Ministry of National Health Services,
Regulations and Coordination
Government of Pakistan

NATIONAL OXYGEN THERAPY GUIDELINES FOR CHILDREN

PAKISTAN PEDIATRIC ASSOCIATION PPA

unicef

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National Oxygen Therapy Guidelines for Children

GOVERNMENT OF PAKISTAN
MINISTRY OF NATIONAL HEALTH SERVICES,
REGULATIONS & COORDINATION

Islamabad the 28th June, 2022

Secretary

Subject: **NATIONAL OXYGEN THERAPY GUIDELINES FOR CHILDREN**

On behalf of the Ministry of National Health Services, Regulations & Coordination, Secretary, M/o NHSR&C is pleased to endorse the first edition of the National Oxygen Therapy Guidelines for Children. These guidelines have been developed in response to the need for evidence-based standards in improving quality of care in monitoring and managing children on oxygen therapy. These Guidelines have been developed in line with the National Health Vision 2016-25, with the focus to improve quality of care and improving health outcomes for all, with particular emphasis on newborn and child health status.

2. This document was developed and contextualized for Pakistan based on existing global guidelines, Secretary M/o NHSR&C believes that the guidelines will prove to be a useful tool for provincial healthcare professionals at all facility levels and recommends all concerned to ensure these guidelines are put into practical use as intended, and thus achieve the objectives of improving quality of care and reducing mortality of neonates and children on oxygen therapy.

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Foreword

Infant and child mortality rates reflect a country's socio-economic status and quality of life. Although globally much progress has been made over the last decade, with a decline in under five mortality rates from 93 deaths per 1,000 live births in 1990 to 37 per 1,000 live births in 2020. This latter figure is still high and is equivalent to 1 in 27 children dying before reaching the age of five.

In Pakistan the under five-year-old mortality rate was 74 per 1,000 live births (2018). Neonatal mortality rates have decreased gradually over the decades and are currently 40 per 1,000 live births. Pneumonia is one of the most common childhood illnesses and the single largest infectious cause of death in children. Pakistan has one of the largest numbers of child pneumonia deaths in the region. It was the cause of death in 14% of under five-year-old children in 2018 and was the third most common cause of death in this age group. An estimated 12-20 children will die from pneumonia before their fifth birthday. Many of these deaths are preventable and treatable with use of simple, low-cost interventions and care.

Hypoxemia or insufficient oxygen in blood is a common and potentially lethal complication of pneumonia and other Acute Respiratory tract Infections (ARIs) such as bronchiolitis, and bronchial asthma in under five-year-olds. According to the WHO, about 13% of under five-year-olds with hypoxemia were due to pneumonia that required treatment in health care settings. Early detection of hypoxemia, oxygen therapy and monitoring can improve the outcome of children with these conditions. In countries like Pakistan, healthcare facilities may have systems in place to deliver oxygen therapy, but due to irregular supplies, inadequate maintenance of equipment, lack of training of staff and guidelines, the services remain inaccessible to sick children. With this backdrop in mind, it was essential to develop the first National Oxygen Therapy Guidelines for Children to improve the quality of care in monitoring and managing children on oxygen therapy at all levels of healthcare facilities. The Ministry of National Health Services, Regulations & Coordination, in collaboration with Health Services Academy, Islamabad and Pakistan Pediatric Association (PPA), with support from global partners UNICEF and WHO, has developed the National Oxygen Therapy Guidelines for children in June 2022. These guidelines have been mainly adapted from WHO recommendations, and supplemented by best practices and technical expertise from Pakistan Pediatric Association. The guidelines focus on improving the quality of care for severely ill children in primary, secondary, and tertiary level facilities. The importance of early detection of hypoxemia, the sources and use of oxygen therapy, and monitoring of children on oxygen treatment with appropriate infection control measures are detailed in the document. Training materials based on the guidelines have also been formulated. It is hoped that the guidelines will be put to practical use at all healthcare facility levels in the country, and the provinces will ensure the implementation of this useful document in

improving quality of care for children, and reducing neonatal and child mortality in their respective regions.

I wish to acknowledge and commend the technical expertise of Pakistan Pediatric Association, the contributions of Health Services Academy, Islamabad, the support of development partners UNICEF and WHO, and the provincial representatives who took part in consultative workshops in developing these guidelines.

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Acronyms

AHA	American Heart Association
ARI	Acute Respiratory Tract Infections
BP	Blood Pressure
CFT	Capillary Filling Time
COVID 19	Corona Virus Disease 2019
CPAP	Continous Positive Airway Pressure
HBB	Helping Babies Breath
ICU	Intensive Care Unit
IMNCI	Integrated Management of Neonatal and Childhood Illness
NIRS	Near-Infrared Spectroscopy
IPC	Infection Prevention Committee
LED	Light Emitting Diodes
MDG 4	Millennium Development Goal 4
PEEP	Positive End Expiratory Pressure
PPHN	Persistent Pulmonary Hypertension of Newborn
PPE	Personal Protective Equipment
RDS	Respiratory Distress Syndrome
ROP	Retinopathy of Prematurity
SDG	Sustainable Development Goal
WHO	World Health Organization

Acknowledgements

The Ministry of National Health Services, Regulations and Coordination (MoNHS, R&C), in collaboration with Pakistan Pediatric Association (PPA) and Health Services Academy (HSA) Islamabad, and UN partners UNICEF and WHO has developed the National Guidelines on Oxygen Therapy for Children in June 2022. These guidelines will be a major contribution in improving quality of care in managing and monitoring children on oxygen therapy.

The Ministry of National Health Services, Regulations & Coordination (MoNHS,R&C) would like to extend its sincere thanks to the organizations and persons involved in contributing time and effort in developing the National Guidelines on Oxygen Therapy for Children. Particular mention and thanks to the content developers from Pakistan Pediatric Association, UNICEF HQ and Regional Office for their dedicated time and review of resource material. Special thanks to the provincial representatives for their feedback in the National Consultative Workshop in April 2022. Other key contributors whose hard work, dedication and efforts in leading the process of developing the guidelines is highly appreciated by the Ministry; and include the following:

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Table of Contents

List of Figures

List of Tables

Chapter 1
1. INTRODUCTION

1.1. Background

Globally, over the last decade there has been a decline in under five mortality rates from 93 deaths per 1,000 live births in 1990 to 37 per 1,000 live births in 2020 (UNICEF). This is equivalent to 1 in 11 children dying before reaching five years of age as compared to 1 in 27 in the year 2020. More than 80% of the total number (five million) of under five-year-old deaths occur in two regions – Sub Saharan Africa and Southern Asia, and in terms of live births these account for 53% in the year 2020 [1].

Pneumonia is one of the most common childhood illnesses and the single largest infectious cause of death in children. According to UNICEF and WHO reports, over 800,000 deaths every year in under five-year-olds (including over 153,000 neonatal deaths) are due to pneumonia. This accounts for 14% of all deaths in children under five years old; and contributes to 22% of deaths in children aged 1-5 years. Many of these deaths are preventable and treatable with use of simple, low-cost interventions and care [2, 3].

Hypoxemia or insufficient oxygen in blood is a common and potentially lethal complication of pneumonia and other Acute Respiratory tract Infections (ARIs) such as bronchiolitis, and bronchial asthma in under five-year-olds. Hypoxemia can also occur in non-respiratory acute childhood illnesses such as sepsis, encephalitis/meningitis, malaria, malnutrition, acute febrile encephalopathy and in neonates with sepsis, and prematurity. According to the WHO, about 13% of under five-year-olds with hypoxemia were due to pneumonia that required treatment in health care settings. It was estimated that many others did not access health care, and were thus unaccounted for. Hypoxemia is often not given priority in resource constrained settings, despite evidence that shows routine and systematic screening for hypoxia along with adequate supplies of oxygen can improve quality of care and reduce child mortality in developing countries [4, 5]. Early detection of hypoxemia, oxygen therapy and monitoring can improve the outcome of children with these conditions [6].

In Pakistan the under five-year-old mortality rate was 74 per 1,000 live births (2018). Neonatal mortality rates have decreased gradually over the decades and are currently 40 per 1,000 live births. Pneumonia was the cause of death in 14% of under five-year-old children in 2018 and was the third most common cause of death in this age group. Pakistan has one of the largest number of child pneumonia deaths in the region [2,7]. In countries like Pakistan, healthcare facilities may have systems in place to deliver oxygen therapy, but due to irregular supplies, inadequate maintenance of equipment, lack of training of staff and guidelines, the services remain inaccessible to sick children [5,8]. Under the Essential Package of Health Services all health care facilities should have medical oxygen supplies. The timely detection of hypoxemia using pulse oximetry, and appropriate use of oxygen therapy with monitoring of children on oxygen is crucial in reducing the mortality of children.

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1.2. Purpose of the manual

The guidelines focus on improving the quality of care for severely ill children in primary, secondary, and tertiary level facilities. The importance of early detection of hypoxemia, the sources and use of oxygen therapy, and monitoring of children on oxygen treatment with appropriate infection control measures is the focus of the guidelines. The objectives include

- Increase awareness for improving the availability of oxygen therapy for children
- Identification and management of hypoxemia in severely ill children
- Improve monitoring of children while on oxygen therapy
- Increase practical skills of health care providers for oxygen therapy
- Ensure use of infection prevention measures during oxygen therapy

1.3. Target audience

The guidelines are aimed at clinical and administrative personnel in primary, secondary and tertiary level facilities. These include

- Health Care Providers
- Policy Makers
- Child Health Program Managers
- Health Facility Administrators
- Allied Health Professional Staff involved in the care of children
- Medical And Paramedical Pre-Service Training Institutions

1.4. Development process

The guidelines were developed by

- Desk review of available documents and evidence-based studies
- National consultative process with stakeholders led by Health Services Academy, Islamabad; in collaboration with Pakistan Pediatric Association (PPA) and UNICEF

Chapter 2
2. HYPOXEMIA AND HYPOXIA

It is important for healthcare providers to be clear on definitions of terms around oxygen levels and saturation.

2.1. Definitions

- **Hypoxemia** means low level of oxygen in blood (low blood oxygen saturation).
- **Hypoxia** is inadequate oxygen in tissues for normal cell and organ function, and hypoxia results from hypoxemia.

Arterial oxygen saturation is referred to as SaO_2 when measured by gas analysis and as SpO_2 when measured by pulse oximetry. The normal range of SpO_2 at sea level is 97–99%, with a lower limit (mean minus 2 standard deviations) of 94%. [9] Therefore, the percentage is lower in children living at high altitude because of a lower partial oxygen pressure (PaO_2) at higher altitude (see **Figure 1**).

In practice, the threshold at which oxygen is given is often SpO_2 < 90%, which corresponds to the flat part of the hemoglobin–oxygen dissociation curve (**see Figure 2**) and represents a safe margin of error where there are sufficient oxygen supplies. Small reductions in SpO_2 below 90% may represent a dangerous fall in PaO_2 (steep part of the curve).

Oxygen therapy at higher thresholds than 90% SpO_2 are required in some conditions, such as serious impairment of oxygen delivery from the lungs to body tissues and when the vital organs are particularly susceptible to low oxygen delivery. Examples include severe anemia (in which hemoglobin may be normally saturated but provides insufficient oxygen because of less hemoglobin), severe heart failure, severe sepsis, brain injury or in critically ill children with emergency signs. In these conditions, especially during the resuscitation phase, oxygen should be given if the SpO_2 is < 94%.

2.2 Transport, delivery, and consumption of Oxygen

Oxygen is transported from air that we breathe to cells where it is utilized in energy generation. At each step the partial pressure of oxygen decreases in a process known as the oxygen cascade.

Atmosphere to Alveolus

The air (atmosphere) has a total pressure of 760 mm Hg at sea level (1 standard atmosphere). Oxygen constitutes 21% of air. The partial pressure of oxygen (PO_2) in dry air at sea level is therefore 159mm Hg (21/100 x 760 = 159). However, by the time the inspired air reaches the trachea it has been warmed and humidified by the upper respiratory tract. At 37° C the water vapor pressure in the trachea is 47 mm Hg. Taking the water vapor pressure into account, the PO_2 in the trachea when breathing air is (760-47) x21/100 = 150 mm Hg.

By the time the oxygen has reached the alveoli the PO_2 (PaO_2) falls to about 100 mm Hg. This is because of a balance between two processes: the removal of oxygen by the pulmonary capillaries and its continual supply by alveolar ventilation (breathing).

Alveolus to Blood

As the blood returning from tissues traverses the lung via pulmonary capillaries, oxygen diffuses from alveolus to blood. In a 'perfect lung' the PO_2 of pulmonary venous blood would be equal to the PO_2 in the alveolus (PaO_2). Three factors may cause the PO_2 in the pulmonary veins to be less than the PaO_2. These are ventilation/perfusion mismatch, shunt, and diffusion defects.

Ventilations/perfusion (V/Q) Mismatch

Diseased lungs may have marked mismatch between ventilation and perfusion, some alveoli are relatively over ventilated while others are relatively over perfused. V/Q mismatch decreases the PaO_2 in pulmonary capillary blood. Even normal lungs have some degree of ventilation/perfusion mismatch; the upper zones are relatively over ventilated while the lower zones are relatively over perfused and under ventilated.

Shunt

Occurs when deoxygenated venous blood from the body passes unventilated alveoli to enter the pulmonary veins and the systemic arterial system with an unchanged PO_2 (40 mm Hg). Atelectasis (collapsed alveoli), consolidation of the lung pulmonary edema or small airway closure will cause shunts.

Pulmonary Fibrosis

Normally oxygen diffusion from alveolus to pulmonary capillaries is complete by the time blood traverses through one third of the capillaries. Diffusion defects are rarely a cause of hypoxia except in disease with pulmonary fibrosis.

