saturation (usually a minimum of 60 mmHg of PaO_2 or 90 percent of SpO_2) with the lowest possible fraction of inspired oxygen (FiO_2). However, variations may occur depending on the underlying condition, as seen in some cases of chronic obstructive pulmonary disease (COPD), myocardial infarction (MI), stroke, or oxygen sensitivity (O'Driscoll et al. 2017).

Medical oxygen can be provided to patients from multiple sources, including liquid medical oxygen (LMO) tanks, PSA plants, cylinders, or concentrators, and is directed to the patient's bedside in emergency rooms, operation theaters, intensive care units, and other settings. The bedside oxygen supply uses connectors (such as flowmeters and humidifier bottles) with the delivery devices, which are commonly categorized as simple low-flow oxygen to noninvasive ventilation (NIV) and mechanical ventilation. Table 2 provides details based on expert opinions from clinicians. Oxygen purity varies by source (LMO: 99.5 percent v/v; PSA: 93 ±3 percent v/v; concentrator: 82 ±3 percent v/v; cylinder: 90–99.5 percent v/v).

Basic low-flow oxygen is typically the first-line therapy for hypoxemic respiratory failure, employing devices with typical flow rates of 0.5–1 LPM for neonates, 1–2 LPM for children, and 2–4 LPM for adults (Vates 2011; Rolfe and Paul 2018). Nasal cannulas are usually the most comfortable and easy devices, but a face mask can be used for higher flow rates (for example, up to 10 LPM). At these low flow rates, oxygen can be safely provided without humidification or blending with air, as the nasopharynx mixes and humidifies the inhaled gas adequately.

Where additional respiratory support is needed, this can be provided via high-flow devices (for example, high-flow nasal cannula [HFNC]), positive airway pressure (for example, bilevel positive airway pressure [BiPAP], continuous positive airway pressure [CPAP] machines), mechanical ventilators, and extracorporeal life support (ECLS) (previously known as "extracorporeal membrane oxygenation") machines. (HFNC) delivers heated and humidified oxygen at a flow rate of 2L/kg in children and up to 60 L/min in adults and is commonly used to provide higher inspired concentrations. (BiPAP) and (CPAP) machines are NIV devices that provide positive airway pressure to help keep the airways open and are often used for sleep apnea, certain chronic respiratory conditions, and acute hypoxemic respiratory failure. Their flow rates vary (6–30 L/min) and are generally lower than for (HFNC.) They use a noninvasive interface, such as a face or nasal mask. In contrast, delivery directly from a ventilator through an endotracheal or tracheostomy tube is called "invasive ventilation."

Table 2. Typical Oxygen Flow Rates for Adults

S No.	Device	Oxygen flow rate	FiO_2
1	Nasal cannula	1-6 L/min	0.24-0.4
2	Simple face mask	5-10 L/min	0.4-0.6
3	Nonrebreather mask	10-15 L/min	0.6-0.9
4	Venturi mask	2-15 L/min	0.24-0.5
5	High-flow nasal cannula	15-60 L/min	0.3-1.0
6	BiPAP & CPAP (Noninvasive mechanical ventilation)	6-30 L/min	0.6-0.8
7	Endotracheal tube (Invasive mechanical ventilation)	60-120 L/min	0.3-1.0

The type of oxygen delivery device used for a child depends on their needs, their daily activities, and the source of oxygen. Some common devices include nasal cannula, oxygen hood, nasal CPAP system, and ventilator.

As a standard protocol, airways must be either patent or secured before initiating oxygen therapy. Oxygen should be administered carefully to avert potential complications, such as hyperoxaemia and lung injuries, and weaned upon reaching the target peripheral saturation or by clinical judgment. For patients sensitive to oxygen levels, titration is imperative.

The WHO and Indian Pharmacopoeia Commission (IPC) qualify the medical use of oxygen at 93 ±3 percent v/v (gaseous) or 99.5 percent v/v concentration (liquid) (IPC 2022). However, other products with varying oxygen concentrations may also be considered if approved by the designated national or regional authority (WHO 2022). The oxygen is always mixed with medical or atmospheric air before it reaches the lungs, so it rarely makes a clinical difference if the source is 99 percent or 85 percent. The British Thoracic Society guidelines do not recommend oxygen to treat breathlessness without hypoxia, as it might mask an evolving hypoxia (IPC 2022) or result in hyperoxia, lung injury, and worsening of the clinical condition. Hence, the risk–benefit ratio should be assessed before any decision making.

Not all dyspneic patients exhibit hypoxemia; this is commonly absent in anxiety-related conditions, rendering oxygenation unnecessary. Using pulse oximeters, the level of oxygen saturation of hemoglobin in the arterial blood can be continuously measured and patient response to oxygen therapy monitored. These are early-warning devices that can detect hypoxia much sooner than the anesthesia provider can see clinical signs of hypoxia, such as cyanosis, making them essential for safe anesthesia. They are accepted as the global standard for detecting and monitoring hypoxemia and, with an appropriate oxygen supply, necessary for the efficient and safe use of oxygen (WHO and UNICEF 2019).

The next few sections summarize supplemental oxygen therapy recommendations for common clinical conditions but are not intended to substitute for or overrule clinical judgment. Beyond oxygen therapy, a comprehensive range of therapeutic strategies include the management of shock, empirical treatment, triaging, and specialized care. Detailed pharmaceutical management is beyond the purview of this guidance.

Common Indications for Oxygen Therapy

Cardiovascular Disease

Cardiovascular disease (CVD) is an umbrella term for conditions affecting the heart and blood vessels. It encompasses a range of diseases, each with its unique characteristics and risk factors. CVD is a leading cause of morbidity and mortality and a major contributor to health system expenditure. According to the Global Burden of Disease 2019, the prevalence of ischemic heart disease (IHD) is 2,548.89 per 100,000, and it contributes to 16.17 percent of total deaths, and the prevalence of stroke is 1,311.47 per 100,000, and it contributes to 11.59 percent of total deaths (Vos et al. 2020).

Some of the common CVDs that may require oxygenation are as follows:

1. IHD or coronary artery disease: characterized by narrowing of the coronary arteries that can lead to chest pain (angina) or heart attack (MI)
2. Stroke: a disruption of blood flow to the brain resulting in neurological consequences
3. Cardiac failure: a condition where the heart is unable to effectively pump blood, thus impairing the gaseous exchange in the lungs and reducing oxygenation to the body
4. Heart valve disease: a condition that interferes with normal blood flow within the heart and has symptoms of chest pain, shortness of breath, and fatigue
5. Cardiomyopathy: a disease of the heart muscle that affects contractions and blood flow
6. Congenital heart defect: a defect since birth that may require surgical repair if severe

Management of CVD depends on the severity and underlying causes. Early diagnosis, lifestyle modifications, medication, pulmonary rehabilitation, oxygen therapy, and surgical interventions can be used. We will summarize the role of supplemental oxygen therapy for MI, stroke, heart failure, and cyanotic heart diseases.

