Hypoxia and Oxygen Therapy

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Objectives

- Student will be learned of:
  - Oxygen cascade from atmosphere to mitochondria
  - Oxygen in blood: transfer, content
  - Hypoxia: Definition and types
  - Oxygen delivery systems
  - Oxygen toxicity
  - Guideline for oxygen therapy in acutely hypoxemic patient

Oxygen from atmosphere to alveoli

- O_2 in air 21% {760 mmHg * 21% = 160 mmHg (21 Kpa)}

1. Humidified Tracheal Gas = (760mmHg – 47 mmHg H_2O) X 0.21 = m150 mmHg (19.8 Kpa)
2. The Alveolar Gas = 106 mmHg (14 KPa)

- Once the air reaches alveoli diffusion occurs through the capillary alveoli interface

- Partial pressure of oxygen differs till oxygen reaches mitochondria in cells:

1. The Arterial Blood = 100 mmHg (13.3 Kpa)
2. The Capillary Blood = 45-55 mmHg (6.7 Kpa)
3. The cytoplasm = 7.5-40 mmHg (1-5 KPa)

Oxygen in blood

- Arterial O_2 content (CaO2):

  = (1.39 x[Hb]xSaO_2)+(0.003xPaO_2) ml/dL

- Venous O_2 content (CvO_2)

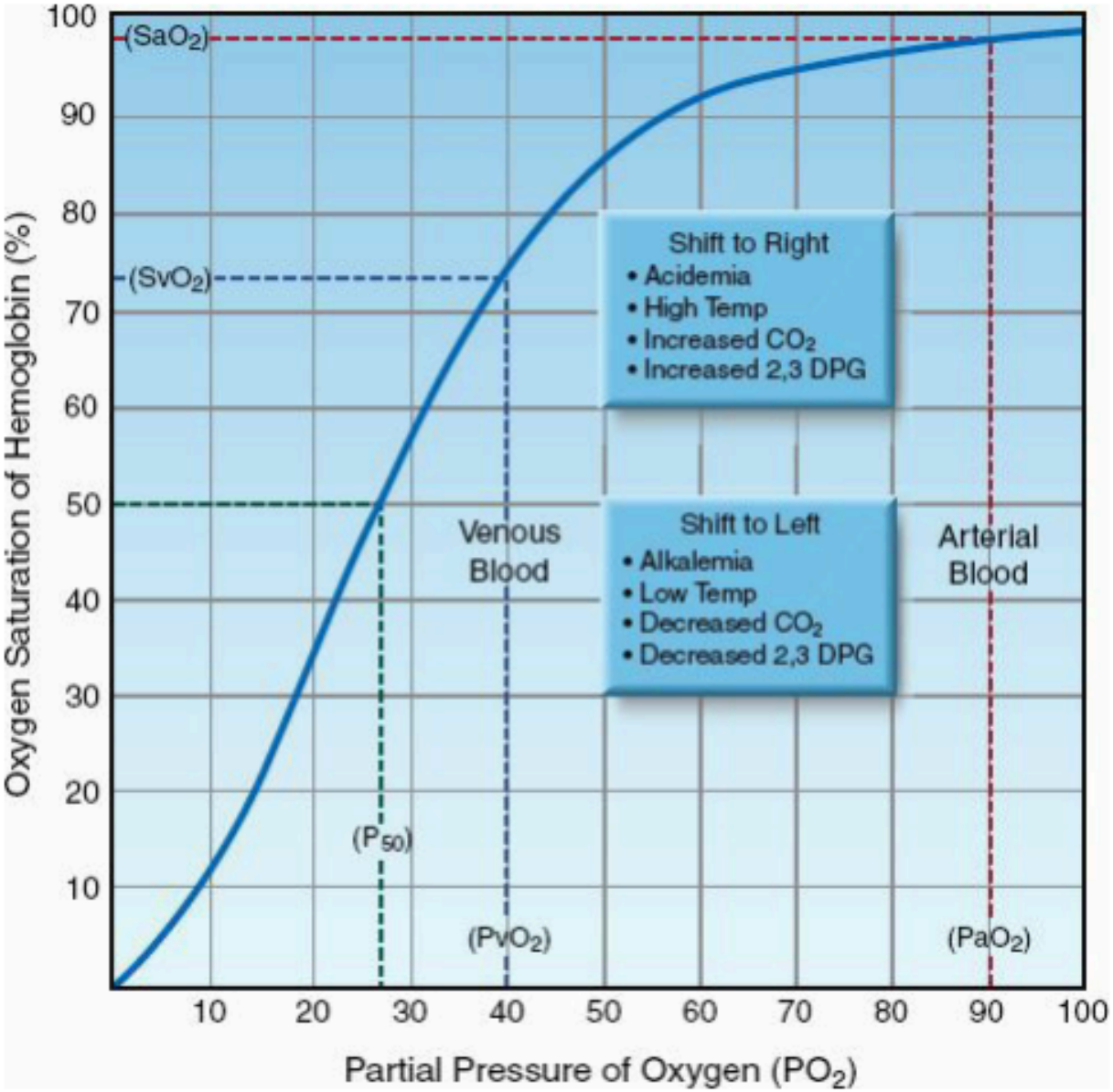
  = (1.39 x[Hb]xSvO_2)+(0.003xPvO_2)

- O_2 delivery:
  = Cardiac output x CaO_2
  ✔ The amount of oxygen flux is normally: 850-1200 ml/min OR 500-700 ml/min/m^2

- The amount of oxygen consumption
  = Cardiac Ouput x (Arterial Oxygen Content – Mixed Venous Oxygen Content)
  = 240-270 ml/min AT REST (120-160 ml/min/m2).

