

SPECIAL COMMUNICATION

PEDIATRIC OXYGEN THERAPY: A CLINICAL UPDATE

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Oxygen therapy is a life-saving, medical intervention in the management of hospitalized children. The goal of oxygen therapy is to prevent or treat tissue hypoxia. Oxygen should be prescribed according to the principles of drug prescription, however, use of oxygen in clinical practice is often inappropriate without knowledge of its potential risks and benefits. This article summarizes practical aspects of clinical use of oxygen in terms of indication, administration, and monitoring, weaning, discontinuation and oxygen toxicity to rationalize therapy and achieve maximum benefits.

Keywords: Oxygen; administration; device; children

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INTRODUCTION

Oxygen therapy is defined as the administration of oxygen at concentration greater than ambient air (>21%) with the intent of treating or preventing symptoms of hypoxia.¹ History regarding identification of oxygen as a chemical element and a therapeutic modality is contentious. Oxygen was discovered as “dephlogisticated air” in 1774 by Joseph Priestly, however, it was during early 20th century that with pioneering work of Haldane therapeutic use of oxygen was rationalized.² Oxygen therapy is one of the most commonly employed medical interventions in hospital practice; prevention and treatment of hypoxemia is the most common indication for oxygen therapy.³ Few recent reports on clinical audit of oxygen therapy in hospitalized patients demonstrated a misuse of oxygen therapy.^{4,5} There is limited information available in literature on oxygen therapy in children.⁶ The purpose of this review is to provide updated information on paediatric oxygen therapy with special emphasis on delivery methods. This article reviews paediatric oxygen therapy in terms of indication, administration, monitoring, weaning, discontinuation and adverse effects of improperly administered oxygen therapy.

Oxygen is essential for living. Few organs like heart, brain and kidney need high amounts of oxygen for their survival based on their cellular requirement. Oxygen requirement may also be increased in few instances like, exercise, fever, trauma and burns, etc.^{7, 8} The human body however does not have a store of oxygen in the body.

Oxygen moves down a partial gradient from air through the respiratory tract to mitochondria of cells-this is known as ‘oxygen cascade’.⁹ The transport of oxygen involves a series of convective and diffusive processes from air to cell. Convective oxygen transport refer to bulk movement of oxygen in air or blood while diffusion transport refers to

passive movement of oxygen down its concentration gradient across tissue barriers.^{3,10}

Indications for Oxygen therapy

Acute hypoxemic respiratory failure is a common and major cause of morbidity and mortality among children.^{11,12} Hypoxia is the most important indication for oxygen therapy through any delivery device.^{8,9} Acute respiratory distress/failure due to croup, asthma or pneumonia, etc. are also indications for oxygen therapy.^{12,13} According to current paediatric advance life support (PALS) guidelines, oxygen supplementation with highest concentration should be initiated in emergency conditions like cardiorespiratory arrest and then tapered to keep pulse oximetry saturation above 94% for most clinical situations after return of spontaneous circulation.¹⁴ Hypoxia can also result from different acute conditions like severe anaemia, low cardiac output syndrome, severe sepsis, severe trauma, surgical intervention and anaesthesia; all need supplemental oxygen therapy due to tissue hypoxia despite normal PaO₂/SpO₂ (Normoxemic hypoxia).¹⁵

Oxygen therapy should be cautiously supplemented in certain clinical scenarios like chronic respiratory failure and congenital heart diseases with large left to right shunt to avoid pulmonary over-circulation by supplemental oxygen.

Principles of Oxygen Administration

Oxygen is one of the most commonly applied therapies in acutely ill children and adults. However, administration of oxygen requires patient selection, choice of appropriate delivery method according to patient size and need, monitoring with therapeutic goal and discontinuation.^{3,12}

Methods of Oxygen Delivery

Wall source and portable oxygen cylinders are the main sources of oxygen for clinical application among hospitalized children.

