Hypoxia and Oxygen Therapy

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Objectives

- Oxygen from atmosphere to mitochondria
- Oxygen in blood
- Hypoxia and types of hypoxia
- Oxygen delivery systems
- Guideline for oxygen therapy in acutely hypoxemic patient

Oxygen from atmosphere to alveoli

- O_2 in air 21%
- Entrance of air into alveoli is through negative pressure developed in thorax during normal respiration
- Partial pressure of oxygen differs through out the process:

1. Atmospheric Air = 160 mmHg (21 Kpa)
2. Humidified Tracheal Gas = 150 mmHg (19.8 Kpa)
3. 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 Mitochondria = 7.5-40 mmHg (1-5 KPa)

Oxygen in blood

- Arterial O_2 content:

$CaO_2 = (1.34 \times [Hb] \times SaO_2) + (0.003 \times PaO_2)$

- Venous O_2 content:

$CvO_2 = (1.34 \times [Hb] \times SvO_2) + (0.003 \times PvO_2)$

- O_2 delivery= cardiac output x CaO_2
- The amount of oxygen flux is normally:

  850-1200 ml/min

  OR

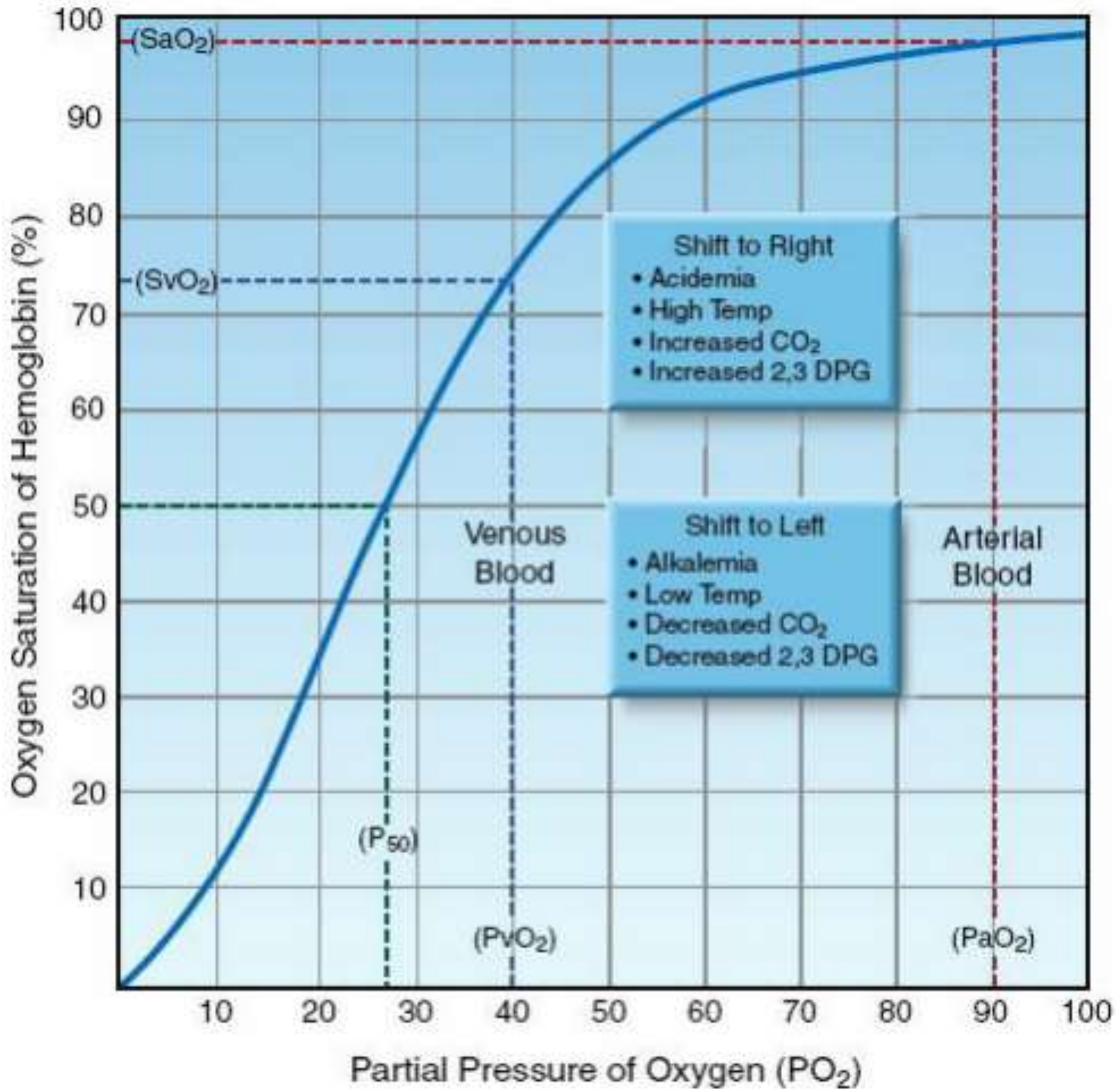
  500-700 ml/min/m^2

- 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 : Fever, Sepsis, Shivering, Restlessness, Hypercatabolism

