Hypoxia and Oxygen Therapy

Dr Mahir Hussein Al Saadawi
Anaesthesia and I.C. Consultant

- *The administration of supplemental oxygen is one of the world's most used therapies and is a cornerstone of care in the intensive care unit (ICU).*
- *Correct administration of oxygen is lifesaving, but many times it is given without careful evaluation of its potential benefits and side effects.*
- *Oxygen is the commonest drug used in patients admitted in Intensive Care Unit.*
- *Like other drugs oxygen also carries a clear indication for treatment and appropriate methods for its delivery.*
- *Inappropriate dose and failure to monitor can have serious consequences.*
- *Vigilant monitoring is essential to detect and correct adverse effects.*

Previous study

- *Hypoxemia should certainly be avoided, but the fact that the liberal administration of oxygen to patients in intensive care units and emergency rooms tend to increase morbidity and mortality.*
- *In emergency situations, oxygen therapy can be lifesaving for patients with hypoxemia, but harmful effects of exposure to high oxygen concentrations (oxygen toxicity) have long been known.*
- *Within a few years of the introduction of oxygen therapy, the issue of potential oxygen toxicity was raised.*
- *Today, we know that increased concentrations of oxygen free radicals cause cellular damage which can lead to apoptosis or necrosis, especially in the presence of other factors, such as, for example, infection.*
- *Cell death triggers the release of mediators, causing, in combination with oxygen free radicals, further cell damage; thereby a vicious cycle is initiated and maintained.*

Assess the Need for Oxygen Therapy

- *Provide oxygen for measured hypoxemia and not only for breathlessness.*
- *Measure oxygen saturation and if it is below 90%, provide supplemental oxygen.*
- *If pulse oximetry signal not adequate, check arterial PaO_2.*
- *Record approximate FiO_2 given and oxygen saturation or PaO_2/FiO_2 ratio in patient's chart and monitor it at interval as per hospital protocol.*
- *Set a target of oxygen saturation for each patient, low normal (88–92%) for COPD, target for not at risk of hypercapnic respiratory failure is 94–98%.*
- *In emergency situations (e.g., cardiorespiratory arrest, acute cardiogenic pulmonary edema, or stroke), oxygen administration may be initiated empirically, pending detailed clinical and laboratory evaluation.*
- *Investigate and manage underlying cause of hypoxemia simultaneously.*
- *Supplemental oxygen improves oxygenation, but does not treat the underlying causes of hypoxaemia which must be diagnosed and treated urgently.*
- *Oxygen delivery devices and flow rates should be adjusted to keep the oxygen saturation in the target range.*
- *Prompt clinical assessment is needed if oxygen therapy needs to be initiated or increased due to a decreasing saturation level.*

Definitions

Anoxia:

- *Anoxia is a severe condition characterized by the complete absence of oxygen supply to body tissues and cells.*
- *It typically occurs when there is a total lack of oxygen, such as when someone is suffocating or drowning and cannot breathe at all.*
- *Anoxia can result in rapid and severe damage to tissues, including brain damage, if not promptly addressed*