Oxygen Delivery

Whenever body tissues face stress, the first physiological response is an increased metabolic demand, which increases oxygen demand. The quantity of oxygen made available to the body in one minute is known as the oxygen delivery.

Oxygen delivered = O_2 carrying of blood x cardiac output

(Hb in gms x 1.34 x % O_2 saturation of Hb) x (stroke volume x heart rate)

PO_2 = O_2 carrying capacity x cardiac output

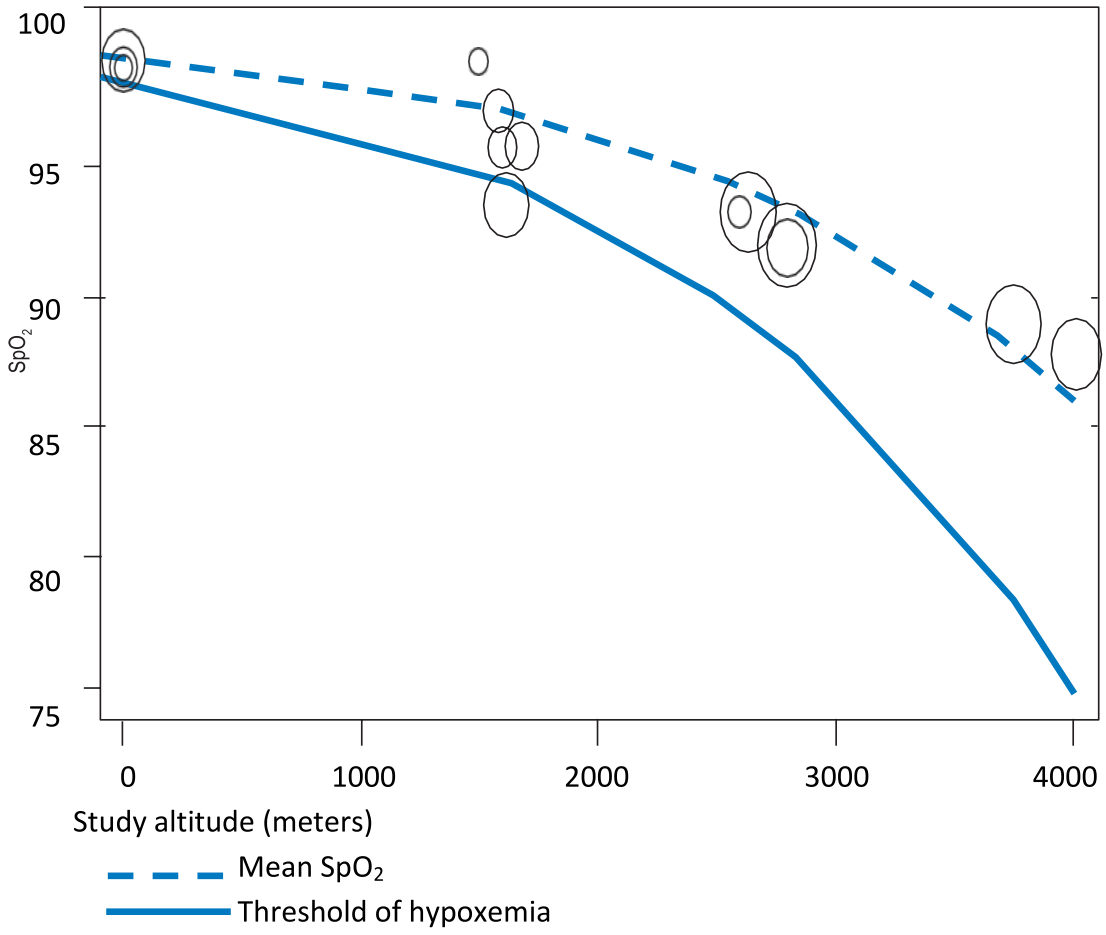
Oxygen Consumption

Normally, more oxygen is delivered to cells than they actually use, and whenever the demand increases (e.g., during exercise) the cardiac output increases to increase the supply. In disease states, a low cardiac output, low hemoglobin concentration and low hemoglobin saturation will decrease the oxygen delivery to tissues. When the delivery falls relative to

consumption, tissues extract more oxygen from hemoglobin leading to a fall in mixed venous oxygen saturation. Beyond a certain point this compensation does not occur leading to anaerobic metabolism, lactate generation and metabolic acidosis.

2.3 Special considerations

In patients with diagnosed congenital heart diseases (large Ventricular septal defect, large Atrial Septal Defect, large Patent ductus arteriosus, Aortopulmonary window, Aterioventriculoseptal defect) oxygen saturation as low as 88% occurs, and sometimes 85% to 92% is recommended level. As higher oxygen saturation in these patients can worsen the respiratory distress leading to respiratory failure due to increased pulmonary blood flow. Similarly, in patients with chronic lung diseases, saturations of 88-92% is acceptable and in severe cases saturation of 85% is also acceptable.



Circle size proportional to the precision of transformed study SpO_2 estimate.

Figure 1: Threshold of hypoxemia at different altitudes

Oxygen is transported in the blood in two forms: physically dissolved in plasma (2%) and chemically bound to the hemoglobin molecule in red blood cells (98%). The amount of oxygen in the blood (sum of both forms, dissolved and bound to hemoglobin) is described in ml of O_2 per 100 ml blood (or volume %).

(Oxygen bound to hemoglobin) (Dissolved Oxygen in Plasma)

CaO_2 = 1.34 x Hemoglobin x Saturation (SaO_2) + 0.003 x Arterial partial pressure of oxygen (PaO_2)

In order to determine how much oxygen is dissolved in plasma, the arterial oxygen tension or partial oxygen pressure (PaO_2) is measured (in mm Hg or kPa). The PaO_2 is a measure of only oxygen molecules dissolved in plasma and not of those bound to hemoglobin; however, as there is a dynamic equilibrium between freely dissolved and hemoglobin bound oxygen molecules, oxygen saturation can be calculated from the PaO_2. This relation is described by the hemoglobin - oxygen dissociation curve (**see Figure 2**).

The "gold standard" for measuring arterial oxygen tension (PaO_2) and for calculating oxygen saturation is blood gas analysis. This method is however invasive, painful, and distressing to the patient. Additionally, the blood gas machines and reagents are very expensive. Therefore, it is not appropriate in most district hospitals in developing countries.

The main carrier of oxygen in the blood is hemoglobin, each hemoglobin molecule can carry four oxygen molecules. The oxygen content of hemoglobin is expressed as oxygen saturation (SO_2), i.e., the ratio between hemoglobin carrying oxygen (oxyhemoglobin) and total hemoglobin. When arterial hemoglobin oxygen saturation is measured by arterial blood gas analysis, it is known as SaO_2. When it is measured non-invasively by pulse oximetry, it is known as SpO_2 (hemoglobin oxygen pulsed saturation), which is related to PaO_2, and is therefore used to define hypoxemia in these guidelines (**see Figure 2**).

The hemoglobin-oxygen dissociation curve

The hemoglobin-oxygen dissociation curve mathematically equates the percentage oxygen saturation of hemoglobin (SpO_2 or SaO_2) to the PaO_2 in blood. The number of O_2 molecules dissolved in plasma determines (with other factors) how many molecules will bind to hemoglobin. At high PaO_2 (i.e. in the lungs), oxygen will bind to hemoglobin. In tissues deprived of oxygen, the PaO_2 will decrease (the dissolved oxygen moves from the blood to tissues) and, consequently, the hemoglobin releases oxygen.

However, the tendency of hemoglobin to bind oxygen is not linear. Each hemoglobin molecule can carry four oxygen molecules, and the tendency to bind oxygen molecules becomes greater after the first molecule has been bound; therefore, the dissociation curve has a sigmoid shape. As the maximum amount that can be bound is reached and the hemoglobin becomes saturated with oxygen, little additional binding occurs, and the curve levels out. Thus, at high oxygen pressure, relatively large changes in pressure lead to only small changes in oxygen saturation (flat part of the curve). However, below an oxygen saturation of 90%small falls in PaO_2 result in much larger falls in SpO_2 (steep part of the curve).

It is important to note that the dissociation of oxygen is also directly affected by changes in temperature, pH and 2, 3-diphosphoglycerate.

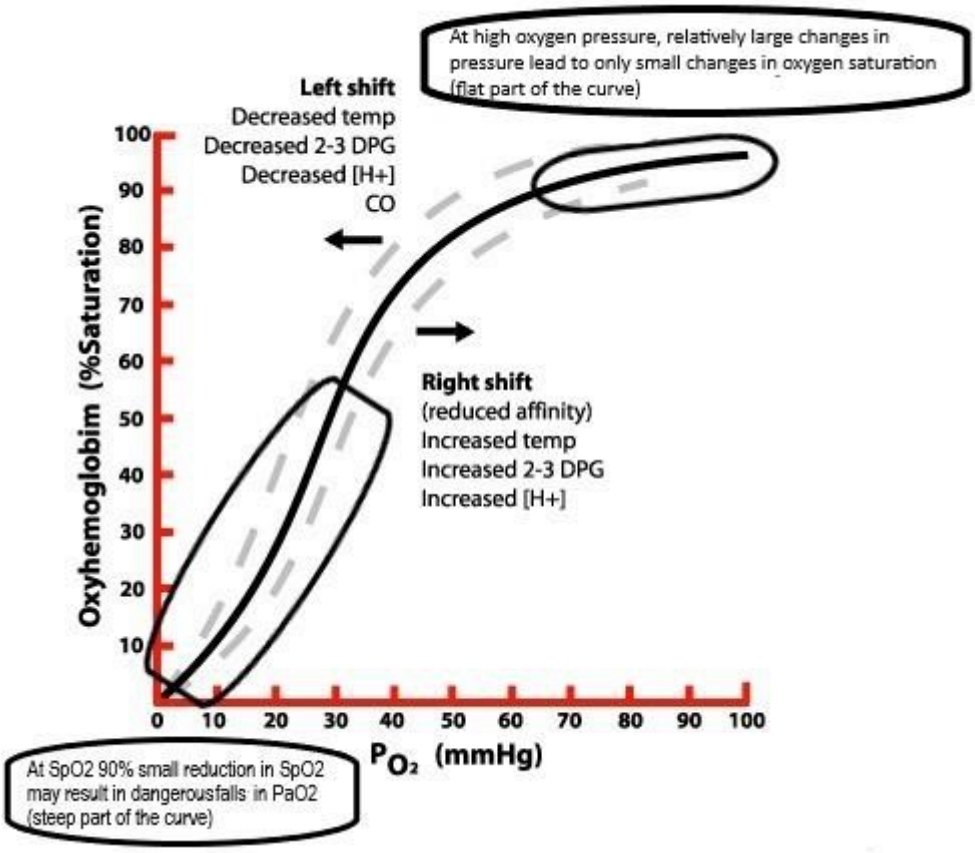


Figure 2: Hemoglobin-oxygen dissociation curve

2.4 Common causes of Hypoxemia

Various conditions **(Table 1)** and circumstances can interfere with the body's ability to deliver normal levels of oxygen to the blood. [10]

Table 1: Common causes of Hypoxemia

Neonates	Children
Respiratory distress syndrome	Pneumonia
Perinatal asphyxia	Bronchiolitis
Transient Tachypnea of newborn	Asthma
Pneumonia	Heart failure or cardiac arrest
Meconium aspiration syndrome and other aspirations	Meningitis
Congenital heart diseases	Sepsis
Severe Anemia	Severe Anemia
Circulatory shock	Circulatory shock

2.5 Key Messages

- Hypoxemia is a life-threatening condition
- Hypoxemia occurs frequently in children with pneumonia, common neonatal conditions, and trauma or perioperative emergencies
- Hypoxemia can be treated easily by giving oxygen
- Arterial oxygen saturation (oxygen level in the blood) is referred to as SaO_2 or SpO_2
- The normal range of SpO_2 at sea level is 94 – 100%
- Children living at high altitude are used to living with lower oxygen saturation; therefore, the threshold for giving oxygen is lower at higher altitude. However, at high altitude severe pneumonia can progress more quickly to severe hypoxemia, so that oxygen is more likely to be required

Chapter 3
3. DETECTION OF HYPOXEMIA

Clinicians can detect hypoxemia from clinical signs, with pulse oximeter or by blood gas analysis. This section outlines these methods and explains the advantages and disadvantages of each.

Severe hypoxemia can often be recognized by certain clinical signs, which are blue coloring of the tongue or gums (central cyanosis), nasal flaring, inability to drink or feed (when due to respiratory distress), grunting with every breath and depressed mental state (i.e., drowsy, lethargic). In some situations, and depending on the overall clinical condition, children with the following fewer specific signs may have hypoxemia: severe lower chest wall indrawing and head nodding **(Table 2),** fast breathing **(Table 3)**. These are important signs for all health workers to know, and it is essential that they are able to recognize very sick patients. However, even the best observations of clinical signs commonly result in misdiagnosis of hypoxemia in children with normal oxygen saturation or failure to detect hypoxemia in others.

Pulse oximetry is the most accurate non-invasive method for detecting hypoxemia. It is used to measure the percentage of oxygenated hemoglobin in arterial blood (SpO_2). The pulse oximeter consists of a computerized unit and a sensor probe, which is attached to the patient's finger, toe, or ear lobe. The oximeter displays SpO_2 with an audible signal for each pulse beat, a pulse rate, and in most models a graphical display of the blood flow past the probe (the plethysmographic or pulse wave). The technology is robust and the cost quite low. Pulse oximeters can be used to detect and monitor hypoxemia, make more efficient use of oxygen supplies, and improve patient monitoring; they are cost–effective for district hospitals [11].