- *Oxygen consumption increase in* : Exercise, Fever, Sepsis, Shivering, Restlessness, Hypercatabolism
- *Oxygen consumption decreased in* : Cooling, Paralysis, Mechanical Ventilation

Oxyhemoglobin dissociation curve



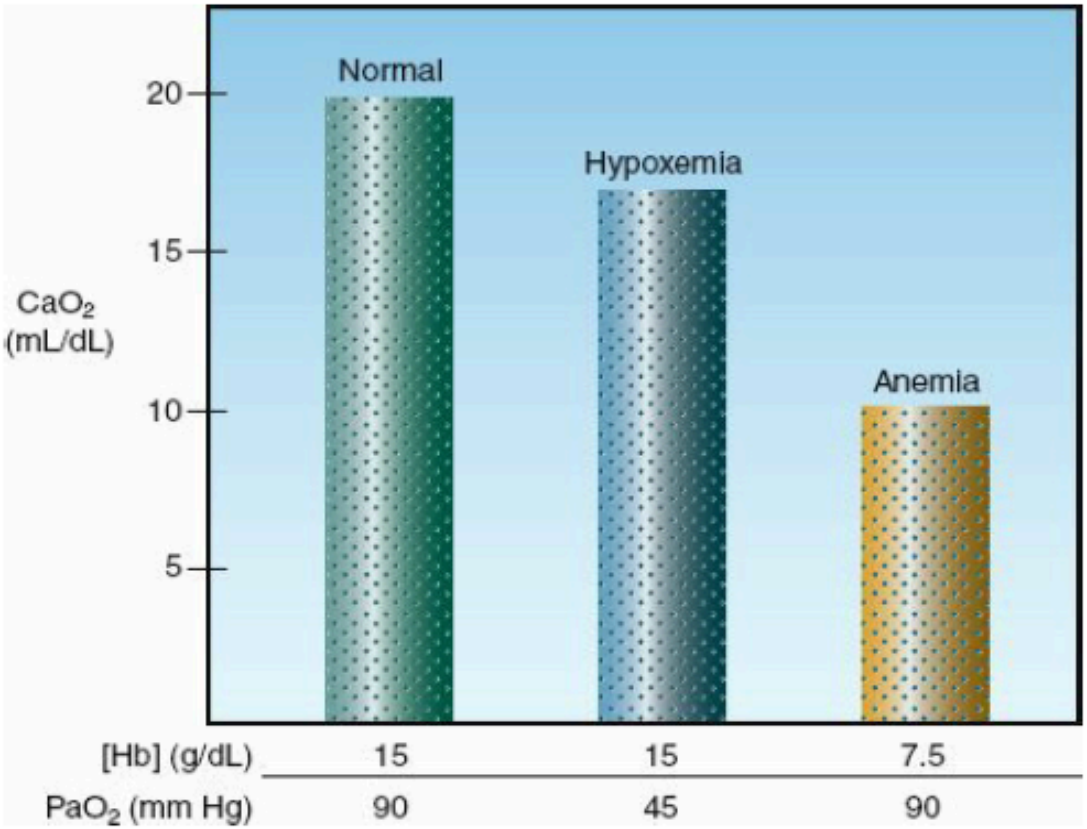


FIGURE 10.2 The effects of equivalent (50%) reductions in hemoglobin concentration [Hb] and arterial PO_2 (PaO_2) on the oxygen content in arterial blood (CaO_2).

ml/dL) 0.003xPaO_2)+(x[Hb]xSaO_2 1.39= (

Hypoxia

- HYPOXIA:- is reduced Oxygen for tissue respiration
- Anoxia:- complete absence of oxygen in tissues
- Hypoxemia: decreased level of oxygen in arterial blood

- Can be acute such as in :
  - Respiratory depression
  - Airway obstruction
  - Atelectasis
  - Ventilation/perfusion mismatch
  - Reduced functional residual capacity

- Can be chronic: after adaptation to high altitude or chronically developing lung diseases affecting oxygen transfer in the lung

Acute hypoxia

- Direct effects:

1. Cyanosis
2. Confusion, Drowsiness
3. Excitement
4. Headache
5. Nausea
6. Myocardial Depression
7. Arrhythmias
8. Bradycardia
9. Renal Impairment

- Indirect effect: mediated by stimulation of baroreceptors in carotid and aortic bodies:
  1. Tachycardia
  2. Hypertension
  3. Hyperventilation

Level of consciousness

- According to the degree of oxygen saturation in arterial blood:

  @ 85 % Saturation Mental Impairment

  @ 75 % Saturation Severe Mental Impairment

  @ 65 % Saturation Unconsciousness

Chronic Hypoxia

Effects of chronic hypoxia:

1. Hyperventilation
2. Polycythemia
3. Increased 2-3-DPG
4. Proliferation of peripheral capillaries
5. Alteration in Intracellular Oxidative Enzymes

Types of Hypoxia

- Hypoxic Hypoxia: occurs when there is inadequate arterial oxygenation due to
- Anemic Hypoxia: occurs when there is inadequate hemoglobin content.
- Circulatory Hypoxia: occurs when there is inadequate perfusion
- Histotoxic Hypoxia: occurs when the cells in the body are unable to utilize oxygen.

Hypoxic Hypoxia

- It is a state where there is inadequate arterial oxygenation due to decrease in alveolar PaO2
- The Blood carrying capacity and blood flow is normal
- Causes include:
  - Low FiO2
  - Airway obstruction
  - Abnormal gas exchange membrane: *pneumonia, fibrosis, pulmonary edema, etc..*

Hypoxic Hypoxia

- Pathophysiology:

Due to reduction in partial pressure of arterial oxygen, the peripheral chemoreceptors stimulate the respiratory center to increase ventilation which leads to a decrease in carbon dioxide and shifting of oxygen-hemoglobin dissociation curve to the left.

Anemic Hypoxia

- It is a state in which there is a decrease in hemoglobin carrying capacity of oxygen, or hemoglobin level.

❑ Seen in: Anemias, CO poisoning, Blood loss etc..

- Hypoxia increases during exercise and improves during rest.

- Carbon monoxide poisoning.
  - Carbon monoxide has 250 times higher affinity to hemoglobin when compared to oxygen.
  - The partial pressure of oxygen doesn't change in arterial blood. only the arterial oxygen content decreases, therefore, there is no respiratory center stimulation. The treatment is to provide 100% oxygen.

Circulatory Hypoxia

- It is a state where there is decrease in cardiac output therefore decreasing oxygen delivery to tissue (Oxygen flux)
- There is normal PaO_2

Oxygen content = $(1.39 \times [Hb] \times SaO_2) + (0.003 \times PaO_2)$ ml/dL

Oxygen flux= Oxygen content X C.O

Histotoxic Hypoxia

- It is a state where there is impairment in tissue utilization of oxygen in the presence of normal blood flow, normal oxygen carrying capacity in blood, and normal PaO2.