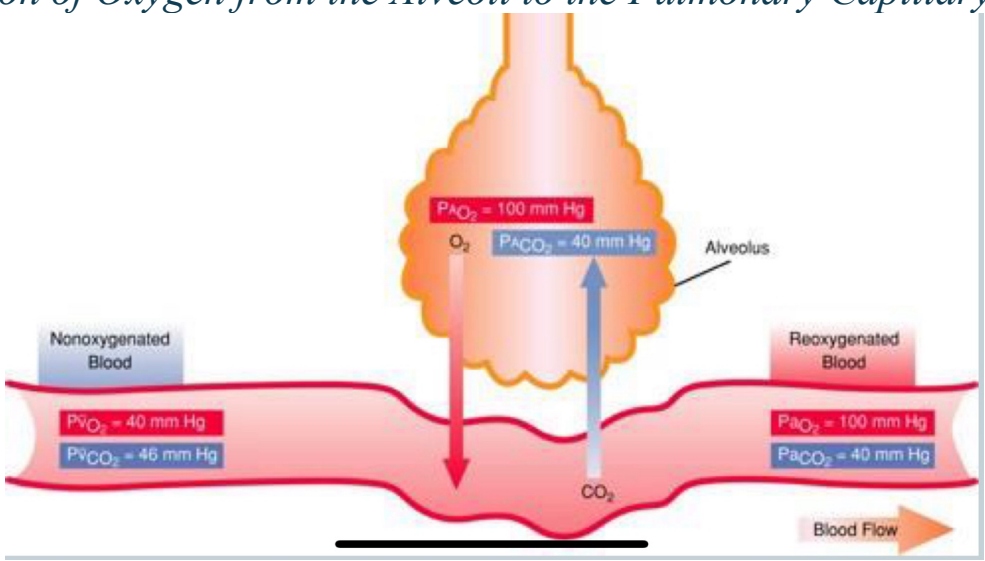
Hypoxemia:

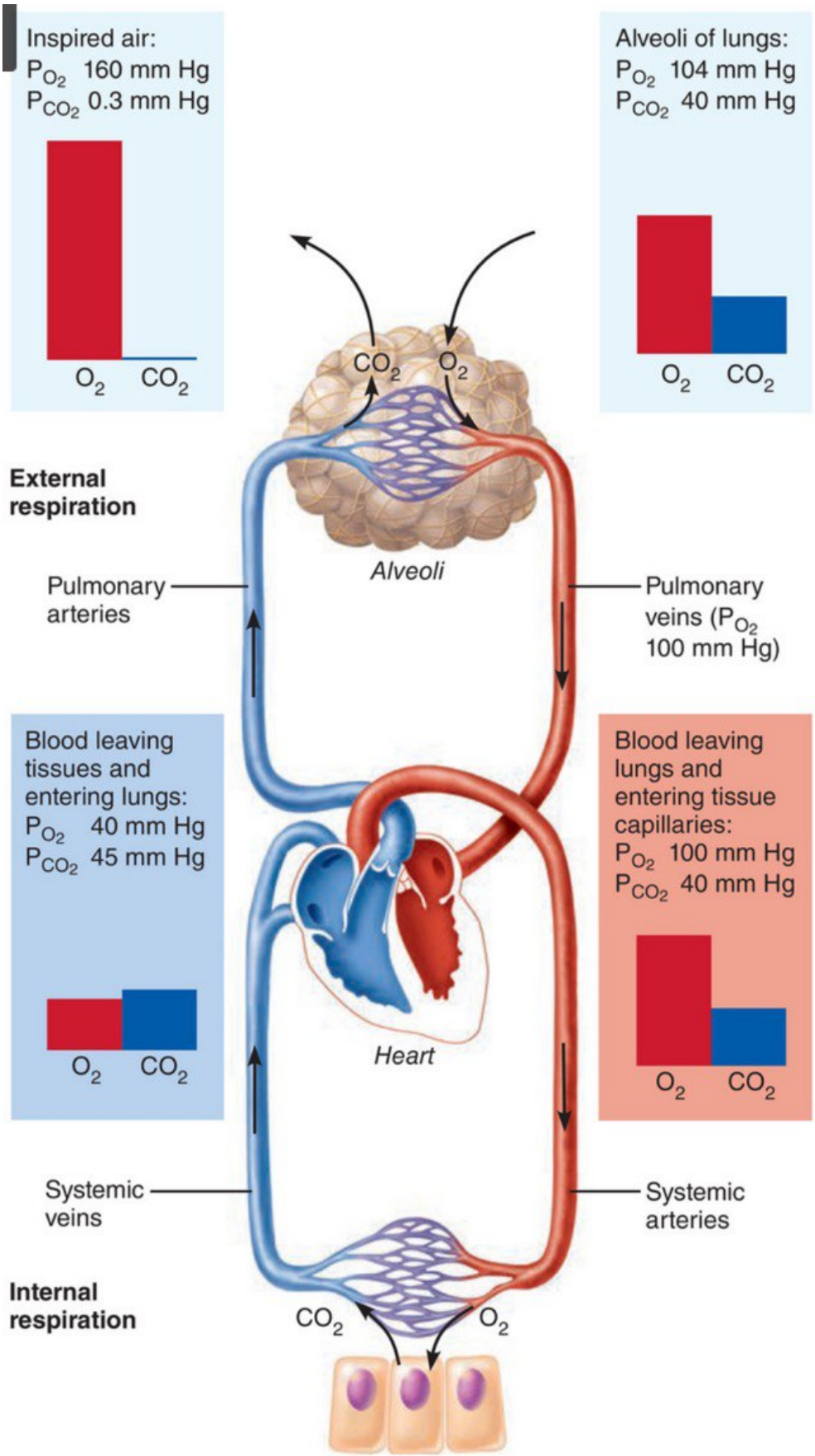
- *Hypoxemia specifically refers to the presence of low oxygen levels in the bloodstream. It is a measurement of the oxygen content in the blood, typically measured as partial pressure of oxygen (PaO_2) in arterial blood.*
- *Hypoxemia can occur in various conditions, such as*
  - *Lung diseases (e.g., chronic obstructive pulmonary disease, pneumonia).*
  - *Cardiovascular problems (e.g., heart failure).*
  - *During certain medical procedures.*
- *Hypoxemia can lead to hypoxia if oxygen delivery to tissues is compromised, as oxygen in the blood is what carries oxygen to body cells*

