

Pathophysiology of Respiratory Failure and Use of Mechanical Ventilation

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Definition

■ Respiratory failure is a syndrome of inadequate gas exchange due to dysfunction of one or more essential components of the respiratory system:

■ Chest wall (including pleura and diaphragm)

■ Airways

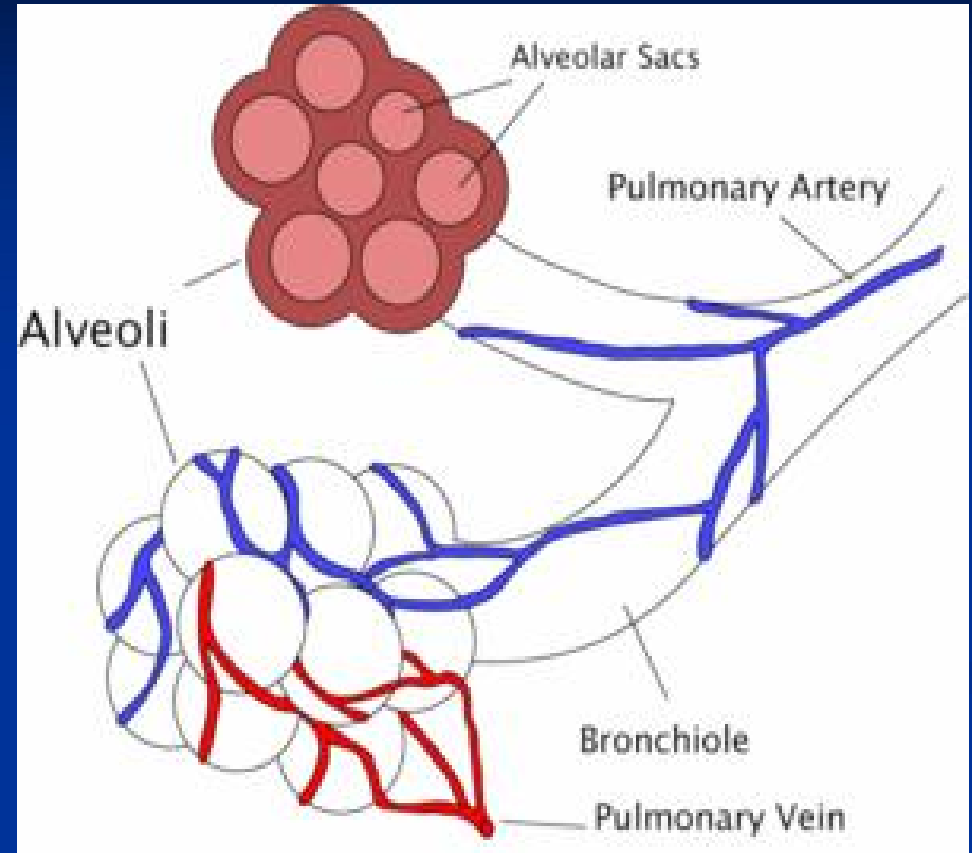
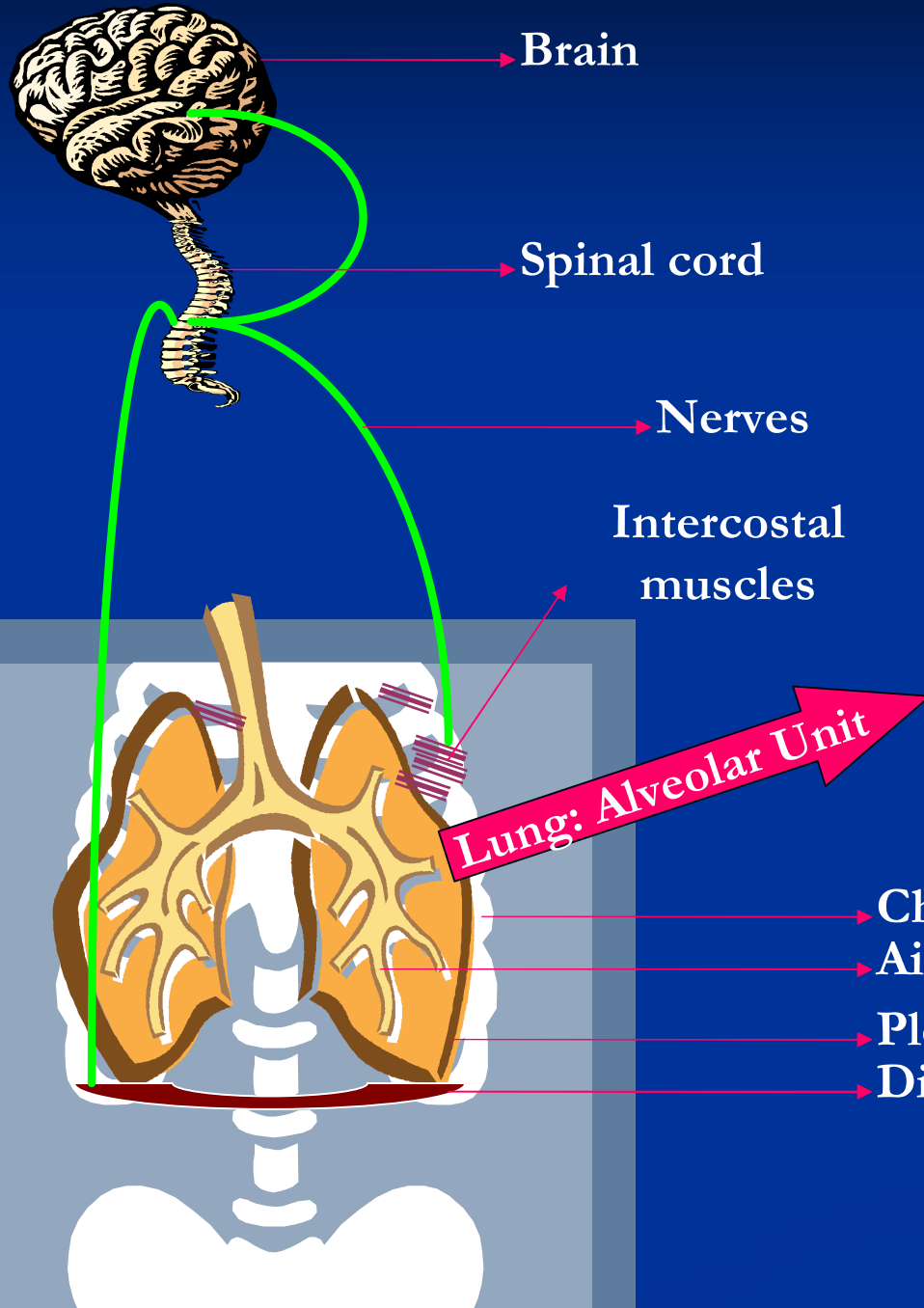
■ Alveolar–capillary units

