RESPIRATORY FAILURE

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Terminology

- **Respiratory failure:** the acute or chronic inability of the respiratory system to maintain adequate gas exchange.
  - Hypoxemic respiratory failure: defined as a $PaO_2 < 60$ mm Hg (8 kPa)
  - Hypercapnic respiratory failure: defined as a $PaCO_2 > 50$ mm Hg (6.5 kPa)
  - Hypoxemic and hypercapnic respiratory failure can occur together.
- **Respiratory arrest:** the complete cessation of breathing in patients with a pulse
- **Respiratory distress:** A clinical syndrome associated with breathing disorders

When does a patient develop Respiratory Failure?

Respiratory failure occurs when **oxygenation** and **ventilation** are

insufficient to meet the **metabolic demands** of the body as the respiratory system fails in oxygenation or carbon dioxide elimination or both.

The patient's general state, respiratory effort, and the potential for impending exhaustion are more **important indicators** than ABG values.

RF is diagnosed when the patient's respiratory system loses the ability to provide sufficient oxygen to the blood, and hypoxemia develops, or when the patient is unable to adequately ventilate, and hypercarbia and hypoxemia develop.

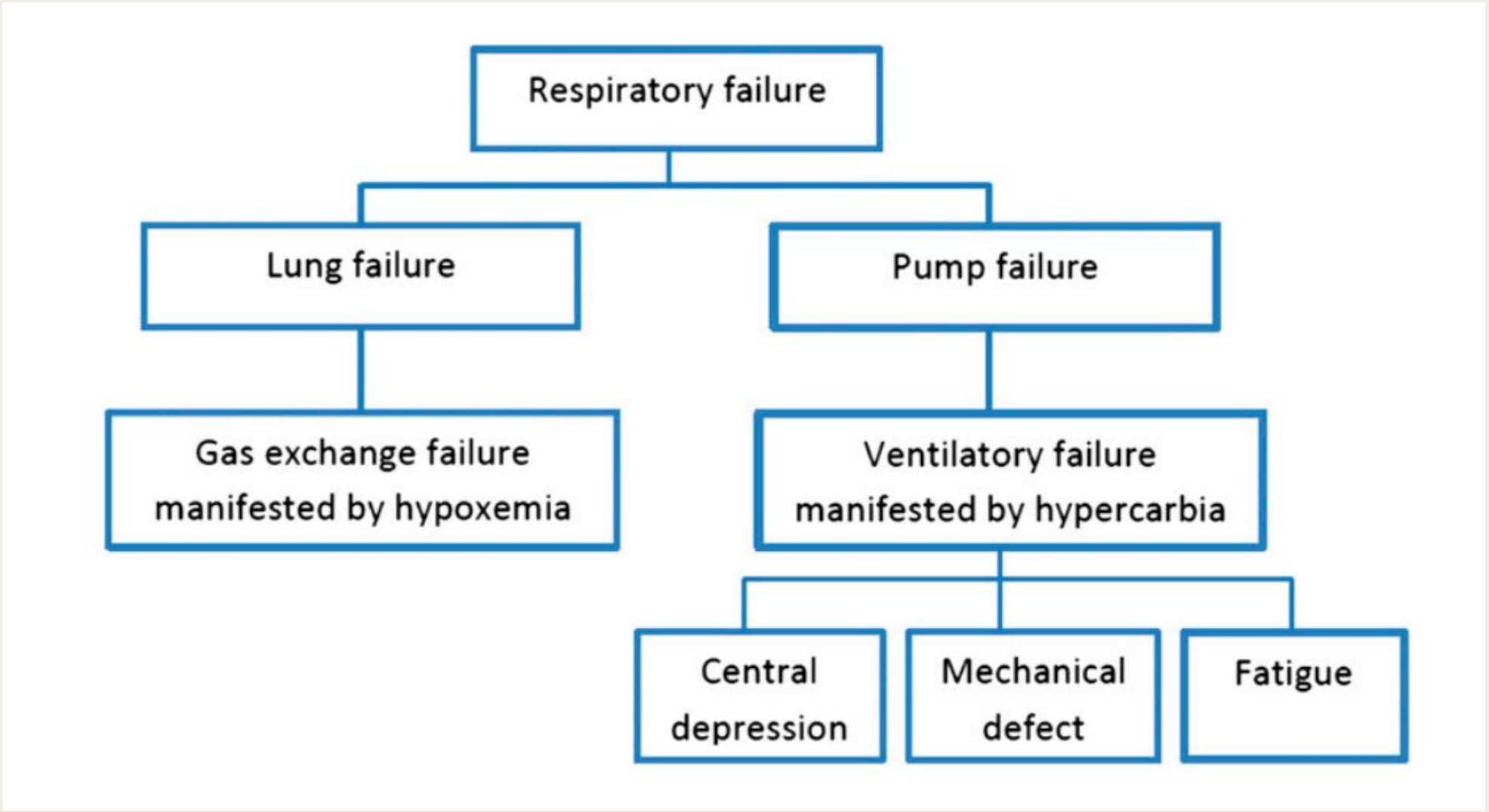
Types of Respiratory Failure

Gas Exchange Abnormality

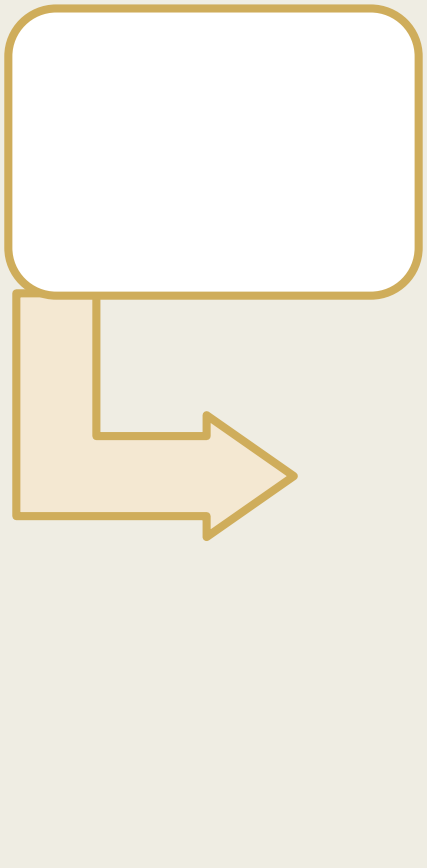
- Type 1: Hypoxemic Respiratory Failure
- Type 2: Hypercapnic Respiratory Failure
- Type 3: Peri-Operative Respiratory Failure
- Type 4: Shock

Duration

- Acute: over minutes to hours
- Chronic: in several days or longer (longstanding)


Respiratory failure
Lung failure
Pump failure
Gas exchange failure manifested by hypoxemia
Ventilatory failure manifested by hypercarbia
Central depression
Mechanical defect
Fatigue

Type I respiratory failure [Hypoxemic]

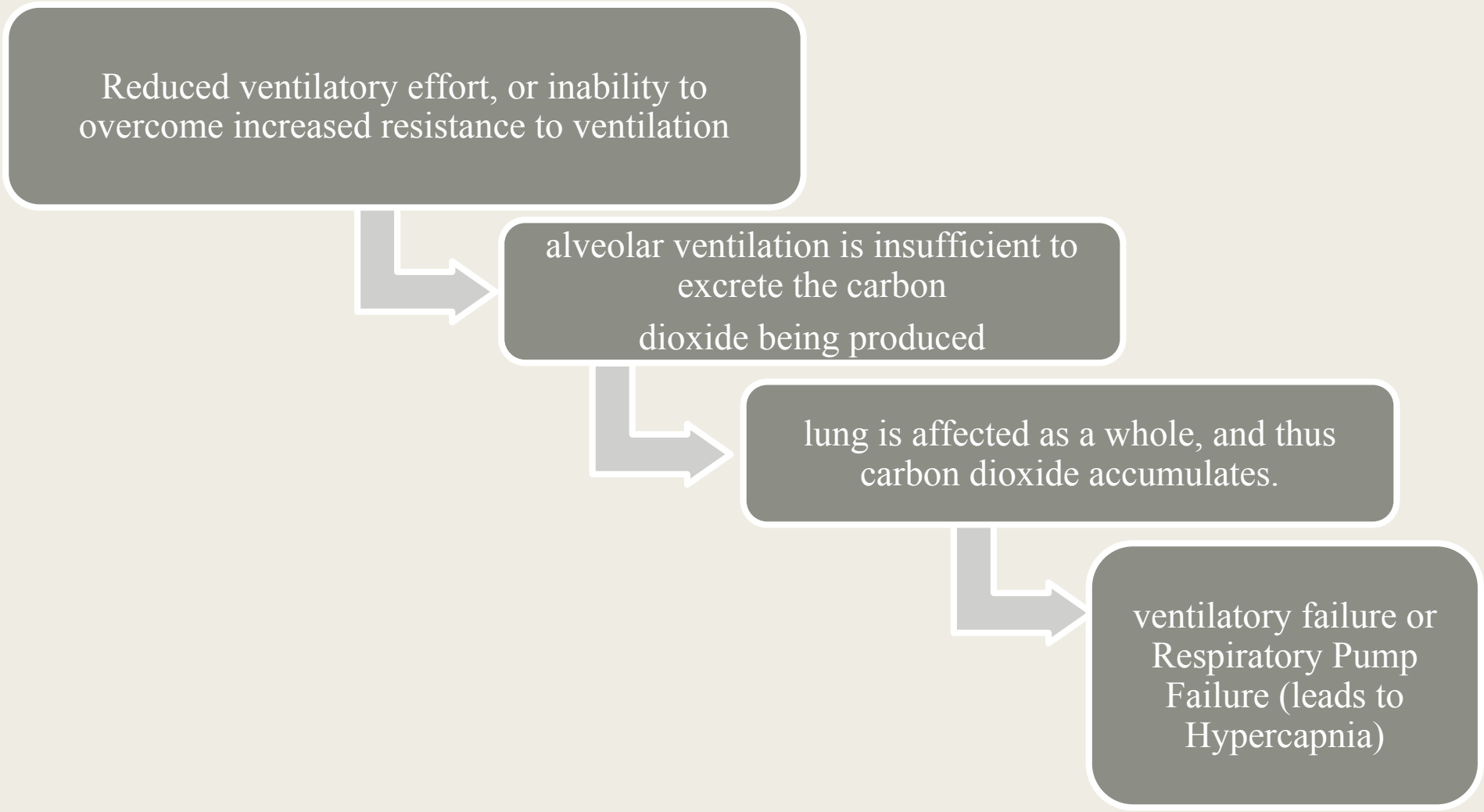


Prevents adequate oxygenation of the blood (hypoxemia)

Less functioning lung tissue is required for carbon dioxide excretion than is needed for oxygenation of the blood.

- Hypoxemic Respiratory Failure

Type II Respiratory Failure [Hypercapnic]



Type 1 vs Type 2

Type	Type 1 (hypoxemic respiratory failure)	Type 2 (hypercapnic respiratory failure)
Definition	•Respiratory failure characterized by hypoxemia and normocapnia or hypocapnia on arterial blood gas analysis	•Respiratory failure characterized by hypercapnia and normoxemia or hypoxemia on arterial blood gas analysis
PaO2	•↓ (< 60 mm Hg)	•Normal or ↓ (< 80 mm Hg)
PaCO2	•Normal or ↓ (< 33 mm Hg)	•↑ (> 50 mm Hg)

Duration

- **Acute** respiratory failure: develops over minutes to hours as a result of an acute illness or insult

- **Chronic respiratory failure**: longstanding respiratory failure resulting from chronic illness (e.g., COPD, ILD, obesity hypoventilation syndrome)

- In patients with hypercapnia, a normal pH suggests chronic CO2 retention while a low pH raises concern for acute or acute-on-chronic CO2 retention, which requires immediate intervention
- In acute hypercapnic respiratory failure, the pH decreases below 7.35 and for patients with underlying chronic respiratory failure, the PaCO2 increases by 20 mm Hg from baseline.

Epidemiology

- **Infants and young children have a higher frequency of respiratory failure.**

- Approximately half of respiratory failure cases are seen in the neonatal period, resulting from complications of prematurity and transitioning to extrauterine life.

- In addition, developmental differences between children and adults also explain the higher incidence.

You are seeing 2 brothers ages 2 months and 6 years, respectively, for upper respiratory tract infection. Rapid antigen testing suggests infection with respiratory syncytial virus. Which of the following factors is most important in placing the younger sibling at greater risk of developing respiratory decompensation compared with his older brother?

A. Decreased accessory muscle use.

B. Decreased airway size.

C. Decreased chest wall compliance.

D. Decreased lung compliance.

E. Greater reliance

Approximately **half** of respiratory failure cases seen in the **neonatal** period, WHY?

1. Infants and young children have a smaller upper airway, with the subglottic area being the narrowest; any inflammatory process can result in airway narrowing and subsequently in increased work of breathing

2. Immature stages of lung growth and development present with fewer numbers of alveoli, smaller intrathoracic airway caliber with little cartilaginous support, and underdeveloped collateral ventilation.

3. Infants respiratory muscles have reduced type 1 muscle fibers, specifically the diaphragm resulting in lower respiratory tract muscle bulk and reserve.

4. Infants chest wall is more compliant than in adults because of a less bony thorax, compromising thoracic expansion, and may result in accessory muscle use and paradoxical patterns of respiration.

5.Bradypnea, apnea, or tachypnea commonly results from the immaturity of the respiratory center.

All these factors result in a higher metabolic demand per kilogram of body weight, resulting in increased work of breathing and early fatigue

In Summary:

Smaller upper airway (comparing with adults) with subglottic area is the narrowest.

Immature stage of lung development present with fewer number of alveoli , smaller intrathoracic airway caliber , and underdeveloped collateral ventilation

Infant respiratory muscle have reduced Type I muscle fibers(specially the diaphragm)

Bradypnea , Apnea, or tachypnea results commonly from immaturity of respiratory center

Pathophysiology

- Respiration involves the **nervous, cardiovascular , musculoskeletal, and respiratory systems.**

- The causes of respiratory failure can come from any of these systems.