- Causes:
  - Cyanide poisoning,
  - Hydrogen sulphide posoning(H2S)
  - Drugs (Nitroprusside)

Oxygen delivery systems

- Indication: Hypoxia of any type:
- Scenarios:
    1. Respiratory pathology and Failure: Pneumonia, IRDS, atelectasis, COPD, Asthma, etc…
    2. Cardiovascular dysfunction: Heart Failure, cardiopulmonary resuscitation, shock of any cause
    3. Increased Metabolic Demands: hyperthermia, thyrotocosis, pheochromaocytoma etc…
    4. Carbon Monoxide (CO)-Poisoning
    5. Postoperative States

FiO_2 :

Fractional Inspired O2 concentration

- The percentage of Oxygen in the inspired gas mixture:

  - Room Air: 21%
  - Pure oxygen source : 100%

:Types of oxygen therapy devices

1:- Variable performance : Variable **FiO_2** output based on patient effort

2:- Fixed performance : Same **FiO_2** output regardless of patient effort

For an average healthy 70-kg adult

- Tidal Volume (Vt) : 500 ml= 0.5 Liter
- Respiratory Rate (RR): 12 breath/min 5 seconds for each respiratory cycle.
- I:E ratio 1:2
  - 1.7 seconds for inspiration &
  - 3.3 seconds for expiration.

Inspiratory flow rate (L/min)= 0.5L/(1.7/60)min = 18 L/min

👆 A hypoxic patient will inevitably have a higher inspiratortory flow rate due to his increased respiratory rate !!

Variable performance
:Simple Face Mask- 1

Variable performance

1- **Simple Face Mask:**

- Low flow delivery system.
- Plastic body with side holes on both sides, a port to connect to oxygen source, and an elastic band to fix the mask to patient face
- The holes will allow ambient air to come in and allows exhaled gas to vent out, during the expiratory phase the fresh oxygen supplied helps in venting the exhaled gas. And the body of the mask is filled with oxygen ready for next inspiration.
- During inspiration oxygen is diluted by the air drawn in through the holes when the inspiratory flow rate exceeds the flow of oxygen supply. The peak inspiratory flow rate increases further during deep inspiration and during hyperventilation thus diluting further.

Variable performance: *Face Mask*

- FiO_2 is dependent on oxygen flow rate, size of oxygen reservoir and respiratory pattern.
- 5L/min of oxygen flow delivers an FiO2 of about 35 -40% providing normal respiratory pattern.
- Can achieve a maximum of 60%.
- Indications: used only when a fixed oxygen concentration is not critical.
- Contraindications: patient who depends on hypoxic drive.
- Advantages:
  - Great patient comfort,
  - Low cost, simple,
  - Can manipulate FiO_2 without changing appliance. (just increase of decrease fresh gas flow)
  - Can use aerosolized bronchodilators (salbutamol etc…)
- Disadvantage:
  - If there is no expiratory pause , rebreathing will occur. (apparatus dead space 100-200ml) maybe a problem in those who can't compensate by increasing alveolar ventilation.
  - Tight fitting mask increase rebreathing (Sense of warmth and humidity).
  - Doesn't permit oral feeding

Variable performance: *2- Nasal cannula*

”Nasal prongs“

Variable performance

2: Nasal cannula:

- Ideal for patient who is on long term oxygen therapy.
- Has two prongs which protrude about 1 cm into the nose and held in place by an adjustable head strap
- Entrainment of ambient air by the nostrils, and the nasopharynx acts a reservoir of fresh gas.
- FiO_2 ranges from 24% to 44% (with oxygen flow rates 1-6L/min. (1-2% increase in FiO2 per 1 liter increase in Oxygen flow).
  - Higher flow rates are not comfortable for the patient so usually we use 2-4L/min. Therefore, FiO2 depends on flow rate of oxygen, the patient's tidal volume, inspiratory flow rate and respiratory rate. With the volume of nasopharynx, mouth breathing causes inspiratory air flow which entrains oxygen from the nose.

Variable performance *(.. Nasal Cannula)*

- Advantages: increased compliance from the patient, patient can eat, drink and talk
- Disadvantages: trauma and irritation to the nasal mucosa, not appropriate for those who have blocked nasal passages.
- Contraindication: patient who requires high flow of oxygen (high ventilatory demands)

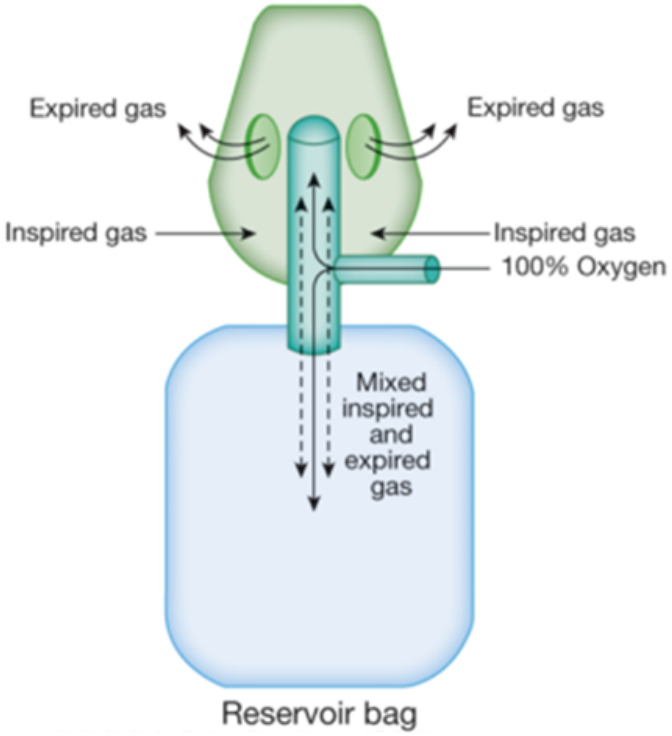
Variable performance - Face mask with reservoir bag (600-800 ml):- 3

3-A. Partial rebreather:

- Allows the gas exhaled in initial phase of expiration to return to the reservoir bag. As exhalation proceeds, the flow rate will decrease, becoming less than the oxygen flow rate. At this point, the exhaled gas can no longer return to the reservoir bag.

- Since the initial expired gas is the anatomical dead space gas, it is largely devoid of carbon dioxide (CO_2). Because the gas in the reservoir bag is under positive pressure, inhalation will draw primarily from the gas in the bag.