Hypoxia:

- *Hypoxia refers to a condition where there is an insufficient supply of oxygen to body tissues and cells, but it does not necessarily mean a complete lack of oxygen.*
- *Hypoxia can be caused by various factors, such as*
  - *Reduced oxygen levels in the air (e.g., at high al-tudes),*
  - *Decreased oxygen-carrying capacity of the blood (e.g., due to anemia).*
  - *Impaired lung function.*
  - *Poor circulation.*
- *There are different degrees of hypoxia, ranging from mild to severe, depending on the extent of oxygen deprivation. It can be chronic or acute.*

Diffusion of Oxygen from the Alveoli to the Pulmonary Capillary Blood




Inspired air:
P_{O_2} 160 mm Hg
P_{CO_2} 0.3 mm Hg
O_2 CO_2
Alveoli of lungs:
P_{O_2} 104 mm Hg
P_{CO_2} 40 mm Hg
O_2 CO_2
CO_2 O_2
External respiration
Alveoli
Pulmonary arteries
Pulmonary veins (P_{O_2} 100 mm Hg)
Blood leaving tissues and entering lungs:
P_{O_2} 40 mm Hg
P_{CO_2} 45 mm Hg
O_2 CO_2
Blood leaving lungs and entering tissue capillaries:
P_{O_2} 100 mm Hg
P_{CO_2} 40 mm Hg
O_2 CO_2
Heart
Systemic veins
Systemic arteries
Internal respiration
CO_2 O_2
O_2 CO_2
Tissues:
P_{O_2} less than 40 mm Hg
P_{CO_2} greater than 45 mm Hg

Identify Type of Hypoxia

- *Hypoxia is of four types:*

1. ***Hypoxemic hypoxia*** *is characterized by low O_2 levels in the arterial blood often due to respiratory problems that hinder O_2 exchange in the lungs. May be because of:*
    a) *Low FiO_2, hypoventilation*
    b) *Ventilation perfusion mismatch*
    c) *Diffusion defect.*
    d) *Shunt effect.*

2. ***Anaemic hypoxia*** *result from a reduced oxygen carrying capacity of the blood, typically due to a decrease in the number of red blood cells or decrease in the hemoglobin content. May be because of:*
    a) *A decreased hemoglobin levels.*
    b) *CO poisoning.*
    c) *Excessive blood loss.*
    d) *Methemoglobinemia.*
    e) *Iron deficiency.*