- In general the pathophysiologic mechanisms that lead to respiratory failure **involve primarily either:**

1. **V/Q mismatch**
2. **impairment of oxygen transfer at the alveolar-capillary membrane(diffusion)**

1- Ventilation-perfusion mismatch (v/q)

Alveolar gas exchange depends on:

A. ventilation of the alveoli

B. circulation of blood through the alveolar capillaries.

You need both **oxygen in the alveoli, and adequate blood flow** past alveoli to pick up oxygen, other wise oxygen cannot be delivered

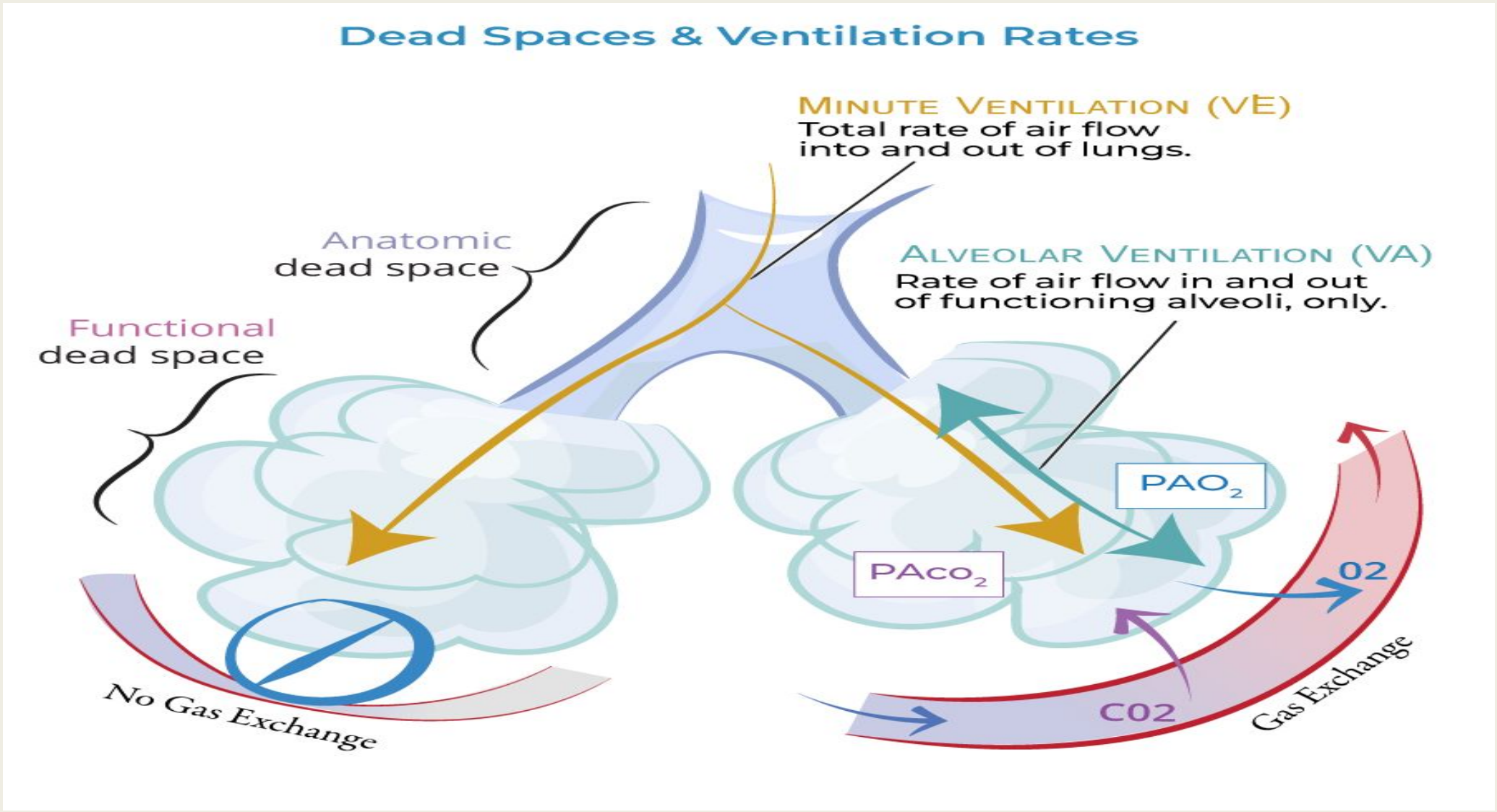
A. **High V/Q ratio** is when the alveoli are **well ventilated** but are **not well perfused**. High V/Q ratios act **like dead space**.

B. Low V/Q ratio is when the alveoli units are **well perfused** but **are not well ventilated**. Low V/Q ratios **act like shunts**.

A. Dead Space

Dead Space: Portion of inspired air that doesn't take part in gaseous exchange with pulmonary capillary blood.

There are three types of dead space: anatomic, physiologic, and equipment that dead space belonging to any airway equipment being used to assist ventilation.


Dead Spaces & Ventilation Rates
MINUTE VENTILATION (VE)
Total rate of air flow into and out of lungs.
Anatomic dead space
Functional dead space
ALVEOLAR VENTILATION (VA)
Rate of air flow in and out of functioning alveoli, only.
PAO2
PACO2
02
C02
Gas Exchange
No Gas Exchange

Anatomic Dead Space

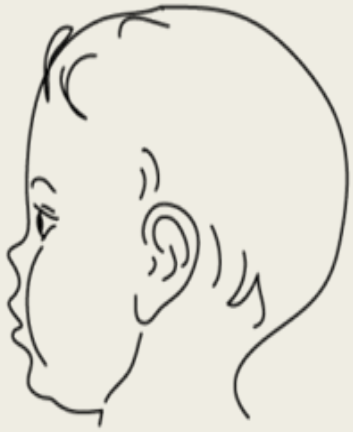
- Composed of the **upper airway structures** that don't take part in the gas exchange [nasal passage , nasopharynx, larynx, trachea and large airway]

- About 1/3 of each normal breath we take is anatomic dead space, which means that a third of each breath is essentially wasted.

- **Dead space is age dependent**.

It's highest in the infant at 3 ml/kg ideal body weight and is about 2 ml/kg in older children and adults. An adequate tidal volume must include enough volume to also fill the dead space, otherwise not enough air enters the alveoli and the patient hypoventilates.

Healthy teenage boy
60 kg (132 lb)
TV = 480 ml (8 ml/kg x 60kg)
anatomic deadspace: 120 (2 ml/kg X 60)
alveolar ventilation: 360 ml (480-120)
Volume: about a can of soda



Healthy infant
2.7 kg (6 lb)
TV 22 ml (8 ml/kg x 2.7 kg)
anatomic deadspace: 8 (3 ml/kg x 2.7)
alveolar ventilation: 14 ml (22-8)
Volume: < 1 tablespoon

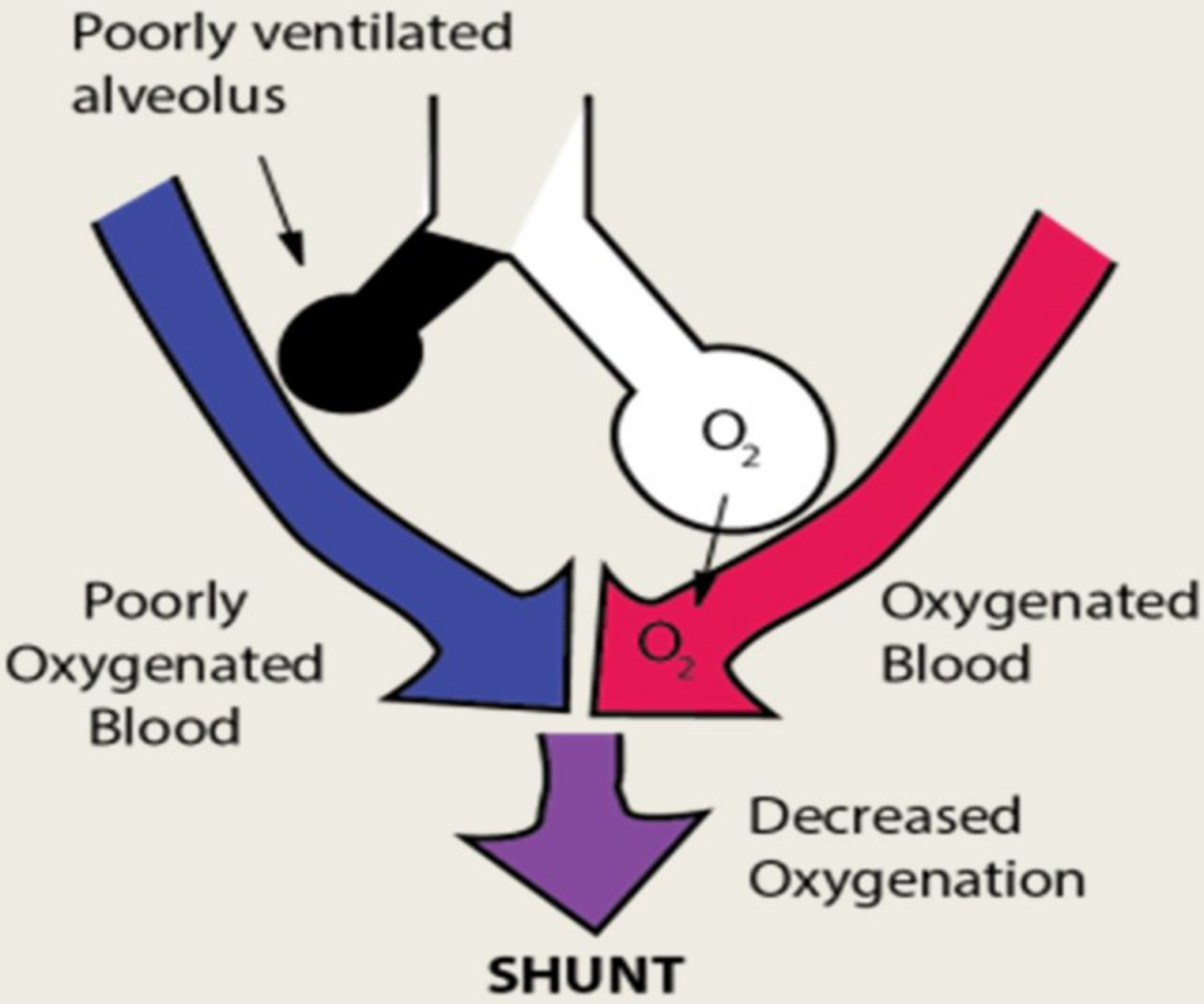
Physiologic Dead Space

- A second type of dead space, physiologic dead space, consists of alveoli that are ventilated but lack capillary blood flow to pick up oxygen and drop off carbon dioxide. In other words, they are not perfused
- Many things can impair alveolar perfusion and increase physiologic dead space such as:

1. cardiovascular shock (blood flow to the lungs is decreased),
2. emphysema (lots of enlarged alveoli with less surface area and fewer alveolar capillaries)
3. pulmonary embolus (flow is blocked by clot).

B- Pulmonary Shunt

- Another contributor to ventilation perfusion mismatch is shunt. Shunt is the opposite of dead space and consists of alveoli that are perfused, but not ventilated.
- Blood flowing past poorly ventilated alveoli doesn't pick up additional oxygen. This poorly oxygenated blood returns to the heart and mixes with oxygenated blood coming from other areas of the lungs that are ventilated. The mixture lowers the total oxygen content of the arterial blood, producing hypoxemia. The larger the shunt, the lower the oxygen content .
- Giving a patient with an intrapulmonary shunt 100% oxygen to breathe won't increase the PaO2 much


Poorly ventilated alveolus
O_2
O_2
Poorly Oxygenated Blood
Oxygenated Blood
Decreased Oxygenation
SHUNT

? Common causes of shunt occur in lung tissue disease and include:

1. pneumonia and pulmonary edema: some alveoli filled with fluid
2. tissue trauma: alveolar wall swelling
3. atelectasis: collapse of alveoli from failure to expand, or absorbsion of the air out of the alveoli without replacing it
4. mucous plugging: air can’t get into the alveoli
5. pulmonary arteriovenous fistulas

SHUNT VERSUS DEAD SPACE

SHUNT	DEAD SPACE
The pathological condition, which results when the alveoli of the lungs are perfused with blood as normal, but the ventilation fails to supply the perfused region	The volume of air, which does not take part in the gas exchange as it remains in the conducting airways or reaches alveoli, which are not perfused
Blood Supply: Normal	Blood Supply: Poor
Ventilation: Poor	Ventilation: Normal
Types: Anatomical shunt and capillary shunt	Types: Anatomical dead space and alveolar dead space
Causes: Pneumonia and pulmonary edema, tissue trauma, atelectasis, mucus plugging, pulmonary arteriovenous fistulas, etc.	Causes: Cardiovascular shock, emphysema, pulmonary embolism (PE), etc.

2- Diffusion

- Diffusion limitation is the impairment of transfer of oxygen at the alveolar-capillary membrane. This can result from alveolar or interstitial inflammation and fibrosis. Diffusion limitation usually coexists with V/Q mismatch.

- **Causes of V/Q mismatch and impaired gas exchange:**
- Pulmonary conditions that involve the bronchi **(eg, status asthmaticus and bronchiolitis)**

- inflammation or infection of the parenchyma

(eg, pneumonia, aspiration, cystic fibrosis, and ciliary dysmotility)

Diffusion

?Even if ventilation and perfusion are matched, gas exchange requires diffusion across the interstitial space between alveoli and pulmonary capillaries. Under normal conditions, there is sufficient time for the pulmonary capillary blood to equilibrate with alveolar gas across the interstitial space. When the interstitial space is filled with inflammatory cells or fluid, diffusion is impaired. Because the diffusion capacity of CO2 is 20 times greater than that of O2 , diffusion defects manifest as hypoxemia rather than hypercarbia.

?Therefore, with diffusion defects, lethal hypoxemia will set in before clinically significant CO2 retention results. In fact, in such situations, PaCO 2 is often decreased because of the hyperventilation that accompanies hypoxemia. Presence of hypercarbia in diseases that impair diffusion is indicative of alveolar hypoventilation from coexisting airway obstruction, exhaustion, or CNS depression.

? Examples of disease that impair diffusion are interstitial pneumonia, ARDS, scleroderma, and pulmonary lymphangiectasia.

Introduction Summary

- Respiration involves the nervous, cardiovascular, musculoskeletal , and respiratory systems.
- The causes of respiratory failure can come from any of these systems and are expansive .
- The pathophysiologic mechanisms that lead to respiratory failure involve primarily either V/Q mismatch or impairment of oxygen transfer at the alveolar-capillary membrane.
- A high V/Q ratio is when the alveoli are well ventilated but are not well perfused. High V/Q ratios act like dead space .
- A low V/Q ratio is when the alveoli units are well perfused but are not well ventilated. Low V/Q ratios act like shunts.
- These 2 common pathophysiologic mechanisms of respiratory failure are observed in a variety of diseases. Pulmonary conditions that involve the bronchi (eg, status asthmaticus and bronchiolitis) or inflammation or infection of the parenchyma (eg, pneumonia, aspiration, cystic fibrosis, and ciliary dysmotility) result in airway obstruction and/or parenchymal loss, leading to V/Q mismatch and impaired gas exchange.

***Asthma and respiratory failure

- Specifically, status asthmaticus occurs because of progression of **airway inflammation, bronchospasm, and mucous plugging during days to weeks or sudden onset of asphyxia from bronchospasm**

- In either case, airway obstruction **causes V/Q mismatch, incomplete alveolar gas exchange, and lung hyperinflation**

- **End-expiratory alveolar pressure increases** as a result, creating an **autopositive end-expiratory pressure state**.

- **Work of breathing is increased** to overcome the autopositive end-expiratory pressure for inspiratory flow to occur,eventually leading **to inspiratory muscle fatigue and respiratory failure**.

***Cystic fibrosis and respiratory failure

- In cystic fibrosis, similarly, an **acute pulmonary exacerbation can result in airway obstruction and mucous plugging,** leading **to V/Q mismatch and reduced functional residual capacity**

- **Increased work of breathing** results in **respiratory muscle fatigue**, leading to **hypoventilation, hypercarbia, and respiratory failure**.

- In addition to V/Q mismatch, **impairment of gas exchange at the alveolarcapillary membrane** is observed in progressive cystic fibrosis disease with pulmonary fibrosis and destruction

- **Another causes**:
- Obstruction from infectious causes
- foreign-body aspiration
- Burn injuries
- Anaphylaxis
- decreased muscle tone from depressed consciousness
- neuromuscular disorders
- CNS disorders(apnea of prematurity head trauma; intracranial bleeding; hypoxic ischemic encephalopathy; and cerebral palsy).

TABLE 1. Causes of Respiratory Failure

Lung and airway disorders
Lung parenchyma
• Bronchiolitis
• Severe asthma
• Aspiration
• Pneumonia
• Pulmonary edema
• Cystic fibrosis
Airway
• Laryngotracheobronchomalacia
• Croup
• Tracheitis
• Vascular malformations (ring, sling, right-sided aortic arch)
• Subglottic stenosis, complete tracheal ring

Respiratory pump failure
• Restrictive lung disorders (kyphoscoliosis)
• Chest wall abnormalities: congenital or traumatic (flail chest)
• Neuromuscular disorders (phrenic nerve paralysis, myopathies, muscular dystrophies)
• Diaphragmatic disorders (paralysis, congenital diaphragmatic hernia)
Respiratory center failure
• Brain injuries (traumatic)
• Central nervous system infection (controlled mechanical ventilation) or hypoxic encephalopathies
• Drug overdose or adverse effects
• Congenital (leukomalacia) or genetic disorders (congenital hypoventilation syndrome)
Failure to meet increased metabolic needs
• Septic shock

Approach to patient with respiratory failure

EMERGENCY

- Respiratory support should be urgently provided for a patient with significant **tachypnea**, **retractions**, **grunting**, **nasal flaring**, and **head bobbing** (De Musset's sign)
- Delay in respiratory support may lead to increase in fatigue ,shallow breathing , reduced consciousness and cyanosis .