Blood gas analysis is another very accurate method for detecting hypoxemia. It is used to measure the partial pressure of oxygen (PaO_2), carbon dioxide, blood pH and also the concentrations of the main electrolytes. This method has several drawbacks. Blood gas analyzers are very expensive, and the chemical reagents represent a high recurrent cost, which may be unaffordable for hospitals with limited resources. Inaccurate measurements can easily result from factors such as a poorly taken sample (especially from a struggling or uncooperative child), delay in transfer of the sample to a laboratory, inadequate storage conditions before analysis and inadequate maintenance or quality control in the laboratory. The method is also invasive and uncomfortable, as it requires drawing of the blood. Therefore, blood gas analysis is not suitable for most hospitals with limited resources.

Table 2: Recommendations for detecting Hypoxemia

	RECOMMENDATION	QUALITY OF EVIDENCE
1.	**Use Pulse oximetry to detect hypoxemia.**[a]	
	Pulse oximetry is recommended for determining the presence of hypoxemia and for guiding administration of oxygen therapy to infants and children.	Strong recommendation (low-quality evidence)
2.	**When clinical signs are used to detect hypoxemia in children.**[b]	
i)	Use pulse oximetry whenever possible for the detection of hypoxemia in children with severe lower respiratory tract infections. If oximetry is not available, the following clinical signs could be used to determine the use of oxygen therapy: Central cyanosis (except cyanotic congenital cardiac diseases) Nasal faring Inability to drink or feed (when due to respiratory distress) Grunting with every breath Depressed mental state (i.e., drowsy, lethargic) Convulsions	Strong recommendation (low-quality evidence)
ii)	In some situations, and depending on the overall clinical condition, children with the following less specific signs may also need oxygen: Severe lower chest wall in-drawing Increased respiratory rate (see Table 3) Head nodding	Strong recommendation (Very low-quality evidence)

a Although no studies have been reported for the comparison of measuring arterial blood gases with pulse oximetry in children, a meta-analysis of studies in adults showed a very high correlation[12]. Pulse oximetry is noninvasive, easy to do and does not require any special skills.

b Clinical signs are very unreliable for detecting hypoxemia and should not be relied upon except when pulse oximetry is not available.

3.1 Clinical signs

Clinical signs are not reliable predictors of hypoxemia, and their use alone for diagnosis can lead to false-positive or false-negative results. However, in many situations such as in primary health facilities or triage in an outpatient or emergency department, it may not be possible to perform pulse oximetry. Different clinical signs are indicative of hypoxemia in neonates, children, and adults. It is important that health workers can identify very sick

patients clinically and can identify the clinical signs of hypoxemia, rather than relying on monitoring equipment that is not available or functions poorly**.**

3.1.1 In neonates

The signs of hypoxemia in neonates and young infants are not specific, sometimes resulting in delayed recognition by parents and presentation at a relatively advanced stage. Even an experienced health worker may find it difficult to detect hypoxemia**.** As in older infants and children (see next section), no single clinical sign can be used to identify all hypoxemic neonates. Several studies have shown that in neonates, as in infants and children, fast breathing is both insensitive (i.e. many children with hypoxemia may not have fast breathing) and nonspecific (i.e. many children with fast breathing are not hypoxemic) for detecting hypoxemia. As in older children, cyanosis is the most specific clinical sign, but more than one fourth of neonates with hypoxemia are not identified as cyanosed.

These considerations argue strongly for the use of pulse oximetry in the management of sick neonates and the importance of teaching health workers to screen for these common clinical signs. Monitoring of apnea is also recommended for in-patient monitoring of very low-birth-weight infants and premature neonates, when available [10].

3.1.2 In children

This section describes the clinical signs that suggest hypoxemia in children. The precision of clinical signs for predicting hypoxemia has been reviewed [6, 13].

Central cyanosis

Oxygenated hemoglobin is red, while deoxygenated hemoglobin is blue. If the red cells in the blood are not fully loaded with oxygen, the skin and mucous membranes appear blue. This is known as central cyanosis (see **Figure 3**).

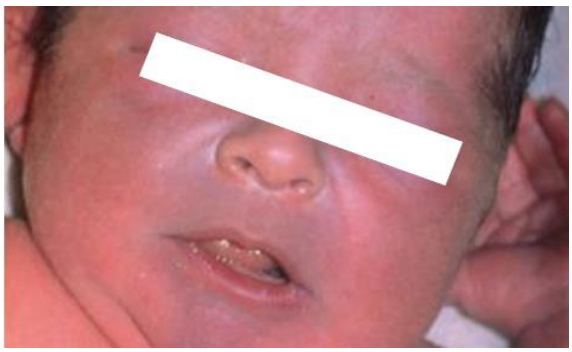


Figure 3: Infant with central cyanosis

Identification of central cyanosis can be difficult. Examine the tongue or gums (not the lips) under sunlight or the light from an incandescent light bulb (even healthy people may look slightly blue under fluorescent light). If unsure, compare the color of the child's tongue with that of the mother's. Blue discoloration of the nail beds indicates peripheral cyanosis, which can occur with intense vasoconstriction as a result of hypothermia, exposure to low environmental temperature or circulatory shock. Sometimes, peripheral cyanosis occurs without hypoxemia.

In children with severe anemia or with heavily pigmented mucous membranes, cyanosis may be detectable only at severe levels of hypoxemia[14]. Central cyanosis is insensitive for accurate detection of hypoxemia, as it is detected in less than 50% of all children with hypoxemia. It is, however, highly specific for detecting hypoxia: virtually all children with central cyanosis have hypoxia and should therefore receive oxygen [13].

Increased respiratory rate

According to Integrated Management of Neonatal and Childhood Illness (IMNCI) fast breathing is considered if respiratory rate is of 60/min or more at 2 months of age, 50/min or more at 2 months to 1 year and 40/min or more up to 5 years (see **Table 3**). The respiratory rate is affected by age [15, 16], malnutrition [17], altitude [18, 19] and the presence of anemia or fever [20]. It is best measured by observing the movement of the chest wall over 60 seconds [21] . Most of the studies that suggest that an increased respiratory rate is a useful indicator of hypoxemia were conducted at high altitude [18, 19]. At sea level, it is a poorer predictor [22], and the results depend on the cut-off point selected. With a higher cut-off, fewer children will be identified, but a higher proportion of them will have hypoxemia [6, 15]. In most circumstances, tachypnea alone (with no other signs of severe respiratory distress or hypoxemia) is not a useful indicator for oxygen therapy [23].

Table 3: Age and Breath counts per minute

If the child is:	Child has fast breathing if breath count for 1 minute
Less than 2 months	60 breaths per minute or more
2 months to < 12 months	50 breaths per minute or more
12 months to 5 years	40 breaths per minute or more

(Ref: Integrated Management of Childhood Illness, 2017)

Coma, severe lethargy, or prolonged convulsions

Coma or prolonged convulsions (lasting more than a few minutes) put a child at significant risk for hypoxemia. These conditions may be associated with depression of the respiratory drive, leading to hypoventilation, or may compromise airway protection and lead to aspiration. Coma is a nonspecific sign of hypoxemia: many children with long-standing coma do not have hypoxemia. All children with coma should be examined closely for other clinical signs indicating hypoxemia (cyanosis, chest indrawing) or airway obstruction (stridor) and should be given oxygen if there is any uncertainty. Children in a coma because of an acute illness (such as meningitis, trauma, and cerebral malaria) and those who have prolonged convulsions should receive oxygen immediately. At the same time, it is vital to ensure a

patent airway, protect the airway from further compromise (such as aspiration) and ensure adequate breathing (ventilation).

Severe lower chest in-drawing

Chest in-drawing is the inward movement of the lower chest with inspiration (see **Figure 4**). In lower chest wall in-drawing, the lower chest wall goes in when the child breathes in, if only the soft tissue between the ribs or above the clavicle goes in when the child breathes, this is not considered as lower chest wall in-drawing. Because chest in-drawing is a key sign in the diagnosis and classification of pneumonia, many children hospitalized for pneumonia may display it to some degree. It is therefore difficult to quantify the usefulness of severe in-drawing in predicting hypoxemia. In the absence of pulse oximetry to confirm whether hypoxemia is present, children with severe lower chest indrawing should be classified as having severe respiratory distress and indicates that the child needs oxygen.

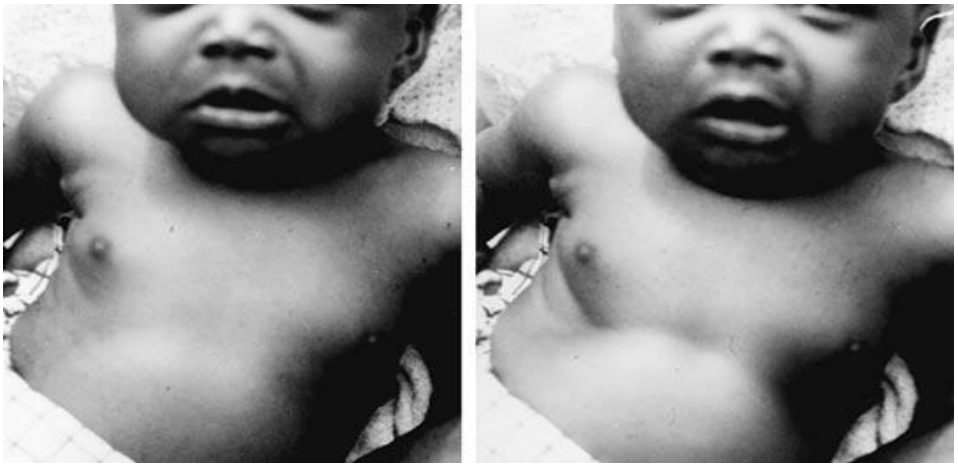


Figure 4: Severe lower chest wall in-drawing indicates that this child needs oxygen

Head nodding, grunting or nasal flaring

Grunting on expiration with every breath and nasal flaring are important signs of severe respiratory distress, especially in infants, and indicate the immediate need for oxygen. In head nodding, the head nods downwards towards the chest each time the child breathes in as a result of the use of accessory muscles in breathing. The usefulness of this sign has not been widely studied. Two studies at the same site showed that most children with this sign are hypoxemic; however, many hypoxemic children do not have this sign [22, 24].

Crepitations or crackles

Crepitations or crackles are abnormal respiratory sounds that can be heard with a stethoscope, resulting from the passage of air through fluid in the respiratory tract (either the bronchi or alveoli). Several studies have found this sign to be significantly associated with hypoxemia, particularly in younger children [15, 24, 25]. It may be difficult for staff without training in the use of a stethoscope to distinguish this sound.

Inability to drink

In a young infant, inability to feed means taking less than half the usual amount during breastfeeding or bottle-feeding. In an older child, it usually means not being able to drink at all. These cases include infants or children who are too weak to drink when offered fluids, who are unable to suck or swallow, or who vomit repeatedly and keep nothing down. Although breastfeeding children may have difficulty in sucking when their noses are blocked, if they are not severely ill, they can still breastfeed when their nose is cleared; and this should not be classified as "inability to drink". Inability to drink is a nonspecific sign of hypoxemia: less than half of children with this sign have hypoxemia.

3.1.3 Respiratory distress/Respiratory failure

Respiratory distress happens when a person is unable to regulate gas exchange, causing them to either take in too little oxygen or expel too little carbon dioxide. Respiratory failure can follow respiratory distress and causes more severe difficulties with gas exchange. If left untreated, it may be fatal. Clinical definition applies to any patient who has difficulty breathing and either of the following:

- Type 1: hypoxemic PO_2 <60 mm Hg, while breathing room air
- Type 11: hypercapnic PCO_2 > 50 mm Hg, usually with pH <7.35
- Commonly mixed picture is seen in most of the patients with respiratory failure

Table 4: Difference between Respiratory distress and Respiratory failure

	RESPIRATORY DISTRESS	RESPIRATORY FAILURE
AIR WAY	Open without support	Possibly obstructed
RESPIRATORY RATE	Tachypnea	Slow breathing
RESPIRATORY EFFORTS	Increased effort	No effort
LUNG SOUNDS	Clear sound	Abnormal sound
HEART RATE	Tachycardia	Bradycardia
RESPONSIVENESS	Agitated	Failure to response
APPEARANCE	Pale	Cyanotic
OXYGEN SATURATION	>90%	< 90%

3.2 Pulse oximetry

A pulse oximeter measures oxygen saturation of hemoglobin in the blood by comparing the absorbance of light of different wavelengths across a translucent part of the body. Pulse oximetry is the best method available for detecting and monitoring hypoxemia.

3.2.1 Clinical use

Even the best combinations of clinical signs commonly lead to misdiagnosis of hypoxemia in some patients who have normal oxygen saturation or fail to detect some hypoxemic

patients. Pulse oximetry correctly identified hypoxemia in 20–30% more children than with clinical signs alone [22, 24, 26]. When used correctly, pulse oximetry allows reliable monitoring with little or no distress to the patient and is an accepted standard for detecting hypoxemia [27].