oxygen consumption decreased in : Cooling, Paralysis, Mechanical Ventilation

Oxyhemoglobin dissociation curve



Oxygen content

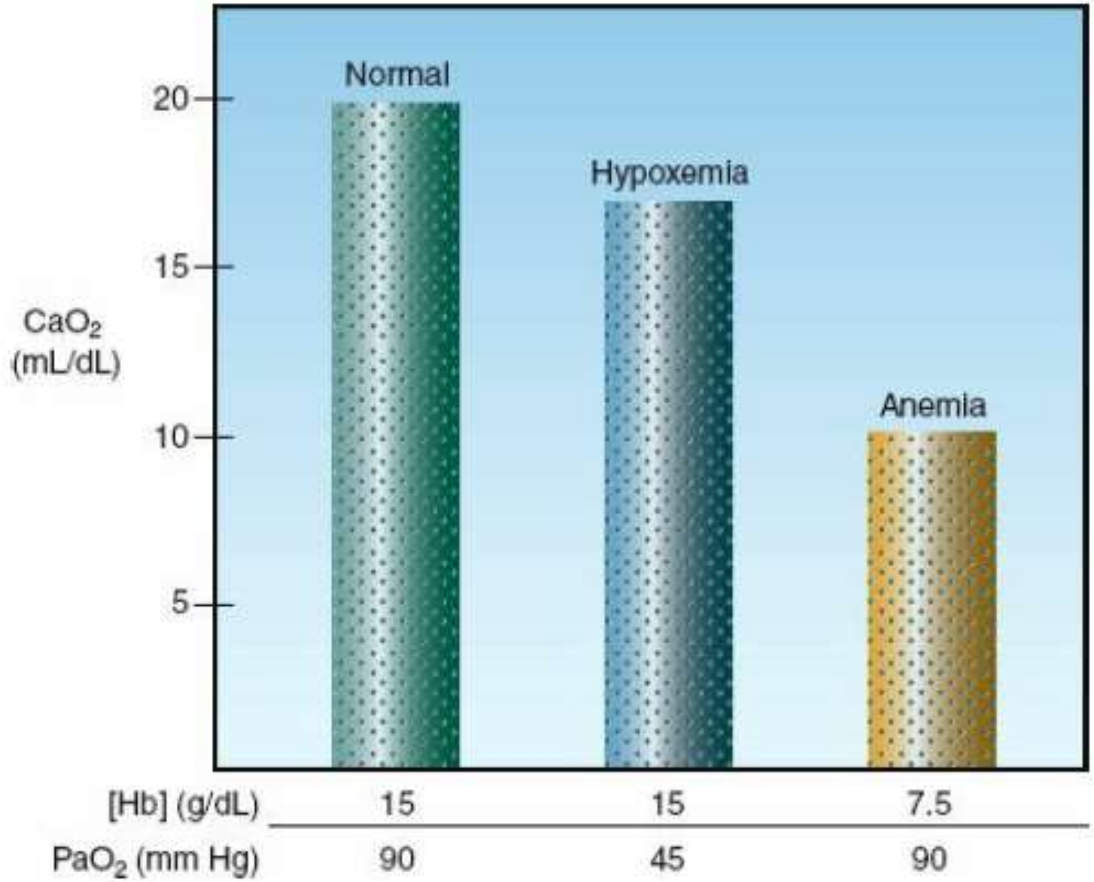


FIGURE 10.2 The effects of equivalent (50%) reductions in hemoglobin concentration [Hb] and arterial PO_2 (PaO_2) on the oxygen content in arterial blood (CaO_2).

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 :

1. Respiratory depression
2. Airway obstruction
3. Atelectasis
4. Ventilation/perfusion mismatch
5. 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 effect:

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

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

1. 85 % Saturation = Mental Impairment
2. 75 % Saturation = Severe Mental Impairment
3. 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

1. Hypoxic Hypoxia: occurs when there is inadequate arterial oxygenation due to respiratory problems
2. Anemic Hypoxia: occurs when there is inadequate hemoglobin content
3. Circulatory Hypoxia: occurs when there is inadequate perfusion
4. 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.
- Blood carrying capacity and blood flow is normal
- Causes include:

1. Low inspired PO2 (for example: High altitude)
2. Decreased ventilation due to airway obstruction for example in bronchial asthma
3. Defect at capillary-alveolar interface
4. A-V shunts

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 anemia or gas poisoning.
- 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.
- There is normal PaO_2

Histotoxic Hypoxia

- It is a state where there is impairment in tissue utilization of oxygen in presence of normal blood flow, normal oxygen carrying capacity in blood, and normal PaO_2
- Mainly due to cyanide poisoning

Oxygen delivery systems

- When is it indicated?