3. ***Stagnant hypoxia*** *occurs when there is reduced blood flow or circulation, leading to inadequate O_2 delivery to the tissues. May be because of diminished capillary perfusion due to:*
        a. *Decreased heart rate*
        b. *Decreased cardiac output*
        c. *Shock*
        d. *Embolism*
        e. *Exposure to cold weather*

4. ***Histotoxic hypoxia*** *arises from conditions that impair the ability of tissues to use O_2 efficiently, even when O_2 delivery is adequate.*
    a) *The oxidative enzyme mechanism of the cell is impaired as a result of:*
        - *Cyanide poisoning*
        - *Alcohol poisoning*
    b) *Rarely accompanied by hypoxemia but is accompanied by increased venous PO_2 levels.*

Initiate Oxygen Administration

- *Before giving oxygen, one needs to ensure patency of the airways. This might require endotracheal intubation or tracheostomy.*
- *It is generally customary to start with a high FiO_2—100% for cardiorespiratory arrest and 50–100% for acute hypoxemic respiratory failure.*
- *The FiO_2 can be increased or decreased after the assessment of clinical and laboratory response to the initial administration.*
- *Relatively lower concentrations are used in patients with hypercapnic respiratory failure (such as COPD) with the preexisting chronic hypoventilation.*
- *High concentration of oxygen may worsen CO_2 retention and cause CO_2 narcosis by abolishing the hypoxic respiratory stimulation. However, optimum FiO_2 must be ensured since hypoxia is always more deleterious than hypercapnia. Various devices can be used for applying oxygen.*

Source: Most well-equipped ICUs have continuous pressurized oxygen and air supply available at each bed. In this fashion, both oxygen and air can be simultaneously fed into an oxygen blender to control the output FiO_2. Oxygen cylinders and concentrators are required as a backup source in case of failure of central supply.

Identifying and Treating Underlying Causes:

- *Effective management of hypoxia in the ICU requires addressing the underlying medical conditions or contributing factors.*
- *Common causes of hypoxia in the ICU include:*
  - *Acute respiratory distress syndrome (ARDS).*
  - *Pneumonia.*
  - *Pulmonary embolism.*
  - *Heart failure.*
  - *Sepsis.*

- *Targeted therapies, such as antibiotics for infections or diuretics for pulmonary edema, may be administered as appropriate.*

- *Mechanical Ventilation*
  - *In cases of severe hypoxia or respiratory failure, mechanical ventilation is employed to support oxygenation and ventilation.*
  - *Ventilators can provide precise control over oxygen levels, positive end-expiratory pressure (PEEP), and other parameters.*
  - *Ventilatory strategies, including lung-protective ventilation, are employed to minimize ventilator-associated lung injury.*

Oxygen Delivery Devices

1. *Low flow oxygen systems:*
   Low flow oxygen systems or delivery devices does not meet the patients inspiratory flow demands. Therefore room air must make up the remainder of the patient's tidal volume. The percentage of oxygen delivered by low flow devices is variable depending on patient's tidal volume, respiratory rate, inspiratory time and ventilatory pattern
   a. *Nasal Cannula (delivers 24–40% of oxygen at a flow rate of 1–6 L/min)*
   b. *Nasal Reservoir Cannula (Reservoir stores upto 20 mL of oxygen, delivers 22–35% of oxygen at a flow rate of 1–4 L/min)*
   c. *Pendant Reservoir Cannula (delivers 22–35% of oxygen at a flow rate of 1–4 L/min)*
   d. *Simple Oxygen Mask (delivers 35–50% of oxygen at a flow rate of 5–10 L/min)*
   e. *Partial Re-breathing Mask (delivers 40–70% of oxygen at a flow rate of 10–15 L/min)*
   f. *Non Re-breathing Mask (delivers 60–80% of oxygen at a flow rate of 10–15 L/min)*
   g. *Transtracheal Oxygen Catheter (delivers 22–35% oxygen at a flow rate of 1–4 L/min)*