Table 5: Triage of all children and neonates with emergency, priority sign should be screened by pulse oximetry and oxygen given in any sign of hypoxemia

EMERGENCY SIGN	PRIORITY SIGN
Emergency signs include: • Obstructed or absent breathing • Severe respiratory distress • Central cyanosis • Signs of shock: cold hands, capillary refill time > 3 sec, high heart rate with weak pulse, and low or unmeasurable blood pressure • Coma or seriously reduced level of consciousness • Convulsions • Signs of severe dehydration in a child with diarrhea: lethargy, sunken eyes, very slow return of the skin after pinching or any two of these	Priority signs that must also be recognized are: • **T**iny infant: any sick infant aged <2months • **T**emperature: child is very hot • **T**rauma or other urgent surgical condition • **P**allor (severe) • **P**oisoning (history of) • **P**ain (severe) • **R**espiratory distress • **R**estless, continuously irritable, or lethargic • **R**eferral (urgent) • **M**alnutrition: visible severe wasting • **O**edema of both feet • **B**urns (major) These signs can be remembered from the mnemonic **3TPR MOB**
SIGN OF HYPOXEMIA	
Oxygen should be given to children with any of the following signs: • $SpO_2 \leq 90\%$ • Central cyanosis (expect cyanotic congenital cardiac disease) • Nasal flaring • Inability to drink or feed (when due to respiratory distress) • Grunting with every breath • Depressed mental state (i.e., drowsy, lethargic) In some situations, and depending on the overall clinical condition, children with the following less specific signs may also require oxygen: • Severe lower chest wall indrawing • Increased respiratory rate (see **Table 3**) • Head nodding, i.e., a nodding movement of the head, synchronous with respiration and indicating severe respiratory distress	

As not all patients with clinical signs sometimes associated with hypoxemia have this condition, use of pulse oximetry can also reduce unnecessary oxygen administration, thus ensuring the most efficient use of an expensive resource. The technology is robust, and the price of pulse oximeters is now lower than in the past. Pulse oximetry is an important intervention in hospitals in which large numbers of children with acute respiratory disease are cared for [28]. Pulse oximetry should therefore be performed on all patients admitted to an inpatient ward with respiratory illness, emergency signs or any sign of hypoxemia. During triage, all patients with clinical signs of hypoxemia and children and neonates with any "emergency or priority" sign should be screened by pulse oximetry [29] (see **Table 5**), to ensure identification of patients most likely to be hypoxemic. Hypoxemia on pulse oximeter below 70% saturation is not reliable and arterial blood gas analysis is needed for further analysis of SaO_2.

3.2.2 Features of a pulse oximeter

Alarm

A low-battery alarm is essential to alert health workers when the machine should be plugged into a power supply (alternating current [AC] mains). A pulse oximeter must be connected to mains power whenever it is not being used in the ward. If the internal battery discharges, the pulse oximeter will work only if it is plugged into the mains, and its usefulness as a portable monitoring tool will be limited.

Sensors

A wide range of probes are available in different sizes. It is important to choose a sensor probe that is appropriate to the size of the patient. Some are disposable; they can be reused for several patients, but they are difficult to clean, and the adhesive wears off after a few uses. There are several types of longer-life digital probes, which are more expensive but durable. For adults, there are hard plastic finger clips (see **Figure 5**), but these will not attach well to infants or children.

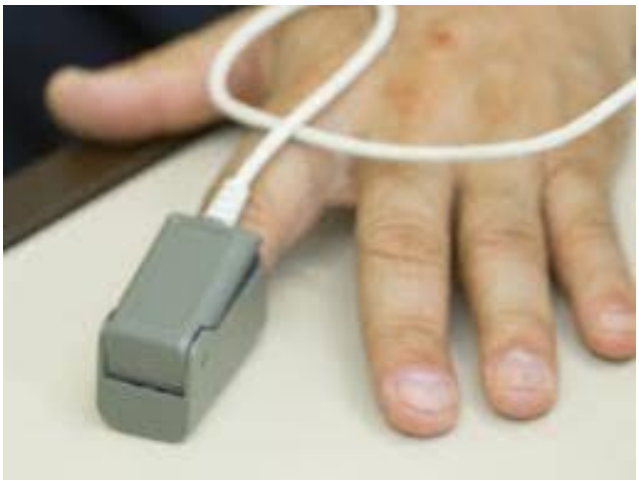


Figure 5: Hard plastic finger clip for adults

A type of probe that can be used for patients of all ages and sizes is a device with a soft rubber pocket (see **Figure 6**). As the casing is soft, the probe generally molds to the digits of children and adults. These soft probes are ideal for spot checks and daily monitoring, as they do not require adhesive.

Figure 6: Soft rubber sensor probe

Another alternative is the "Y-sensor" digital probe (see **Figure 7**), but these require some form of attachment to the hand, foot, toe, or finger. They can be ideal for neonates and young children and can be attached to the foot or hand of very low-birth-weight neonates. Some probes are designed to be attached to the ear lobe, but they are generally less useful for a range of ages or for spot checks and daily monitoring.

Figure 7: Y-sensor probe

The probes and connecting cables are delicate and are easily damaged if stepped on. Cables break more frequently as the pulse oximeters age. Finger clip-on sensors last about 6 months on average and can be used on many children during this time [28]. It is important always to have a spare probe available in case one fails.

Displays

Examples of pulse oximeter displays showing normal and abnormal readings are given below.

Figure 8 shows a pulse oximeter with a normal reading of neonate (pulse rate = 127 beats/min: SpO_2 = 99%) and a plethysmographic (pulse) wave indicating a good arterial trace and a valid reading.

Figure 8: Pulse oximeter showing a normal reading

In **Figure 9** shows an abnormal reading (pulse rate = 162 beats/min: SpO_2 = 89%). In this case, the plethysmographic (pulse) wave is uneven, indicating a poor arterial trace. The accuracy of the heart rate reading should be checked by comparing the number on the pulse oximeter display with auscultation of the heart and counting the true beats. A poor pulse waveform on the pulse oximeter, as in this case, is usually due to inadequate attachment of the sensor probe to the skin, especially on an active child, or to poor peripheral perfusion. This SpO_2 reading is not valid, and the probe should be repositioned.

Figure 9: Pulse oximeter showing a poor plethysmographic (pulse) wave

In **Figure 10** (pulse rate = 122 beats/min; SpO_2 = 89%), the pulse oximeter has a good plethysmographic wave, indicating a valid arterial trace. Therefore, the SpO_2 reading, which is abnormally low (89%), is accurate and indicates that the patient is hypoxemic. Oxygen should be given. Note the increased heart rate, which is common in seriously ill patients.

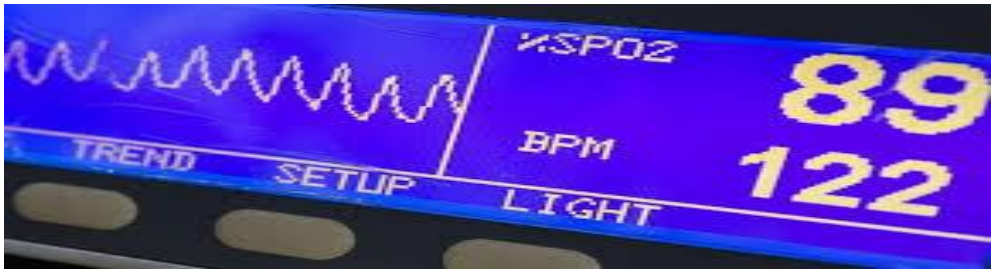


Figure 10: Pulse oximeter showing a good plethysmographic (pulse) wave and low oxygen saturation

3.3. Blood gas analysis

Blood gas analysis can be used to measure the PaO_2 and carbon dioxide in arterial (or venous or capillary) blood. It also indicates the blood pH, which is often abnormal in seriously ill patients: metabolic acidosis (low blood pH) is commonly seen when there is major disturbance of the circulation, as in severe dehydration, severe sepsis, and severe malaria. Thus, blood gas analysis provides information on oxygenation, ventilation, and circulation. And electrolyte concentrations (particularly sodium and potassium) are measured in the same blood sample and analyzer. Electrolyte abnormalities are common in seriously ill patients.

Blood gas analysis has several drawbacks. The blood gas analyzers (see **Figure 11**) are more expensive and require more resources than pulse oximeters (see **Table 6**). The procedure is invasive, painful and distressing to children and infants; and the analysis provides information for only one time. Furthermore, without an arterial cannula for repeated blood sampling, arterial blood gas analysis is rarely a practical means for monitoring changes in response to therapy. Venous and capillary blood are easier to monitor than arterial blood but are of no use for determining oxygenation.

Inaccurate information can result from many factors, such as a poorly taken sample (especially from a struggling or uncooperative child), delay in transfer to a laboratory,

inadequate storage conditions before analysis and inadequate maintenance or poor-quality control in the laboratory.

Blood gas analysis requires expensive chemical reagents, resulting in high recurrent costs. Lack of consumables including reagents, is one of the most common reasons that medical equipment is under-used[30].

Nevertheless, blood gases provide information that cannot be obtained with pulse oximetry. The carbon dioxide level in arterial blood helps in assessing alveolar ventilation and monitoring trends in the efficiency of ventilation. The pH is a direct indicator of overall acid–base status in arterial, arterialized capillary and venous blood. The probable cause of pH disturbances can be inferred only from the partial pressure of carbon dioxide and the blood bicarbonate concentration (or the base excess or deficit). In sick children in developing countries, metabolic acidosis is the commonest pH abnormality, occurring in severe sepsis, severe diarrhea, and severe malaria due to hypovolemia or shock. Less common but important conditions include diabetic ketoacidosis, predominantly due to the accumulation of ketone bodies, and some cases of poisoning with acidic compounds, such as aspirin overdose, ethylene glycol ingestion and carbon monoxide intoxication. Blood gas analysis can also be used to monitor, and trouble shoot critically ill children on mechanical ventilators especially in the absence of end tidal CO_2 monitoring.

Figure 11: Blood gas Analyzer

Table 6: Comparison of pulse oximetry and blood gas analysis

FACTOR TO BE CONSIDERED	PULSE OXIMETRY	ARTERIAL BLOOD GAS
Pain and distress to patient	Minor discomfort from being held	Major discomfort from blood sampling
Risk to staff	Nil	Potential for needle stick injury
Suitability for monitoring	Continuous or regular spot checks	Information for only a single time
Cost	Low to moderately expensive[a] plus moderate recurrent costs (sensor probes)	Very expensive plus high recurrent costs for reagents and maintenance
Skill required	Use and interpretation can be taught to nurses and non-specialist health workers.	High level of laboratory expertise and skill in clinical interpretation
Indication of ventilation adequacy	Yes	Yes (more reliable)
Indication of acid-base state or electrolytes	No	Yes
Major sources of error	• Poor skin perfusion • Movement artefact • Greater margin of machine error at lower SpO_2	• Uncooperative child • Clotted specimen • Air in syringe • Laboratory handling

[a] Depending on the model and sophistication of the pulse oximeter; however, robust low-cost models that can be used for the interventions described have become available.

3.4: Near-Infrared Spectroscopy (NIRS)

Near-infrared spectroscopy (NIRS) is a spectroscopic method that uses the near-infrared region of the electromagnetic spectrum (from 780 nm to 2500 nm) as shown in **Figure 12**. It provides information about the oxygen saturation of hemoglobin within the microcirculation in the brain (cerebral NIRS) or in the peripheral tissues (peripheral NIRS) [31].

Figure 12: Near-Infrared Spectroscopy (NIRS)

3.5 KEY MESSAGES

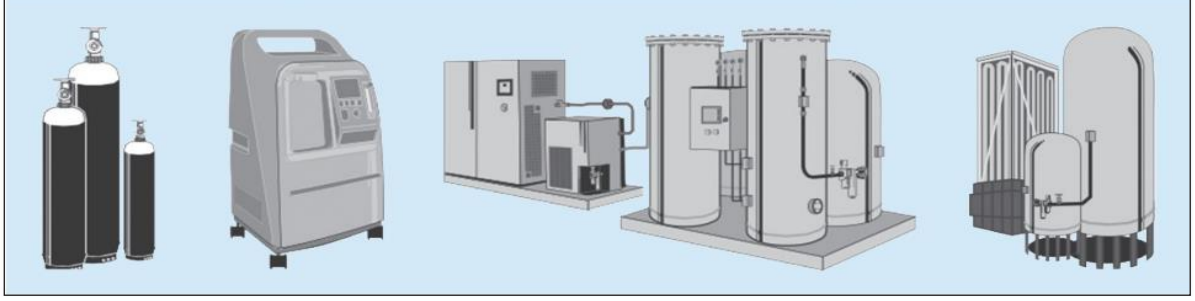
- Hypoxemia can be detected from clinical signs, with a pulse oximeter or by blood gas analysis
- Pulse oximetry should be used in hospitals for accurate detection of hypoxemia
- Where pulse oximetry is not available, clinical signs may provide useful criteria for deciding whether to provide oxygen
- Blood gas analysis is significant in managing sick babies; but may not be available or affordable in peripheral hospitals with limited resources, as the analyzers are expensive and the chemical reagents represent a high recurrent cost. However, its use is encouraged in tertiary care hospitals and intensive care facilities
- Children with any of the following signs are likely to be hypoxemic: central cyanosis, nasal flaring, inability to drink or feed (when due to respiratory distress), grunting with every breath, and depressed mental state (i.e., drowsy, lethargic)
- In some situations, and depending on the overall clinical condition, children with the following less specific respiratory signs may also be hypoxemic: severe lower chest wall in drawing, increased respiratory rate and head nodding (i.e., a nodding movement of the head, synchronous with respiration and indicating severe respiratory distress)
- Other clinical conditions that may be associated with hypoxemia include prolonged convulsions, acute coma, acute neurological problems due to airway obstruction or impaired ventilatory effort, severe sepsis, heart failure or very severe anemia

Chapter 4
4. SOURCE & DELIVERY OF OXYGEN

4.1 Sources of oxygen

The sources of oxygen and its delivery method usually depend on the facility and the availability of resources. The most common sources of oxygen that will be used are cylinders and concentrators, while liquid oxygen/ oxygen plant is used in tertiary care.