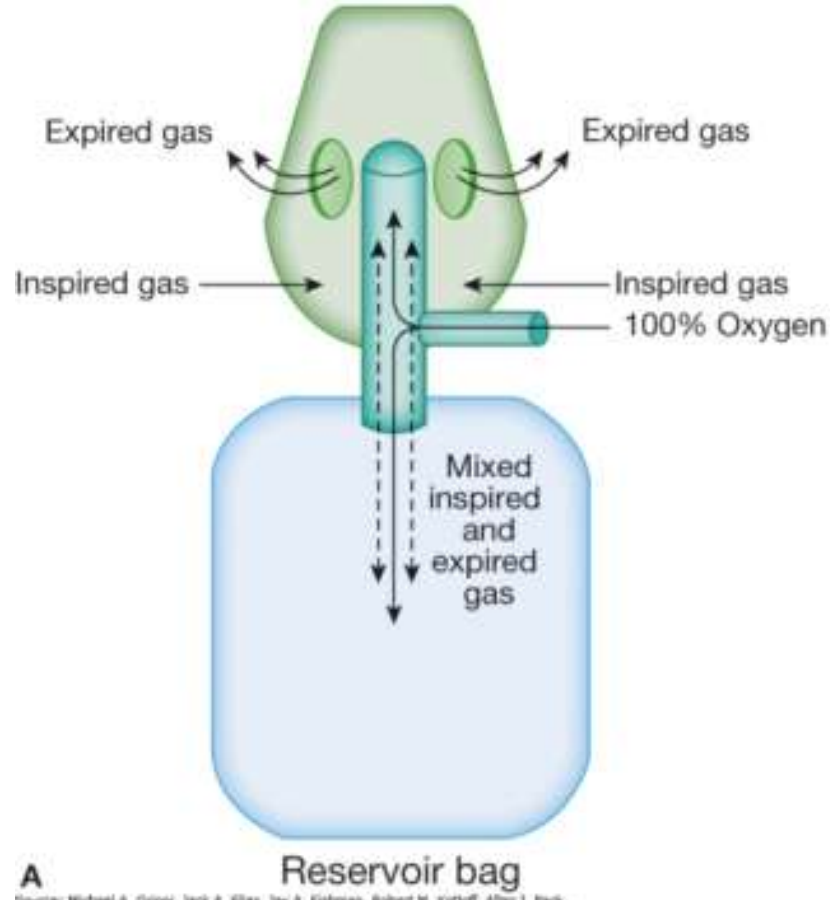
1. Cardio Pulmonary Resuscitation (CPR)
2. Respiratory Failure
3. Cardiac Failure
4. Shock of any Cause
5. Increased Metabolic Demands
6. Carbon Monoxide (CO)-Poisoning
7. Postoperative States

- Types :

✓ Variable performance
✓ Fixed performance

Variable performance

Face mask



Partial rebreather system

Variable performance

- 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.
  - FiO_2 is dependent on oxygen flow rate, size of oxygen reservoir and respiratory pattern.
  - 5L/min of oxygen flow delivers an FiO_2 of about 35 -40% providing normal respiratory pattern. A minimum of 5L/min is needed to clear exhaled gas from mask. Can achieve a maximum of 60%.
  - Indications: used only when a fixed oxygen concentration is not critical.
  - Contraindications: patient who depends on hypoxic drive
  - Advantage: great patient comfort, low cost, simple, can manipulate FiO_2 without changing appliance. Can use aerosolized bronchodilators.
  - 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

- Face mask with reservoir bag (600-800ml):
- ➢ Partial rebreather:
  - Allows the gas exhaled in initial phase of expiration to return to the reservoir bag. As exhalation proceed the flow rate will decrease becoming less than the oxygen flow rate at this point the exhaled gas can no longer return to reservoir bag. Since the initial expired gas is the anatomical dead space gas it is largely devoid of 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 FiO_2 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 good seal can affect oxygen delivery
- ➢ Non rebreather:
  - The expiratory ports on the mask are covered with flaps that allow exhaled gas to escape but prevent inhalation of room air. With a one way valve.
  - FiO_2: Theoretically can achieve 100% , but because of leaks around the mask it is around 80% with flow of 10-15L/min.