For MI with hypoxemia, supplemental oxygen helps to reduce the infarct size and complications. The choice of delivery device and source is determined based on the patient's specific needs and respiratory condition and type of health care facility. Oxygen flow rates are selected depending on the level of hypoxemia, and both low- and high-flow devices should be available. If the oxygen requirement is low, oxygen can be delivered via nasal cannula at flow rates of ≤6 L/min. If it is higher, HFNC, NIV (BPAP or CPAP), or invasive mechanical ventilation may be used. However, in patients without documented hypoxemia, oxygen therapy has not proven to have clear benefit (O'Driscoll et al. 2017; Cabello et al. 2016; Stub et al. 2015).

Similarly, although managing stroke involves medications, oxygen is often administered as part of the initial care. Increasing the oxygen levels in the bloodstream limits brain damage. In severe cases, especially when the ability to breathe is compromised, mechanical ventilation may be necessary. Some medical centers use hyperbaric oxygen therapy (HBOT), where 100 percent oxygen is administered in a pressurized chamber (a pressure above the sea level: >1 atm abs). The increased pressure delivers higher oxygen levels, potentially promoting recovery.

Managing heart failure involves a combination of medications and surgical interventions. Oxygen supplementation is lifesaving in hypoxemic cardiac failure, as it increases oxygen levels in the blood and alleviates symptoms. This reduces the need for intubation and mechanical ventilation. However, routine use of high concentrations of oxygen for normoxemic patients may result in hyperoxemia, so oxygen therapy requires the guidance of a qualified professional.

Cyanotic heart defects are a group of congenital defects that result in symptoms of low oxygen levels, such as cyanosis, shortness of breath, and fatigue; Tetralogy of Fallot is one of the most common. Treatment typically involves surgical correction and oxygen therapy. In older children and adults, SpO_2 is not targeted, and oxygen is required to alleviate symptoms. As with other clinical conditions requiring oxygen therapy, the choice of delivery device and source is based on the respiratory condition and type of health care facility. In patients with minimal requirements, a nasal cannula or oxygen mask is used. However, when the requirement is higher, high-flow devices are used. Where indicated, mechanical ventilation (noninvasive or invasive) may be considered. Oxygenation may be required even after surgical correction. Regular medical follow-ups and ongoing care are essential for long-term monitoring.

Respiratory Diseases

Respiratory diseases may range from mild or temporary to severe, chronic, and life threatening. As with CVD, these diseases are among the leading causes of morbidity and mortality and a major contributor to health system expenditures. According to the Global Burden of Disease 2019, the prevalence of lower respiratory tract infection (LRTI) is 141.77 per 100,000, and it contributes to 4.41 percent of total deaths, and the prevalence of COPD is 2,744.26 per 100,000, and it contributes to 5.8 percent of total deaths (Vos et al. 2020).

Some of the common respiratory diseases that may require oxygenation are as follows:

1. Asthma: an allergic condition that results in narrowed airways and breathing difficulties
2. COPD: a progressive lung disease that presents as a combination of two issues in variable proportions, usually associated with smoking or exposure to biomass fuel:
    a. Chronic bronchitis: an inflammation of the airways that results in narrowing and producing excessive mucus, along with cough and breathing difficulties
    b. Emphysema: destruction of air sacs (alveoli) that reduces the surface area for gas exchange, resulting in difficulty in exhaling air and decreased blood oxygen levels
3. Pneumonia or LRTI: a lung infection that can be acquired in the community or from a health care facility
4. COVID-19: a respiratory infection caused by the Severe Acute Respiratory Syndrome Coronavirus 2 virus and declared a pandemic in March 2020 (although the majority of patients do not need oxygen, those who do may show varying levels of severity—nonsevere, severe, or critical)
5. Tuberculosis: a bacterial infection caused by *Mycobacterium tuberculosis* and commonly affecting the lungs that can be classified in multiple ways depending on the anatomical site (pulmonary or extrapulmonary), bacteriological analysis (smear positive or negative), history of treatment (new patient or relapse/failure/default), and human immunodeficiency virus (HIV) status (oxygen is essential, particularly when the lungs are significantly involved)
6. Acute respiratory distress syndrome (ARDS): a severe lung condition often caused by infections, injuries, or underlying medical conditions that leads to rapid onset of severe respiratory failure, requires intensive care, and has high mortality
7. Interstitial lung disease: a group of usually immunological disorders that may have multisystem involvement and cause inflammation and scarring of the lungs
8. Lung cancer: one of the leading causes of cancer-related deaths worldwide and the third most common in the United States; commonly caused by smoking and carcinogen exposure (non-small-cell is more common than small-cell lung cancer)
9. Cystic fibrosis: a genetic disorder that leads to thick and sticky mucus in the airways
10. Respiratory failure: a state of inadequate oxygenation and/or incomplete elimination of carbon dioxide (CO_2)

Managing respiratory ailments depends on the disease severity and underlying causes. Early diagnosis, medication, lifestyle modifications, and sometimes oxygen therapy and surgical interventions are part of the treatment approach. Usually, for most respiratory disorders, oxygen is pivotal in stabilization and treatment. This document also presents the role of supplemental oxygen therapy in managing pneumonia (including COVID-19).

Pneumonia can be classified in various ways, including the origin of infection, etiology, and patient age. Diagnosis is based on specific clinical, laboratory, and radiological signs (Table 3). Various pathogens can cause it (Tables 4 and 5) (Metlay et al. 2019). Pneumonia is defined as hospital acquired (HAP) or nosocomial when it occurs 48 hours or more after admission. Ventilator-associated pneumonia is a type of HAP that develops after endotracheal intubation.

HAP pneumonias are commonly caused by *P. aeruginosa*, *E. coli*, *K. pneumoniae*, and *Acinetobacter* species, and methicillin-resistant *S. aureus*, as these bacteria are more prevalent in hospitals/health care facilities. Antibiotics are the mainstay for management, and the standard empiric therapy for severe CAP includes beta lactam combined with macrolide or fluroquinolone (Metlay et al. 2019). Drainage of secretions, oxygenation, fluid, nutrition, and glycemic control are also essential components. HAPs are usually resistant to several antibiotics.

Depending on an individual patient's clinical condition and tolerance, the mode, dose, and duration of oxygen therapy is decided to manage their pneumonia. The modes may be through simple oxygenation or ventilation. As discussed, the common delivery systems for simple oxygenation are nasal cannula, simple face mask, nonrebreather mask, or high-flow devices.