2. *High Flow Oxygen Delivery Devices*
    a. *Air Entrainment Mask (Provides 24–50% of oxygen) The jet size of the entrainment port determines the FiO2. The larger the jet size the less air entrained and higher the FiO2. Smaller the jet size more air entrained and lower the FiO2. The larger the entrainment port more air entrained and lower the FiO2. Similarly, smaller the entrainment port less air entrained and higher the FiO2.*
    b. *Aerosol Mask (This mask delivers 21–100% of oxygen depending on the nebulizer setting at a flow rate of 8–15 L/min)*
    c. *Face tent (It delivers 21–40% of oxygen depending on the nebulizer setting at a flow rate of 8–15 L/min)*
    d. *T- piece (It delivers 21–100% of oxygen at a flow rate of 8–15 L/min)*
    e. *Tracheostomy mask (It delivers 35–60% of oxygen at a flow rate of 10–15 L/min)*
    f. *High Flow nasal Cannula (Flows up to 8 L/min are used on infants and up to 60 L/min on adults and provide an oxygen percentage of up to 100%)*
        I. *High flow devices set on 60% or higher may deliver a total flow rate less than 25–30 L/min. Thereby not meeting the patient's inspiratory demands.*
        II. *To ensure adequate flow rate on a device along with high percentage of oxygen it is always better to use two flow meters connected together instead of one.*
        III. *To ensure adequate flow rates, set the flow meter to a rate that delivers a total flow of at least 40 L/min.*
        IV. *Increasing the flow on high flow device does not increase delivered FiO2. It only increases the total flow.*

Monitoring Oxygen Therapy

- *Arterial Blood Gas*
  - *Perform arterial blood gas analysis before oxygen therapy is started and measure again within 2 h of starting oxygen therapy and FiO2 should be adjusted accordingly.*
  - *An adequate response to oxygen therapy is defined as PaO2 of more than 60 mmHg and SpO2 of more than 90%.*
  - *Frequency of arterial blood gas monitoring depends on the severity of respiratory failure and hypoxemia.*
  - *Arterial blood gas also monitors the total oxygen content of the blood which helps in calculation of oxygen delivery and consumption.*
- *Pulse oximetry: measures spO2 and is easily available.*
- *Co-oximetry: This is used to measure hemoglobin, oxyhemoglobin and carboxyhemoglobin separately.*
- *Mixed venous oxygen saturation (SvO2):*
  - *Monitoring oxygenation at tissue level with the help of pulmonary artery catheter.*
  - *Can be measured by taking blood sample from the proximal pulmonary artery.*
  - *This reflects the amount of oxygen "leftover" in the venous blood after body tissues have removed (used) whatever oxygen they needed.*

Complications of Oxygen Therapy

- *Oxygen Toxicity*
  - *Oxygen is a drug when given in excess it causes toxicity.*
  - *It is the partial pressure of oxygen and not the FiO2 which is responsible for the toxic effect of oxygen along with partial pressure of oxygen.*
  - *The duration of exposure is also an important criterion for development of oxygen toxicity.*

1. *The primary effect of oxygen toxicity is on the central nervous system which includes tremors, twitching and convulsions.*
2. *High partial pressure of oxygen also damages the capillary endothelium in the lungs. Later on, patient may develop*

pulmonary arterial hypertension. The goal should be to use the lowest possible FiO2 to achieve adequate tissue oxygenation.