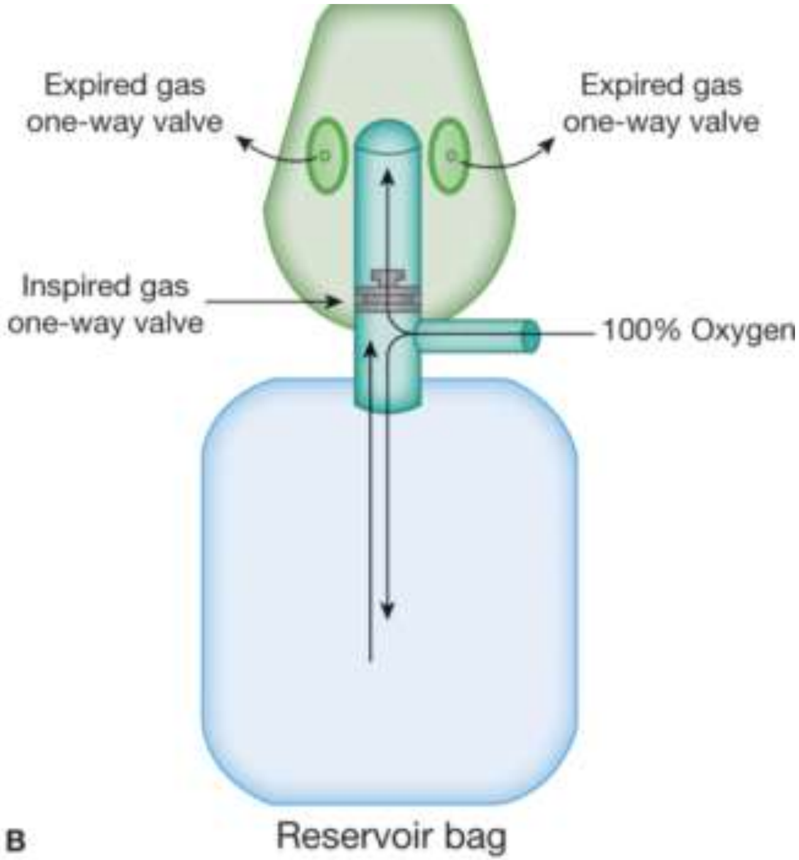
- ➢ Indication for each is a patient who is suspected for hypoxemia despite simple face mask applied and has a normal respiratory pattern

- ➢ In general face masks can cause dryness to the eyes because of leaking , as well as, it is not suitable for patients who are claustrophobic.

Variable performance

- Nasal cannula:
- Ideal for patient who is on long term oxygen therapy
- Two prongs which protrude about 1 cm into the nose held in place by an adjustable head strap
- Entrainment of ambient air by the nostrils and the nasopharynx acts a reservoir.
- FiO2 ranges from 24% to 40% with oxygen flow rates 1-6L/min but high 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.
- 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

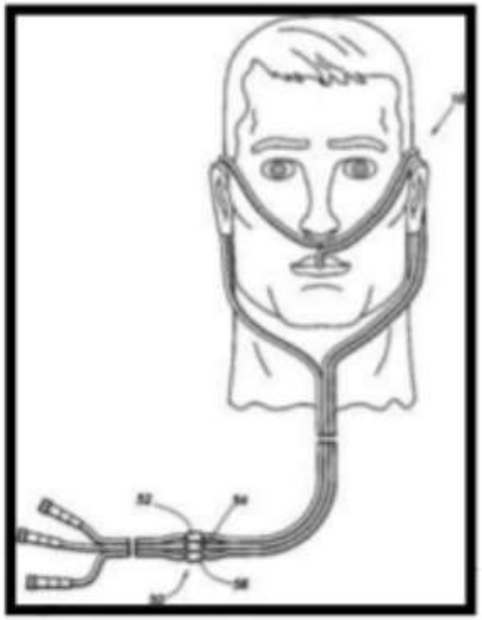


Non rebreather mask

Nasal Cannula

Nasal cannula

- Simple plastic tubing + prongs with an over the ear adjustments.
- Sizing available for adults children and infants.
- Fio2 increases app. 1-2% with every increase in o2 flow per litre.
- Flow > 5lt/min is less tolerated due to flow jet in nasal cavity