Where standard oxygenation fails, the patient may require assistance in ventilation (noninvasive, such as BiPAP/CPAP, or invasive). Noninvasive ventilation is preferred if the sensorium and hemodynamics are stable. Severe pneumonia, as in those with ARDS or respiratory failure, may require endotracheal intubation and invasive mechanical ventilation. Post extubation, a low dose of oxygen through oxygen mask or nasal cannula should be continued until the desired oxygen saturation levels are achieved.

The COVID-19 pandemic highlighted the importance of building resilient oxygen ecosystems, as hypoxemia was commonly seen in severe and critical infections (Li and Ma 2020; Reyes et al. 2020) (Table 6). Asymptomatic or mildly symptomatic patients may have features of underlying hypoxia (aptly labeled “happy hypoxia”) and also require oxygen therapy. In these patients, adopting an awake prone position for at least six hours per day improves oxygenation and decreases the risk of endotracheal intubation (Li and Ma 2020; Center for Devices and Radiological Health 2023). In moderate to severe cases, high-flow delivery systems are preferred, as they provide humidified oxygen and better patient tolerance. However, given the potential risk of aerosol spread with high-flow oxygen, it requires standard precautions.

Apart from supplemental oxygen therapy, various medications, such as antivirals, antibiotics, and steroids, may be part of COVID-19 management. Experimental agents (remdesivir, tocilizumab, interferons, plasma) had demonstrated variable efficacy and were also considered case by case during the COVID-19 pandemic.

Table 3. 2007 Infectious Diseases Society of America/American Thoracic Society Criteria for Severe Community-Acquired Pneumonia

Major criteria	Minor criteria
• Septic shock with need for vasopressors • Respiratory failure requiring mechanical ventilation	• Respiratory rate ≥30 breaths/min • PaO_2/FiO_2 ratio ≤250 • Multilobe infiltrates • Confusion/disorientation • Uremia (blood urea nitrogen level ≥20 mg/dl) • Leukopenia (white blood cell count <4,000 cells/µl) • Thrombocytopenia (platelet count <100,000/µl) • Hypothermia (core temperature <36.80C) • Hypotension requiring aggressive fluid resuscitation

Table 4. Etiological Agents of Neonatal Pneumonia

Bacterial	Viral	Atypical
Group B Streptococci	Respiratory Syncytial Virus	*Chlamydia spp.*
Streptococcus pneumoniae	Human Metapneumovirus	*Mycoplasma spp.*
Enteric gram-negative *bacilli*	Influenza Virus A	
Listeria monocytogenes	Influenza Virus B	
Staphylococcus aureus	Severe Acute Respiratory Syndrome Coronavirus 2	
	Human Rhinovirus	
	Herpes Simplex Virus	
	Other Human Beta Coronavirus	

Table 5. Etiological Agents of Community-Acquired Pneumonia in Adults

Bacterial	Viral	Atypical
Streptococcus pneumoniae	Respiratory Syncytial Virus	*Chlamydia* spp.
Hemophilus influenzae	Human Metapneumovirus	*Mycoplasma* spp.
Moraxella catarrhalis	Influenza Virus A	*Legionella pneumophila*
Klebsiella pneumoniae	Influenza Virus B	
Staphylococcus aureus	Severe Acute	
	Respiratory Syndrome Coronavirus 2	
	Human Rhinovirus	
	Herpes Simplex Virus	
	Other Human Beta Coronavirus	

Continuous monitoring of oxygen saturation and vital signs are crucial. Once the target SpO_2 is achieved or as per clinical discretion, oxygen can be weaned.

Table 6. Severity of COVID-19 Infections

Severity	COVID-19 signs
Nonsevere	No signs of respiratory insufficiency
Severe	Oxygen saturation <90%, signs of pneumonia or respiratory distress
Critical	Signs of sepsis and septic shock; requires life-sustaining treatment

Compliance with strict infection control measures is essential. This includes donning personal protective equipment, including a well-fitting N95 mask. Oxygen should be administered in an isolated room or a room with a similar patient cohort. Placing a bacterial/viral filter between the reservoir bag and mask during bag-mask ventilation is important. Intubation must be attempted only by skilled professionals. Bronchodilation through nebulizers is contraindicated in COVID-19 infections and should be replaced with metered dose inhalers to reduce the spread of infection.

Pediatric COVID-19 cases must be handled with special care. Airway suctioning for meconium clearing should be avoided in neonates. CPAP should be preferred over HFNC, and an aerosol box during intubation is recommended. Neonates must be kept in incubators and placed six feet apart. Although bacterial/viral filters are recommended for manual ventilation, to avoid hypercapnia, filters should be avoided in extremely low birthweight babies (<1,000 grams).

Neonatal Disorders

Neonatal disorders manifest during the first 28 days of life. Various factors, including genetics, environment, or infections, may play a role in disease development. According to the Global Burden of Disease 2019, the prevalence of neonatal disorders is 1,195.73 per 100,000, and they contribute to 3.33 percent of total deaths. The prevalence of congenital birth defects is 657.35 per 100,000 and they contribute to 0.97 percent of total deaths (Vos et al. 2020).

Some of the common neonatal conditions that may require oxygenation are as follows:
1. Infections and sepsis
2. Respiratory distress syndrome (RDS)
3. Birth asphyxia (perinatal or neonatal)
4. Congenital defects of the heart and lungs

Management of neonatal disorders depends on disease severity and underlying causes. Early diagnosis, medications, oxygen therapy, and surgical corrections are often required. Surfactant replacement therapy is also helpful in RDS. We summarize the role of supplemental oxygen in the management of RDS and birth asphyxia.

Neonatal RDS, also known as "infant RDS," predominantly affects premature newborns. It is characterized by immature lung development and insufficient surfactant production. Birth asphyxia (perinatal or neonatal), another neonatal condition, commonly occurs due to prolonged labor, placental anomalies, or umbilical cord compression. Both conditions result in breathing difficulties and hypoxemia. These can cause developmental delays, cerebral palsy, intellectual disabilities, seizures, and even death. As these are medical emergencies, it is crucial to administer oxygen in a timely manner to minimize complications and improve chances of survival.

The mode, dose, and duration of oxygen therapy is decided depending on the condition and oxygen saturation levels. Some common methods of delivery are as follows:

- Nasal CPAP – refers to a constant flow of air through small prongs in the nostrils. The positive pressure keeps the air sacs open and allows the baby to breathe comfortably.
- Mechanical ventilation – refers to using a ventilator to deliver oxygen and control breathing. This is required in severe cases of RDS, such as when the infant's lungs are extremely underdeveloped and unable to maintain adequate oxygen levels.
- High-frequency ventilation – uses a breathing machine to deliver lower-pressure air puffs into the lungs.
- ECLS – uses a heart-lung pump to give temporary life support. Standard treatment guidelines for birth asphyxia have been published by the Indian Council of Medical Research (ICMR) (ICMR and Department of Health Research Ministry of Health and Family Welfare Government of India 2020).