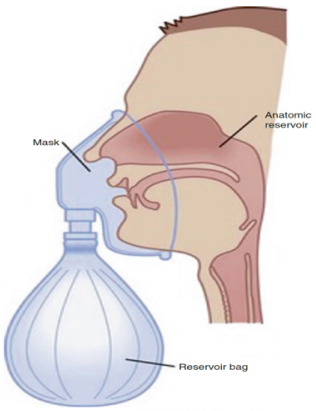
3. *Depression of Ventilation—This is a common observation in patients with COPD and chronic hypercapnia.*
    a. *It has got a direct relationship with accompanying elevation in arterial partial pressure of carbon dioxide (PaCO2) along with suppression of the hypoxic drive.*
    b. *In these patients normal response to high PaCO2 is blunted.*
    c. *Management of hypoxemia with supplemental oxygen should never be avoided in these patients.*
4. *Hypoxemia is primarily sensed by peripheral chemoreceptors. Increase in blood oxygen level in these patients suppresses the peripheral chemoreceptors which depresses the ventilatory drive and elevates the PaCO2.*

- *Retinopathy of Pre-Maturity*
    - *It occurs in pre matured low birth infants who receive supplemental oxygen.*
    - *Excess oxygen causes retinal vasoconstriction which leads to necrosis of blood vessels. As a compensatory mechanism neovascularization occurs. Hemorrhage of these newly formed vessels causes scarring behind the retina.*
    - *Other factors which give rise to this condition are hypercapnia, intra ventricular hemorrhage, infection, lactic acidosis, anemia, hypocalcemia and hypothermia.*
    - *The recommended preventive measure is to keep the partial pressure of oxygen (PaO2) less than 80 mm Hg.*

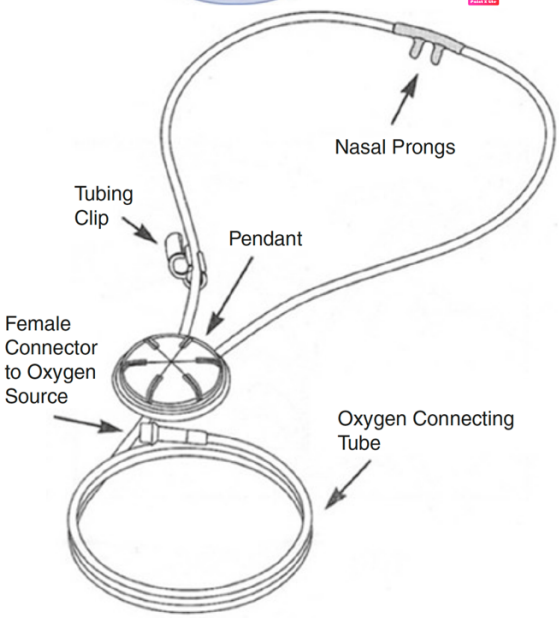
- *Absorption Atelectasis*
    - *FiO2 of greater than 0.5 presents a risk of absorption atelectasis, it happens because of denitrogenation. Breathing high level of oxygen quickly depletes the nitrogen level in alveoli and blood. With rapid denitrogenation the total gas pressure in the alveolus progressively decreases.*

- *Fire Hazard*

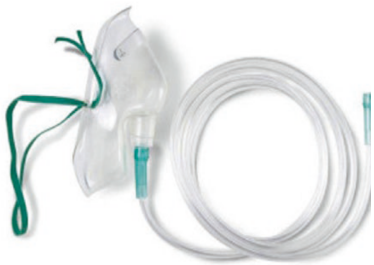
Nasal reservoir cannula.