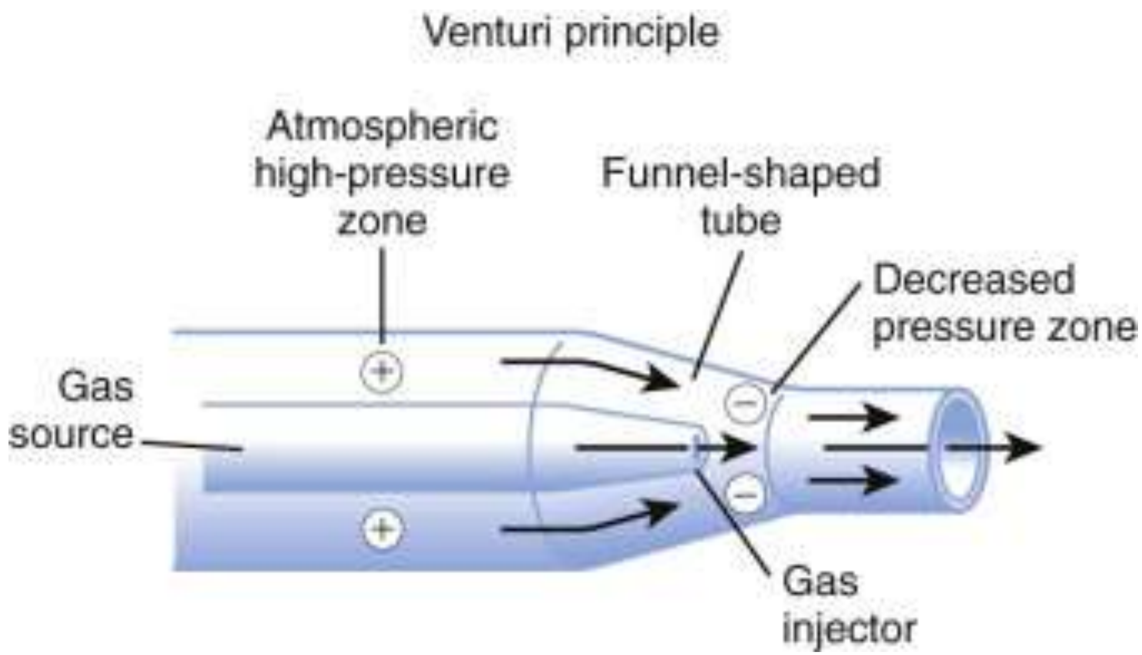
1 - 24%
2 - 28%
3 - 32%
4 - 36%
5 - 40%
6 - 44%

Variable performance

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

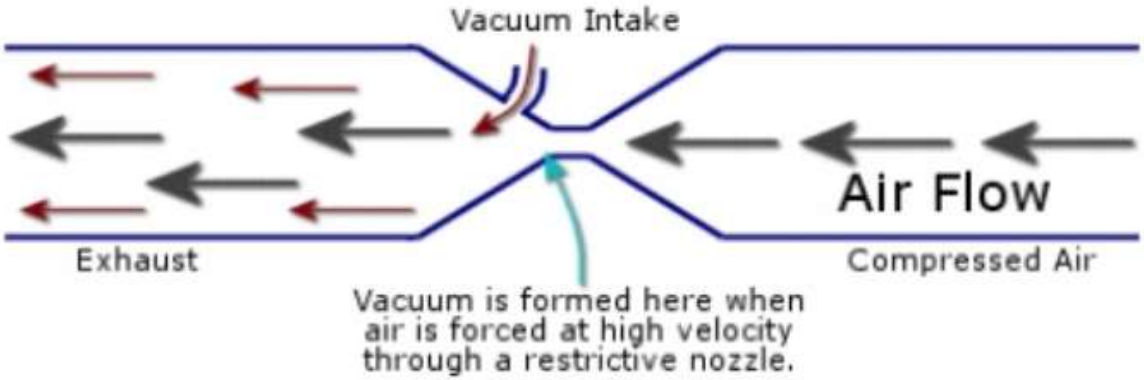
High FiO_2 delivered	Low FiO_2 delivered
Low peak inspiratory flow rate	High peak inspiratory flow rate
Slow respiratory rate	Fast respiratory rate
High fresh oxygen flow rate	Low fresh oxygen flow rate
Tightly fitting face mask	Less tightly fitting face mask