CLINICAL PRESENTATION

- Depends on the underlying cause and the level of hypercapnia and hypoxemia.
- Infants and children most commonly present with increased work of breathing

  -Tachypnea -grunting -nasal flaring -retractions

- these signs of increased work of breathing **are blunted in those with neuromuscular disorders**. These patients **instead present with tachypnea and shallow breathing without retractions**
- Additional signs and symptoms due to hypercapnia and hypoxemia
- Impending respiratory failure :

  -dyspnea -Mood changes -Disorientation -pallor -fatigue
- Acute hypercapnia :

  -Flushing -agitation -restlessness - headache - tachycardia
- Chronic hypercapnia presenting with worsening of hypoxemia and hypercapnia
- Sever CO2 retention :

  -decreased consciousness -coma -depressed deep tendon reflexes
- Chronic hypoxemia complications:

-cyanosis -polycythemia -core pulmonale -pulmonary hypertension

TABLE 2. Signs and Symptoms of Hypoxia and Hypercapnia

HYPOXIA	HYPERCAPNIA[a]
Mild	Mild
• None or depressed efficiency	• Flushed skin • Headaches
Moderate	Moderate
• Dyspnea	• Tachypnea
• Headaches, dizziness	• Tachycardia
• Fatigue	• Dyspnea
• Pallor	• Muscle twitches, depressed tendon reflexes
• Tachycardia, cardiac arrhythmias	• Drowsiness, confusion
• Hypertension • Mood changes: euphoria, disorientation, or depression • Ataxia, tingling	• Hypertension
Severe	Severe
• Cyanosis	• Papilledema
• Hypotension • Bradycardia • Visual impairment • Loss of consciousness, seizures, coma	• Coma

Hypoxia and hypercapnia

History and Physical Examination

History

1. Determine the need for emergency interventions

-Vital signs -level of consciousness -work of breathing

- respiratory support is needed when :

✔ Tachycardia

✔ Grunting

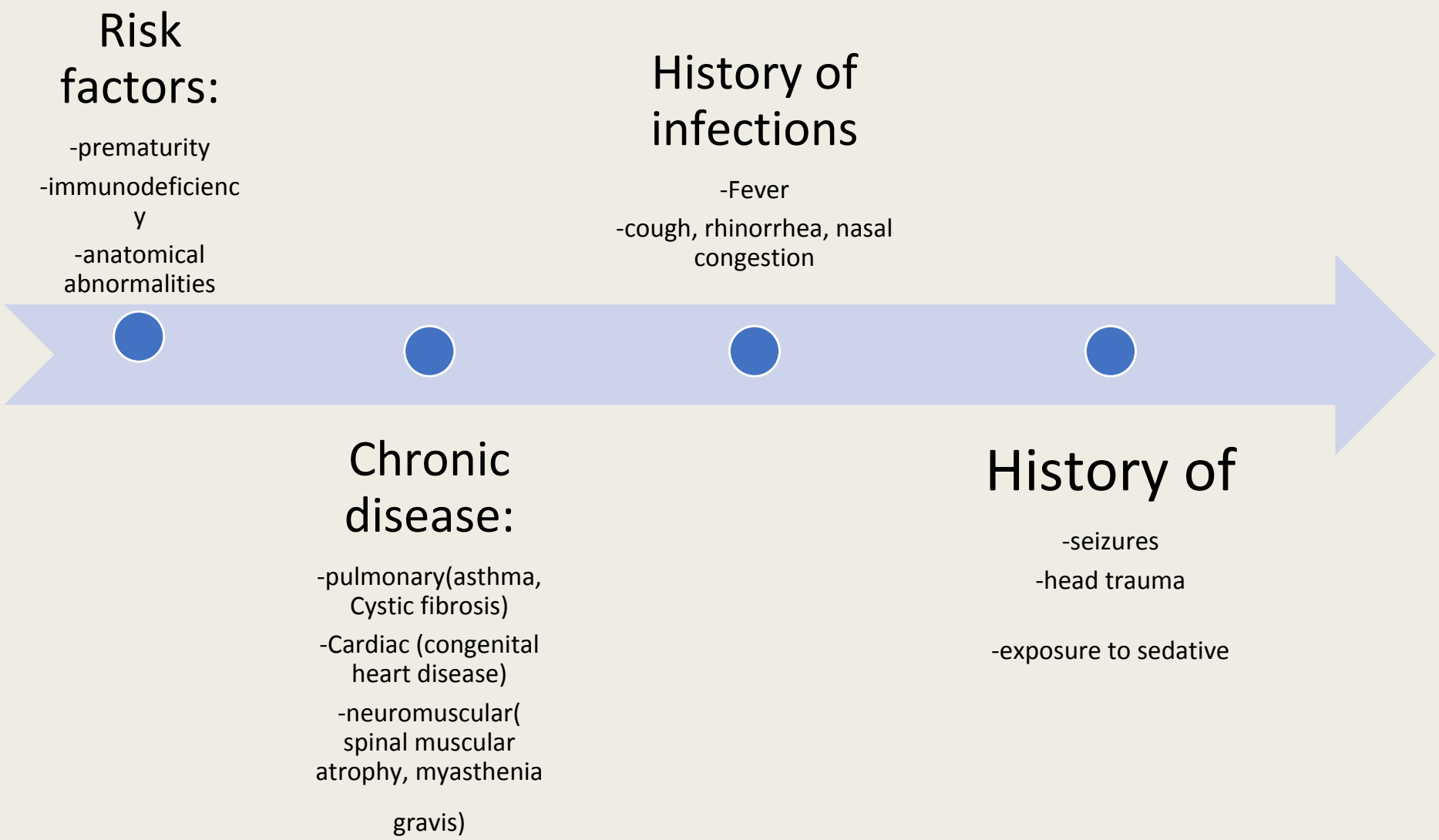
✔ Retractions

✔ Nasal flaring

Delay in support may lead to patient becoming increasingly fatigued : shallow, rapid breathing with decreased level of consciousness and cyanosis

2. The next step is comprehensive history to evaluate the likely causes of respiratory failure

ask about:



Physical examination

- *Vital signs* (severity of respiratory failure)

1.Respiratory Rate:

tachypnea:

- Early compensatory mechanism
- Must know Normal range for age
- Normally increased while eating, sleeping, increased activity

Bradypnea :

- Respiratory center Failure
- Neuromuscular Disorders (no retractions)

2.Heart Rate : increased to maintain adequate oxygen delivery

3.Blood pressure : normal to high (decreased if decompensated)

Normal Vital sign Ranges according to age

Heart Rate (rate/min)		
Age	**Awake Rate**	**Sleeping Rate**
Newborn to 3 months	85 to 205	80 to 160
3 months to 2 years	100 to 190	75 to 160
2 to 10 years	60 to 140	60 to 90
>10 years	60 to 100	50 to 90

Respiratory Rate (breaths/min)	
Age	**Rate**
Infant	30 to 60
Toddler	24 to 40
Preschooler	22 to 34
School-age child	18 to 30
Adolescent	12 to 16

Definition of Hypotension by Systolic Blood Pressure and Age	
Age	**Systolic Blood Pressure**
Term neonates (0 to 28 days)	<60 mm Hg
Infants (1 to 12 months)	<70 mm Hg
Children 1 to 10 years (5th BP percentile)	<70 mm Hg + (age in years x 2) mm Hg
Children >10 years	<90 mm Hg

4.Pulse Oximetry :

-estimates oxygen saturation of hemoglobin

- Oxygen saturation of 90% reflects PaO2 of 60%
- Only measures Saturation (not content nor delivery)
- In patients with CO poisoning saturation will be overestimated due carboxyhemoglobulinemia
- When increased methemoglobin saturation will be overestimated
- Patients with poor tissue perfusion (shock, hypovolemia, hypothermia) saturation will be underestimated

❑ *chest wall examination*:

asymmetric expansion:

- Pneumothorax
- Moderate to sever empyema
- Pleural effusion
- Chest trauma

Paradoxical Movement : Respiratory distress

❑ *Auscultation* : to assess the symmetry and quality of air movement and presence of any added sounds

- expiratory wheezing: disease of lower airway (Asthma)
- Local or asymmetric wheezing: airway obstruction (mass or foreign body)
- Inspiratory stridor: upper airway narrowing or obstruction(laryngomalacia, croup, tracheitis, subglottic stenosis, vascular rings)
- Crackles or rales: small airway disease (pneumonia, pulmonary fibrosis, Interstitial pulmonary process)

❑ *Cardiac Examination*

❑ *Neurological Examination*:

GCS :8 or below needs intubation and mechanical ventilation

Muscle strength decreased in:

- Mitochondrial disease
- GBS
- Spinal muscular atrophy
- Duchene muscular dystrophy

- Laboratory and radiographic studies are helpful in the assessment of respiratory failure and the monitoring of the response to therapeutic management.
- However, emergency respiratory support should be initiated when indicated and not be delayed while awaiting results of diagnostic studies.

Laboratory studies

- Arterial blood gas
- End tidal carbon dioxide
- Oxygen saturation
- Complete blood cell count with differential
- Renal and liver function Tests

❑ ABG

- The arterial blood gas accurately measures the extent of the gas exchange abnormality and confirms the type and chronicity of respiratory failure.
- Normal arterial blood gas values are as follows:

✔ pH 7.4 (reference range, 7.38–7.42)

✔ PO2, 80to 100mmHg

✔ PCO2, 35 to 45 mm Hg

✔ oxygen saturation, 95% on room air

✔ bicarbonate, 22 to 26mEq/L; and base excess,2 toþ2mEq/L.

- In acute respiratory failure, PaO_2 is less than 60 mm Hg, pH is below 7.35, $PaCO_2$ is greater than 50 mm Hg, and serum bicarbonate concentration is low or normal.
- In chronic carbon dioxide retention, carbon dioxide is increased, pH is normal, and serum bicarbonate concentration and base excess are increased.

- The arterial blood gas of the patient with an opiate overdose differs based on the severity of the overdose:

 In *mild to moderate* opiate overdose, respiratory acidosis is observed with a pH below 7.35, $PaCO_2$ greater than 50 mm Hg, and a low or normal serum bicarbonate concentration.

 In *severe* opiate overdose, a mixed respiratory and metabolic acidosis is observed.

TABLE 3. Interpretation of Blood Gas Results[a]

CONDITION	pH	$Paco_2$	BASE EXCESS
Acute respiratory acidosis or acute hypoventilation	↓	↑	↔
Acute respiratory alkalosis or acute hyperventilation	↑	↓	↔
Acute or chronic respiratory acidosis	↓	–/↑	↑
Acute metabolic acidosis with respiratory compensation	↓	↓	↓
Chronic respiratory acidosis with metabolic compensation	Normal/slightly ↓	↑	↑

↓=*decrease;* ↑=*increase;* ↔=*no change.*

❑ End-tidal carbon dioxide

is measured from expired air from the nose by a capnometer and is a common and reliable tool used in the emergency department and critical care setting.

- The complete blood cell count helps to assess such causes as infection, anemia, or polycythemia.

- In addition, respiratory, blood, urine, and pleural cultures and polymerase chain reaction can be performed when indicated to identify the specific bacterial cause.

- Renal and liver function tests provide clues to the cause of or identify complications associated with respiratory failure

- Electrolyte abnormalities, such as hypernatremia or hyponatremia, cause seizures, and hyperkalemia causes cardiac arrhythmia

Radiography

- Chest radiography should be performed in patients who present with respiratory failure to help identify or confirm the **cause** of the respiratory failure.

- **ARDS:**

Bilateral airspace infiltrate

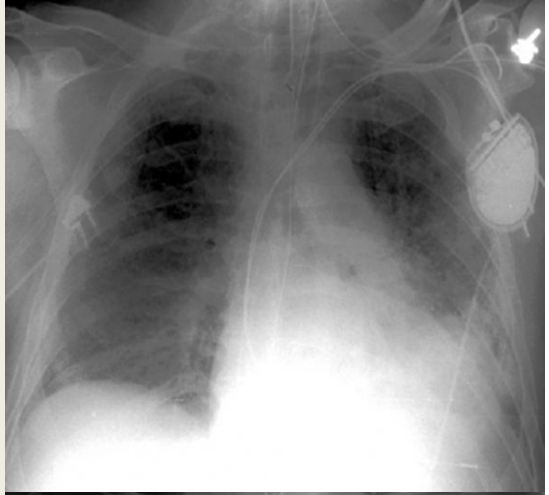
- **Pneumonia:**

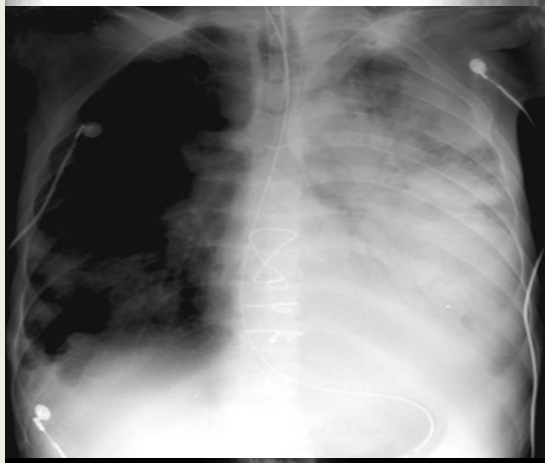
Extensive left lung pneumonia caused respiratory failure (Hypoxia is due to intrapulmonary shunting)

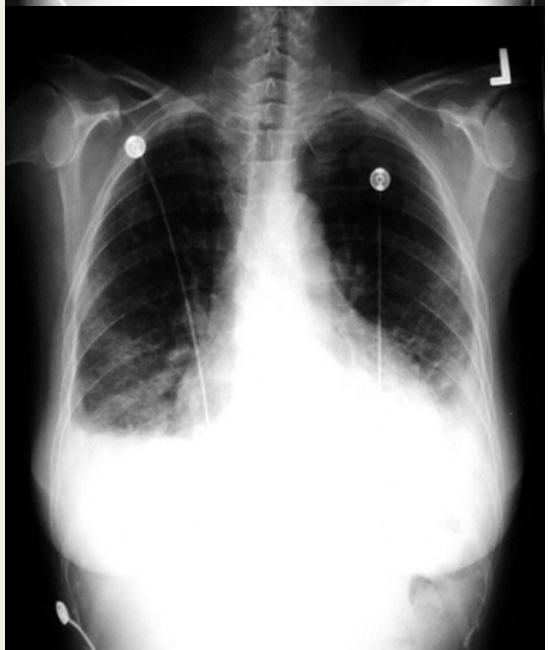
- **SLE:**

Diffuse alveolar damage characteristic lesion of acute lupus pneumonitis.