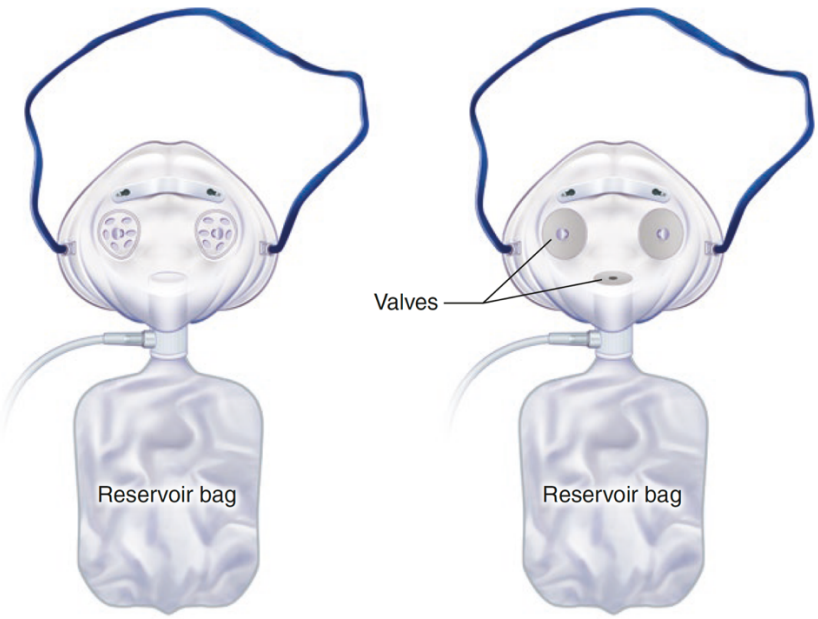
Nasal cannula



Simple oxygen mask

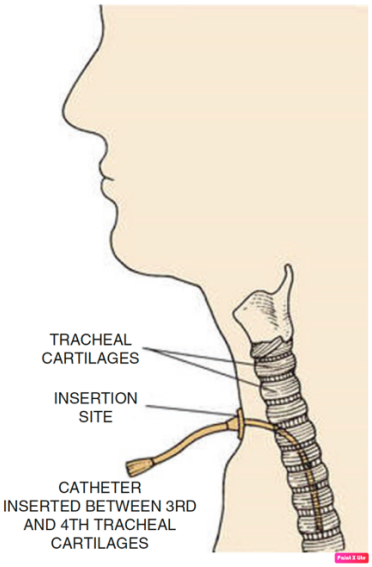


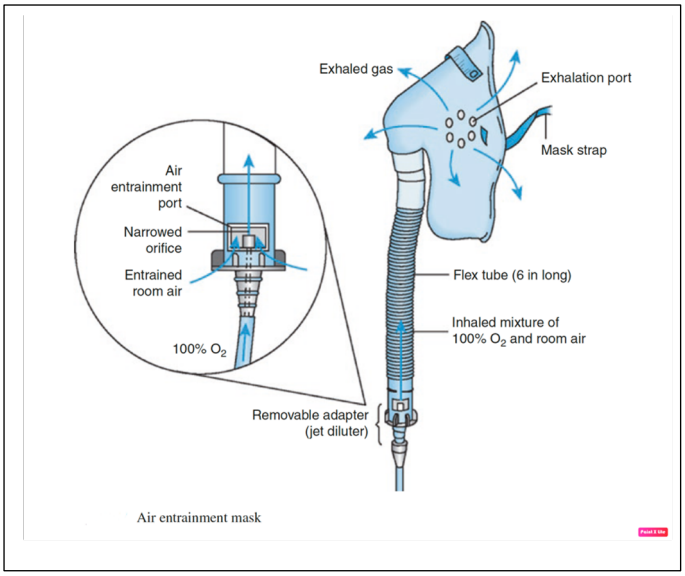
Pendant reservoir cannula



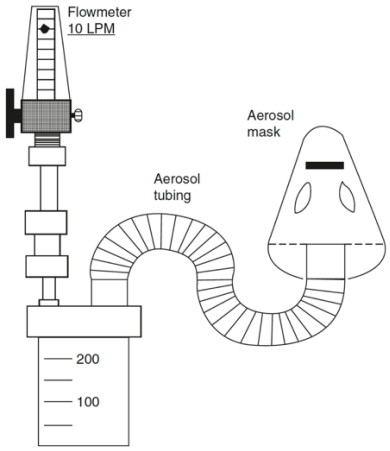
Partial re-breathing and non re-breathing mask.