The aim of supplemental oxygenation is to maintain oxygen saturation in the blood while avoiding excessive exposure. Continuous monitoring of vital signs is essential, as hyperoxia can lead to complications such as retinopathy of prematurity, bronchopulmonary dysplasia, or encephalopathy (Ali et al., 2021).

Anaphylaxis

Anaphylaxis is a potentially life-threatening reaction that can occur rapidly after exposure to an allergen, such as certain foods, insect stings, medications, or materials. It constricts the airways, resulting in wheezing, shortness of breath, and cyanosis. Management is a multipronged approach that includes stabilization with drugs (epinephrine, antihistamines, and glucocorticosteroids), fluids, and oxygen and addressing the underlying cause.

The aim of oxygen therapy is to attain the target saturation and manage respiratory distress. For milder cases, the commonly used delivery devices are nasal cannulas and face masks. Endotracheal intubation may be required for cardiac or circulatory arrest. For anaphylaxis with predominant cardiovascular reaction and significant hypoxemia, a mask with a reservoir bag helps to increase inspired oxygen content above 0.5 (Ring et al. 2014). A pulse oximeter is used to continuously monitor oxygen saturation levels and assess the effectiveness of therapy.

Drowning

Drowning results from submersion or immersion in liquid and can compromise respiration. Although the majority of victims aspirate little liquid and recover spontaneously, management of significant aspiration is done by rescue and resuscitation emergency teams. For conscious patients, basic life support and in-water resuscitation by trained rescuers has favorable outcomes. For cardiac arrest, cardiopulmonary resuscitation (CPR) and the principles of management of airway–breathing–circulation should be followed. If the lungs are flooded with fluid, a face mask can be used to administer oxygen up to 15 L/min. However, for clinical deterioration or fatigue, early intubation and mechanical ventilation are indicated. Mechanical ventilation must not be weaned for at least 24 hours. For patients admitted in the intensive care unit, ARDS guidelines for ventilation are followed.

Head Injury

Head injury results from trauma to the skull or brain and requires urgent treatment to secure the airway and maintain ventilation and circulation. A variety of medications (including mannitol and steroids) and neurosurgical interventions are often required.

Both hypoventilation and hyperventilation should be avoided. Hypoventilation results in increased CO_2 levels in the blood, cerebral hyperemia, and increased intracranial pressure; hyperventilation results in vasoconstriction and tissue hypoxia. Ventilatory settings for FiO_2 should be adjusted to achieve a PaO_2 of ~90 mmHg. As with other conditions, oxygen is weaned once the target SpO_2 is achieved or as per clinical discretion (Dash and Chavali 2018).

Poisoning (carbon monoxide)

Carbon monoxide (CO) is a colorless and odorless gas produced during incomplete burning of organic matter.It has a higher affinity to hemoglobin than that of oxygen. Inhaling excessive amounts results in loss of consciousness, arrhythmias, seizures, or sometimes death. CO poisoning is diagnosed by measuring CO levels in hemoglobin.

For suspected CO poisoning, the patient must be immediately removed from the exposure site and administered high-flow (100 percent) normobaric oxygen via a nonrebreathing face mask (irrespective of pulse oximetry or PaO2). Since oxygen delivery via a nonrebreather mask shortens the half-life of CO from 320 to 80 minutes, therapy must be continued for 4–5 hours or until reversal of symptoms. Hyperbaric oxygen therapy (HBOT) benefits are maximized if administered within the first 6 hours of exposure. It decreases the half-life of CO in blood and increases the concentration of oxygen so that nonbound oxygen is delivered to the tissues. CPR may be required for an unconscious individual. Increased muscle activity and seizures should be treated with dantrolene or diazepam.

Sepsis

Sepsis is a life-threatening medical emergency that occurs when the immune system overreacts to an infection (Table 7) (Thompson et al. 2019). It can be categorized into three stages: (1) initial sepsis (2) severe sepsis (3) septic shock.

During the initial stage of sepsis, the immune response results in fever, rapid heart rate and breathing, an altered mental status, and abnormal laboratory results. If not managed in time, the patient can progress to severe sepsis or septic shock, with worsening of organ functions, hemodynamic issues, breathing difficulties, and deterioration of the sensorium. The Sequential Organ Failure Assessment (SOFA) criteria, quick SOFA criteria, National Early Warning Score, and the Modified Early Warning Score are commonly used screening tools. An acute change in total a patient's SOFA score by ≥2 points following an infection signals organ dysfunction.

Table 7. Etiological Agents of Sepsis

Site	Etiological agent
Pulmonary	*Streptococcus pneumoniae, Staphylococcus* spp., *Mycoplasma* spp., *Legionella* spp., gram-negative bacilli, viruses
Abdominal	Enteric gram-negative bacilli (for example, *Escherichia coli*, *Klebsiella* spp., *Enterococcus* spp., anaerobes, *Candida* spp.)
Skin/soft tissue	*Streptococcus* spp., *Staphylococcus aureus*, gram-negative bacilli
Urinary	Gram-negative *bacilli*, *Enterococcus* spp.
Intravascular catheters	Methicillin-resistant *Staphylococcus aureus*, coagulase negative *Staphylococcus* (CONS), Gram-negative bacilli
Central nervous system	*Neisseria* spp., *Streptococcus pneumoniae,* Gram positive *cocci*
Endocarditis	Methicillin-sensitive *Staphylococcus aureus*, CONS

Management includes source control, antibiotics (empiric within an hour of resuscitation), fluids (crystalloids as the first line), vasopressors, supportive oxygen therapy, treating complications, and constant monitoring (Forrester 2023; Evans et al. 2021).

Usually, for mild hypoxia, oxygen is administered by mask or nasal prongs. However, HFNC is preferred for moderate to severe hypoxia, as it can deliver oxygen at 60 L/min. Mechanical ventilation and tracheal intubation may be required in severe hypoxia with respiratory failure. Although oxygen therapy has an anti-inflammatory effect and is a lifesaving agent, hyperoxia in sepsis can escalate multiorgan failure by stimulating the release of excessive reactive oxygen species (Vincent et al. 2017). Oxygen is weaned once sepsis is controlled and target SpO_2 achieved.

Home Care

Oxygen therapy may be required in home settings, as it helps to improve survival and reduce the risk of recurrent hospitalization. Concentrators and cylinders are the oxygen sources used.