■ Pulmonary circulation

■ Nerves

■ CNS or Brain Stem

Respiratory System



Epidemiology

- Incidence: about 360,000 cases per year in the United States
- 36% die during hospitalization
- Morbidity and mortality rates increase with age and presence of comorbidities

Classification

- Type I or Hypoxemic ($\text{PaO}_2 < 60$ at sea level): *Failure of oxygen exchange*
 - Increased shunt fraction (Q_S/Q_T)
 - Due to alveolar flooding
 - Hypoxemia refractory to supplemental oxygen
- Type II or Hypercapnic ($\text{PaCO}_2 > 45$): *Failure to exchange or remove carbon dioxide*
 - Decreased alveolar minute ventilation (V_A)
 - Often accompanied by hypoxemia that corrects with supplemental oxygen

Classification

- Type III Respiratory Failure: *Perioperative respiratory failure*
 - Increased atelectasis due to low functional residual capacity (FRC) in the setting of abnormal abdominal wall mechanics
 - Often results in type I or type II respiratory failure
 - Can be ameliorated by anesthetic or operative technique, posture, incentive spirometry, post-operative analgesia, attempts to lower intra-abdominal pressure
- Type IV Respiratory Failure: *Shock*
 - Type IV describes patients who are intubated and ventilated in the process of resuscitation for shock
 - Goal of ventilation is to stabilize gas exchange and to unload the respiratory muscles, lowering their oxygen consumption