- Can achieve a maximum FiO2 of 70% with a 6-10L/min

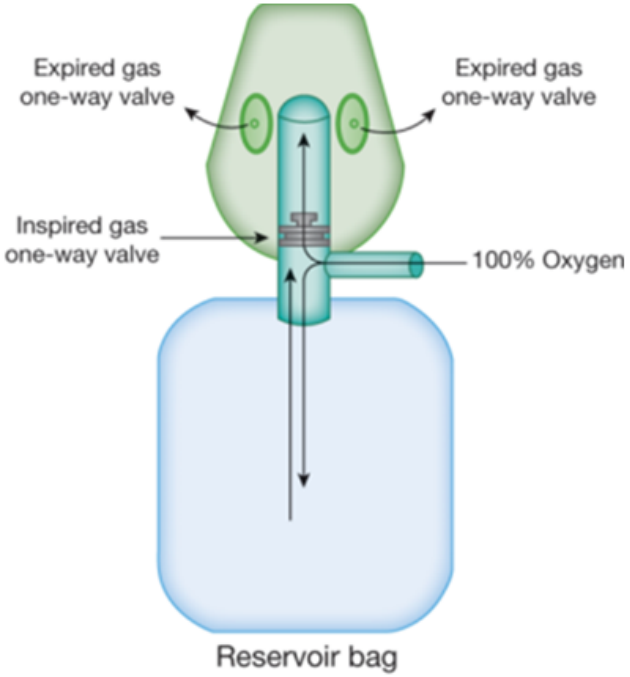


- Advantages: plastic bags are transparent under the chin (comfortable)
- Disadvantages: same as face mask, and aerosolized bronchodilator therapy is not possible with reservoir bag devices. Lack of a good seal can affect oxygen delivery.

Variable performance - Face mask with reservoir bag (600-800 ml):- 3

3- B. Non rebreather:

- The expiratory ports on the mask are covered with flaps that allow exhaled gas to escape while preventing the inhalation of room air.
- Also, a one-way valve is positioned between the mask and the reservoir bag which prevents exhaled gas from entering the bag.
- FiO**2**: Theoretically can achieve 100%, but because of inevitable leaks around the mask, it is around 80% with a flow of 10-15L/min.



Variable performance

) General for Face mask with reservoir bag(

- Indication for each is a patient who is suspected of hypoxemia despite a simple face mask being applied and has a normal respiratory pattern.

- In general, face masks can cause:
  - Dryness in the eyes due to gas leakage.
  - It is not suitable for patients who are claustrophobic.

Variable performance

Table 6.2 Factors that affect the delivered FiO_2 in the variable performance masks

High FiO_2 delivered	**Low FiO_2 delivered**
Low peak inspiratory flow rate	High peak inspiratory flow rate
Slow respiratory rate	Fast respiratory rate
High fresh oxygen flow rate	Low fresh oxygen flow rate
Tightly fitting face mask	Less tightly fitting face mask