Home oxygen therapy can be of the following types:

- Long-term oxygen therapy (LTOT) – lasts for 15–18 hours per day. LTOT is indicated for COPD, end-of-life\ palliative care, and other chronic causes of hypoxia. Although several studies have highlighted the positive impact of LTOT over a certain period, evidence is still lacking on its compliance, target saturation, and weaning in home settings.
- Ambulatory oxygen therapy – refers to oxygen for hypoxia from daily activities or exercise.
- Short-burst oxygen therapy – refers to oxygen in short bursts or a short time without hypoxia. It is usually after physical exertion.
- Nocturnal oxygen therapy – refers to use of oxygen at night.

As oxygen can be a potential fire hazard, the following precautions must be observed:

- Keep the oxygen source in the open.
- Maintain a distance of five feet or more between the oxygen source and heat.
- Do not administer medical oxygen when cooking.
- Do not use electrical appliances and gadgets near the oxygen source.
- Do not smoke at home or use aerosol-generating devices where oxygen sources are kept.
- Keep a fire extinguisher as a standby, and ensure caretakers are aware of fire safety.

HBOT

HBOT is usually available at specialized tertiary care centers and commonly indicated for air or gas embolism, CO poisoning, acute thermal burns, decompression sickness, necrotizing soft tissue infections, crush injuries, refractory osteomyelitis, arterial insufficiencies, and severe anemia. It may not be safe or effective for HIV/AIDS, brain and spinal cord injury, heart disease, stroke, asthma, depression, and sports injuries (Johns Hopkins Medicine 2022). Patients must be evaluated for hypoglycemia or risks of seizure in advance.

Palliative Care

Palliative care is decided based on patient needs rather than prognosis and aims to enhance quality of life, especially for serious illnesses and end-of-life care. It helps to relieve pain, breathlessness, fatigue, nausea, and vomiting. The usual treatment includes analgesics, antiemetics, bronchodilators, and oxygen. Oxygen has been demonstrated to improve quality of life and alleviate symptoms, especially for those with moderate to severe dyspnea. For patients with PaO_2 >55 mmHg, oxygen delivered at a rate of 2 L/min via nasal cannula does not offer a significant improvement over ambient air. Physicians often prescribe palliative oxygen for patients with refractory dyspnea and PaO_2 >55 mmHg. Historically, health care judgments about palliative oxygen have been supported by a compassion-based justification. Nonpharmacological treatment should also be considered for end-of-life care.

Oxygen Audit and Good Clinical Practices

Oxygen Audit

Amid the challenges posed by the COVID-19 pandemic, numerous Indian states proactively issued directives emphasizing the critical significance of oxygen audits. These guidelines further underscored the establishment of institutional audit committees tasked with formulating comprehensive oxygen policies and audit protocols. The purpose of such audits extends to meticulously examining various operational facets, including oxygen prescriptions, individual patient usage, supply chain intricacies, and equipment management. This strategic approach not only promotes the judicious use of oxygen but also enhances the overall oxygen equipment infrastructure and supply chain resilience, particularly in the face of emergencies such as the pandemic (O'Driscoll et al. 2017; Dodd et al. 2000).

An oxygen audit is a versatile process that can be executed by either an internal committee, comprising professionals spanning diverse roles, such as physician, finance manager, technician, pharmacist, and nursing staff, or external agencies with specialized expertise. Initiatives centered around audit-based sensitization programs have demonstrated their efficacy, yielding a substantial 20–25 percent reduction in medical oxygen requirements and consumption (Singh and Singh 2022).

Recognizing the imperative for robust health systems and elevated clinical care standards, capacity-building and program surveillance emerge as indispensable components of any public health initiative. In response to the unique challenges posed by the pandemic, the Ministry of Health and Family Welfare, Government of India, took a proactive step by launching the National Oxygen Stewardship Program. It is specifically designed to equip health care workers with the requisite skills to use oxygen judiciously throughout a patient's journey, while aiming to minimize wastage (Chand 2022). This holistic approach reflects a concerted effort to fortify health care infrastructure and optimize oxygen use during health emergencies.

Good Clinical Practices

Adhering to good clinical practices is crucial during oxygen administration, and the following recommendations are essential:

1. Preassessment of Oxygen Saturation: Before oxygen therapy, it is imperative to determine the oxygen saturation, as not all individuals experiencing breathlessness may be suitable candidates.
2. Specifying Target Oxygen Saturation: Target oxygen saturation should be explicitly specified based on clinical condition.
3. ABG Analysis for Severe Hypoxia: For severe hypoxia or patients at risk of hypercapnic respiratory failure, regular ABG analysis is recommended, guided by clinical discretion.
4. Continuous Monitoring of Oxygen Saturation: Initially, oxygen saturation should be closely monitored, preferably via real-time continuous monitoring. Once the patient achieves clinical stability, oxygen administration can be reconsidered. If the target oxygen saturation is not attained, the flow rate should be increased or the mode of delivery re-evaluated.
5. Caution in Weaning or Discontinuation: Weaning or discontinuation of oxygen therapy requires careful consideration and should be undertaken with continuous monitoring.
6. Infection Control Practices: For suspected respiratory infection, strict adherence to infection control practices is essential. The patient may be isolated in a single room with negative pressure ventilation or placed in a dedicated ward.

Healthcare professionals should wear appropriate personal protective equipment, including a properly fitted N95 mask, based on the type of infection.

By following these recommended practices, healthcare providers can ensure the safe and effective administration of oxygen while prioritizing patient well-being and infection control.

Appendix

Appendix 1. Oxygen Sources

Medical oxygen is manufactured either in liquid form by air separation units (ASUs) (via a cryogenic distillation process) or in gaseous form by oxygen plants (via pressure swing adsorption [PSA] technology). A tertiary care hospital has four dierent types of oxygen sources: two are manufacturing (PSA plants and oxygen concentrators [OCs]), and two are storage (liquid medical oxygen [LMO] tanks and gaseous cylinders) (Table 8).

Air Separation Unit/Plant

An ASU produces 99.5 percent oxygen from ambient air by cryogenic fractional distillation (air-liquefaction process), and extraction at sub -181°C. ASU is typically set up for medium- to large-scale production and caters to industrial sector, with 5–10 percent of oxygen diverted toward medical supply (Figure 1).

LMO is transported using specialized insulated tankers and stored at health care facilities either in tanks (1–20 kL) or dura/microcylinders that are periodically refilled by the tankers (Figure 2). The tank supplies a centrally piped system throughout the health facility by self-vaporization, without a need for power supply. Micro/dura cylinders are portable cryogenic liquid cylinders with a capacity of 150–450 L and ideal for temporary user point applications with built-in vaporizer coils and option for an external vaporizer.