Oxygen Cylinders	Oxygen Concentrators	Oxygen plant	Bulk liquid oxygen
-Oxygen produced in manufacturing plants by cooling air until it liquefies > distilling the liquid to separate pure oxygen > passed through a liquid oxygen pump into cylinders	- It draws in air from the environment, (21% O_2, 78% N_2 and 1% other gases)> extract the nitrogen to leave almost pure oxygen. -Supply oxygen at a concentration of 90%-96% with a maximum flow rate between 5-10L/min[2]	-It is a large onsite, central source of oxygen that is piped directly to terminal units within patient areas	-Bulk liquid oxygen is generated off site and stored in a large tank and supplied throughout a health facility via a central pipeline system
- Can be used for any O_2 need/high pressure/ambulatory/ back up for other support	-Deliver O_2 bedside or proximity to patient areas (up to 4 patients at the same time when used with flow splitters or flow meters)	- Can be used for all O_2 needs including high pressure supply	-It can be used for all oxygen needs, including high pressure and in facilities where power supply is intermittent or un-reliable
- Energy consuming process - Regular Filling is required	- Portable - Requires continuous and reliable power - Need cylinders for back up	- Plants can generate oxygen and it requires a reliable source of power	
- Can be used at primary/secondary and possibly tertiary level hospital	- Can be used at primary/secondary and possibly tertiary level hospital	Secondary and tertiary level hospital	Secondary and tertiary level hospital



4.2 Distribution

To supply the oxygen as clean, highly pure and under stable pressure it is distributed via central pipe system or within a tube.

4.3 Regulation and conditioning

- For the delivery of Oxygen therapy to patients, there are several devices which play different roles in regulation and conditioning of Oxygen gas
- Thorpe tube flow meters (see **Figure 13**) are calibrated to a specific medical gas (oxygen or air) and come in dedicated flow rate ranges appropriate for different patient groups (e.g., neonate, infant, child, and adult).

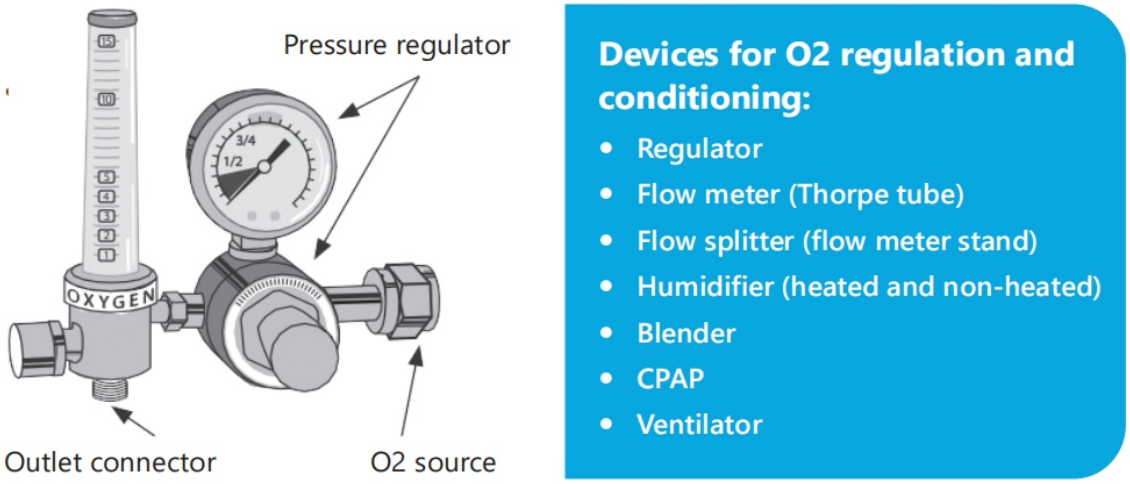


Figure 13: Thorpe Tube flow meter with pressure regulator and outlet connector

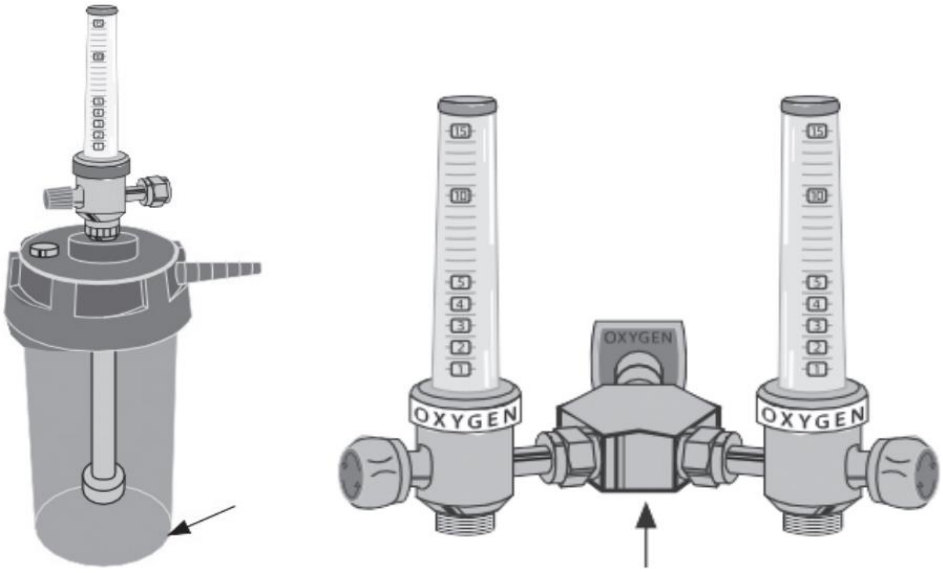


Figure 14: Humidifier bottle and flow splitting device (dual flow meter from a single wall source for use in two patients)

4.4 Oxygen Blender

To avoid retinopathy of prematurity (ROP) and brain damage in preterm babies, mixing congenital heart disease and chronic lung disease in children; oxygen blenders are used to control oxygen therapy/delivery (see **Figure 15**).

Figure 15 Oxygen blender

4.4.1 Oxygen Blenders

The air/oxygen blender is **a precision proportioning device for mixing medical grade air and oxygen to any concentration from 21% to 100% oxygen** and delivering it to a variety of respiratory care devices. There are two types of blenders available

- Low flow
- High flow

4.4.1.1 Low Flow Blender:

- Specifically designed for low flow general purpose applications
- maximum flow: 4 to 5 Liter/min
- FiO_2 range: 0.21 + 0.01 to 1.0

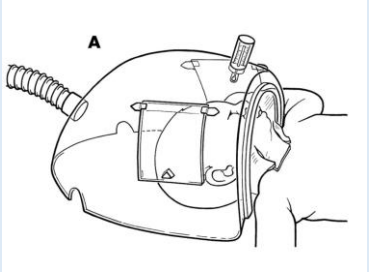
4.4.1.2 High Flow Blender:

- Specifically designed for High flow general purpose applications
- Maximum flow: 100 liter/min
- FiO_2 range: 0.21 + 0.01 to 1.0

4.5 Oxygen delivery devices

There are several devices that connect oxygen source with the patient for delivery of oxygen (see **Table 7**). The selection of devices depends on clinical needs of patient and device capability.

Table 7 Description and comparison of different sources of oxygen delivery devices

	Nasal cannula or prongs	Nasal Catheter	Head Box/Face mask
Type	Semi Invasive	Semi Invasive	Non-invasive
Description	Plastic tubes that end in two short, tapered prongs that are placed in the nostrils	Thin flexible tube that is passed into the nose and ends with its tip in the nasal cavity	These are simple, partial rebreathing and non-rebreathing type
Clinical Application and/or use case	Low- flow oxygen therapy	Low- flow oxygen therapy	Higher flows are required to achieve adequate concentration of oxygen and prevent carbon dioxide accumulation (FiO_2 needs to be tightly controlled)
Achievable FiO_2	Depends on the Patient but up to 50-55% can be achieved		Depending on the device, can be varied from 21-100%
Merits	Causes less interference with feeding, drinking, and speaking	- Lower cost alternative to nasal cannulas - less likely to be dislodged	- Non-invasive - No increased risk of airway obstruction by mucus or of gastric distention
Drawbacks	- More costly than nasal catheters - Risk of dislodgment - Poor quality tape can cause skin trauma	- More Invasive than nasal cannulas - Insertion requires skilled trained nurse - can become blocked with mucus	- Can interfere with feeding, drinking, speaking - Wasteful of oxygen - Hypercapnia 

Now a days full face mask, mouth and nose mask,and nose mask interface are also used for non-invasive oxygen delivery in some tertiary care settings.

4.6 Key Messages

- The method used to deliver oxygen should be safe, simple, effective, and inexpensive
- Cylinders must be available as back up even if central supply is source of oxygen i.e. oxygen tank/oxygen plant
- Face mask, head boxes, tents are not recommended as they waste oxygen and retain carbon dioxide (CO2)
- Standard low flow rate of oxygen through nasal prongs/nasal catheter is 0.5-5 L/min in neonates, infants, and children
- There is risk of airway obstruction by mucus especially if humidification is not used with high flow of oxygen
- In set ups where neonatal and pediatric ICUs are available, central oxygen supplied with pipes is a preferred way of oxygen therapy. Back up by multiple cylinders is an additional option
- In centers where sick newborn is managed, blenders must be used wherever possible to control the FiO_2 and prevent complications of oxygen
- Oxygen must be used like a drug with dose, mode of delivery, advantages, and side effects

Chapter 5
5. CONTINUOUS POSITIVE AIRWAY PRESSURE (CPAP)/HIGH FLOW NASAL CANNULA (HFNC)

The CPAP is widely used for non- invasive respiratory support in neonates and children, and early use in certain conditions can reduce the need for invasive ventilation.

- Continuous Positive Airway Pressure (CPAP) consists of delivery of mild air pressure to keep the airways open
- CPAP delivers PEEP with a variable amount of oxygen to the airway of a spontaneously breathing patient to maintain lung volume during expiration [32]
- It is indicated for neonates/infants with severe respiratory distress, hypoxemia, and apnea of prematurity, despite receiving oxygen [33,34]
- Several commercial bubble CPAP machines are available with varying prices
- An inexpensive form of bubble CPAP can be made with standard nasal prongs. The method is shown in **Figures 15 and 16**. Oxygen flow rate of 5–10 L/min is required for older children with pneumonia, while 3–4 L/min may be sufficient to generate CPAP in neonates

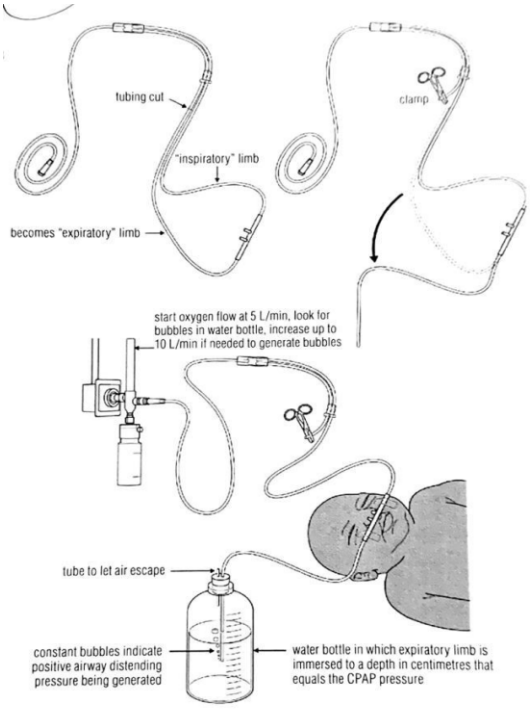


Figure 16: An inexpensive bubble CPAP set up with modified nasal prongs

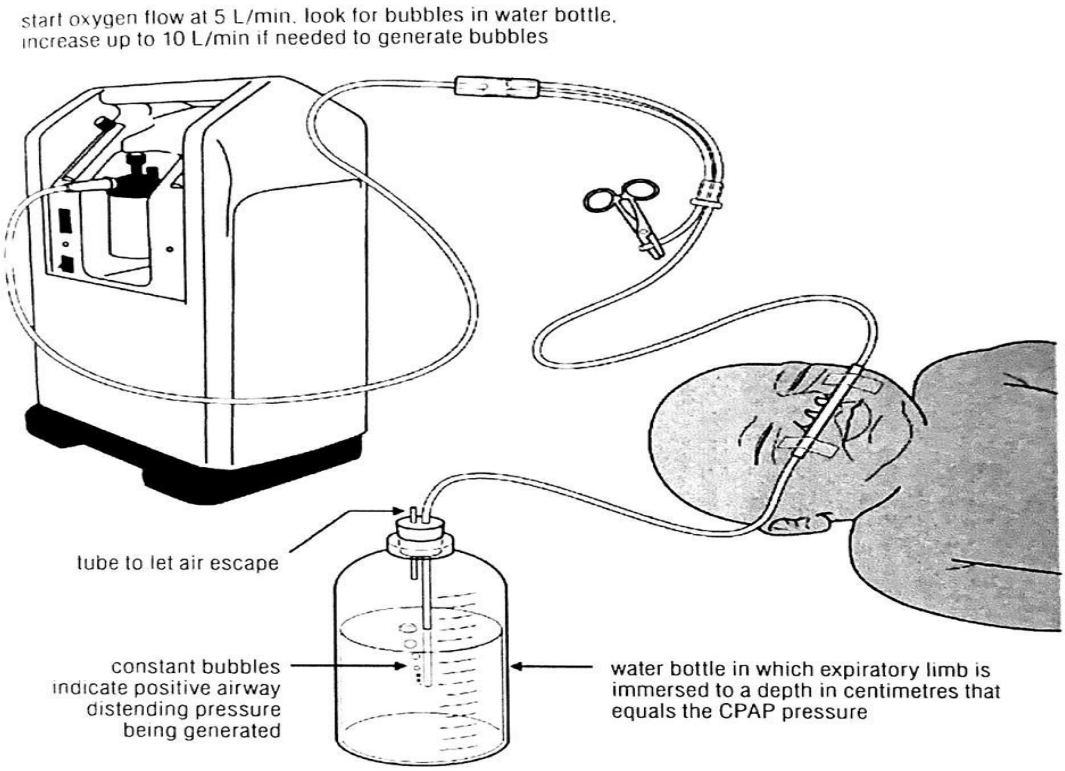


Figure 17: Bubble CPAP with inexpensive modified nasal prongs can be run with an oxygen concentrator

5.1 Beneficial role of CPAP

- Prevents alveolar atelectasis by improving and maintaining Functional Residual Capacity (FRC)
- Corrects ventilation-perfusion abnormalities
- Reduces intrapulmonary shunting
- Decreases total airway resistance, regularizes breathing pattern, reduces work of breathing,
- Reduces apnea and improves oxygenation.