Oxygen delivery systems are broadly categorized as ‘low-flow’ or ‘high-flow’ systems, both of which can deliver a wide range of FiO₂. The

term low and high flow do not reflect the percentage of delivered FiO_2 , but instead refer to delivery of oxygen with respect to peak inspiratory flow rates. The 'low-flow' system provides variable FiO_2 at rates less than peak inspiratory flow rates. Nasal cannula and simple face mask are examples of 'low-flow' systems. A high-flow system provides fixed FiO_2 and/ or provides oxygen that is above the peak inspiratory flow rate. Venturi mask and non-rebreathing mask are examples of high-flow systems.^{15,16}

There is a variety of devices available for the administration of oxygen to infants and children. The choice of system will depend upon the clinical status of patient, delivered dose of oxygen and tolerance by patients.¹⁶ Understanding the various delivery systems of the most commonly used therapies in acute care setting will help avoid iatrogenic errors and enhance ability to deliver effective goal-directed care. Table-1 showed various devices for administration of oxygen and approximately concentration of inspired oxygen.

Nasal Cannula (NC) is simple to use and is usually well tolerated. (Figure-1) Conventional NC is a low-flow system with maximum oxygen flow rates at 4 lit/min in children, providing FiO_2 from 24–40%. For each liter increase in flow, FiO_2 is assumed to increase by 4%.¹⁷ There are several specialized high-flow NCs available (like vapotherm) which involve the delivery of heated and humidified oxygen at rate of 8–40 lit/min. Multiple studies have demonstrated a significant advantage of high-flow nasal oxygen therapy in infants and children with mild to moderate respiratory distress, including reduced need of intubation, less chance of iatrogenic pneumonia, preservation of airway defence reflexes, improvement in patient comfort and less need of ICU stay.^{18,19} Kinikar *et al* has described the simple, inexpensive, indigenous high-flow nasal cannula for infants and children upto 5 years with acute respiratory distress with excellent results especially in resource-limited settings.²⁰

Face masks are frequently used oxygen delivery system for spontaneously breathing patients. There are several sizes and types available which should fit over patient's nose and mouth.

Simple face mask is a 'low-flow' system with a plastic transparent mask which can provide 35–50% FiO_2 with flow rate between 6–10 lit/min depending upon a patient's inspiratory flow rate (Figure-2). It should not be administered below 5 lit/min because it can lead to entrainment of exhaled carbon dioxide (CO_2) and cause CO_2 narcosis.²² It is useful for patients who need moderate oxygen flows to maintain acceptable oxygen saturation.

Partial rebreathing mask is a simple mask with a reservoir bag with a system of valves attached to mask. The initial one-third of exhaled gas flows into reservoir bag and mixes with fresh gas. The rest of exhaled gas is flushed out through ports. FiO_2 ranges between 60–80%. To minimize CO_2 rebreathing, oxygen flow rate must be adjusted to keep the reservoir inflated during the entire ventilatory cycle.

Non-rebreathing Mask: Unlike the partial rebreathing mask, this mask has additional valves preventing entry of exhaled gases into the reservoir bag (Figure-3). With virtually no mixing of gases, these masks can deliver close to 100% FiO_2 . Exhalation occurs through a one-way valve between the mask and atmosphere.

A specialized face mask is also used for non-invasive positive pressure ventilation in patients with acute respiratory failure.

Aerosol masks are 'high-flow' oxygen delivery system for delivery of various respiratory medications like albuterol, ipratropium, epinephrine, etc (Figure-4).

Venturi masks are dilutional masks that work on Bernoulli's principle (jet-mixing (Figure-5)).²¹ There are several advantages of Venturi system which includes: delivery of fixed FiO_2 independent of patient's inspiratory pattern (high-flow device), helps in changing oxygen requirement, humidification is not required, besides being fairly cheap and reliable. It is useful for patients who need limited concentration of oxygen like chronic respiratory failure who depend on hypoxic respiratory drive or neuromuscular disease as well as children with congenital heart defects with increased pulmonary blood flow like large ventricular septal defect, atrioventricular canal defect, etc.