Although ASU may be an economical option in some locations, its management requires technical knowledge and large, well-ventilated spaces. Oxygen produced may be exempted from the requirements to test for CO and CO_2.

Figure 1. Air Separation Unit (Bolbik 2017)

Figure 2. Liquid Medical Oxygen tank (Gaurs 2021)

PSA Plant

A PSA plant produces 93 ±3 percent gaseous oxygen by filtering ambient air via an internal system that separates nitrogen and concentrates oxygen (Figure 3). The concentrations of other gases are variable (CO_2 <300 ppm, water vapor <67 ppm, CO <5ppm, nitrogen monoxide and dioxide <2 ppm, and sulfur dioxide <1 ppm) (WHO 2022). This oxygen can be piped directly to health care facilities or compressed to fill cylinders.

Figure 3. Pressure Swing Adsorption plant[1]

[1] Photo courtesy of CV Raman General Hospital, Bangalore (2024)

Oxygen Concentrator

An OC concentrates oxygen from air, based on the PSA technology (Figure 4). It delivers low-flow, continuous, and clean oxygen (>82 percent) from room air (21 percent) (WHO and UNICEF 2019). Small concentrators are portable and can produce 5–10 L/min; large ones produce up to 25 L/min and are more appropriate for healthcare facilities. Although portable and cost-efficient, concentrators require continuous power and regular maintenance. They can supply multiple patients at the same time and serve at different levels of health care.

Figure 4. Oxygen concentrator (Hrabar 2008)

Oxygen Cylinder

Medical cylinders contain compressed oxygen that are filled at gas manufacturing plants (ASU or PSA) or filling stations (Figure 5). They are of different sizes and named alphabetically, unlike industrial cylinders, which are numbered. The most common type of oxygen cylinders are Type B (1,500 L or 1.5 m3 at 150 bar or ~2,175 psi) and Type D (7,000 L or 7 m3 at 150 bar or ~2,175 psi) (Department of Public Health Government of Maharashtra 2021). The cylinders do not require a power supply. However, accessories, such as pressure gauges, regulators, flowmeters, and humidifiers, are essential. Cylinders can be used at all levels of the health care system.

Figure 5. Oxygen cylinders (Visuals 2021)

Table 8. Types of Oxygen Sources

	ASU	PSA	OC	LMO tanks	Gaseous Cylinder
Mechanism of oxygen production	Cryogenic distillation	Pressure swing adsorption	Pressure swing adsorption	Not applicable	Not applicable
On hospital site or offsite	Offsite	Onsite	Onsite	Onsite	Onsite
Type of source	Liquid production	Gaseous production	Gaseous production	Liquid storage	Gaseous storage
Noise	Yes	Yes	No	No	No
Oxygen capacity	5-20 MT/day (small) 100-500 MT/day (large)	30–3,200 L/min (0.06–6 MT/day)	Up to 25 L/min	Small tanks (micro /dura cylinders): 150 – 450 L Large tanks: 1 -20 kL	~0.002 MT or 1,500 L or 1.5 m3 (B type cylinder) ~0.01 MT or 7,000 L or 7 m3 (D type cylinder)
Oxygen purity	99.5% v/v	93 ±3% v/v	82 ±3% v/v	99.5% v/v	PSA refilled: 90–96% v/v LMO refilled: 99.5% v/v

(continued)

	ASU	PSA	OC	LMO tanks	Gaseous Cylinder
Power requirement	Yes (Not for LMO tank)	Yes	Yes	No	No
Portability	No	No	Yes	Small tanks: Yes Large tanks: No	Yes
Preferred hospital type	Not applicable	Medium, large	Small, medium, large	Large	Small, medium, large
Refilling requirement	Not applicable	No	No	Yes	Yes
Risk of contamination	Low	Low	High	Low	High
Risk of gas leakage	Low	High	High	High	High

Appendix 2. Oxygen Delivery

Various delivery systems exist, depending on patient requirements.

A. Low-flow delivery systems

A low-flow delivery system has flow rates lower than inspiratory demands, using nasal cannula, simple face mask, nonrebreather face mask, venturi mask, or transtracheal oxygen catheter.

- A nasal cannula (Figure 6) delivers oxygen at a flow rate < 6 L/min through small prongs that fit into the nostrils (O'Driscoll et al. 2017). The effectiveness varies from patient to patient, as the breathing pattern and respiratory rate differ for each patient.
- A simple face mask delivers oxygen at a flow rate of 6–10 L/min for a FiO_2 of 40–60 percent and has a port to exhale CO_2 (Figure 7).
- A nonrebreather face mask delivers oxygen at a flow rate of 15 L/min at 85–90 percent concentration (Figure 8). It can provide consistent FiO_2 if the seal with the face is good.
- A transtracheal oxygen catheter is a small-bore plastic cannula that is inserted through a small surgical opening into the trachea.
- The venturi mask is a low-flow mask that works on the Bernoulli principle to entrain room air and deliver pure oxygen through a small orifice, resulting in large flow and predictable FiO_2 (Figure 9).

Figure 6. Nasal cannula (Rawpixel.com 2021)

Figure 7. Simple face mask (R 2019)

Figure 8. Nonrebreather face mask (Hasim 2023)

Figure 9. Venturi mask (Presti 2014)

B. High-Flow Delivery Systems

A high-flow delivery system offers flow rates higher than inspiratory demands, using a high-flow nasal cannula (HFNC), artificial manual rebreather mask, or endotracheal tube.

- HFNC delivers adequately heated and humidified medical gas to up to 60 L/min of flow (O'Driscoll et al. 2017).
- An artificial manual rebreather mask is a hand-operated device used to assist ventilation in patients incapable of breathing adequately (Figure 10).

Figure 10. Artificial manual rebreather mask (YourBestVideo 2022)

C. Mechanical Ventilation

Mechanical ventilation is ventilatory assistance to inspiration, noninvasively or invasively. A ventilator delivers breath in a controlled manner either at a specific rate or through the patient's own breathing efforts that can be controlled through changes in flow or pressure in the circuit.

Noninvasive ventilation (NIV) is respiratory support without tracheal intubation (Popat and Jones 2012). It is the first line of treatment for COPD and mild/moderate hypoxemic respiratory failure in immunocompromised patients. It is contraindicated in severe hypoxemia, hemodynamic instability, low Glasgow coma scale score, and upper respiratory obstruction. Nasal mask, nasal pillow, helmet, and mouthpieces are the commonly used interfaces, and CPAP and BiPAP are the common modes (Table 9, Figure 11).