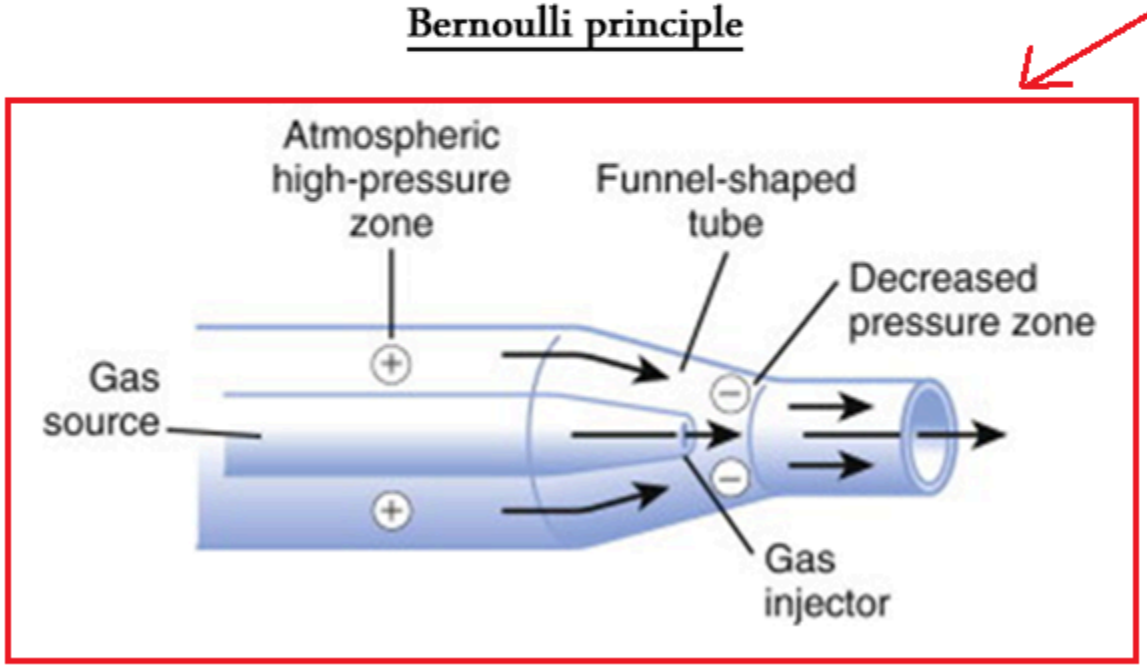
:B:- Fixed performance equipment

Fixed FiO2 output

1. Venturi mask.
2. Non-invasive positive pressure mechanical ventilation.
3. Invasive mechanical ventilation.

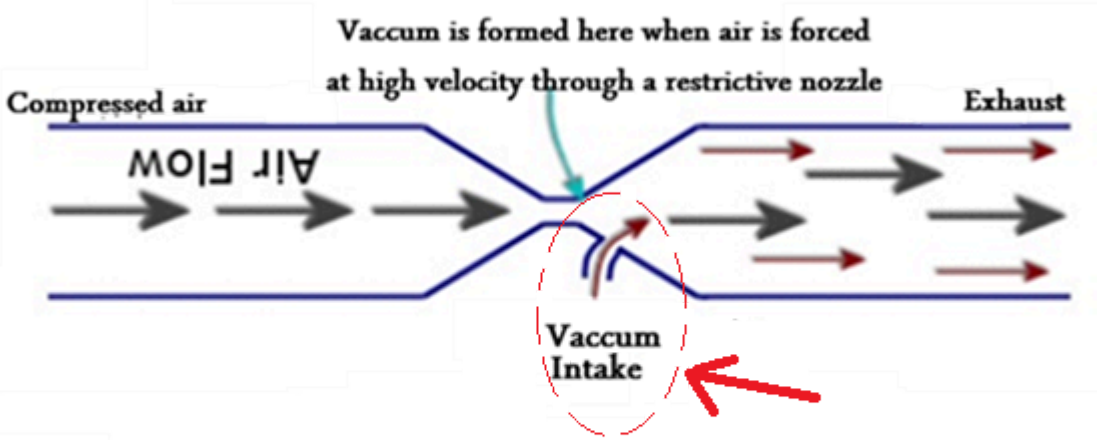
Fixe performance

)®Venturi masks or Ventimask:- (1



Air-entrainment device

Venturi mask

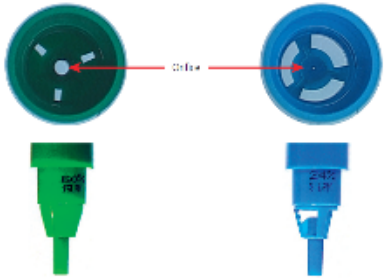


Total energy

$$K_1 + P_1 = K_2 + P_2$$

Venturi system

- A system of High-airflow oxygen enrichment
- The mask's plastic body has holes on both sides. The proximal end consists of a color-coded Venturi device, marked with the recommended oxygen flow rate to provide the desired oxygen concentration.
- Uses the Bernoulli principle, by which it delivers a predetermined and fixed concentration of oxygen to the patient at adequately high flow rates.
- There is a constriction that determines the final oxygen concentration. As oxygen flows through it, a negative pressure is created. If a hole is made in this area, the ambient air is entrained and mixed with the oxygen flow. And so the concentration of oxygen depends on the degree of air entrainment (and consequent dilution).
- The less ambient air entrainment, the more the FiO_2.
- The smaller the orifice is, the greater the negative pressure, so the more ambient air entrained and consequently, lower FiO_2 output.



Venturi

- Because of the high fresh gas flow rate, the exhaled gases are rapidly flushed from the mask, via its holes.
- Venturi devices are produced with FiO_2 outputs of 24%, 28%, 31%, 35%, 40%, 60%.
- A 24% oxygen Venturi mask has an air: oxygen entrainment ratio of 25:1. This means that an oxygen flow of 2 L/min delivers a total flow of 52 L/min, which is well above the peak inspiratory flow rate.
- Indications: for a patient whose ventilation is dependent on hypoxic drive (COPD)
- Advantages: No rebreathing and no increase in dead space.
- Disadvantages: bulky and noisy.

Colour coding

Venturi valve

Color	FiO2	O2 Flow
Blue	24%	2 L/min
White	28%	4 L/min
Orange	31%	6 L/min
Yellow	35%	8 L/min
Red	40%	10 L/min
Green	60%	15 L/min

2:- Non-invasive positive pressure ventilation (NIPPV)

(Oxygen is given under pressure through a tightly fitting face mask or nasal cannula)




It uses positive pressure in the oxygen-enriched air to assist breathing, which will help in:

- ✔ Increasing oxygenation.
- ✔ Reducing the work of breathing.
- ✔ Preventing respiratory muscle fatigue.

NIPPV

- It is used to treat both acute and chronic respiratory failure.

- Offers the benefit of mechanical ventilation without the risk of tracheal intubation

- Requirements:
  1. *Conscious patient*
  2. *Cooperative*
  3. *Active airway reflexes*
  4. *Needs monitoring of the following as contraindications of NIPPV use might develop during management :*
     - *Vital signs.*
     - *Respiratory pattern and ABGs.*

Types

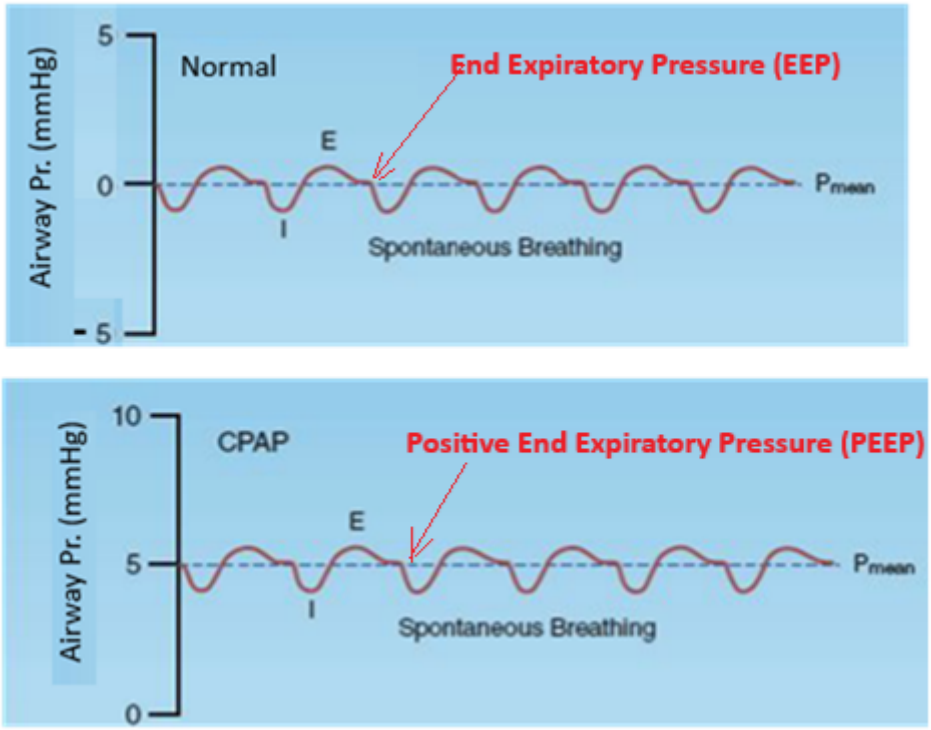
- The positive pressure is of two types:
    1. Continuous positive airway pressure (CPAP): one pressure value throughout the respiratory cycle.
    2. Bi-level positive airway pressure (BiPAP): separate inspiratory and expiratory pressures.