Fixed performance

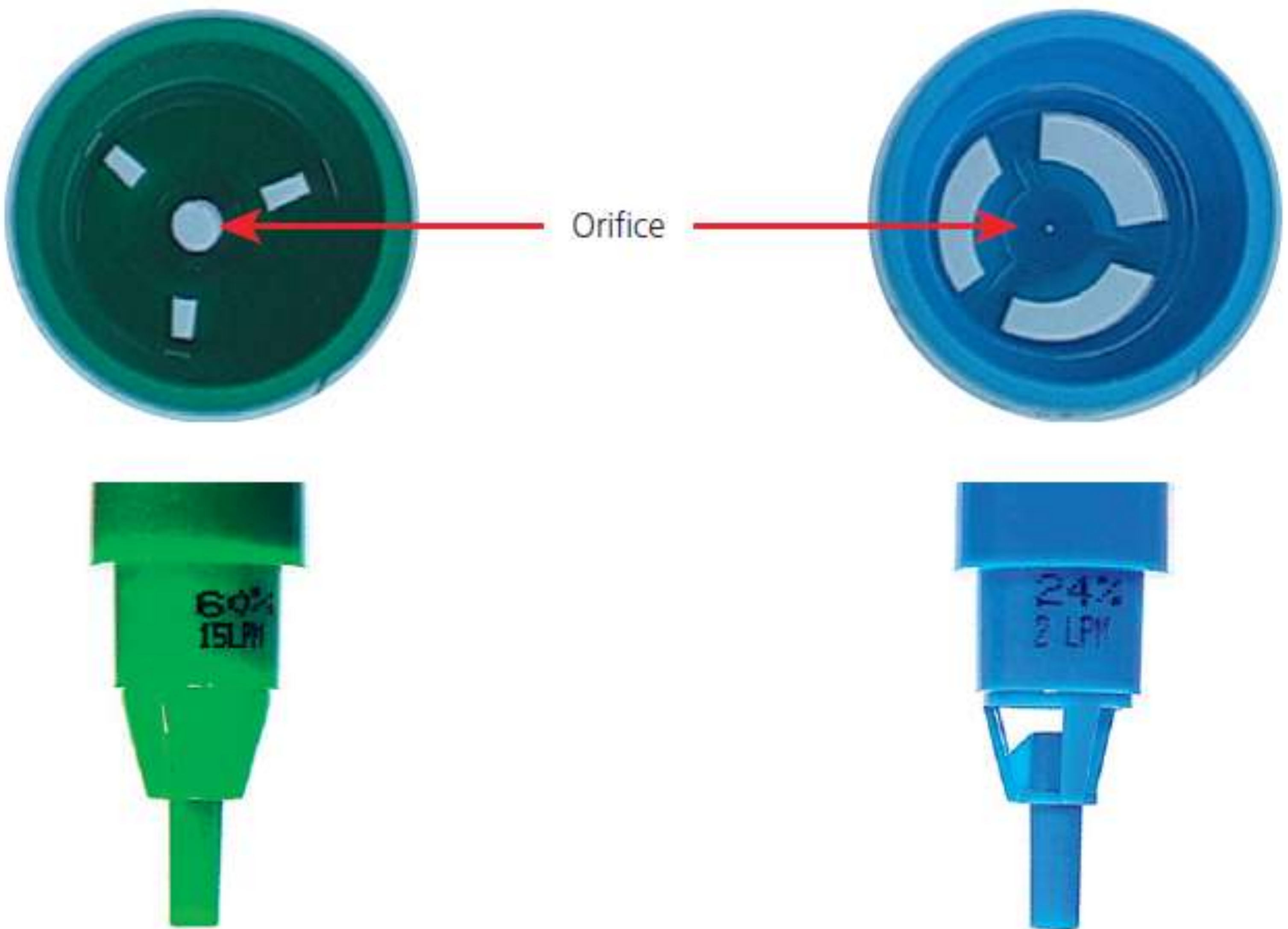


Air-entrainment device
(Venturi masks or Venti masks)

Venturi effect



Fixed Performance



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

Fixed performance

- Venturi mask:
- High-airflow oxygen enrichment
- Plastic body of the mask has holes on both sides. The proximal end consists of a venturi device which are color coded and marked with the recommended oxygen flow rate to provide the desired oxygen concentration.
- Uses the Bernoulli principle, in which it delivers a predetermined and fixed concentration of oxygen to the patient. There is a constriction that determines the final concentration of oxygen. As the flow of oxygen passes through it a negative pressure is created. This causes the ambient air to be entrained and mixed with the oxygen flow. And so the concentration of oxygen depends on the degree of air entrainment. The less entrainment the more the FiO2.
- The smaller the orifice is, the greater the negative pressure, so the more ambient air entrained and thus less FiO2.
- Because of the high fresh gas flow rate the exhaled gases are rapidly flushed from the mask, via its holes. FiO2 : 24%, 28%, 31%, 35%, 40%, 60%.
- A 24% oxygen venturi mask has an air : oxygen entrainment ratio of 25:1. this means an oxygen from of 2L/min delivers a total flow of 50L/min, which is well above the peak inspiratory flow rate.
- Indications: for patient whose ventilation is dependent on hypoxic drive (COPD)
- Advantages: No rebreathing and no increase in dead space.
- Disadvantages: bulky and noisy.