Table 9. Modes of Noninvasive Ventilation

	CPAP	BiPAP
Indication	Respiratory failure Type 1	Respiratory failure Types 1 & 2
Peak expiratory flow rate	5-25 L/min	3-15 L/min
Adjusted fraction of inspired oxygen	21-100%	21-100%
Airflow	Provides single set pressure	Provides pressure settings for inhalation and exhalation

Invasive ventilation is delivering oxygen through an endotracheal tube or tracheostomy. An endotracheal tube is connected to a mechanical ventilator, which tracks oxygen pressure and flow. Tracheostomy is performed given a need for prolonged ventilation, as in upper airway obstruction, failed intubation, or support therapy for head and neck trauma.

Figure 11. Continuous positive airway pressure (sbw18 2017)

Appendix 3. Oxygen Regulation

Oxygen regulation helps to control the oxygen flow as per patient requirements.

A. Flowmeter

A flowmeter (Figure 12) measures and controls the oxygen flow rate. It can be used with piped oxygen or cylinders or is inbuilt in concentrators. The Thorpe tube and bourdon gauge are the commonly used flowmeters.

Figure 12. Flowmeter (Vinten 2017)

B. Humidifier

A humidifier is used to humidify oxygen to protect respiratory mucosa from injuries, as it is a dry and cold gas (Figure 13) (La Fauci et al. 2017). Humidifiers must be disinfected when shared among multiple patients to prevent the risk of hospital-acquired pneumonia. Distilled water should be used and must be changed daily.

Figure 13. Humidifier (Itsanan 2019)

C. Blender

A blender provides an adequate mixture of gases in each breath, as per patientss requirements (Soares et al. 2022). It can be used in home care and circumvents the need for high-pressure air. Blenders modulate the fraction of inspired oxygen.

Appendix 4. Oxygen Monitoring

An oxygen monitor measures the concentration of oxygen in blood. Commonly used devices are the pulse oximeter and multiparameter monitor (Figure 14). The former measures the oxygen saturation in blood; the latter evaluates multiple parameters, such as cardiac activity, hemodynamic performance, and respiratory functions. An arterial blood gas analysis determines oxygen and carbon dioxide levels and the pH balance in arterial blood.

A pulse oximeter works on the principle of infrared emission and wavelength absorption by hemoglobin. The greater the oxygen saturation, the higher the partial pressure of oxygen (normal is above 94 percent). It can be attached to peripheral body parts (fingers, forehead, nose, feet, ears, or toes) and monitors the oxygen tension in blood during various health conditions, such as chronic obstructive pulmonary disease, anemia, cancer, and pneumonia.

Figure 14. Multiparameter monitor (Oleksandr 2019)

Appendix 5. Indian Public Health Standards

The Indian Public Health Standards categorize health care centers into three levels based on population coverage (Tables 10 and 11) (Ministry of Health & Family Welfare Government of India 2022). They recommend number/type of beds, equipment (including oxygen sources), instruments, and human resources for different centers. As per these recommendations, central oxygen storage (pressure swing adsorption plant and liquid medical oxygen tank) should be available at subdistrict and district hospitals, along with a medical gas pipeline system. Type D oxygen cylinders should be available as an alternate emergency/backup source. Most uncomplicated and nonsevere clinical conditions can be managed by primary health care. However, referral to higher levels of care may be essential depending on disease severity. The standards also estimate the peak daily oxygen requirements in district hospitals (Table 12) (Ministry of Health & Family Welfare Government of India 2022).

Table 10. Recommendations for Bed Capacity and Oxygen Sources at Health Facilities

Types of facility	Bed capacity	Oxygen-support beds	OT beds	B Type cylinder	D Type cylinder	Oxygen concentrator (10 LPM)	Recommendations
Health & Wellness Center—Sub Health Center/Urban Health & Wellness Center (HWC-SHC/UHWC)							
HWC-SHC /UHWC	2 (Day Care)	—	—	3	—	1	—
Primary Health Center (PHC)							
PHC—Rural	6	—	—	4	—	1	—
PHC—Urban	6 (Day Care)	—	—	4	—	1	—

Types of facility	Bed capacity	Oxygen-support beds	OT beds	B Type cylinder	D Type cylinder	Oxygen concentrator (10 LPM)	Recommendations
UPHC—24x7	10	—	—	5	—	1	—
Community Health Center (CHC)							
Non-FRU CHC	30	18	2	10	20	5	- D type cylinder manifold 10 x 10 - Reserve cylinders and concentrators
FRU CHC	30	20	2	10	20	5	- D type cylinder manifold 10 x 10 - Reserve cylinders and concentrators
FRU CHC	50	26	2	15	30	7	- D type cylinder manifold 10 x 10 - Reserve cylinders and concentrators - PSA plant/ LMO tank
FRU UCHC	100	43	3	20	40	10	- D type cylinder manifold 20 x 20 - Reserve cylinders and concentrators - PSA plant/ LMO tank
Sub District Hospital (SDH)							
SDH	100	67	9	20	40	10	- D type cylinder manifold 20 x 20 - Reserve cylinders and concentrators - PSA plant/ LMO tank

Types of facility	Bed capacity	Oxygen-support beds	Ventilator supported beds	B Type cylinder	D Type cylinder	Oxygen concentrator (10 LPM)	Recommendations
District Hospital (DH)							
DH	50	34	2	15	30	7	- D type cylinder manifold 20 x 20 - Reserve cylinders and concentrators - PSA plant/ LMO tank
	100	67	9	20	40	10	- D type cylinder manifold 20 x 20 - Reserve cylinders and concentrators - PSA plant/ LMO tank
	200	107	15	Manifold room needs to be established as per the local need of the health care facility			
	300	148	22				
	400	188	28				
	500	232	31				

Source: Ministry of Health & Family Welfare Government of India 2022

Table 11. Recommendations for Staffing Requirements at Health Facilities

Sub Health Center (SHC)	Primary Health Center (PHC)	Community Health Center (CHC)	Subdistrict/District Hospital (SDH/DH)
Rural • Community health officer • Multipurpose worker-female/auxiliary nurse midwife • Multipurpose worker-male **Urban** • Medical officer • Staff nurse • Multipurpose worker-male • Sanitary staff • Security staff	• General medicine • Obstetrics & gynecology • Pediatrician • Ophthalmologist • Dermatologist • Psychiatrist • Medical officer **Allied health** • Staff nurse • Medical laboratory • Technologist/lab technician • Physiotherapist • Counselor • Optometrist/ophthalmic • assistant/vision technician • Dental assistant • Pharmacist	• General medicine • General surgery • Obstetrics & gynecology • Pediatrician • Anesthesiologist • Ophthalmologist • Medical officer • Dentist **Allied health** • Staff nurse • Medical laboratory • Technologist/lab • technician • Clinical psychologist • Physiotherapist • Social Worker • Counselor • Dietician • Electrocardiography technologist/technician • OT technologist/OT • technician • Radiology technician • Optometrist/ophthalmic • assistant/vision technician • Dental technician • TSSU assistant • Pharmacist	**Essential staff** Medical officer General medicine General surgery Obstetrics & gynecology Pediatrician Orthopedic Anesthesiologist Ophthalmologist Dentist ENT Psychiatry Radiologist **Desirable staff** Dermatologist Cardiologist Nephrologist Gastroenterologist **Allied health** Staff nurse Medical lab technologists Pharmacist Clinical psychologist Physiotherapist Medical social worker Dietician Electrocardiography technologist/technician Echo technologist/technician Radiology and radiographer Ophthalmic assistant/vision Technician/optometrists