The same masks (with a silicon rim to form a seal) can be used for both types. However, the difference is in the driving machine settings (ventilator)

NIPPV

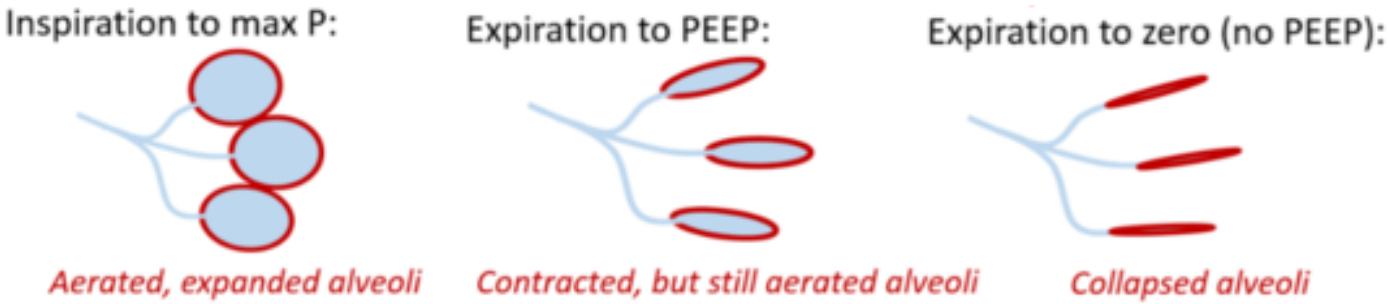
1- CPAP (Continuous positive airway pressure):

Spontaneously breathing at a positive end-expiratory pressure.



>>> CPAP

The principal effect is to increase functional residual capacity



This will leads to increases in:

- *the pressure of oxygen (PaO2)*
- *the pressure in airways*
- *alveolar pressure*
- *surface area of alveoli*

CPAP>>>

- Effects:
  - ✔ Open airways
  - ✔ Improve oxygenation
  - ✔ decreasing atelectasis,
  - ✔ improving alveolar ventilation
  - ✔ decrease work of breathing

decreasing ventilation/perfusion mismatch

CPAP>>>

Indications:

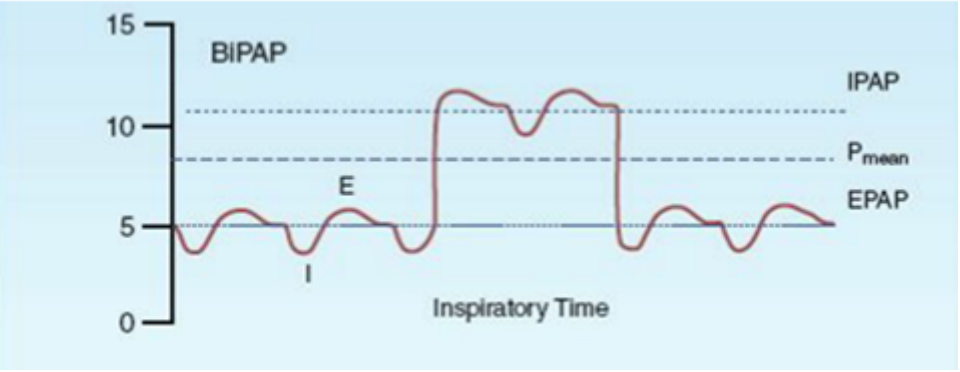
- Obstructive Sleep Apnea (OSA)
- Acute respiratory conditions that may lead to to acute respiratory failure like:
  - Cardiogenic pulmonary edema.
  - Pneumonia (especially if patient is already having chronic lung disease)
  - COPD exacerbations.
  - Blunt chest wall trauma

However, it is mostly beneficial in acute respiratory failure that is due to cardiogenic pulmonary edema - mostly for its hemodynamic support. Its inability to augment the tidal volume limits the benefit of its use in acute respiratory failure to the favor of Bi-level Positive pressure ventilation.

NIPPV

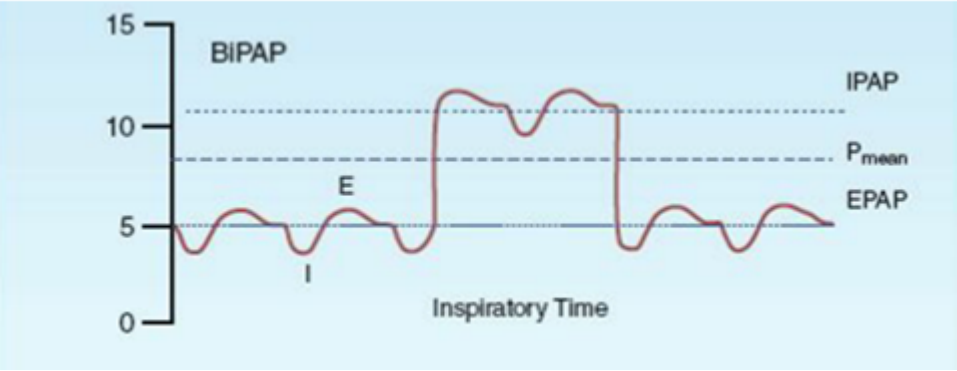
2- BiPAP : (Bi-level positive airway pressure)

- High and low pressures are used in the respiratory cycle:
  - High pressure is called inspiratory positive airway pressure
  - Low pressure is called expiratory positive airway pressure.



BiPAP>>>

- Results in higher mean airway pressure than CPAP which helps in recruitment of alveoli which in turn increase lung compliance resulting in larger tidal volumes.