Transtracheal oxygen catheter





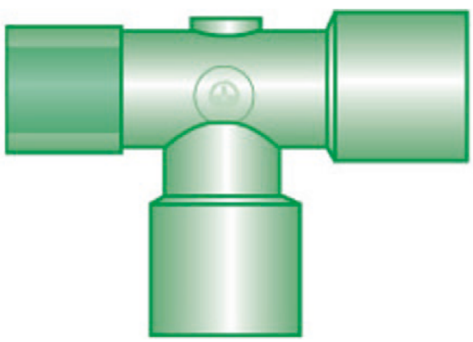
Air entrainment mask



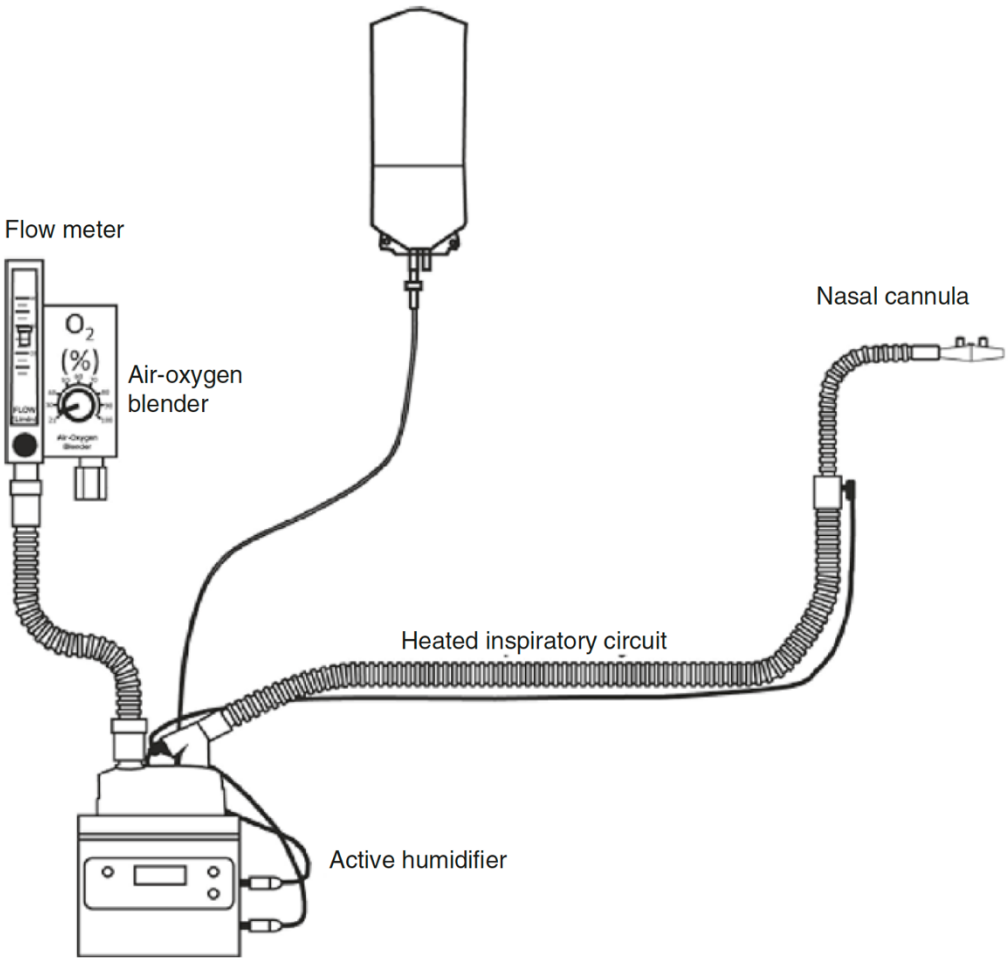
Aerosol mask

Face tent

T-piece



Tracheostomy mask



High flow cannula