Oxygen poisoning occurs after the administration of high concentration of oxygen to breathless patients with large left-right shunt leading to pulmonary vasodilatation with diversion of blood flow into pulmonary circulation instead of systemic circulation. This is a cardiac failure with high pulmonary blood flow leading to tissue ischemia, metabolic lactic acidosis and pulmonary oedema with high SpO_2 and if not reversed, ultimately led to death.

Bag mask ventilation is usually reserved for assisted ventilation for patients with decompensated respiratory failure, after cardiopulmonary arrest and prior to elective intubation. Two types of bags are commonly used for assisted ventilation: Self-inflating (Ambu bags) (Figure-6) and flow-inflating bags (Figure-7).

Enclosure Systems include oxygen hoods and oxygen tents.

Oxyhood is a clear plastic cylinder which is well tolerated by new-borns. It can deliver up to 100% FiO₂ with additional source of oxygen.

Oxygen Tents are clean, plastic shells that surround child's head and upper body. A tent however, limits access to the child by family and clinical staff and it is difficult to see the patient clearly. It is almost obsolete in clinical practice.

Monitoring of oxygen therapy

Continuous monitoring of oxygenation during oxygen therapy in hospitalized setting is recommended. The clinical monitoring includes observation of level of consciousness, cardiorespiratory monitoring like respiratory rate, pattern of breathing, skin and mucosa colour, heart rate, etc. Pulse oximetry (SpO₂) is the most commonly used technology for non-invasive, continuous monitoring of oxygen therapy.^{8,9} It can be periodically verified through the gold standard of PaO₂ and SaO₂ from arterial blood gas to assess tissue oxygenation. Oxygen therapy can be titrated and weaned with continuous SpO₂ monitoring in clinically stable patients.²² Newer generation of pulse oximetry (Massimo) uses signal extraction technology (SET) to reduce false alarms of different artefacts like movement, bright light, colour and even poor perfusion status^{23, 24}. There are few instances where pulse oximetry is not reliable like carbon monoxide poisoning and methemoglobinemia. The nomenclature of oxygen and oxygen-derived variables are shown in Box 1²⁵. The pressure unit conversion is shown in table-2.

However, tissue hypoxia is more common in critically ill patients due to imbalances between oxygen delivery and oxygen consumption despite normal SaO₂ and PaO₂. Adequacy of tissue oxygen is the essence of critical care medicine. Tissue oxygenation can be detected and monitored by measuring the central mixed venous saturation, oxygen extraction ratio, arterial pH and serum lactate level.^{1,2}

Discontinuation of oxygen therapy

Oxygen therapy should be stopped when a patient's clinical condition improves and there is no further need of oxygen.⁹ Oxygen therapy can be stopped either abruptly like postoperative patients or weaned gradually on recovery from respiratory illness. Patients should be monitored for a period of time from 30 min to longer following discontinuation of oxygen therapy.⁴

Oxygen Toxicity

As with other drugs, oxygen can cause adverse effects which have been categorized into three groups and are discussed below.²⁶

1. Physical risks: Oxygen is highly combustible posing a potential fire hazard. Oxygen is dry air

which can cause irritation of mucosa and crusting. If a patient is breathing high concentrations of oxygen, the rate of absorption atelectasis is greatly accelerated, especially in cases of respiratory failure because they often have excessive secretions or cellular debris in their airways.

2. Physiological Risks: Uncontrolled supplemental oxygen in patients with chronic respiratory failure due to chronic obstructive lung disease or neuromuscular failure can lead to coma and death. Supplemental oxygen for respiratory distress in children with large ventricular septal defects can cause pulmonary vasodilatation, leading to diversion of blood to pulmonary circulation instead of systemic circulation. This causes severe metabolic acidosis and even death due to high Qp/Qs ratio (pulmonary blood flow/systemic blood flow ratio).
3. Biochemical and cellular effects: Cellular damage can result due to formation of highly reactive oxygen free radicals (hydroxyl radicals and peroxynitrite) after prolonged exposure to oxygen therapy. Oxidative damage can occur in any cell in the body, with obvious effects observed in lungs, eyes, red blood cell, kidney, and endocrine glands (thyroid and adrenal).