Source: Ministry of Health & Family Welfare Government of India 2022, adapted from IPHS 2022

Table 12. Recommendations for Peak Daily Oxygen Requirement in District Hospitals

District hospital number of beds	Oxygen-supported beds	Ventilatory-supported beds	Oxygen requirement (for oxygen-supported beds, assuming 10 L/min is the requirement) in L	Oxygen requirement (for ventilatory-supported beds, assuming 30 L/min is the requirement) in L	Total oxygen requirement in L/day	Total oxygen requirement in MT/day
50 beds	34	2	489,600	86,400	576,000	0.75
100 beds	67	9	964,800	388,800	1,353,600	1.75
200 beds	107	15	1,540,800	6,48,000	2,188,800	2.8
300 beds	148	22	2,131,200	950,400	3,081,600	4.0
400 beds	188	28	2,707,200	1,209,600	3,916,800	5.1
500 beds	232	31	3,340,800	1,339,200	4,680,000	6.1

Source: Ministry of Health & Family Welfare Government of India 2022, adapted from IPHS 2022

Appendix 6. Oxygen Metrics

Oxygen Conversion Metrics

1. **To Convert Oxygen (Gaseous) from m3 to Metric Ton (MT)**

   Oxygen's density in gaseous form must be taken into consideration.
   1 m3 of oxygen = 1.2987 kg (approx. at room temperature)
   = 1.2987/1000 MT
   = 0.0012987 MT
   Therefore, to obtain the value in MT, multiply the m3 value by 0.0012987.

   For example, 100 jumbo cylinders (D type) = 100 x 7m3 x 0.0012987 = 0.9 MT
   100 B type cylinders = 100 x 1.5m3 x 0.0012987 = 0.19 MT

2. **To Convert kL (Liquid Oxygen) to MT**

   1 L of liquid oxygen = 1.1417 kg
   1 kilo L (kL) = 1,141.7 kg
   Therefore, 1 kL = 1.1417 MT

   For example, 10 kL = 10 x 1.1417 = 11.417 MT

3. **Gas Oxygen LPM to MT/Day**

   First, convert from 1 L/min to 1 L/day.
   1 L/min = 1,440 L/day
   1 L of gas = 0.0012987 kg
   Weight (kg) per day = 1,440 x 0.0012987 = 1.87 kg/day = 0.00187 MT/day
   Therefore, 1 L/min = 0.00187 MT/day

   For example, 500 L/min PSA plant = 500 x 0.00187 = 0.93 MT/day

Oxygen Demand Calculation

1. **Based on Bed Occupancy**

   a. **Low-Flow Bed Demand**

$$= \frac{\text{Number of occupied beds x flow rate (in LPM) X number of minutes in a day}}{\text{1,000 X 770}}$$

$$= \frac{\text{100 beds x 10 (in LPM) X 1,440 minutes}}{\text{1,000 X 770}} = \text{1.87 MT}$$

   b. **High-Flow Bed Demand**

$$= \frac{\text{Number of occupied beds x flow rate (in LPM) X number of minutes in a day}}{\text{1,000 X 770}}$$

$$= \frac{\text{100 beds x 30 (in LPM) X 1,440 minutes}}{\text{1,000 X 770}} = \text{5.61 MT}$$

   c. **Based on Active Caseload**

   For example, active cases: 1,000

   Active cases not requiring oxygen therapy:

   - Cases requiring home isolation: 80% of active cases = 800
   - Cases requiring hospitalization: 8% of active cases = 80

   Active cases requiring oxygen therapy:

   - Cases requiring low-flow oxygen beds: 8% of active cases = 80
   - Cases requiring high-flow oxygen beds: 4% of active cases = 40

As the bed occupancy based on active caseload has been calculated, medical oxygen demand can now be calculated based on the listed formulae in (a) low-flow bed demand and (b) high-flow bed demand.

Oxygen Consumption Calculation

1. **Oxygen Cylinders**

   (i) D type: (no. of D type cylinders ×7)/ 770 (in MT/day)
   For example, 110 x 7/770 = 1 MT/day

   (ii) B type: (no. of B type cylinders ×1.5)/ 770 (in MT/day)
   For example, 110 x 1.5/770 = 0.21 MT/day

2. **LMO (LMO Tank or Dura Cylinders)**

   (i) Dura cylinder (in L): (volume of LMO (in L) × 877.77)/ (770 × 1,000) (in MT/day)
   For example, 200 x 877.77/ (770 × 1,000) = 0.22 MT/day

   (ii) LMO tank (in kL): (volume of LMO (in kL) × 877.77)/770 (in MT/day)
   For example, 1.2 x 877.77/770 = 1.36 MT/day

3. **PSA Plant**

   PSA (in LPM): (no. of hours/day of operation x PSA plant capacity (in LPM))/24×0.00187(in MT/day)
   For example, 12 x 800/24 x 0.00187 = 0.75 MT/day

4. **Concentrators**

   Concentrators: (no. of concentrators x no. of hours/day of operation x flow rate (in LPM))/24×0.00187 (in MT/day)
   For example, 30 x 12 x 10/24 x 0.00187 = 0.28 MT/day

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ONE HEALTH TRUST

One Health Trust
Actionable research to improve health and well-being worldwide

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We live in an interconnected world: the health and well-being of the environment, animals, and humans are intertwined in ways that are increasingly more apparent. Tackling today's greatest challenges— climate change, pandemics, unstable food systems, and drug resistance—requires an approach that recognizes these relationships.

The One Health Trust (OHT) uses research and stakeholder engagement to improve the health and well-being of our planet and its inhabitants. For 15 years, OHT researchers have executed vital research and initiatives on major global health challenges, including COVID-19, antimicrobial resistance, hospital infections, tuberculosis, malaria, pandemic preparedness and response, vaccines, medical oxygen shortages, and noncommunicable diseases. OHT's mandate includes issues related to climate change, biodiversity protection, the social determinants of health, and the effect of changing human diets on the planet.

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