BiPAP>>>

Indications:

- ✔ Acute-on-chronic respiratory acidosis secondary to COPD exacerbation where pH </= 7.35
- ✔ Cardiogenic pulmonary edema.
- ✔ Chest trauma patients with ARF
- ✔ PaCO2 >45mmhg
- ✔ P:F ratio (PaO2/FiO2) <200 >>> (severe respiratory dysfunction)
- ✔ Prevention of endotracheal intubation and mechanical ventilation in a patient that is not immediately deteriorating
- ✔ Signs of impending respiratory failure such as use of accessory muscles, dyspnea and tachypnea.
- ✔ Prevention of post-extubation respiratory failure in high-risk patients
- ✔ Early for immunocompromised patients Post-operative As palliation to dyspneic patients in the setting of terminal cancer or other terminal conditions

Vision BIPAP

- Can set FiO_2 output, up to 100%

Contraindications of NIPPV

Absolute	Relative
.Absence of spontaneous breathing	Anxiety
.Upper airway obstruction	A recent facial, upper airway, or upper GI tract surgery
.Inability to protect the airway	Altered mental status/agitation
.Active vomiting	Bowel obstruction
.Facial trauma or burns	recent facial, upper airway, or upper GI tract surgery
Severe Hemodynamic instability	.Inability to clear secretions
Claustrophobia	Mild to moderate Hemodynamic instability
Pneumothorax with broncho-pleural Fistula (BPF)	Undrained pneumothorax (No BPF)
	Severe COPD with air trapping

Complications of NIPPV

- Mask discomfort,
- Skin Rash
- abrasion or ulcers of nasal bridge
- Claustrophobia.
- Aerophagia & gastric insufflation
- Sialorrhea (excessive salivation or drooling)

Serious complications:

- Pneumothorax, pneumocephalus, Aspiration
- Reduced cardiac preload and hypotension

Invasive Mechanical Ventilation

- Positive pressure ventilation of the lungs through an endotracheal tube or a tracheostomy tube by manual or mechanical means.
- The patient is either comatose (by presenting condition) or rendered comatose by sedative dugs.

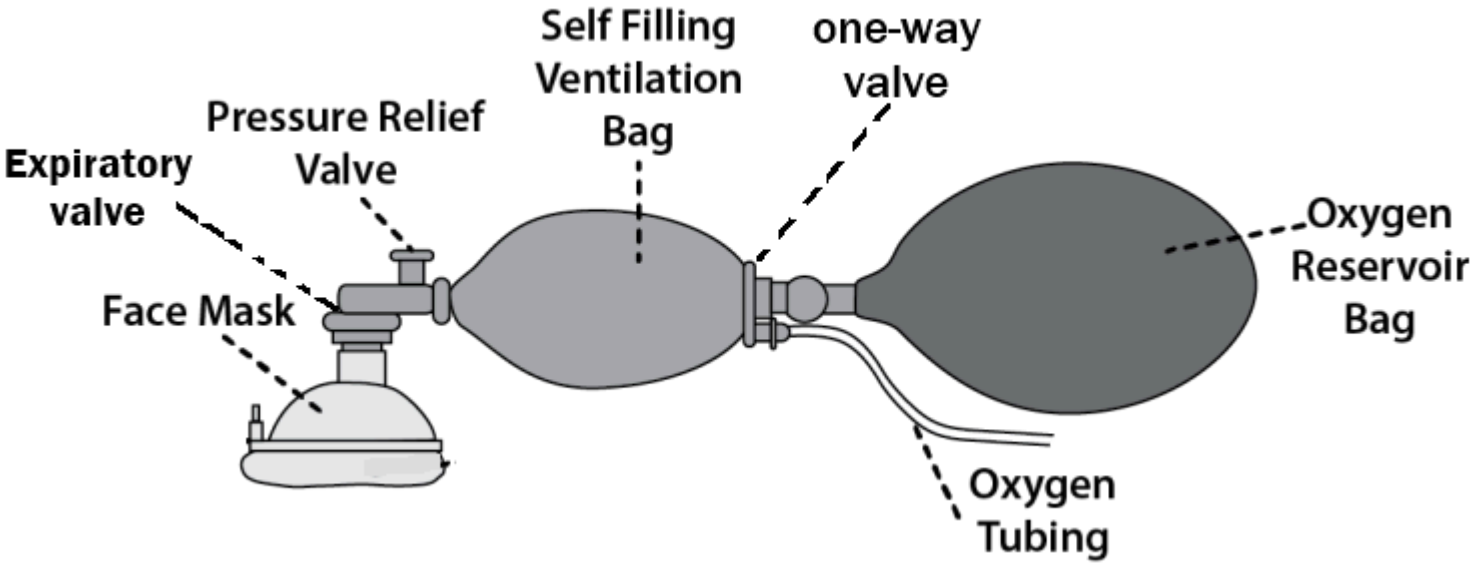
Invasive Positive pressure Ventilation (IPPV) - Mechanical ventilation

Indications

- When NIPPV fails to maintain adequate gas exchange.
- Patient presenting with with respiratory failure: *severe hypoxia PaO2<60 mmHg, Severe hypercapnia PaCO2 >50 , pH<7.35*.
- Apnea: (CNS issue): *drug overdose, head trauma, etc*
- Respiratory muscle weakness or fatigue: *severe tachypnea*
- Neuromuscular disorders. *Myasthenia Gravis, etc*
- Severe hemodynamic instability and shock.
- Major trauma and surgery

Bag-Mask Ventilation
Ambo® Bag

Used in Resuscitation: A basic airway management technique for oxygenation and ventilation until a more definitive airway and IPPV can be established.

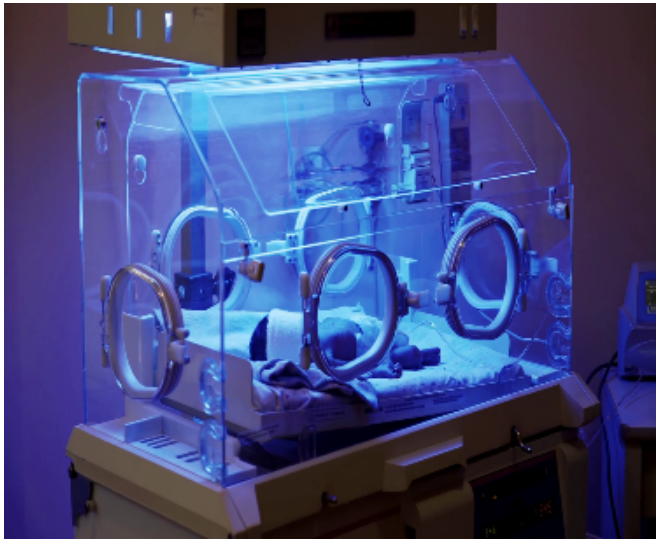


Newer versions have adjustable expiratory valves for producing PEEP effect.