Figure-1: Nasal Prong



Figure-2: Simple face mask



Figure-3: Non-rebreathing Mask

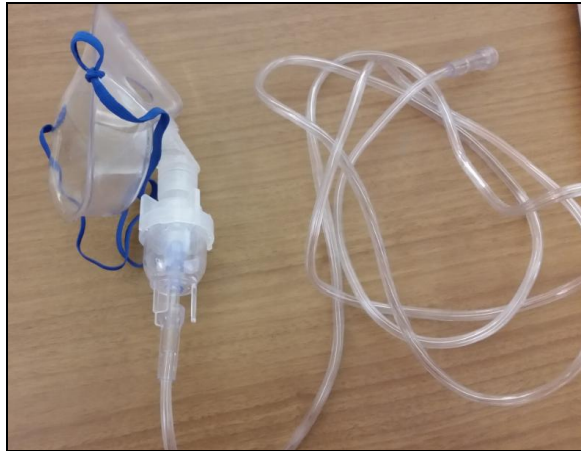


Figure-4: Aerosol Mask



Figure-5: Venturi Mask



Figure-6: Self-Inflating Bag with Reservoir



Figure-7: Flow-Inflating Bag

Table-1: Devices of oxygen therapy

Device	Oxygen Flow (L/min)	Approximate FiO ₂ (%)
Simple nasal cannula	0.25-4 L/min	22-60% (1L/min increase 4% FiO ₂)
High-Flow nasal cannula	8-40	21-100%
Simple face mask	5-10	40-60
Partial rebreathing Bag	6-12	50-75
Non-rebreathing Bag	8-10	90-100
Venturi mask	Variable	25-60 (device-specific)

Box-1: Nomenclature of Oxygen and Oxygen-derived Variables²⁵

Symbol	Interpretation
PaO ₂	Partial pressure of arterial oxygen
PAO ₂	Partial pressure of alveolar oxygen (FiO ₂ X 713) - (PaCO ₂ X 1.2)
PaCO ₂	Partial pressure of arterial carbon dioxide
FiO ₂	Fraction of inspired oxygen concentration
SaO ₂	Arterial oxygen saturation
SpO ₂	Pulse oximetry oxygen saturation
SvO ₂	Mixed venous oxygen saturation
Assessment of Oxygenation	
PaO ₂ / FiO ₂	Ratio of partial pressure of arterial oxygen to fraction of inspired oxygen concentration
SpO ₂ / FiO ₂	Ratio of oxygen saturation to fraction of inspired oxygen concentration
PAO ₂ - PaO ₂	Difference of partial pressure of alveolar to arterial oxygen tension
PaO ₂ / PAO ₂	Ratio of partial pressure of arterial to alveolar oxygen tension
OI	Oxygenation Index MAP X FiO ₂ / PaO ₂
Assessment of Tissue Oxygenation	
CaO ₂	Arterial oxygen content CaO ₂ = (Hb. x 1.34 x SaO ₂) + (PaO ₂ x .003)
CvO ₂	Venous oxygen content CvO ₂ = (Hb. x 1.34 x SvO ₂) + (PvO ₂ x .003)
DO ₂	Oxygen delivery Arterial Oxygen content (CaO ₂) X Cardiac Output (CO) X 10
VO ₂	Oxygen consumption CO X (CaO ₂ - CvO ₂) X 10
OER	Oxygen Extraction Ratio VO ₂ / DO ₂

Box-2: Pressure conversion unit

1 mm Hg= 1.36 cm H ₂ O
1 kPa =7.5 mm Hg [kPa – kilopascal]
1ATM=760 mm Hg [ATM- Atmospheric pressure]
1psi = 1.7 mm Hg [psi – pound square inches]
Wall Oxygen Source – 50 psi = 2585 mm Hg

CONCLUSION

Oxygen therapy is an important intervention in paediatric clinical practice. It should be prescribed like a drug with special emphasis on indication, method of delivery, monitoring, weaning and caution about potential complications.

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