- If a **cardiac cause** of acute respiratory failure is suspected, electrocardiography and echocardiography should be performed







Pulmonary function testing

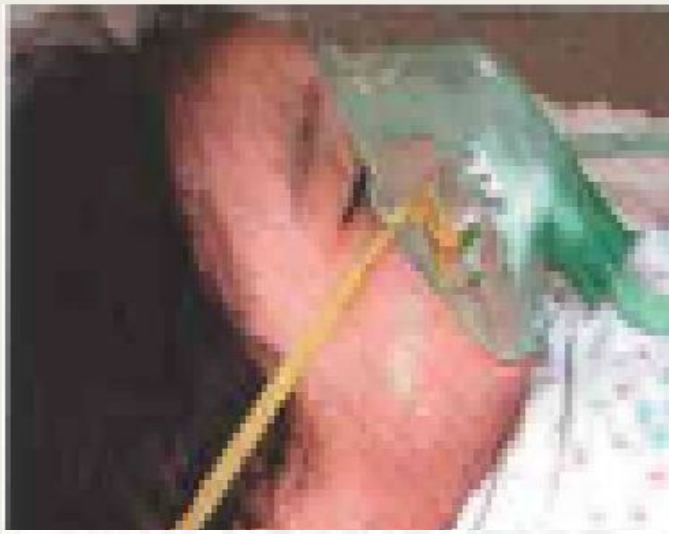
- Pulmonary function testing evaluates the functional status of the respiratory system by measuring the volume and flow of air movement, gas exchange, and strength of the respiratory muscles. Pulmonary function testing includes a group of tests, such as spirometry, lung volumes, diffusion capacity, and maximal respiratory pressures, among others. It helps to determine the characteristics of the respiratory disease and to guide management

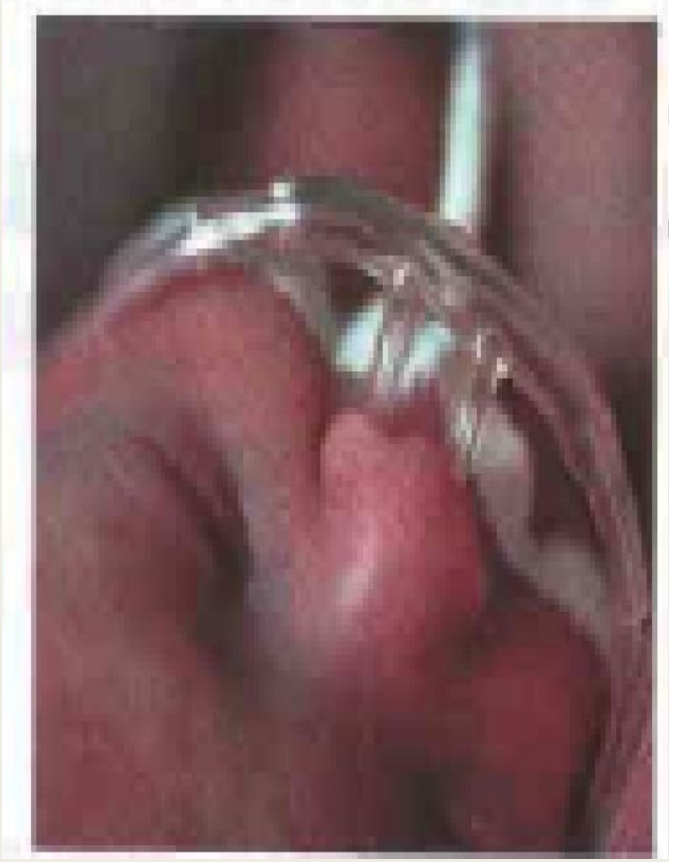
- Pulmonary function testing is not typically performed when the patient is critically ill.

Bronchoscopy

- Flexible bronchoscopy can also be performed to aid in diagnosis and therapeutic management
- Biopsies and bronchoalveolar lavage for microbiologic, cytologic, and histologic testing can be obtained with bronchoscopy.
- When a patient is critically ill, it may not be safe to perform the bronchoscopy because manipulation of the airway may induce bronchospasm or atelectasis

MANAGEMENT OF RESPIRATORY FAILURE





MANAGEMENT

- Early diagnosis, close monitoring , and timely intervention are of utmost importance in a patient presenting with respiratory distress.
- The primary cause of cardiopulmonary arrest in children is unrecognized respiratory failure.
- Interventions in a patient with respiratory failure range from close monitoring and supplemental oxygen to full respiratory support with mechanical ventilation.
- The initial step in the treatment of a patient with respiratory failure is rapid assessment of airway, breathing, and circulation to determine whether the patient needs urgent intervention.

Introduction :

- The administration of oxygen to children requires the selection of an oxygen delivery system that suits the child's age, size, needs, clinical condition, and therapeutic goals.

- Oxygen delivery systems are categorized as low-flow (variable performance) systems or high-flow (fixed performance) systems.

- **low-flow systems** : 100% oxygen mixes with room air during inspiration, and room air is entrained, making the percentage of delivered oxygen variable.

- **High-flow devices :** provide such a high flow of premixed gas that the child is not required to inhale room air.

- Supplemental oxygen therapy is often recommended for children when peripheral oxygen saturation is consistently below 94%.

- A nasal cannula, oxygen mask (e.g., simple face mask, partial rebreathing mask with reservoir, a nonrebreathing mask with reservoir, Venturi mask), face tent, and oxygen hood deliver supplemental oxygen to children to treat hypoxia, respiratory distress, and respiratory failure.

- Because oxygen can dry the respiratory system, many oxygen delivery systems allow for humidification.

cont. introduction

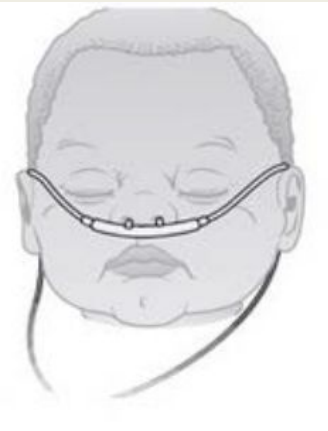
Once patients are evaluated and emergency intervention with intubation and mechanical ventilation is not indicated, **mild** cases of respiratory failure may require only close monitoring and supplemental oxygen as needed by lowor high-flow nasal canula or a nonrebreather mask.

NOTE :
Respiratory drive in patients with chronic respiratory failure is stimulated primarily by hypoxia. Improving oxygenation in these patients can lead to blunting of the hypoxic drive of the respiratory center, resulting in decreased alveolar ventilation and increased carbon dioxide retention and leading to acute respiratory failure on top of chronic respiratory failure.

1- Low-Flow Nasal Cannula

Low-flow nasal cannula remains one of the most common and widely used oxygen delivery devices

Definition : low-flow oxygen device that ends in two short tapered tubes (about 1 cm in length) that distributes oxygen concentrations of 24% to 44% .designed to lie just within the nostrils . They are also called nasal prongs.



Standard flow rates through nasal prongs are :

0.5–1 L/min for neonates

1–2 L/min for infants

1–4 L/min for older children.

There is no risk of gastric distension at standard flow rates, as they cannot be inserted too far into the nasal passage.

Humidification is not required with standard oxygen flow rates, as the natural nasal mechanisms heat and humidify the inspired oxygen

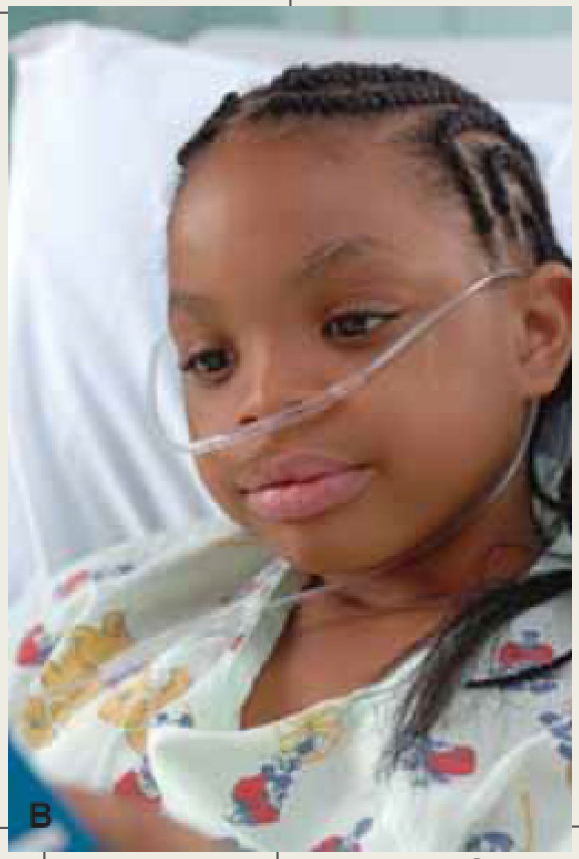
Indications

-Low to moderate oxygen requirement
-No or mild respiratory distress
-Long term oxygen therapy

Advantages

-Less expensive
-Comfortable, well tolerated (For infants and toddlers who may poorly tolerate a mask)
-Able to talk and eat

nasal cannula



Contraindications

- Poor efforts, apnea
- severe hypoxia
- Mouth breathing

Disadvantages

-Doesn't deliver high FiO2
-Irritation and nasal obstruction
-Less FiO2 in nasal obstruction
-FiO2 varies with breathing efforts

nasal cannula	Most patients tolerate this device well, and it is simpler to use than a mask. The fraction of inspired oxygen (FiO_2) varies depending on the flow of oxygen in L/min and the rate and depth of the patient's breathing.	FiO_2: 24% to 38% - Flow: 1 to 2 L FiO_2: 30% to 35% - Flow: 3 to 4 L FiO_2: 38% to 44% - Flow: 5 to 6 L

2- Simple Oxygen Face Mask

- **Definition** : is a low-flow oxygen device . plastic oxygen mask that covers the nose and mouth .
- A simple face mask can deliver 35% to 60% oxygen with an appropriate flow rate of 6 to 10 L/minute.
- A minimum of 6 L/minute of oxygen flow is needed to prevent rebreathing of exhaled carbon dioxide .
- The mask has exhalation ports to allow carbon dioxide to escape as well as mixing delivered oxygen with room air.

simple face mask	This device requires a fairly high oxygen flow to prevent rebreathing of carbon dioxide. About 75% of the inspired volume is room air that the patient breathes through the holes in the side of the mask. An accurate FiO_2 is difficult to estimate.	FiO_2: 35% to 65% - Flow: 8 to 12 L 

Face Mask

Indications:

Medium flow oxygen desired, mild to moderate respiratory distress

• When increased oxygen delivery for short period

Advantage:

-Less expensive

-Can be used in mouth breathers

Disadvantage

- Uncomfortable
- Require tight seal
- Do not deliver high FiO2
- FiO2 varies with breathing efforts
- Interfere with eating, drinking, communication
- Difficult to keep in position for long time
- Skin breakdown

Contraindications:

Poor respiratory efforts, apnea , severe hypoxia

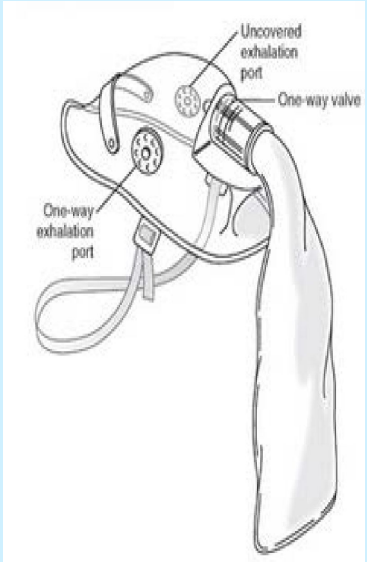
3-Partial rebreathing mask with a reservoir bag

- A *partial rebreathing mask with a reservoir bag* is a face mask that delivers moderate to high concentrations of oxygen.
-the mask have 2 open exhalation ports and contain a valveless oxygen reservoir bag .
- Some exhaled gas can mix with reservoir gas, although most exhaled gas exits the mask via the exhalation ports .
-Through these same ports, room air is entrained, and the partial rebreather mask can provide FIO 2 up to 0.60, for as long as oxygen flow is adequate to keep the bag from collapsing (typically 10-15 L/ min). As with nasal cannulas, smaller children with smaller tidal volumes entrain less room air, and their Fio2 values will be higher.
- Frequent inspection of the reservoir bag is required to ensure that it remains inflated; if it is deflated, exhaled air collects in it, which results in the child rebreathing large amounts of exhaled carbon dioxide.
- The delivered oxygen percentage varies, depending on the rate and depth of the child's breathing.

4- Non re-breather mask

- A *nonrebreathing mask with reservoir* is a high-flow oxygen delivery device used for children requiring a higher concentration of oxygen.
- A nonrebreathing mask can deliver a concentration of up to 95%-100% oxygen with an oxygen flow rate of 10 to 15 L/minute.

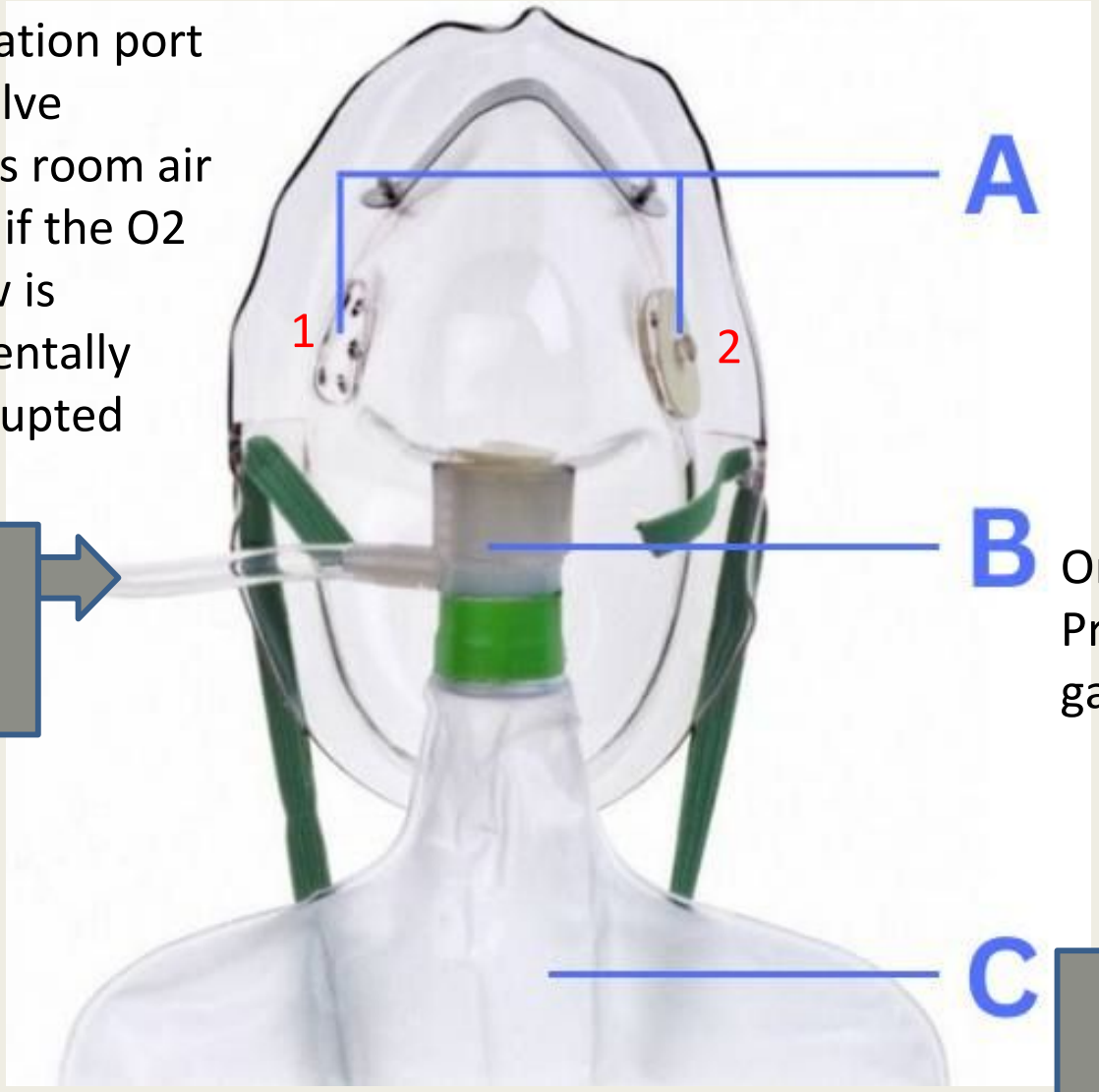
nonrebreather face mask



The reservoir bag allows a higher FiO_2 to be administered. At flow rates slower than 6 L/min, the risk of rebreathing carbon dioxide increases. A valve closes during expiration so that exhaled air does not enter the reservoir bag and is not rebreathed. The valves on the side ports of the mask allow exhalation but close on inspiration to prevent inhalation of room air.