5.2 Indication of CPAP

5.2.1. Neonates:

- Respiratory Distress Syndrome (RDS)
- Apnea of prematurity (especially obstructive apnea)
- Post extubation in preterm VLBW infant
- Transient Tachypnea of Newborn (TTNB)/ delayed adaptation
- Pneumonia
- Meconium aspiration/ other aspiration syndromes
- Pulmonary hemorrhage
- Laryngomalacia/ tracheomalacia/bronchomalacia

Respiratory distress can be assessed by using Silverman-Anderson Score which can be done clinically (see **Table 8**).

Table 8: Silverman-Anderson Score

FEATURES	SCORE 0	SCORE 1	SCORE 2
Chest movement	Equal	Respiratory lag	Seesaw respiration
Intercostal retraction	None	Minimal	Marked
Xiphoid retraction	None	Minimal	Marked
Nasal flaring	None	Minimal	Marked
Expiratory grunting	None	Audible with stethoscope	Audible without stethoscope

[Avery ME, Fletcher BD. The lung and its disorder in the new-born. Philadelphia, W.B. Saunders Company. 1974 (Courtesy of W.A. Silverman).

Interpretation

a) Score 4-7 = Respiratory distress
b) Score >7 = Impending respiratory failure

5.2.2. Infant and Children:

- Pneumonia
- Bronchiolitis
- Post-extubation
- Obstructive upper airway disease
- Neuromuscular diseases
- Congestive heart failure
- Left ventricular heart disease

5.3 Contra-indication of CPAP

- Conditions with imminent ventilatory support (severe cardio-respiratory compromise and poor respiratory drive)
- Certain congenital malformations of the airway (Choanal atresia / Cleft palate / Tracheo-esophageal fistula/Congenital diaphragmatic hernia)
- Progressive respiratory failure with PCO2>60 mmHg and/or inability to maintain oxygenation (PO2<50 mmHg)
- Lack of oxygen drive

5.4. CPAP is functioning

If child is comfortable, pink and has

- Normal Capillary Refill Time (CRT)
- Normal blood pressure
- Improving respiratory distress
- No cyanosis
- Audible air entry on auscultation
- SPO2 within normal range (according to age)

5.5. Weaning from CPAP:

- Hemodynamically stable, no signs of respiratory distress, adequate lung expansion
- While using blender, reduce FiO_2 in steps of 0.05 to 0.3, and then decrease pressure in steps of 1-2cm H_2O until 3-4 cm H_2O
- While using bubble CPAP, decrease pressure in steps of 1-2cm H_2O until 3-4 cm H_2O and the flow should be constant.

High Flow Nasal Cannula *(HFNC)*

High-Flow Nasal Cannula (HFNC) oxygen therapy is a recent technique delivering a high flow of heated and humidified gas[35]. HFNC is simpler to use and apply than Non-Invasive Ventilation (NIV) and appears to be a good alternative treatment for hypoxemic acute respiratory failure. HFNC is increasingly utilized in pediatrics, delivering humidified air and oxygen for respiratory distress causing hypoxia and /or hypercarbia [35, 36, 37,38]. In the Intensive Care Unit (ICU), it has been associated with better tolerance, lower complications, and lower cost. HFNC is usually started at a rate of 1 Litre/kg/min with 0.5-0.6 FiO2 and can be increased up to 3 litre/kg/min. (see **Figure 18**)

5.6. Indication for High Flow Nasal Cannula

5.6.1. Neonates:

- Respiratory Distress Syndrome (RDS)
- Apnea of prematurity (especially obstructive apnea)
- Post extubation in preterm VLBW infant
- Transient tachypnea of Newborn (TTNB)/ delayed adaptation
- Pneumonia
- Meconium aspiration/ other aspiration syndromes
- Pulmonary hemorrhage
- Laryngomalacia/ tracheomalacia/bronchomalacia

5.6.2. Infant and Children:

- Pneumonia
- Acute severe asthma

- Bronchiolitis
- Post-extubation
- Obstructive upper airway disease
- Neuromuscular diseases
- Congestive heart failure
- Left ventricular heart disease
- Acute hypoxemic respiratory failure
- Pre oxygenation before intubation or during bronchoscopy
- Postoperative respiratory failure

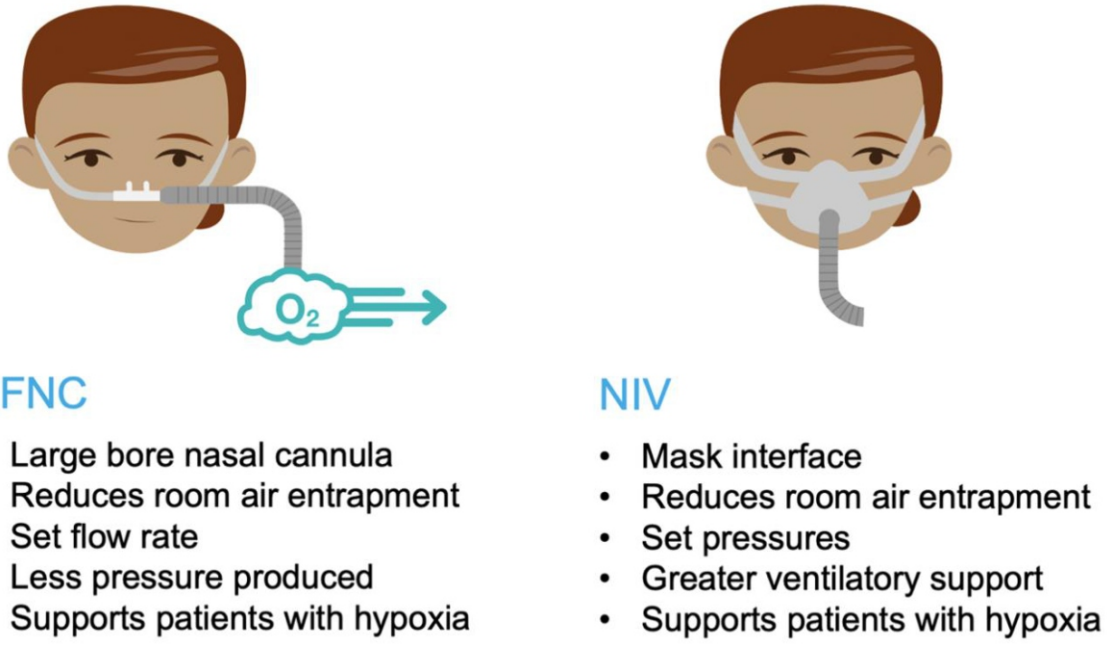


Figure 18: High Flow Nasal Cannula (HFNC) and Non Invasive Ventilation (NIV)

5.7. Weaning from HFNC:

- Hemodynamically stable, no signs of respiratory distress, adequate lung expansion
- Reduce FiO_2 in steps of 0.05 to 0.3, and then decrease flow in steps of 1-2 Litre/min until 5 Litre/min

5.8 KEY MESSAGES

- Continuous positive airway pressure (CPAP) keeps the airway open by maintaining the Functional Residual Capacity (FRC)
- Oxygen Flow rate of 5-10 litre/min is required for older children, while 3-4 litre/min is sufficient to generate CPAP in Neonates
- Weaning while using blender CPAP, reduce FiO_2 in steps of 0.05 to 0.3, and then decrease pressure in steps of 1-2cm H_2O until 3-4 cm H_2O

- Weaning while using bubble CPAP, decrease pressure in steps of 1-2cm H_2O until 3-4 cm H_2O and the flow should be constant
- In most circumstances, HFNC is the preferred oxygen delivery method for an optimal balance between safety, efficacy, and efficiency
- HFNC is usually started at a rate of 1 Litre/kg/min with 0.5-0.6 FiO2 and can be increased up to 3 litre/kg/min
- Weaning HFNC require reduction in FiO_2 in steps of 0.05 to 0.3, and then decrease flow in steps of 1-2 Litre/min until 5 Litre/min

Chapter 6

6. HUMIDIFICATION

The process in which the moisture or water vapor or humidity is added to the air without changing its dry bulb (DB) temperature is called humidification process. Some oxygen delivery methods require use of humidifiers for the patient's comfort.

Oxygen therapy can be delivered with low or high flow systems. All high flow systems require humidification, depending on oxygen system delivery and patients' requirements.

6.1 Rationale

- Oxygen can be humidified with the aim of reducing sensations of dryness in the upper airways, though low-flow rate of fewer than 5 liters of oxygen per minute via soft plastic nasal cannula do not need humidification
- Humidification is needed when oxygen is given via a nasopharyngeal catheter and patients with an endotracheal tube or a tracheostomy
- For neonates, oxygen should be administered through an oxygen blender and humidified; even if low flow rates of oxygen are used and administered via nasal cannula

6.2 Unheated Bubble Humidifiers

It is a simple, low-cost device, used when higher than standard flow is required, which reduces the dryness of supplied oxygen by bubbling it through water at room temperature, firmly attached to the oxygen outlet, filled with clean water. (See **Fig 19**)

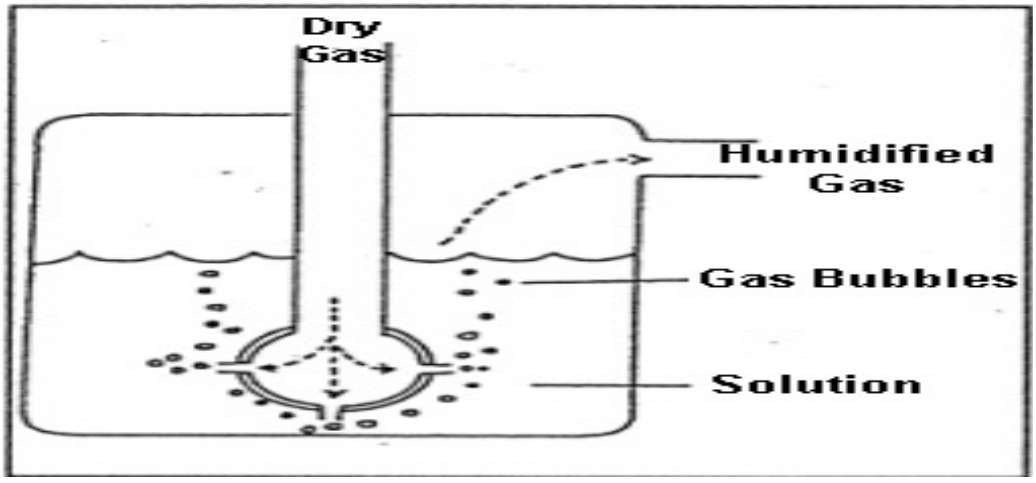


Figure 19: The Bubble Humidifiers Schematics

6.3 Heated Humidifiers

More effective than unheated [39], however they are moderately expensive and require a continuous power supply. (See **Figure 20**)

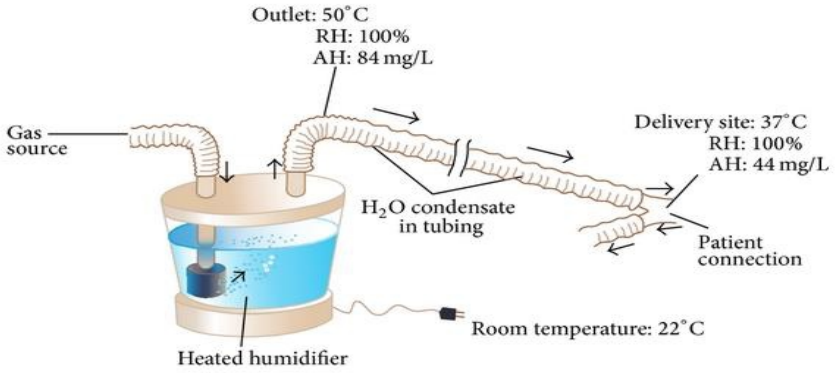


Figure 20: Heated Humidifier

6.4 Safety

Care must be taken to prevent contamination in humidification. The flow meter should be cleaned regularly, clean water must be used, and new tubing used for each patient [40, 41, 42].

6.5 Key Messages

- Humidification is required if oxygen is supplied from a cylinder
- It is required when oxygen is delivered through a nasopharyngeal catheter, endotracheal tube, and tracheostomy
- When oxygen is delivered at higher than standard flow rate > 4 litres/min through nasal catheter or nasal prongs, humidification is required

Chapter 7
7. MONITORING CHILDREN WHILE ON OXYGEN THERAPY

Appropriately trained personnel must supervise children on oxygen therapy to prevent complications of oxygen administration.

7.1. Monitoring:

- Position of nasal prong or catheter (at least 3 hourly check)
- Connections are secure for interface
- Blockage of prongs/catheters with mucus secretions
- Any injury at interface site
- Oxygen flow rate
- Settings: FiO_2, PEEP and oxygen flow
- Monitoring of oxygen saturation
- Signs of respiratory distress: respiratory rate, chest in-drawing
- Any slow or shallow breathing (signs of inadequate ventilation)
- Consciousness level (irritable or drowsy)
- Perfusion – CFT (Capillary Filling Time), BP, peripheral pulses, urine output
- Abdominal distension especially in NIV.
- When to do chest X-ray:
    - If inadequate lung expansion
    - To assess the lung condition

7.2. Pulse oximetry monitoring

- Continuous monitoring with pulse oximetry can be used for weaning off oxygen when clinically stable
- If pulse oximeters are inadequate in number, then all patients on oxygen support should be monitored at least 4- hourly and assessed for weaning off oxygen

7.3 Criteria for weaning off oxygen therapy

If following conditions are met, then trial of weaning from oxygen can be given.