Fixed performance

Non invasive positive pressure mechanical ventilation

These masks can be used for
Continuous positive airway pressure
and
Bilevel positive airway pressure

Fixed Performance

- The masks presented can be used for CPAP or BiPAP, the difference lies in the ventilator setting
- However the vision BiPAP has a different ventilator through which one can set the FiO_2

Fixed performance

Non invasive mechanical ventilation 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. Protected airway reflexes
4. Needs monitoring of vital signs as contraindications might develop.
5. Monitoring of respiratory pattern and ABGs as contraindications might develop

- Bilevel positive airway pressure:

- ➢ Mask with silicon caution to form a seal
- ➢ High and low pressure is used:
  - ➢ High pressure is called inspiratory positive airway pressure
  - ➢ Low pressure is called expiratory positive airway pressure.
- ➢ 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.
- ➢ Disadvantages: the mask can abrade the nose. Claustrophobia.

Fixed performance

Continue on BiPAP:

- Indications:
  1. signs of respiratory failure such as use of accessory muscles, dyspnea and tachypnea.
  2. Gas-exchange abnormalities (pH<7.35)
  3. PaCO2 >45mmhg
  4. PaO2:FiO2 <200
  5. Use in acute exacerbation of COPD with hypoxemia, and in cardiogenic edema
- Contraindications:

  Absolute: respiratory and cardiac arrest

  Relative : 1. discomfort from the mask

  2. high risk of aspiration because of impaired mental status unless it is due to hypercapnia

  3. active vomiting

  4. large volume of secretions

  5. recent upper airway or gastrointestinal surgery

- CPAP:
- Spontaneously breathing at a positive end-expiratory pressure.
- The principal effect is to increase functional residual capacity
- Indications: used for obstructive sleep apnea. And indications mentioned for BiPAP
- Disadvantages: does not augment the tidal volume which limits its use in acute respiratory failure. (the principal use of it in acute respiratory failure is in cardiogenic pulmonary edema and mostly for its hemodynamic support.)

CPAP versus PEEP

CPAP (continuous positive airway pressure) and PEEP (positive end expiratory pressure) are terms that commonly cause confusion. In some contexts they appear to be interchangeable but in others they do not. It may be helpful to consider the effect they have during spontaneous and positive pressure ventilation modes separately.

CPAP/PEEP in unassisted spontaneous ventilation

When the patient is breathing spontaneously (whether intubated or not) with no assistance from the ventilator, PEEP is the term used for pressure applied to the airway during expiration only. Examples of PEEP include a partially closed APL valve on the breathing system in theatre (when the FGF is insufficient to keep the bag fully inflated between breaths), or more simply, when a person breathes out through pursed lips or a straw. Note that no positive pressure is applied to inspiration in either of these examples.

CPAP is when the pressure is both constant (i.e. of unchanging magnitude) and continuous (i.e. present throughout inspiration and expiration). The classic example of this is when a passenger puts his head out of a car window and faces the direction of travel. There is a positive pressure applied to the airway during inspiration and the same pressure is applied against expiration.

cessive reduction in venous return. Positive intrathoracic

Mechanical ventilation and CPAP/PEEP

The difference between PEEP and CPAP is less clear during positive pressure ventilation, and many argue that there is no difference in this context.

For a tidal volume to be delivered, the airway pressure must be cycled between a higher pressure and a lower pressure. The lower pressure is known as PEEP and the higher pressure is the sum of the PEEP and the set inspiratory pressure (e.g. a set PEEP of 5 cmH2O and a set inspiratory pressure of 10 cmH2O should give a peak inspiratory airway pressure of 15 cmH2O). The same is true when assisted ventilation modes are used and the patient is making respiratory effort. The higher pressure is the sum of the PEEP and the set inspiratory pressure.

PEEP can therefore be thought of as being present throughout the respiratory cycle during mechanical ventilation – during both inspiration and expiration. During mechanical ventilation, therefore, PEEP becomes a misnomer because it is not just present at the end of expiration. The terms PEEP and CPAP are therefore used interchangeably in this context.

CPAP/PEEP can be generated within an ITU ventilator in one of two ways.

Some ventilators have adjustable expiratory valves that generate a positive back pressure in the breathing system.

Other ventilators generate a constant and adjustable flow of gas through the breathing system, which is analogous to when a passenger puts his head out of a car window. This method allows better dynamic adaptation of positive airways pressure to the patient’s lung mechanics, but increases gas consumption.