FiO_2: 60% to 100% - Flow: 6 to 15 L

Exhalation port
No valve
Allows room air entry if the O2 inflow is accidentally interrupted



Exhalation port
One-way valve
Prevents room air entry

Oxygen feeding line

One –way valve
Prevents flow of exhaled gas into the reservoir

Oxygen reservoir bag

- **Non-rebreather masks**.. include 2 one-way valves, 1 between the oxygen reservoir bag and the mask and the other on 1 of the 2 exhalation ports This arrangement minimizes mixing of exhaled and fresh gas and entrainment of room air during inspiration
- The 2nd exhalation port has no valve, a safeguard to allow some room air to enter the mask in the event of disconnection from the oxygen source. A non-rebreather mask can provide FIO 2 up to 0.95. The use of a non-rebreather mask in conjunction with an oxygen blender allows delivery of FIO 2 between 0.50 and 0.95 (Table 89.8). When supplemental oxygen alone is inadequate to improve oxygenation, or when ventilation problems coexist, additional therapies may be necessary.

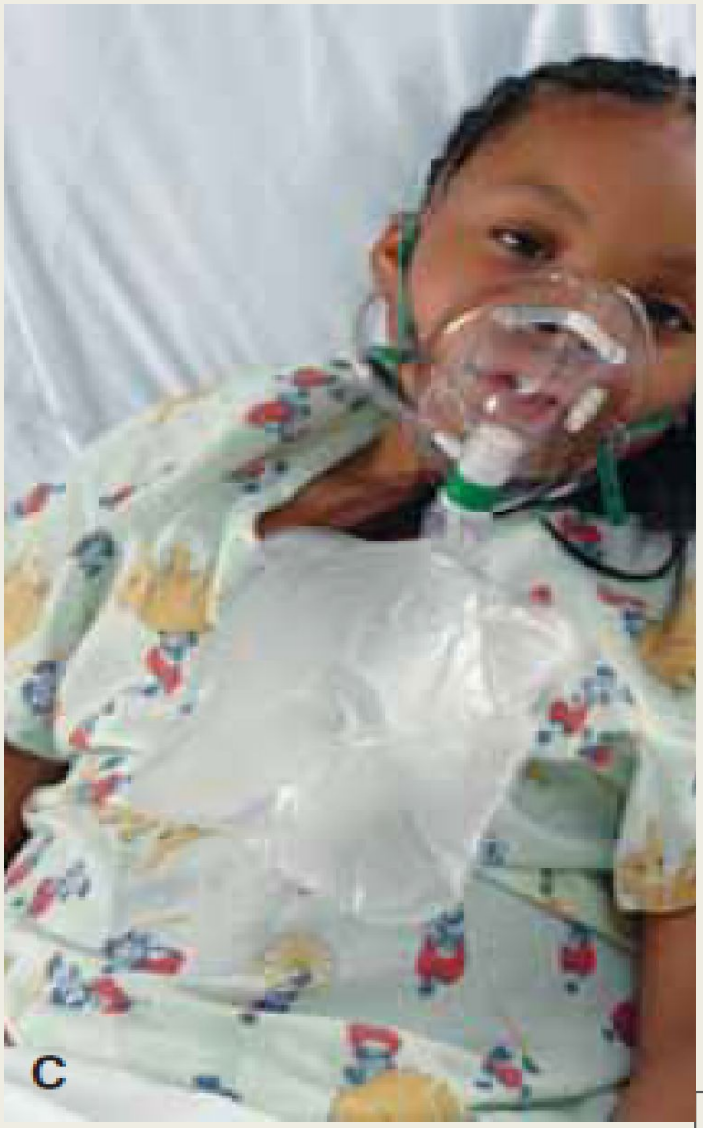
Indications:

-High FiO2 requirement >40%

Advantage:

-Highest possible FiO2 without intubation
-Suitable for spontaneously breathing patients with severe hypoxia

Non re-breather mask



Disadvantage

-Expensive
-Require tight seal, Uncomfortable
-Interfere with eating and drinking
-Not suitable for long term use
-Malfunction can cause CO2 buildup, suffocation

Contraindications

Poor respiratory efforts, apnea, severe hypoxia

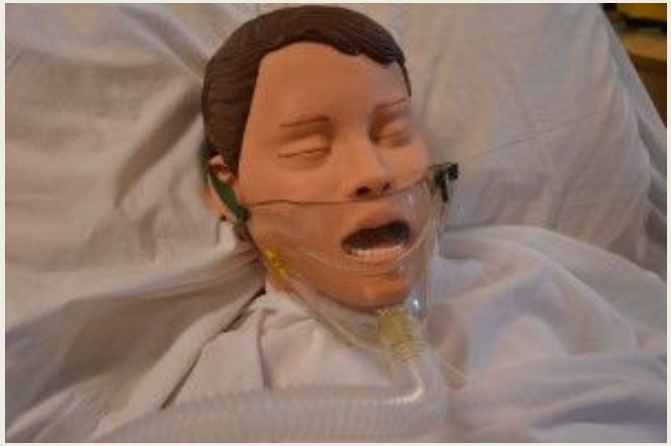
5- Oxygen tent

-Oxygen tents and hoods can provide **high concentrations of humidified oxygen**, which is useful in a child with airway inflammation, epiglottitis (croup), or other respiratory tract infections.

-Clear plastic sheet that cover child's upper body
-FiO2 50%
-Not reliable
-Limit access to patient
-Not useful in emergency situations

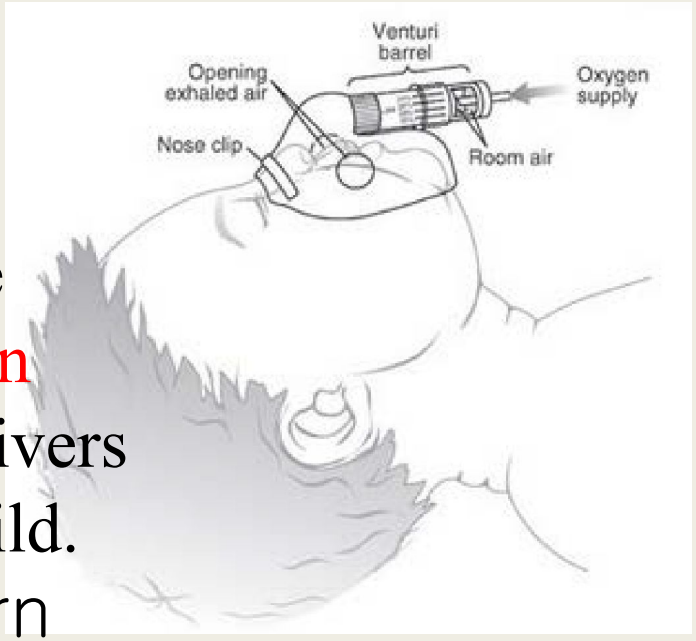
6- Face tent/face shield

High flow soft plastic bucket
Well tolerated by children than face mask
Flow: 10-15 L/min, 40% FiO2
Access for suctioning without need for interrupting oxygen



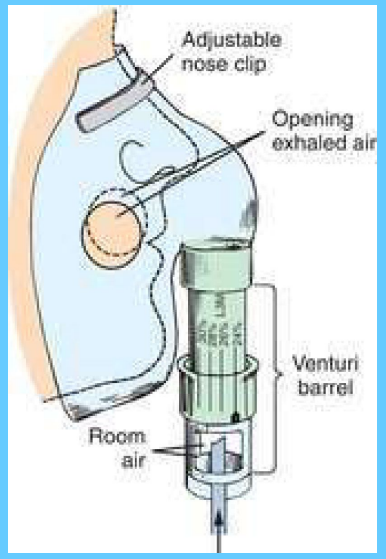
face tent	This soft aerosol mask fits loosely around the patient's face and neck. It is an alternative to an aerosol mask for patients who feel claustrophobic, but it is sometimes difficult to keep in place. It is convenient for providing humidification and oxygenation; however, oxygen concentration	FiO_2: 28% to 100% Flow: 8 to 12 L

7- Venturi Mask:



A *Venturi mask* is a cone-shaped device with entrainment ports of various sizes at its base. The entrainment ports adjust to deliver various oxygen concentrations. The mask is useful because it delivers a more precise concentration of oxygen to the child.

•Often used when a clinician has a concern about CO2 retention

Venturi mask	This device uses different size adaptors to deliver a fixed or predicted FiO_2. The FiO_2 delivered depends on the flow rate and/or entrainment port size. It is used for patients who have COPD when an accurate FiO_2 is essential and carbon dioxide buildup must be kept to a minimum. Humidifiers usually are not used with this device.	FiO_2: 60% to 100% 

Venturi Mask:

indications:

Desire to deliver exact amount of FiO2

Advantage:

-Fine control of FiO2 at fixed flow
-Fixed, reliable, and precise FiO2
-Doesn't dry mucus membranes
-High flow comes from the air, saving the oxygen cost
-Can be used for low FiO2
-Helps in deciding whether the oxygen requirement is increasing or decreasing

Disadvantage

-Uncomfortable
-Expensive
- Cannot deliver high FiO2
-Interfere with eating and drinking

Contraindications

Poor respiratory efforts, apnea, severe
hypoxia

Venticaire®


Integrated Plastic Nose Bridge
Latex Free Strap
22mm Male Swivel Connector
Stepped Mask Construction
Soft Feathered Edges
Available with Nose Clip
Blank Venturi
24% 2 litres/minute
28% 4 litres/minute
31% 6 litres/minute
35% 8 litres/minute
40% 10 litres/minute
60% 15 litres/minute

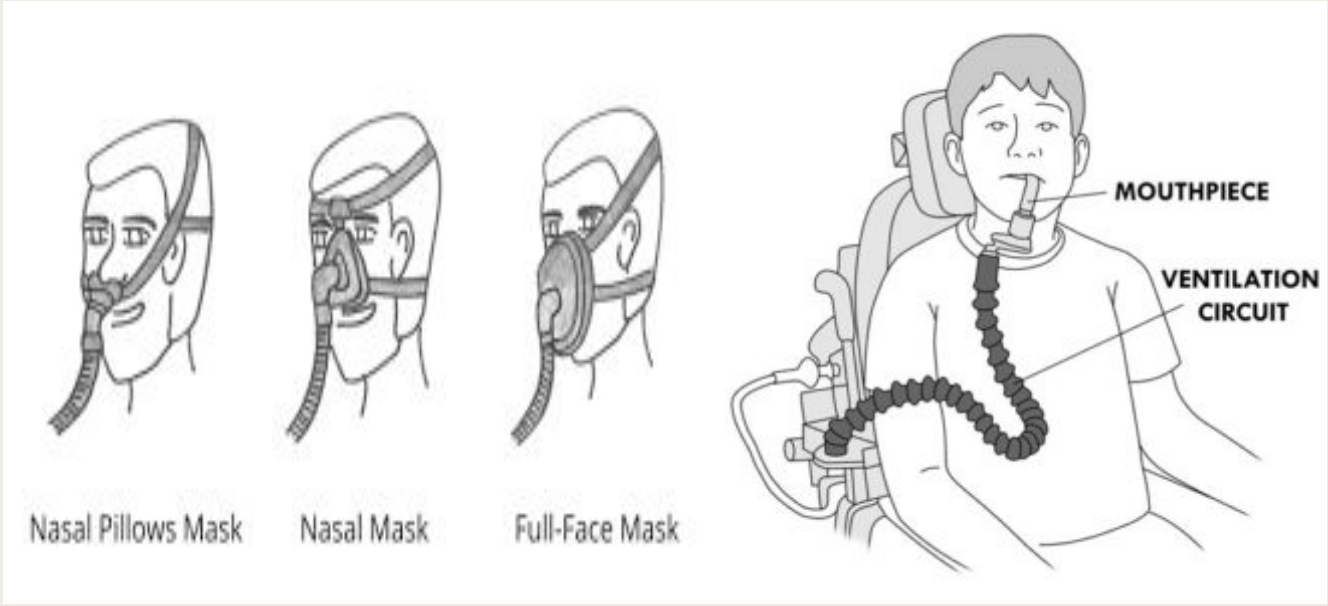
Non-Invasive Ventilation in (NIV)

Definition:

- Mechanical respiratory support without endotracheal intubation
- Positive airway pressure (PAP) delivered through an interface.

Interfaces:

› Nasal pillows
› Nasal mask
› Full face mask
› HFNC
› Mouth piece (daytime)



- Usually refers to Continuous (CPAP) or BiLevel (BPAP)

NIV -Benefits

General benefits of mechanical ventilation

- Relieves some work of breathing by providing some pressure support
- Stent airway open throughout the respiratory system
- Recruitment and improved oxygenation

General risks of invasive ventilation

- No sedation or paralysis needed
- Intact natural airway clearance mechanisms (no plugging of ETT, …)
- No mechanical trauma related to ETT placement

Continuous Positive Airway Pressure (CPAP)

- primarily indicated for use in treating respiratory distress.
- CPAP was adapted for infants in the 1970's as an alternative to the more invasive mechanical ventilation.
- Its primary function is to establish an open airway.
- The circuit is structured such that a continuous flow of humidified oxygen in combination with other compressed gases is delivered.
- CPAP applies continuous positive distending pressure to the airways.
- CPAP is used during spontaneous breathing to prevent the need for mechanical ventilation.

.

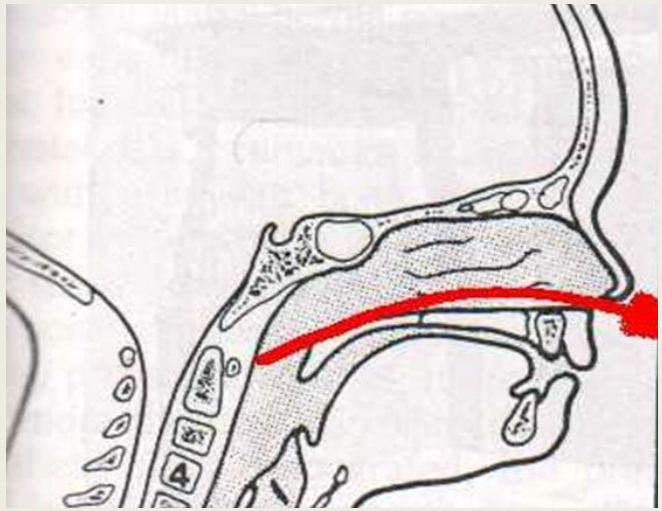
- CPAP does not have the same risk of barotrauma as does mechanical ventilation.
- Also, if nasal prongs are used instead of an endotracheal tube, the chance of infection decreases. Less invasive equals less danger to the patient. Endotracheal tubes often create a ridge in the soft palate of the neonate when the need for mechanical ventilation is lengthy.

Typically, CPAP settings would begin with expiratory positive airway pressure of 4 to 6 cm H_2O. This pressure is delivered to the patient continuously through the respiratory cycle on inspiration and expiration

Continuous positive pressure ventilation (CPAP) provides a set positive airway pressure throughout the patient's breathing cycle. It is commonly used for patients who experience sleep apnea **because the continuous positive pressure keeps the airway open and prevents the upper airway from collapsing**. The usual CPAP pressure is between 5 and 20 cm of water.

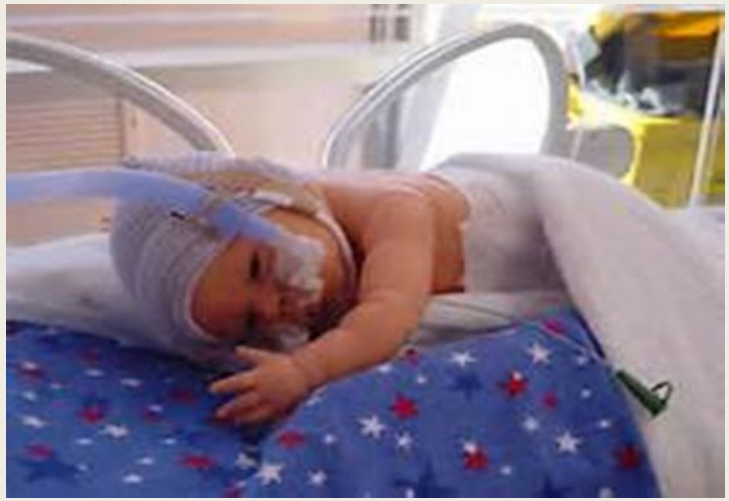
Methods for Delivering CPAP

- CPAP is accomplished by a variety of methods. In one of these, nasopharyngeal prongs that span from the nares to the nasopharynx are used.
- Due to their long length, the airway resistance is higher when compared to other methods. Additionally, they are difficult to insert.
- The most popular methods utilizes either nasal prongs or a mask.