1. If SpO_2 is above 90% and:
    I. No signs of respiratory distress
    II. Child is hemodynamically stable
2. Adequate lung expansion on chest X-ray (optional).

7.3.1 During trial for stopping oxygen:

- Monitor the SpO_2
- If the SpO_2 is ≥ 90%, 10–15 min after the child has been taken off oxygen, leave the oxygen off:
  - Check the SpO_2 again in 1 hour
  - If the SpO_2 is < 90%, resume oxygen and review periodically

**Children should not be discharged until their SpO_2 has been stable at ≥ 90% while breathing room air and until all danger signs have been resolved and appropriate home treatment is organized. (Supplemental oxygen is best interrupted first in the morning, when there are likely to be adequate staff to observe the child throughout the day).

7.4 Care of a child when receiving oxygen:

Children who are on oxygen therapy should be observed following as given in **Table 9.**

Table 9: Care of a child when receiving oxygen

1. Handling	• Gentle handling. • Painful procedure and unnecessary stress should be avoided.
2. Skin	Watch for color, perfusion, areas of pressure points and areas of skin excoriations.
3. Airway	
3.1 Positioning	• Head raised about 30° with neck support can improve breathing • Some hypoxic neonates and young infants may be more stable in the prone position, as long as their faces are not obstructed
3.2 Suctioning	• Assessment of secretions in the nose and mouth • Suctioning is recommended only when required • When the secretions are thick, moisten the nares with normal saline
4. Interface	• Ensure prongs/ catheters are fitted properly into the nares • Watch for symmetry of nose, blanching of the skin and any skin break down
5. Fluid and Nutrition	• Withhold oral feeds while the child has severe respiratory distress to avoid the risk of aspiration • Ensure good nutrition as soon as respiratory distress resolves
6. Orogastric tube	• Pass an orogastric tube and keep the proximal end of tube open • If the infant is being fed while on oxygen, close the tube for half an hour after giving feeds and keep it open for the next 90 minutes (if fed 2hourly)
7. Oxygen delivery system	• Check whether flow rate is adequate or not in any delivery system • Bubble chamber should be monitored for bubbling and the level of

7. Oxygen delivery system	• Check whether flow rate is adequate or not in any delivery system • In CPAP, check the set pressure (PEEP), FiO_2 flow rate regularly • Bubble chamber should be monitored for bubbling and the level of water
8. Humidifier	• Set temperature of 37°C on the humidifier • Adequate water in the chamber • No condensation in the inspiratory limb and some condensation in the expiratory limb are proof of good and adequate humidification • The humidification chamber should be set at invasive mode in automatic humidification
9. CPAP	• In CPAP, the cap should cover the ears and fit properly • Watch for twisting of the nasal interface, blanch the tip of nose and assess for perfusion integrity

7.5 Oxygen Toxicity:

Oxygen toxicity results from exposure to high concentration of oxygen. It has several harmful effects on the body. Oxidative damage may occur in any cell of the body, but the most affected systems are as follows:

System	Effects of hyperoxia
Respiratory System	Chronic Lung Disease.
Eyes	Retinopathy of Prematurity (ROP) in preterm infants.
Central Nervous System	Convulsions, unconsciousness (Paul Bert Effect).

7.6 Key Messages

- Children receiving oxygen should be monitored clinically and at least twice a day by pulse oximetry
- SpO_2 is the most critical vital sign; therefore, pulse oximetry is an invaluable routine monitoring tool
- A nurse should check every 3 hourly that the prongs or catheter are in the correct position and not blocked with mucus, that all connections are secure, that the oxygen flow rate is correct, that the airways are not obstructed by mucus and that there is no abdominal distension. Prongs or catheters should be removed and cleaned at least twice a day
- Hypoxemia may last from several hours to several weeks; the usual duration is 2-5 days
- At least once a day, children who are clinically stable (have no emergency signs and $SpO_2 \geq 90\%$) should be disconnected from oxygen for 10-15 min and carefully examined for changes in clinical signs and SpO_2 to determine whether supplemental oxygen is still required

- Children should not be discharged until their SpO_2 has been at ≥ 90% while breathing room air for at least 24hrs and until all danger signs have resolved and until appropriate home treatment has been organized

Chapter 8
8. INFECTION PREVENTION MEASURES

Besides maintaining aseptic precautions for handling of respiratory equipment, the following criteria should be followed in all health care facilities:

- There will be Infection Prevention and Control (IPC) committee and IPC guidelines in the facility
- All staff will be aware of IPC guidelines and instructions will be available at each point of care
- Facility will have designated hand washing areas with water and soap
- There will be adequate hand hygiene supplies (70% alcohol-based solutions)
- Facilities will have environmental cleaning and safe waste management protocol and practice

8.1 Cleaning of Equipment

Table 10: Use of disinfectant and frequency of cleaning of equipment

Respiratory equipment	Frequency of cleaning	Disinfectant
Cylinder	Weekly	Exterior of oxygen cylinder cleaned with mild disinfecting cleaning agent or a diluted solution of bleach (5.25% sodium hypochlorite). Solution of 1:100 to 1: 10 of bleach to water can be used. Rinse solution off after 10 minutes and dry.
Nasal Cannula/ catheter/ tubing	These are single use products and should be discarded after each use.	
Cylinder, valve, flow meter	Weekly	Wet cloth
Oxygen concentrator	Weekly	Filter cleaned in warm, soapy water and dried with an absorbent towel.
Thorpe tube flow meter	Daily (disconnect all connections before cleaning)	Exterior cleaned with cloth dampened with mild detergent and water. Wipe exterior dry with clean cloth.

Thorpe tube flow meter	Daily (disconnect all connections before cleaning)	Do not spray anything directly onto flow meter. Exterior cleaned with cloth dampened with mild detergent and water Wipe exterior dry with clean cloth.
Humidifiers	Water level should be checked twice daily and topped up as necessary. Water in the humidifier should be changed daily. Humidifier, water jar, catheter must be washed and disinfected to prevent bacterial colonization*. Humidifier bottle if used have to disinfect and refill with distilled water.	Soap and water, rinse with clean water and dry in air before use
Pulse oximeter	Wipe after each use	Alcohol swab
CPAP/HFNC	Always use disposable circuits. No need to replace circuit routinely. Fill the Humidifier chamber with Distilled water. Use Auto-fill option for filling the chamber.	Clean the equipment with a soft cloth

*Once a week (for the same patient) and in between patients, all the components of the humidifier should be soaked in a mild antiseptic solution for 30 minutes, rinsed with clean water and dried in air. Allowing the humidifier to dry completely will discourage bacterial colonization. At every change, check for leakages between the flow meter and humidifier and between the humidifier and oxygen delivery device. A spare, clean humidifier filled with clean water should always be available, so that oxygen therapy is not interrupted while the humidifier is being cleaned.

8.2 Key Messages

- Follow the IPC committee and IPC guidelines for infection prevention measure
- All the health care providers should be aware for IPC guidelines
- All the tubing should be single use and must be discarded after each use
- Humidifier and water jar, catheter must be washed and disinfected to prevented bacterial colonization

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DISCLAIMER: National Guidelines on Oxygen Therapy for Children do not endorse any particular manufacturer's equipment for use. This is only for educational and training purposes.

Annex-I

Monitoring Checklist for children receiving Oxygen therapy (nasal prongs/nasal catheter/hood box/face mask)

(Will be filled up by nurse in each shift/day)

Date:

Monitoring parameters	Morning Time:	Evening Time:	Night Time:
A. Clinical			
Heart rate (/min) Respiratory rate (/min)			
Chest retraction			
Silverman-Anderson score			
CRT			
SPO_2			
B. Oxygen delivery device			
Cylinder			
Concentrator			
Flow rate (/min)			
Oxygen tubes patent			
C. Humidification			
Present/ absent			
Temp in humidifier			
D. Interface			
Nasal prongs/nasal catheter/ hood box/face mask			
Size appropriate or not			
Skin near interface (intact/ redness/ excoriation)			
E. Head & neck position			
Days on oxygen			
Assessment: (stable/ respiratory distress increased)			
Filled up by nurse (name)			

Annex-II

Monitoring Checklist for children while getting CPAP

(Will be filled up by nurse in each shift/day)

Date:

Monitoring parameter	Morning Time:	Evening Time:	Night Time:
A.Clinical:			
Heart rate (/min)			
Respiratory rate (/min)			
CRT			
Chest retraction			
Silverman-Anderson score			
Abdominal girth (cm)			
B.Equipment:			
PEEP (cm H20)			
Flow rate (L/min)			
FiO2 (%)			
Humidification (present or absent)			
Temp of humidifier			
Water in bubble chamber up to the level (present or absent)			
Bubbling is present in water chamber			
Corrugated tubing are correctly placed			
C.Interface:			
Prongs/ mask			
If prongs –touching collumella or not			
Nasal septum area (any redness/ skin excoriation/ swelling/ damaged)			
Chin strap if used (tight/loose)			
D. Position of baby's head and neck			
Days in CPAP			
Assessment: (stable/ respiratory distress increased)			
Filled up by nurse (name)			

Annex-III

Patient Individual Case sheet

Patient information		Treatment
Name		
Patient ID/registration #		
Sex		
Age		
Weight		
Date:		
Diagnosis		
Physical examination		
Medical follow up (last date)		
Child Consciousness (Active/lethargy/Unconscious)		
Pulse		
BP		
Temp		
SpO2		
Respiratory Rate		
Severe Chest indrawing (Y/N)		
Central cyanosis (Y/N)		
Lung examination		
Head nodding (Y/N)		
Any injury/inflammation at the oxygen interface site (Y/N)		
Investigation		
TC, DC, HB%, ESR		
Blood Film		
Urine RE		
Stool RE		
RBS/FBS		
CXR		
USG		
Other-		

Annex- IV

Daily Monitoring Chart

Guidance: Should be filled up 6 hourly and monitor frequency will depend patient condition (if required)																
Date:																
1. Patient information																
Patient ID:																
Child name:																
Gender:																
Age:																
Weight:																
Diagnosis:																
	Day 1				Day 2				Day 3				Day 4			
2. Vital sign																
Consciousness level																
Pulse rate																
Temperature																
SpO2																
Respiratory rate																
Severe Chest indrawing (Y/N)																
Central cyanosis (Y/N)																
Lung examination																
Head nodding (Y/N)																
Any injury/inflammation at the oxygen interface site (Y/N)																
3. Fluid balance (record volume and times)																
IV																
By nasogastric tube																
Oral																
Fluid output																
4. Treatment given																
Name of treatment																
Oxygen Flow Rate (LPM)																
5. Feeding/nutrition																
Child breastfed																
Drink taken																
Food taken																
Feeding problems (given details)																
Weight																
Outcome																

Annex-V

Daily Monitoring Checklist for Hypoxemic cases - Oxygen therapy

(Will be filled up by doctor/nurse/others in each shift for all Hypoxemia cases admitted in the unit)

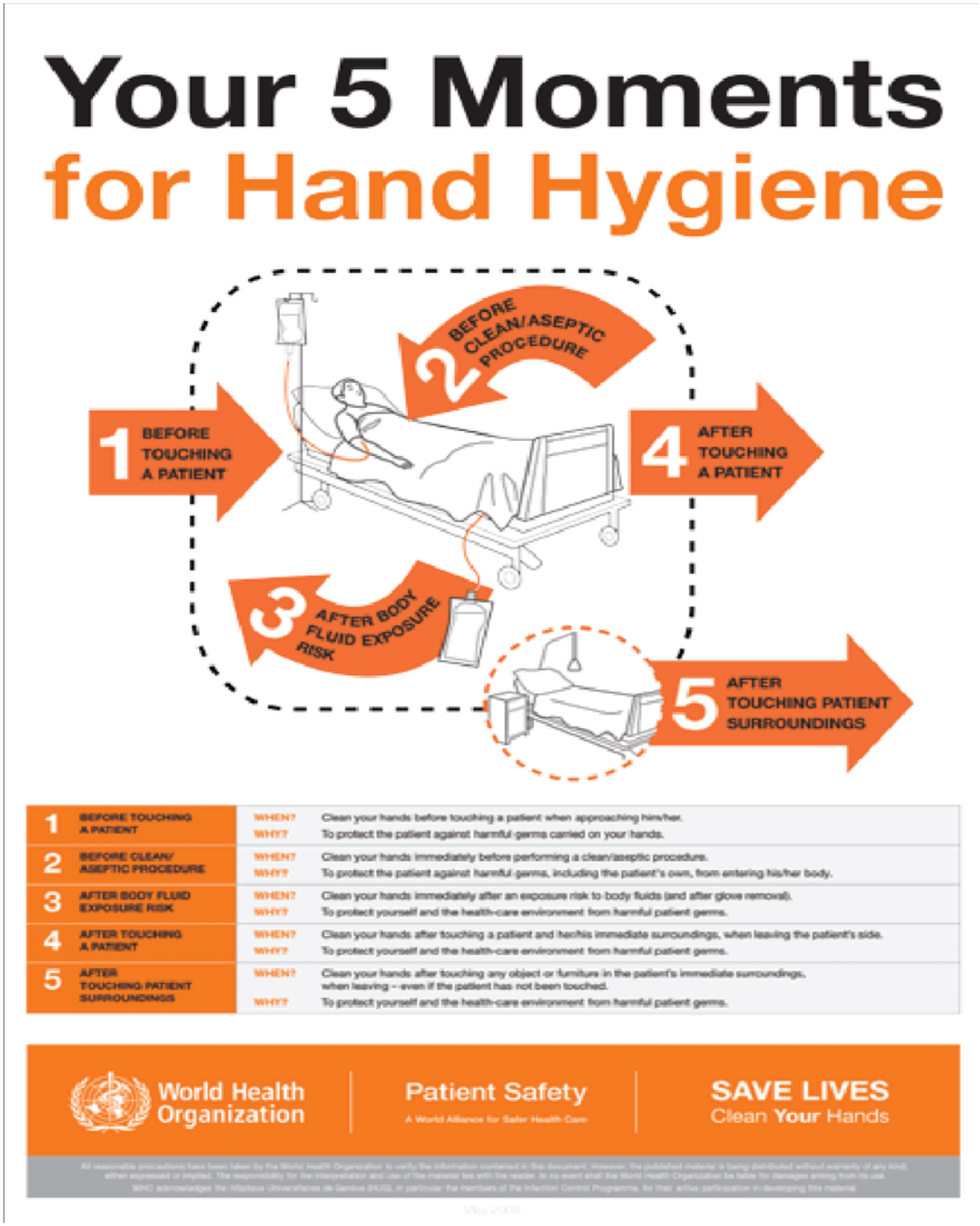
Name:
Patient ID:
Bed no:
Date:
Time:
Diagnosis.....With Hypoxemia