Bag-Mask Ventilation: BMV

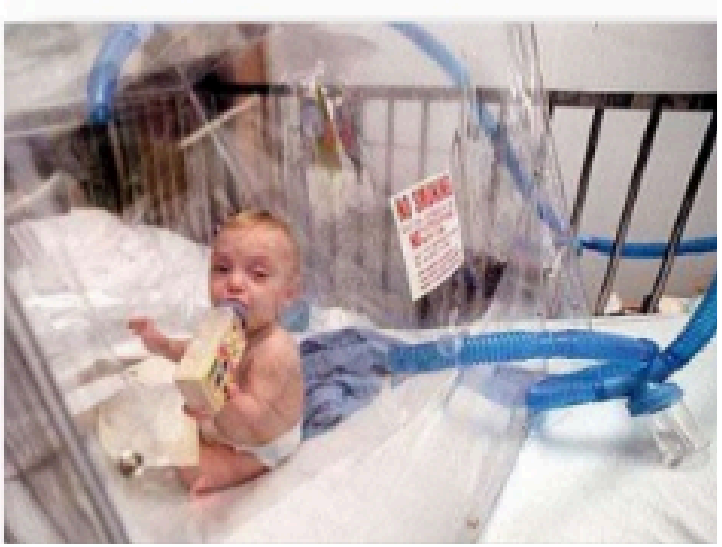
- **Enables manual IPPV**
- **Self-inflating bag with an oxygen connection. It is equipped with: One-way valve/ three ports (inspiratory inlet, expiratory outlet, connection to mask or tube), and a reservoir for oxygen to increase FiO2.**
- **The non-rebreathing inspiratory valve has a silicone rubber membrane, a small dead space, and low flow resistance. The valve allows excess inspiratory gas to be channeled directly to the expiratory outlet, bypassing the patient port.**
- **Requires good seal and practice to improve the ventilation.**
- **Difficult BMV can be due to: Facial hair, Obesity, Age >55 years old, Lack of teeth, History of snoring.**
- **Some bags have one-way expiratory valves to prevent the entry of room air, which allows delivery of more than 90% oxygen to ventilated and spontaneously breathing patients. Bags lacking this feature deliver a high concentration of oxygen during positive-pressure ventilation (PPV) but provide only 30% oxygen during spontaneous breaths.**
- **Indication: respiratory failure (severe hypoventilation, RR<8breaths/minute), transport of an intubated patient, short-term ventilation.**
- **Absolute contraindication: obstructed upper airway.**
- **Advantages: it is a simple portable device with high FiO2, and possible PEEP output**
- **Disadvantage: opening of the lower esophageal sphincter (risk of aspiration) , needs practice, and uncontrolled hyperventilation**

Oxygen delivery systems in pediatrics



Pediatric incubator

Oxygen hood



Oxygen tent

Oxygen delivery systems in pediatrics

- Pediatric incubator:
  - A variable performance device
  - Can be used in neonates and infants only
  - At flow rate of 8-15L/min can provide FiO2 of 40-50%
  - Provide neutral thermal environment, humidification and oxygen delivery
  - Transparent so allows visualization of the patient

- Pediatric oxygen Hood:
  - A variable performance device
  - Can be used in neonates and infants only
  - At flow rate of 10-15L/min can provide FiO2 of 80-90%
  - Provide control of temperature, humidity and oxygen
  - Is transparent so it allows visualization of the patient

- Pediatric oxygen tent:
  - A variable performance device.
  - Patient can move around in his bed without the need for a face mask
  - Can be used for kids
  - Maintains humidity
  - At flow rate of 12-15L/min can provide FiO2 of 40-50%

Guideline for oxygen therapy in acutely hypoxemic patient

- Oxygen is used to treat hypoxemia, not breathlessness.
- The underlying causes of hypoxemia must be diagnosed and treated: supplemental oxygen improves oxygenation, but does not treat the underlying cause.
- Monitoring is essential, and pulse oximetry must be available in all locations where emergency oxygen is used.
- In patients without risk of hypercapnia, oxygen should be prescribed to achieve a target saturation of 94–98% for most hypoxic patients. Start treatment with FiO2 of 24-28% via facemask or nasal cannula and titrate upward as needed.
- In patients at risk of hypercapnic respiratory failure (e.g., COPD), a target saturation of 88–92% is used.

>>>>

Guideline for oxygen therapy in acutely hypoxemic patient

- Treatment starts with FiO_2 of 24-28% via facemask or nasal cannula. Blood gas analysis is done in 30-60 minutes.
- If the patient has respiratory acidosis (pH < 7.35) and is hypercapnic ($PaCO_2$ > 45), call senior help and consider NIPPV or IPPV if still hypoxic. If the patient is hypercapnic but not acidotic (pH<7.35), continue with the same saturation target,
- Prompt clinical assessment is required if oxygen therapy needs to be initiated or increased due to a falling saturation level at any time.
- As the patient's clinical condition improves, FiO_2 is lowered to the minimum required to achieve the target Saturation.
- Oxygen should be discontinued once the patient can maintain saturation within or above the target range breathing air.
- In neonates and infants HbO_2 saturation targets are between 90-94%, with lower target values in cases of cyanotic congenital heart disease.

Complications of Oxygen therapy

- Dryness & Irritation to the nose and face
- Cough, chest pain, dyspnea, and hemoptysis.
- Morning headaches
- Nausea
- Feeling of tiredness
- Sinus congestion and a runny nose.
- Ear pain due to middle ear injuries.
- Visual blurring and cataract.
- Dizziness, disorientation, twitching, and seizures.
- Lung damage (oxygen toxicity): Breathing too much oxygen over a prolonged period of time, leading to the formation of free radicals.
- Risk of fire

Oxygen toxicity

- Continued exposure to high concentrations of oxygen results in heightened free radical production. This may damage the pulmonary epithelium, inactivate the surfactant, form intra-alveolar edema, interstitial thickening, fibrosis, and ultimately lead to pulmonary atelectasis.
- In premature babies:
  - retinopathy of prematurity and retrolental fibroplasia
  - retinal edema
  - Cataract formation (long-term exposure)

Resources

- Essentials of Anesthetic Equipment, 4th edition
- Marino's The ICU book , 4th edition
- Oh's Intensive Care Manual, 7th edition
- Medscape
- New England Journal of Medicine
- PubMed