- Endotracheal Tube
  - Patent airway, airway clearance
  - Disadvantage: plugging, malacia, infection

- Nasal Prongs
  - Decrease infection, no malacia
  - Disadvantage = plugging, pressure necrosis, gastric distention
- Nasopharyngeal prongs
  - Pressure necrosis, infection
- Face Mask
  - **Temporary measure prior to intubation or for apnea episode**



Bilevel positive airway pressure (BPAP)

-provides inspiratory pressure (IPAP) and expiratory pressure (EPAP).

-IPAP is triggered when the patient "pulls negative pressure" (begins inspiration) and provides a set amount of pressure. A standard setting in pediatrics is 10 to 20cmH20. (higher pressure for inhalation (IPAP))

- EPAP is equivalent to CPAP in providing a constant set pressure stenting the airway open. (lower pressure for exhalation (EPAP)).

Bilevel PAP adjust setting

- it is best to start at low pressures and gradually increase the inspiratory pressure (usually to 8 to 14 cm of water) and the end-expiratory pressure (usually to 4 to 6 cm of water).

Bilevel positive airway pressure (BiPAP) provides assistance during inspiration and keeps the airway from closing during expiration. **The benefits of BiPAP include an increase in the amount of air in the lungs at the end of expiration, reduced airway closure, and improved oxygenation**

high-flow nasal cannula (HFNC)

- Noninvasive positive pressure respiratory support is useful in treating both hypoxemic and hypoventilatory respiratory failure

Positive airway pressure helps with aeration of partially atelectatic or filled alveoli, prevention of alveolar collapse at end-exhalation, and increase in functional residual capacity (FRC).

-These actions improve pulmonary compliance and hypoxemia, as well as decrease intrapulmonary shunt

-In addition, positive pressure ventilation is useful in preventing collapse of extrathoracic airways by maintaining positive airway pressure during inspiration. Improving compliance and overcoming airway resistance also improves tidal volume and therefore ventilation

-A highflow nasal cannula delivers gas flow at 4-16 L/min and up to 60 L/min **(1-2 Liter/kg/min.)** and it gives 100% oxygen concentration , with newer systems for older children and adolescents, capable of providing significant continuous positive airway pressure (CPAP)

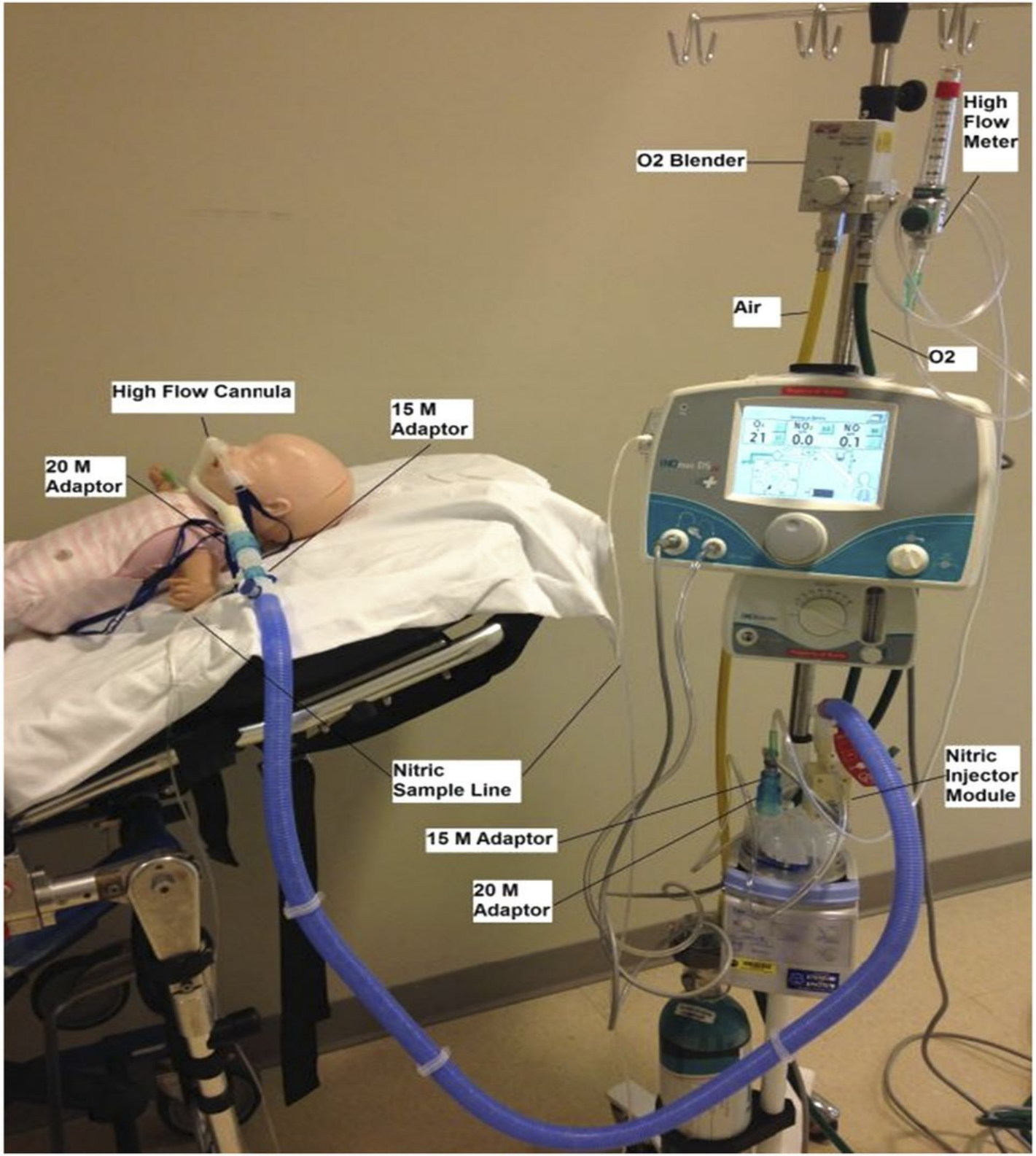
HFNC

- Often used to avoid intubation
- Air is heated & humidified
- High flows are tolerated
- Maximum flow is determined by size of cannula
- Size of cannula is determined by patient size
- Flow > 6 L/min may generate PEEP (positive end expiratory pressure) = 2-5 cm H2O
- For children < 2 yrs, Flow is usually < 8 L
- For older children and adults –flow can go up to 60 L

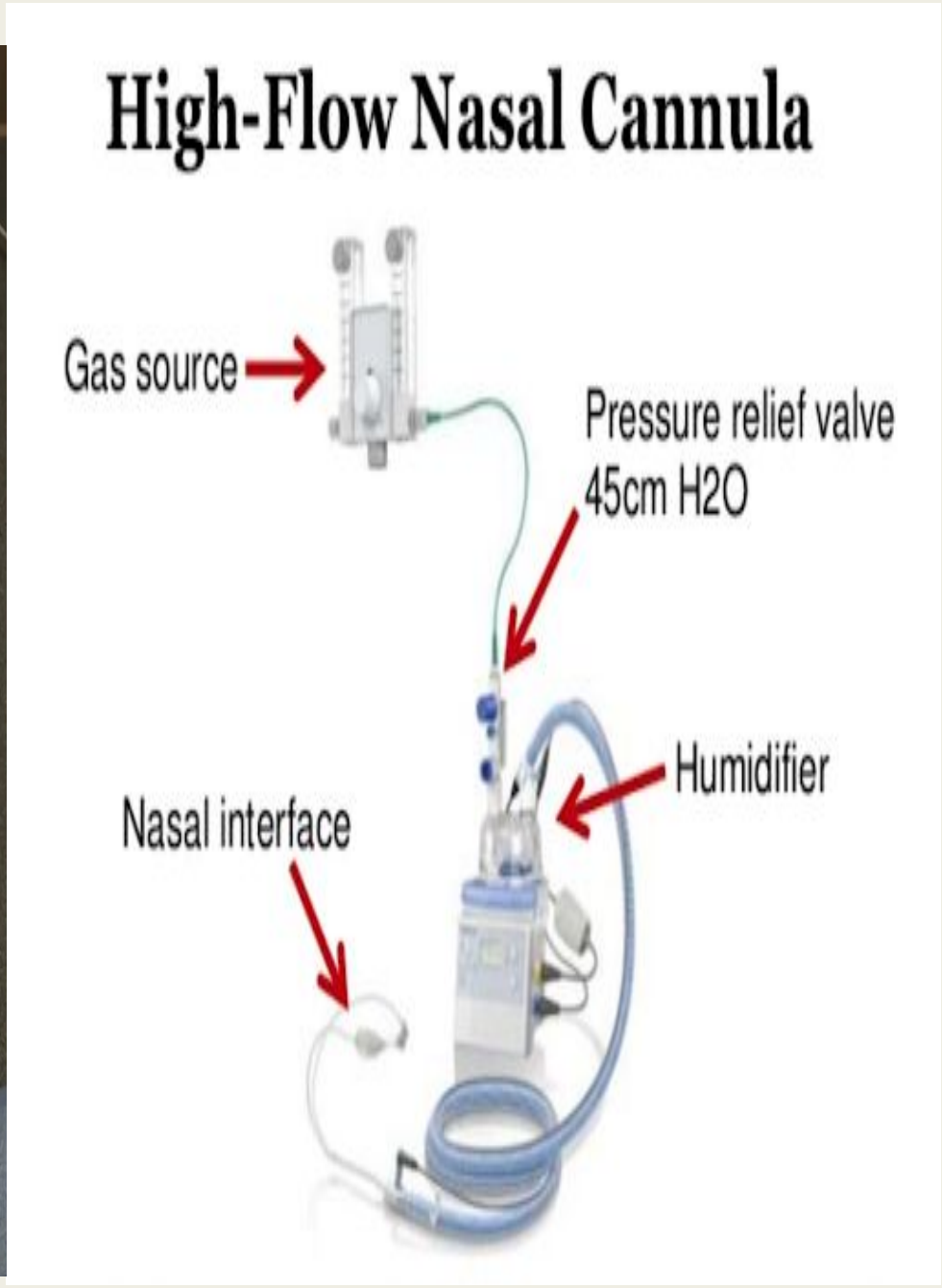
However HFNC cannot be escaped in any peds environment …why ??

- Ease of availability
- Non invasive nature
- Possibility of use in various settings (ER, step down, PICU, transport,…)
- Ease of titration (or perceived ease at least)
- Titrated clinically (often synonymous with subjectively)
- Respiratory rate

Note: HFNC Often used in an attempt to prevent invasive ventilation

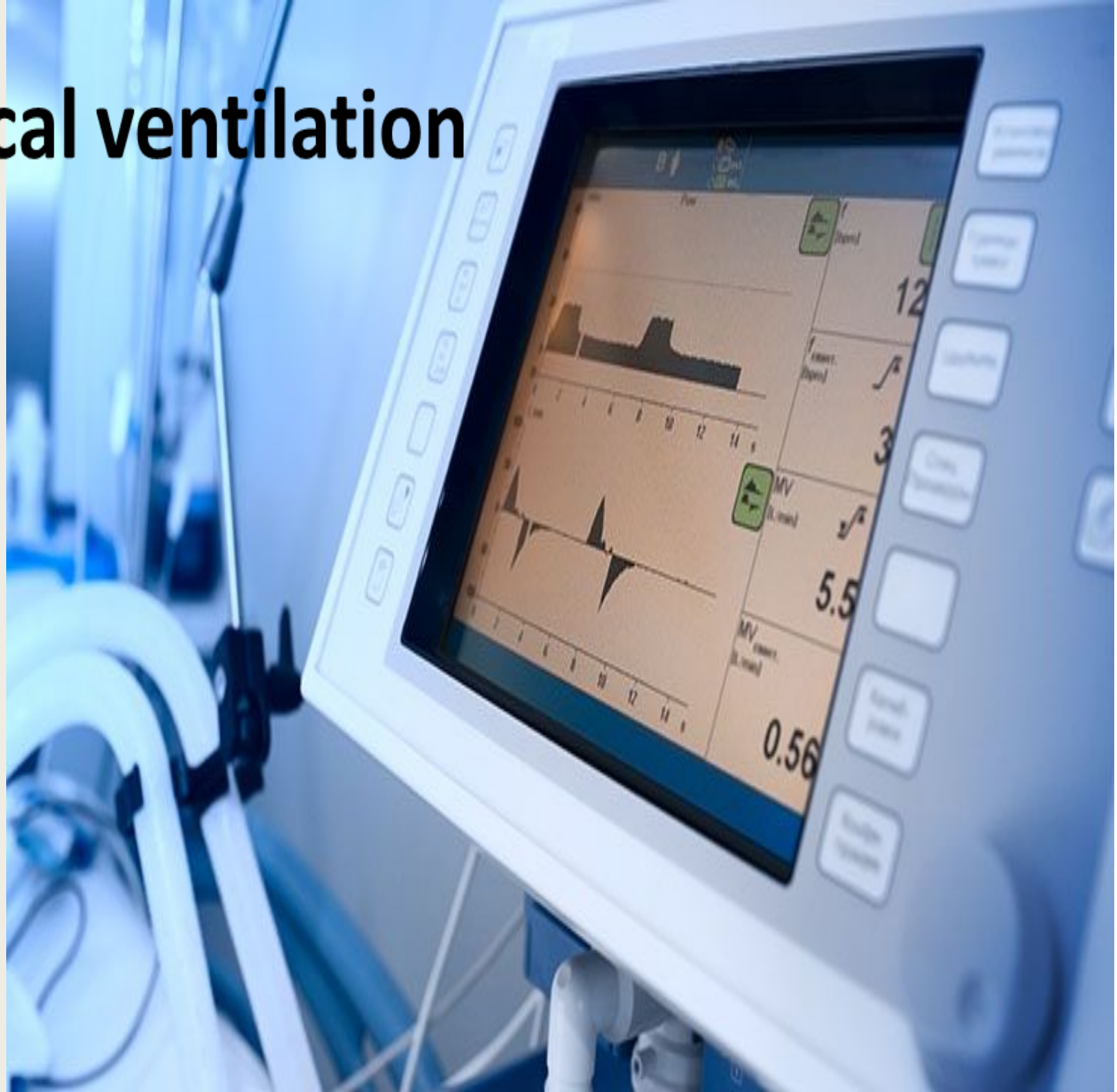

High Flow Meter
O2 Blender
Air
O2
High Flow Cannula
15 M Adaptor
20 M Adaptor
Nitric Sample Line
Nitric Injector Module
15 M Adaptor
20 M Adaptor


HD
EMRAP


High-Flow Nasal Cannula
Gas source
Pressure relief valve
45cm H2O
Humidifier
Nasal interface

Mechanical ventilation

Positive pressure ventilation or mechanical ventilation is most commonly used to manage acute respiratory failure.



1. Introduction:

Mechanical ventilation ： refers to the use of life-support technology to perform the work of breathing for patients who are unable to do this on their own.