Monitoring parameters	Morning Shift Name of Doc/SSN: Time:	Evening Shift Name of Doc/SSN: Time:	Night Shift Name of Doc/SSN: Time:
Patient individual case sheet is available (Yes/No)	**Y / N**	**Y / N**	**Y / N**
Patient individual case sheet is properly filled (Yes/No)	**Y / N**	**Y / N**	**Y / N**
Patient Monitoring Chart is available and properly recorded (Yes/No)	**Y / N**	**Y / N**	**Y / N**
SpO2 and oxygen flow rate is properly filled in monitoring chart (Yes/No)	**Y / N**	**Y / N**	**Y / N**
SPO2 **(add exact value)**			
Oxygen therapy is given according to guideline (Yes/No)	**Y / N**	**Y / N**	**Y / N**
Flow rate (Liter/min) **(add exact value)**			
O2 Flow Rate is as per advice in the case sheet	**Y / N**	**Y / N**	**Y / N**
Oxygen delivery device* and interfaces are functional (Yes/No)	**Y / N**	**Y / N**	**Y / N**
Data entry in register and reporting for hypoxemia are properly done	**Y / N**	**Y / N**	**Y / N**

***Oxygen Delivery devices: Device (e.g. cylinder/Concentrator/Central outlet)**
Interfaces (e.g. nasal prongs/ cannula/Masks)

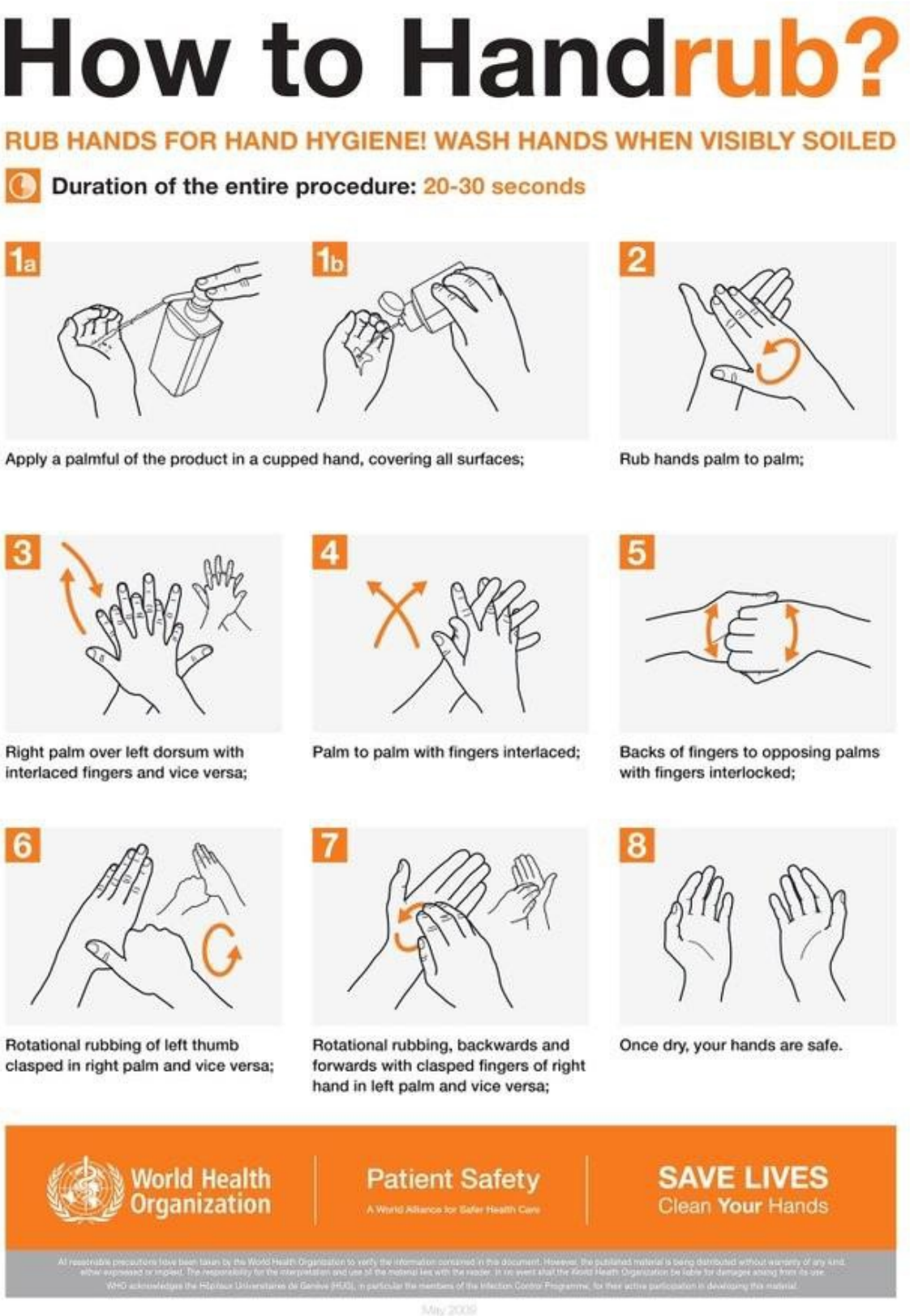
Annex-VI

Infection Prevention Measures



Annex-VII

Infection Prevention Measures



Annex-VIII

A: Requirements of Oxygen Resources at Different Levels of Healthcare Facilities

	Primary Level Facility	Secondary Level Facility	Tertiary Level Facility
Oxygen gas cylinders	✓	✓	✓
Oxygen supply from central line	x	✓	✓
Supply of oxygen tubing and nasal cannulas	✓	✓	✓
Pulse oximeter	✓	✓	✓
Blood pressure monitor	✓	✓	✓
Thermometer	✓	✓	✓
Glucometer & associated supplies	✓	✓	✓
Number of oxygen cylinders per patient	Ensure adequate number of cylinders per patient according to Oxygen consumption (litres per day of 100% O2 consumed)* Cylinder size, storage pressure and volume** along with enough back up from central supply	Ensure adequate number of cylinders per patient according to Oxygen consumption (litres per day of 100% O2 consumed) * Cylinder size, storage pressure and volume** along with enough back up from central supply	Ensure adequate number of cylinders per patient according to Oxygen consumption (litres per day of 100% O2 consumed) * Cylinder size, storage pressure and volume** along with enough back up from central supply

* ***for nasal cannula, face mask and non-rebreather***: *FiO2 is assumed to be 1.0 and flow rates are adjustable in litres per minute. Litre per day consumption of O2 = device flow rate L/min x 60 minutes/hr x 24 hr/day*

* ***for high flow nasal cannula***: *FiO2 is adjustable (defaulted to 1.0) and flow rate is adjustable in litres per minute. Litre per day consumption of O2 = device flow rate L/min x 60 minutes/hr x 24 hr/day; flow rate in LPM=device flow rate x (FiO2 – 0.21)/ 0.79*

* ***for ventilator, CPAP,BIPAP/NIPPV***: *FiO2 is adjustable (defaulted to 1.0) and flow rate is adjustable in litres per minute and dependent on multiple factors. Litre per day consumption of O2 = device O2 consumption rate L/minute x 60 minutes/hr x 24 hr/day; device O2 consumption rate in LPM = (minute ventilation + (bias flow x RR x expiratory time/60) + leak) x (FiO2 – 0.21) /0.79*

Reference: Open Critical Care Oxygen supply & demand calculator https://opencriticalcare.org/oxygen-supply-demand-calculator/

** *refer to manufacturers specifications.*

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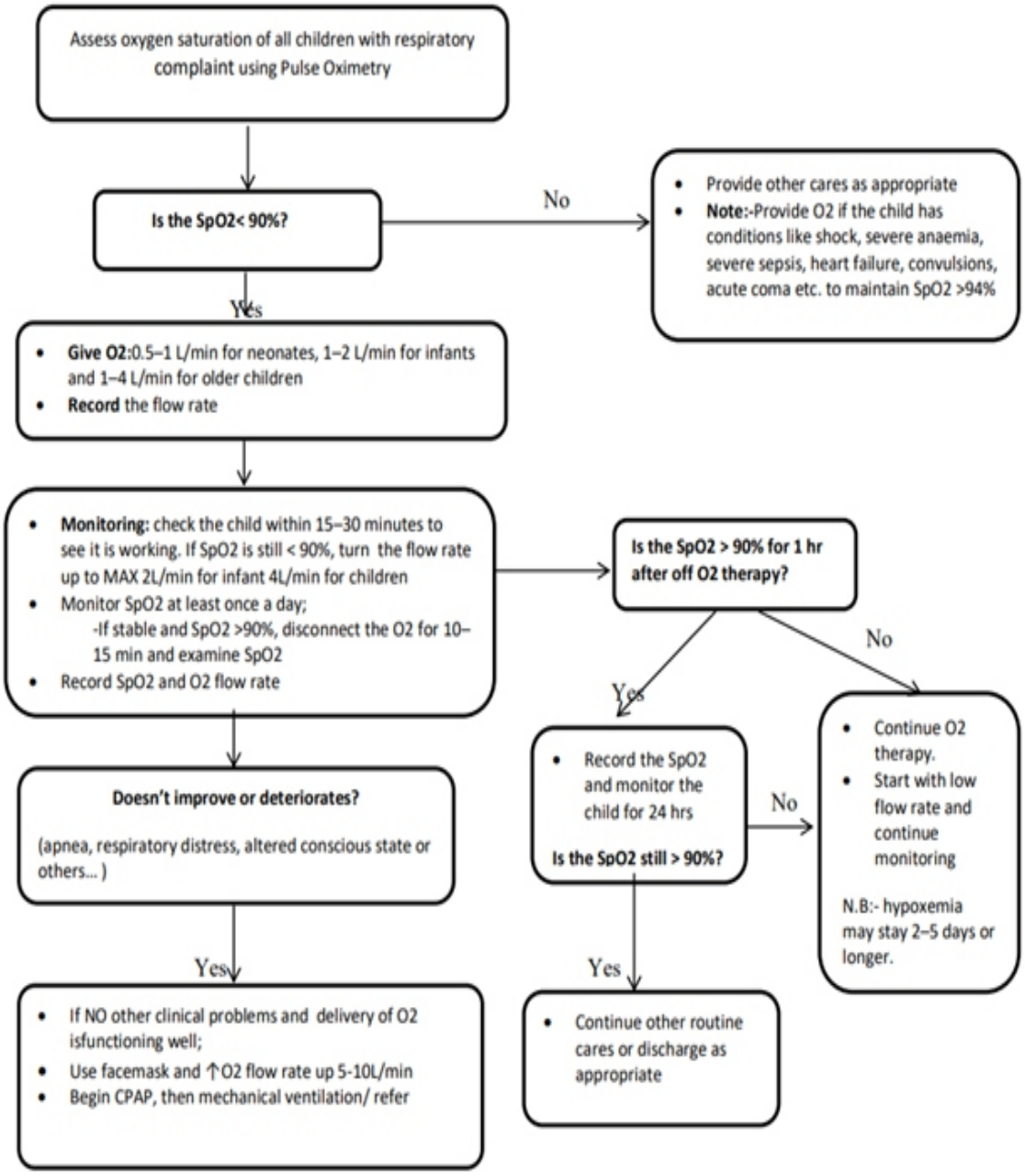
B: Differences between Oxygen Concentrators and Compressed Gas Cylinders

	Oxygen concentrators	Compressed oxygen cylinders
Power source required	Yes, continuously	No
Transport required	Only at the time of installation; refilling not required	Yes, regularly; heavy and costly to transport; refilling required with transport from refilling station to healthcare facility
Exhaustible oxygen supply	No, continuous supply as long as power remains uninterrupted	Yes, depending on the size, storage pressure, and patient needs
User care	Moderate: cleaning of filters and device exterior, and ensure to minimize fire hazard	Minimal: regular checking, and ensure to minimize fire hazard (no grease or flammables)
Initial costs	High	Low (but recurrent costs occur)
Maintenance	Moderate: check for low oxygen output with analyzer	Moderate: check for pressure leaks with gauge
Shifting/transporting patient	Not suitable	Can be used

C: Oxygen Therapy for Children – Flow Chart on Monitoring



Ministry of National Health Services,
Regulations and Coordination
Government of Pakistan