Vision BIPAP

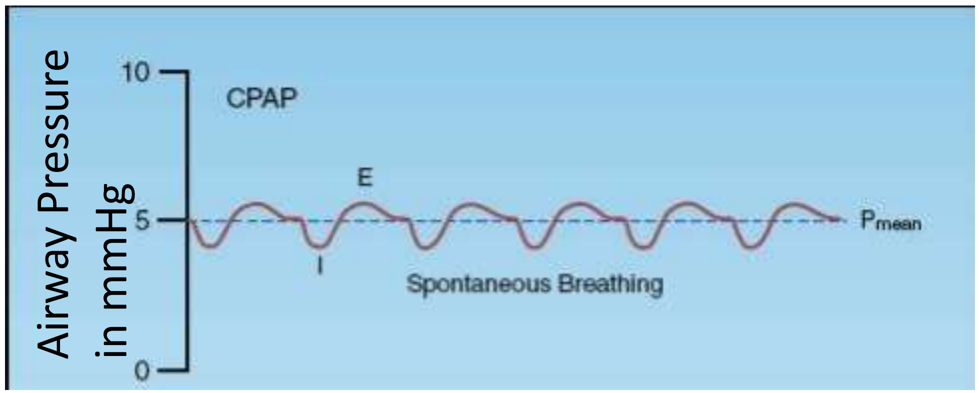
- Can reach FIO2 up to 100%

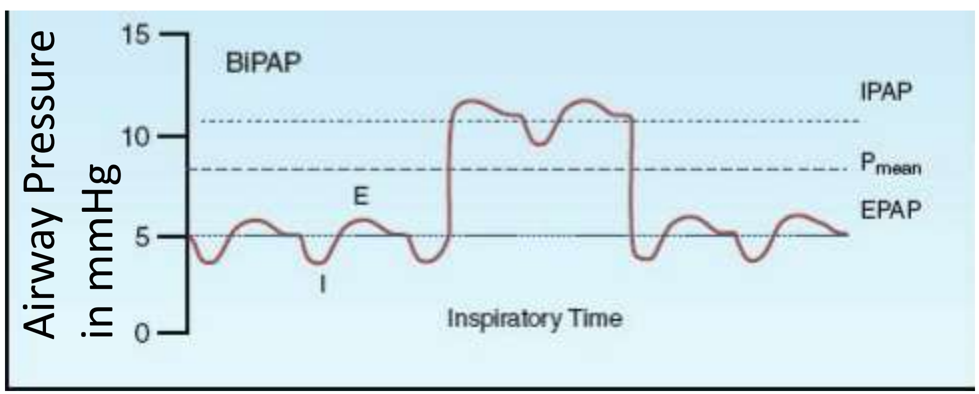
Fixed Performance

- Vision Bipap

CPAP or BIPAP nasal mask

Fixed Performance
Non invasive mechanical ventilation





Bag-Mask Ventilation

Bag-Mask Ventilation

- A basic airway management technique for oxygenation and ventilation until a more definitive airway can be established.
- Manual IPPV
- Self-inflating bag with a connection for added oxygen. One-way valve with three ports; inspiratory inlet, expiratory outlet, connection to mask or tube, a reservoir for oxygen to increase FiO_2.
- The non rebreathing valve has a silicon rubber membrane, has a small dead space and low resistance to flow. 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 : Facial hair, Obese, 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 deliver 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 technique and portable, high FiO_2 , PEEP
- Disadvantage: opening of lower esophageal sphincter (risk of aspiration) , needs practice, 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
  - Transparent so 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

- Assess Airway, Breathing and Circulation
- When the patient is at risk of Respiratory type II failure:
  - ➢ Target saturation is 88-92% whilst waiting for ABGs result

ABGs result :

- ➢ When pH<7.35 and PCO2>45mmHg (6.0 kPa) seek immediate senior review and consider NIV or invasive ventilation. Treat with the lowest FiO2 to keep SpO2 88-92% either via venturi system or NIV/MV
- ➢ When pH>7.35 and PCO2>45mmHg (6.0kPa) treat with the lowest dose venturi mask to maintain SpO2 88-92%. Then repeat ABGs at 30-60 minutes, if pH<7.35 and PCO2 <45mmHg (6.0kPa) seed immediate senior review and consider NIV/MV. Consider reducing FiO2 if PO2 ≥ 60mmHg (8.0kPa)

Guideline for oxygen therapy in acutely hypoxemic patient

- If there is no risk for respiratory failure type II:
  - ➢ Aim for SpO_2 94-98%
  - ➢ When $SpO_2 \leq 94\%$ on air or oxygen:
    - ❖ Commence oxygen at 2-6 L/min via nasal cannula or simple face mask 5-10L/min. Reservoir Bag 15L/min if $SpO_2 < 85\%$
    - ❖ when ABGs results are:
      1. $PCO_2 \leq$ 45mmHg (6.0kPa) treat appropriately aiming to keep SpO_2 94-98%.
      2. $PCO_2 \geq$ 45mmHg (6.0kPa) or respiratory deterioration seek immediate senior review and consider invasive ventilation . Treat urgently aiming for SpO_2 94-98% consider COPD or undiagnosed chronic type II respiratory failure. If likely aim SpO_2 88-92%
      3. Repeat ABGs in 30-60 minutes for all at risk of type II respiratory failure
    - ❖ When $SpO_2 > 94\%$ monitor SpO_2, oxygen is not required unless SpO_2 falls below 94%.

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