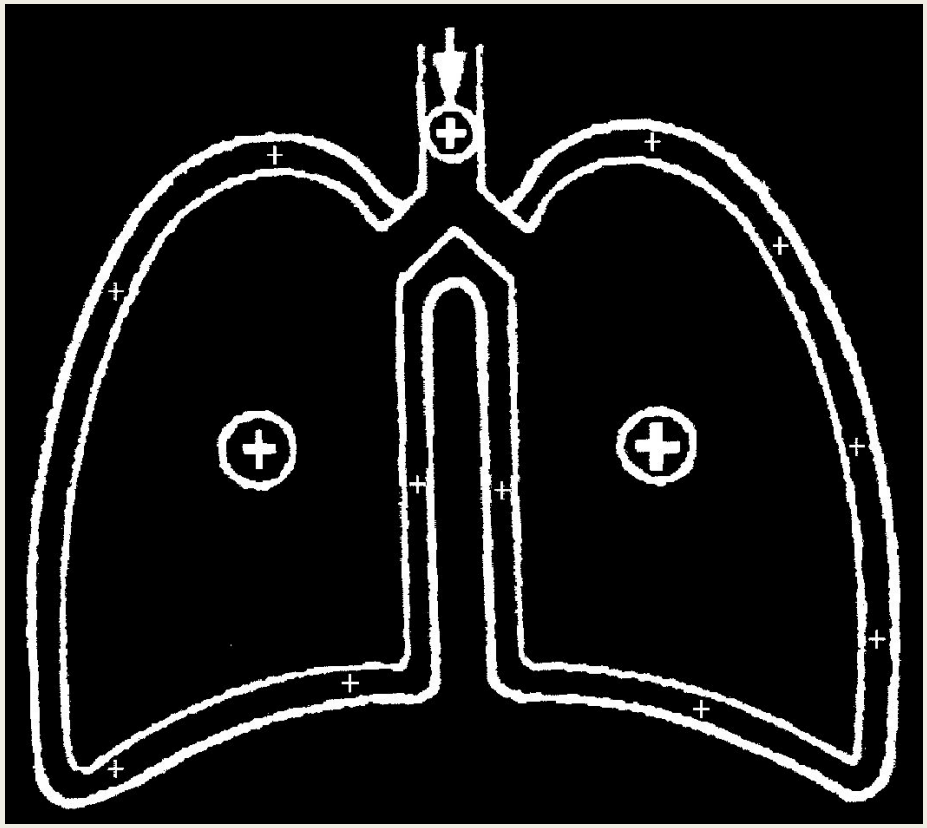
2. Aim:

The overall goals of mechanical ventilation are to optimize gas exchange, patient work of breathing, and patient comfort while minimizing ventilator-induced lung injury.

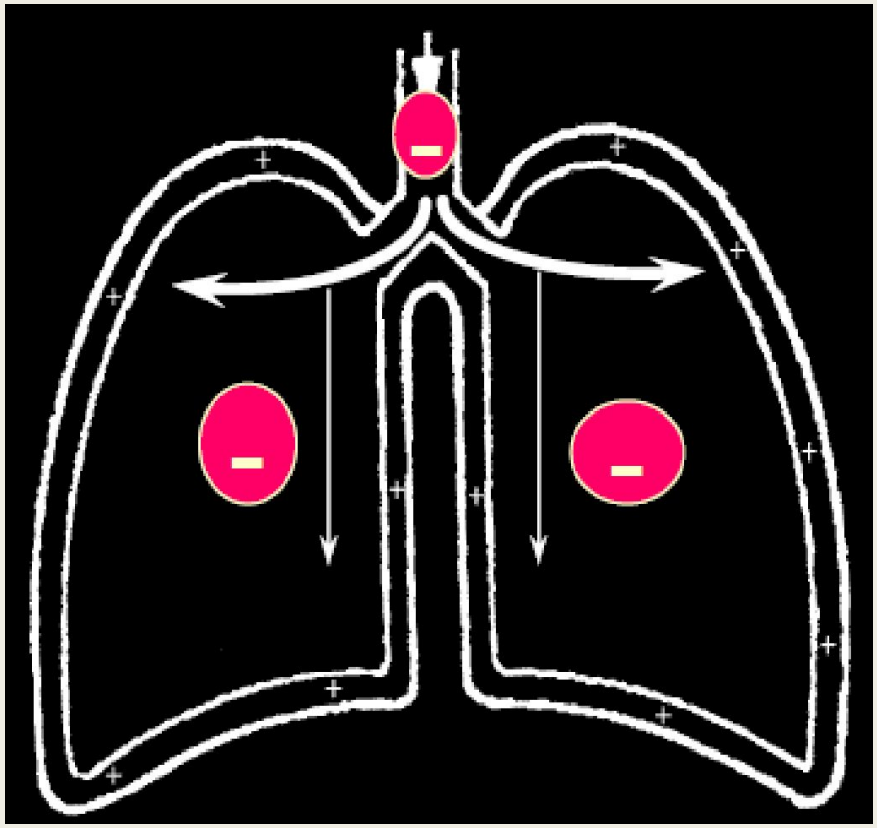
3. The goal of mechanical ventilation

-relieve respiratory distress by decreasing the inspiratory work of breathing
-allowing the lungs to heal
-reversing respiratory muscle fatigue
-preventing further complications due to abnormal gas exchange

Mechanical Ventilation VS Normal ventilation



Mechanical ventilation
Breath is initiated by some form of positive pressure support



Normal ventilation
Breath is initiated by spontaneous negative pressure

Basic parameters in breathing

1- oxygenation

-deals with maintaining of normal blood oxygen levels

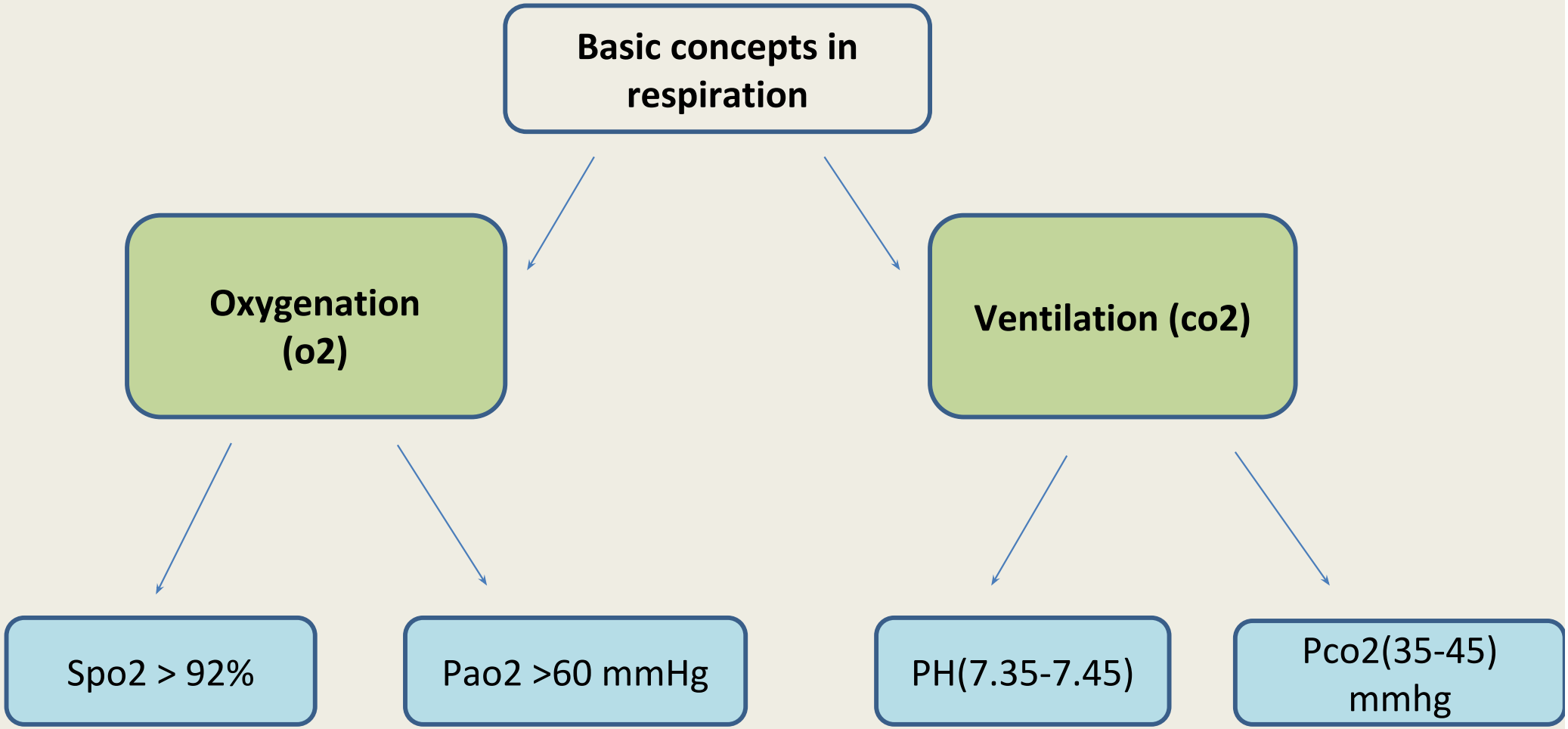
-problems with low oxygen levels in presence of normal CO2 levels is type 1 RF

2- Ventilation

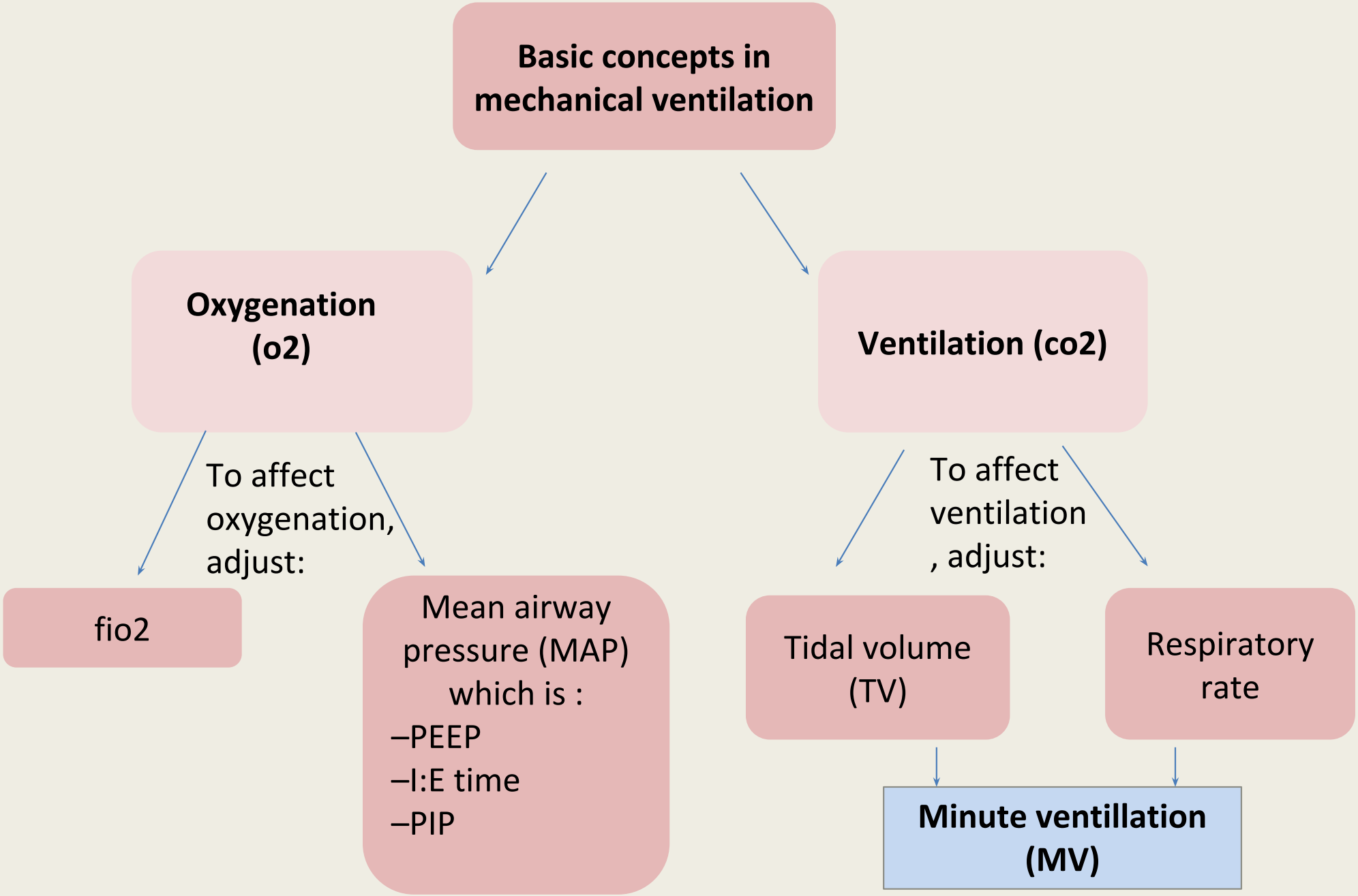
-ventilation deals with maintaining of normal blood co2 levels

-problems with high CO2 levels is called type 2 RF

Basic concepts in respiration



Basic concepts in Mechanical ventilation



Basic parameters to be set on ventilator

- FIO2: fraction of inspired oxygen
- respiratory rate :number of breaths per minute
- Tidal Volume :volume of each breath
- I:E Ratio -the inspiratory time compared to the expiratory time; I + E = total cycle time
- PEEP: positive end expiratory pressure
- mode :AC/PC
- Sensitivity : how responsive the ventilator is to the patient's efforts
- PIP :maximum amount of pressured delivered during each breath
- Inspiratory Time (I time)-the time spent in the inspiratory phase of the ventilatory cycle

Initial Settings

Settings

1–Respiratory Rate: start with a rate that is somewhat normal; i.e., 15 for adolescent/child, 20-30 for infant/small child

2–FiO2: 100% and then titrate it down

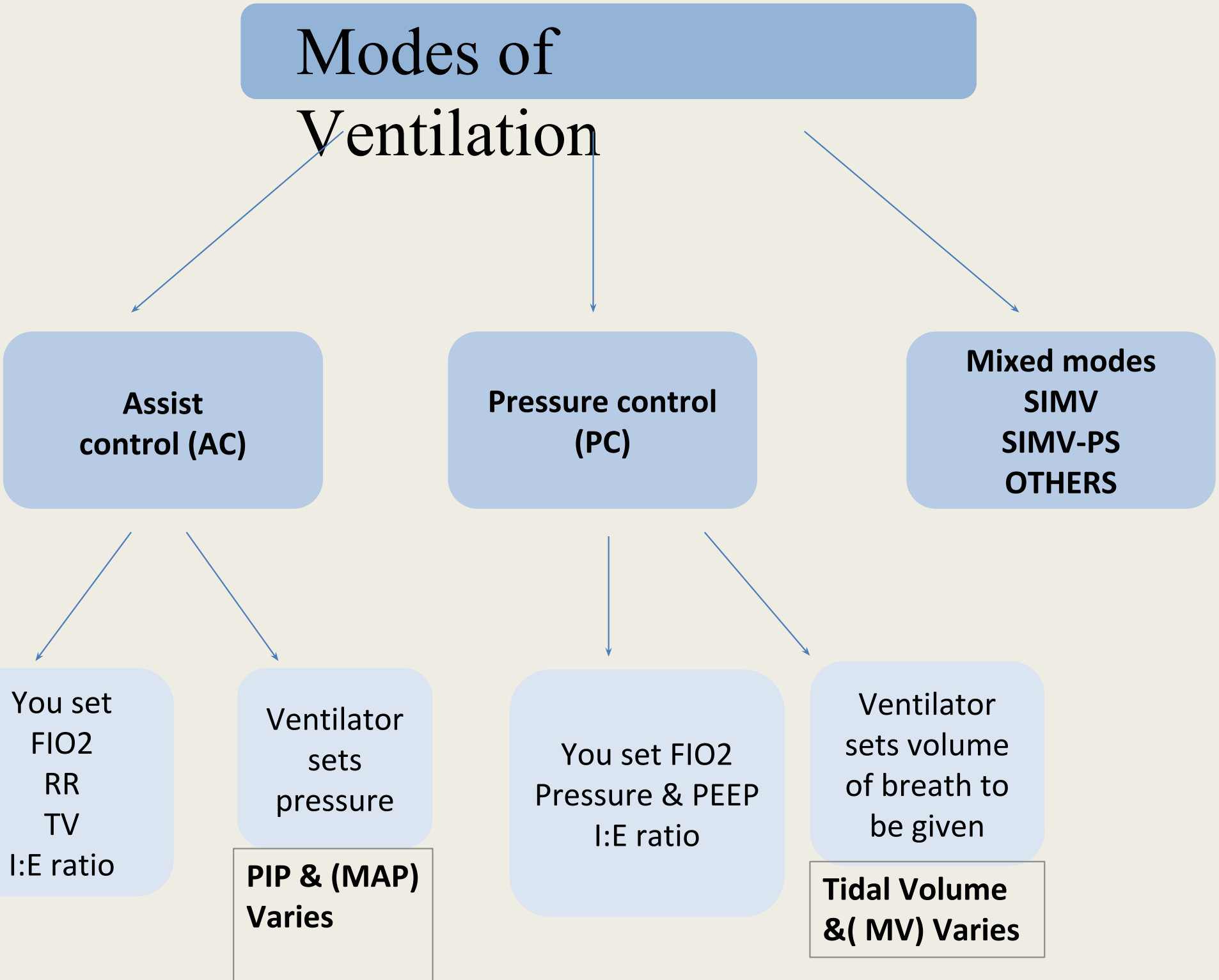
3–PEEP : 3-5 cmH20

4–TV : 8-10 ml/kg (BASED ON IDEAL BODY WEIGHT IN Kg.)

5–PIP : 14-20 cmH2O

6–Pressure support : 5-10 cmH2O

7–Determine the mode: control every breath (A/C) or some (SIMV)


Modes of Ventilation
Assist control (AC)
Pressure control (PC)
Mixed modes
SIMV
SIMV-PS
OTHERS
You set
FIO2
RR
TV
I:E ratio
Ventilator sets pressure
PIP & (MAP) Varies
You set FIO2
Pressure & PEEP
I:E ratio
Ventilator sets volume of breath to be given
Tidal Volume &(MV) Varies

Which mechanical ventilation to use ?

- Depends on the patient condition and diagnosis

- Generally pressure control is preferred in neonates and young infants and volume control in older children

- Mixed modes are used as weaning modes

- Irrespective of mode , it is mandatory to continuously hemodynamically monitor every intubated child with special emphasis on tracheal toilet ,tube positioning ,need for sedation and radiological evaluation

General indication

1- acute respiratory faliure
(assist control)
2-acute respiratory distress syndrome
(pressure control)
3-acute obstructive pathologies
(pressure control)

ABG finding	PIP	PEEP	RR	FIO2	TV
Low O2	Increase	Increase	-	Increase	-
Normal O2	Titrate down	Titrate down gradually if high	-	Titrate down gradually if high	Decrease if high
High co2	-	-	Increase	-	Increase
Low co2	-	-	Decrease	-	Decrease

- There are several types of mechanical ventilators that offer different modes and features. Mechanical ventilators provide positive pressure ventilation by pressure-limited ventilation or volume-limited ventilation

In pressure-limited ventilation , the gas is allowed to flow into the lungs until a preset airway pressure limit is reached, at which time a valve opens, allowing exhalation to ensue

In volume-limited ventilation, gas flows to the patient until a preset volume is delivered to the ventilator circuit, even if this entails a very high airway pressure

One of the factors to consider when deciding which ventilator to use is the mode of mechanical ventilation or the method of inspiratory support . There is limited evidence-based research to demonstrate that the mode affects clinical outcomes; therefore, the decision on which mode to use is based on the capability of available ventilators to manage small infant volumes and clinicians' experience with the mechanical ventilators.

Common modes of mechanical ventilation include controlled mechanical ventilation, assist control, synchronized intermittent mandatory ventilation, and pressure support ventilation.

In the controlled mechanical ventilation mode, the ventilator delivers a preset minute ventilation (preset tidal volume and respiratory rate), and the patient cannot trigger additional breaths above what is set. This mode is usually used for patients who are paralyzed, heavily sedated, or comatose. In the assist control mode, minimum minute ventilation is set, and the patient can trigger additional breaths. If the patient fails to trigger a breath within a selected time, the ventilator delivers the breaths.

The assist control mode is not appropriate when the patient is ready to wean off the ventilator because it gives a full breath each time

The synchronized intermittent mandatory ventilation mode allows the patient to increase minute ventilation by preset breath rate synchronized with spontaneous breathing, rather than patient-initiated ventilator breathing as in the assist control mode

the pressure support ventilation mode, the ventilator delivers a preset pressure support level while the patient triggers each breath
because there is no preset minute ventilation

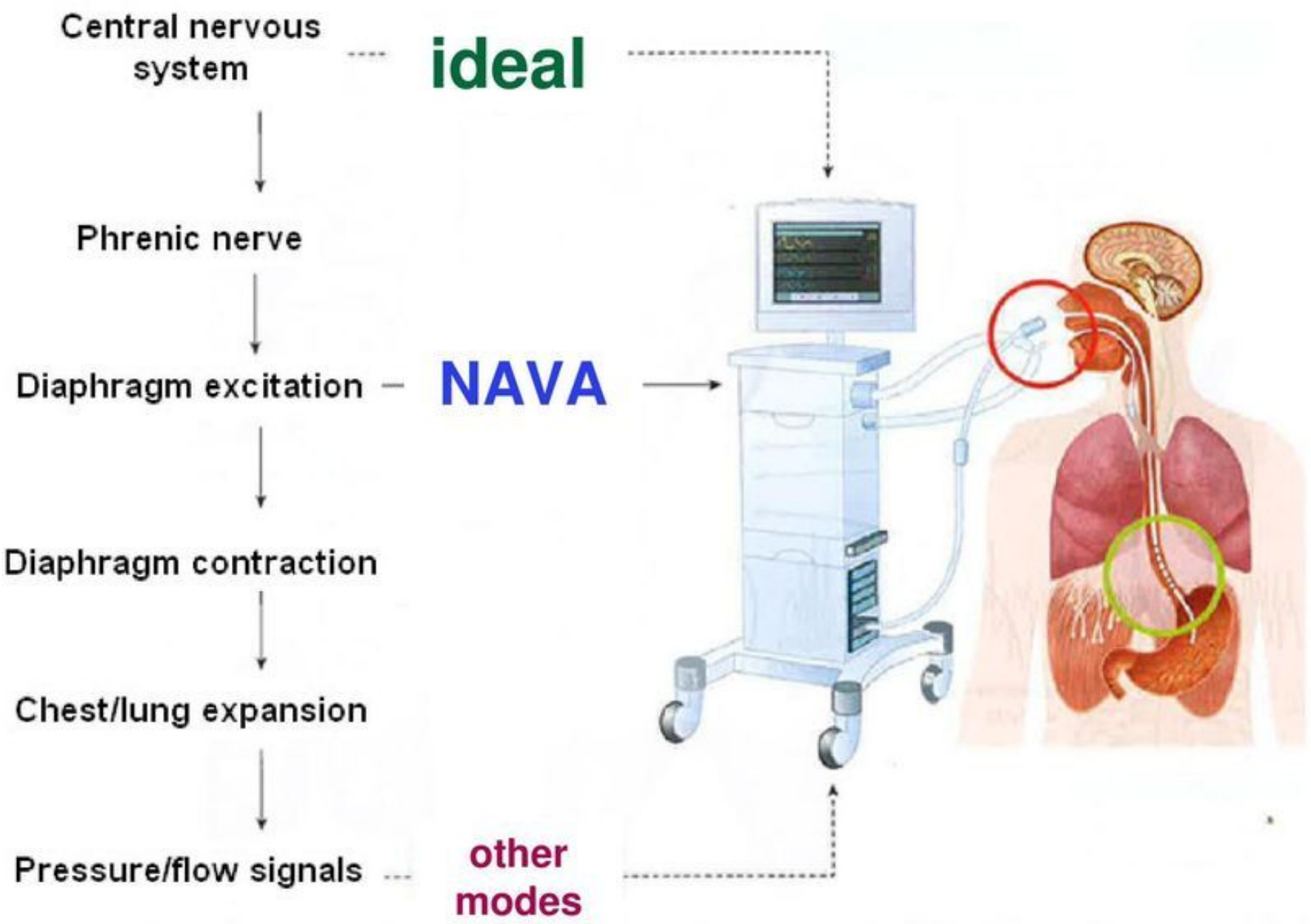
In addition to these conventional modes of ventilation, high-frequency ventilation is commonly used, especially in premature neonates. The high-frequency oscillatory ventilator delivers small tidal volumes by oscillating air movements at an extremely rapid rate (300–1500 breaths per minute). A Cochrane review concludes no difference in benefit between high-frequency oscillatory ventilation compared with conventional ventilation in preterm infants
A previous study found that length of mechanical ventilation, intensive care unit length of stay, and mortality were significantly higher in high frequency oscillatory ventilation patients compared with the controlled mechanical ventilation patients ages 1 to 18 years who were hospitalized in the pediatric intensive care unit of a diverse group of hospitals that care for children in the United States

Newer modalities : include neurally adjusted ventilatory assist (NAVA) and proportional assist ventilation.

These modalities of assisted ventilation require that the patient spontaneously breathes and the delivered airway pressure changes, depending on the patient's breathing effort; thus, varying degrees of unloading of work by the respiratory muscles on inspiration on a breath by breath basis are delivered.

In the neurally adjusted ventilatory assist, an esophageal sensor represents neural output from the respiratory center, controlling the timing and magnitude of the delivered pressure.

Neurally Adjusted Ventilatory Assist



Sinderby in: Tobin. Principles and Practice of Mechanical Ventilation 3rd edition 2012.

Ventilator complications

-infection and lung injury.

- Ventilator-associated pneumonia (VAP) has been described more in adult than children. The estimated incidence of VAP in pediatrics is 3 per 1000 ventilator-days.

-Ventilator-induced lung injury (VILl) is another potential complication of mechanical ventilation. Ventilator-induced lung injury is a result of alveolar overdistension and cyclic atelectasis from high pulmonary pressure and oxygenation. The most common risk factor for ventilator-induced lung injury is acute respiratory distress syndrome. Strategies to prevent ventilator-induced lung injury include using small tidal volumes that range from 6 to 8 mL/kg, applying positive-end expiratory pressure, and maintaining a low plateau airway pressure of 30 cm H2O or less . These strategies are based on adult studies.

-In premature infants particularly, prolonged mechanical ventilation not only leads to acute complications, such as infection and lung injury, but also results in long-term sequelae, such as chronic lung disease and neurodevelopmental delays. Strategies to minimize these complications include preservation of spontaneous breathing by applying patient-triggered and volume target ventilation, administering respiratory stimulants (eg, caffeine), and using nasal continuous positive airway pressure or nasal intermittent positive pressure ventilation after extubation.

Extracorporeal membrane oxygenation (ECMO)

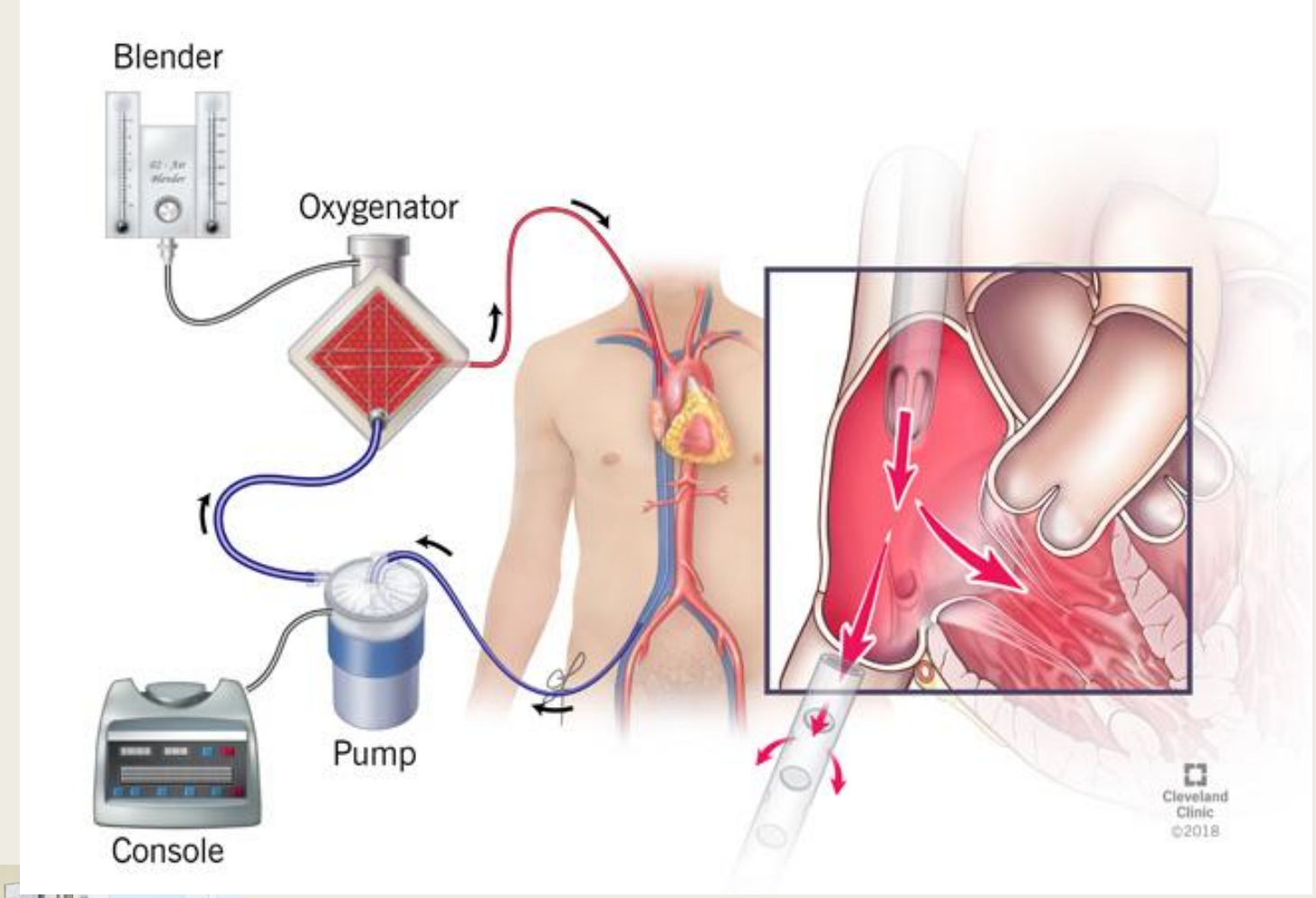
can be considered when all other options have failed and the respiratory failure is a result of a reversible underlying illness. ECMO provides cardiopulmonary support extracorporeally to prevent further lung injury from high pressure ventilation and allow the lungs to heal. ECMO was initially used almost exclusively in neonates. Its use to support older pediatric patients has increased throughout the years. In the past 5 years, there have been approximately 300 to 500 cases annually.

Relative contraindications for ECMO include patients who have irreversible respiratory or cardiac failure, who cannot undergo anticoagulation, and who undergo ventricular assist device implantation.

Complications include bleeding, thromboembolism, and heparininduced thrombocytopenia.

Prognosis depends primarily on the underlying illness. Mortality remains approximately 43%.

Risk factors associated with death include older patient age, other nonpulmonary organ dysfunction, prolonged use of mechanical ventilation (>2 weeks) before ECMO, prolonged ECMO support, and complications during ECMO. A small group of severely compromised children may require prolonged mechanical ventilation. Overall, their prognosis is good compared with adults. Outcomes data reveal that 65% of children who require a post–acute rehabilitation facility for prolonged weaning are eventually discharged to home and that 45% of children discharged to pulmonary rehabilitation were weaned on discharge. Weaning protocols have been established for the management of chronic respiratory failure in children


Blender
Oxygenator
Pump
Console
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Thank you