Classification

- Respiratory failure may be
 - Acute
 - Chronic
 - Acute on chronic
 - E.g.: acute exacerbation of advanced COPD

Pathophysiology: Mechanisms

- Hypoxemic failure
 - Ventilation/Perfusion (V/Q) mismatch
 - Shunt
 - Exacerbated by low mixed venous O_2 (SvO_2)
- Hypercapnic failure
 - Decreased minute ventilation (MV) relative to demand
 - Increased dead space ventilation

Pathophysiology: Etiologic Categories

- Nervous system failure (Type II)
 - Central hypoventilation
 - Neuropathies
- Muscle (pump) failure (Type II)
 - Muscular dystrophies
 - Myopathies
- Neuromuscular transmission failure (Type II)
 - Myasthenia gravis
- Airway failure (Type II)
 - Obstruction
 - Dysfunction

Pathophysiology: Etiologic Categories

- Chest wall and pleural space failure (Type II)
 - Kyphoscoliosis
 - Morbid obesity
 - Pneumothorax
 - Hydrothorax
 - Hemothorax
- Alveolar unit failure (Type I)
 - Collapse
 - Flooding: edema, blood, pus, aspiration
 - Fibrosis
- Pulmonary vasculature failure (Type I)
 - Pulmonary embolism
 - Pulmonary hypertension

Causes

- Type I respiratory failure
 - Pneumonia
 - Cardiogenic pulmonary edema
 - Pulmonary edema due to increased hydrostatic pressure
 - Non-cardiogenic pulmonary edema
 - Pulmonary edema due to increased permeability
 - Acute lung injury (ALI)
 - Acute respiratory distress syndrome (ARDS)
 - Pulmonary embolism (see also type IV respiratory failure)
 - Atelectasis (see also type III respiratory failure)
 - Pulmonary fibrosis

Causes

- Type II respiratory failure
 - Central hypoventilation
 - Asthma
 - Chronic obstructive pulmonary disease (COPD)
 - Hypoxemia and hypercapnia often occur together
- *Neuromuscular and chest wall disorders
 - Myopathies
 - Neuropathies
 - Kyphoscoliosis
 - Myasthenia gravis
 - Obesity Hypoventilation Syndrome

Causes

- Type III respiratory failure
 - Inadequate post-operative analgesia, upper abdominal incision
 - Obesity, ascites
 - Pre-operative tobacco smoking
 - Excessive airway secretions
- Type IV respiratory failure
 - Cardiogenic shock
 - Septic shock
 - Hypovolemic shock

Diagnosis: History

- Sepsis suggested by fever, chills
- Pneumonia suggested by cough, sputum production, chest pain
- Pulmonary embolus suggested by sudden onset of shortness of breath or chest pain
- COPD exacerbation suggested by history of heavy smoking, cough, sputum production
- Cardiogenic pulmonary edema suggested by chest pain, paroxysmal nocturnal dyspnea, and orthopnea

Diagnosis: History

- Noncardiogenic edema suggested by the presence of risk factors including sepsis, trauma, aspiration, and blood transfusions
- Accompanying sensory abnormalities or symptoms of weakness may suggest neuromuscular respiratory failure; as would the history of an ingestion or administration of drugs or toxins.
- Additional exposure history may help diagnose asthma, aspiration, inhalational injury and some interstitial lung diseases

Diagnosis: Physical Findings

- Hypotension usually with signs of poor perfusion suggests severe sepsis or massive pulmonary embolus
- Hypertension usually with signs of poor perfusion suggests cardiogenic pulmonary edema
- Wheezing suggests airway obstruction:
 - Bronchospasm
 - Fixed upper or lower airway pathology
 - Secretions
 - Pulmonary edema (“cardiac asthma”)

Diagnosis: Physical Findings

- Stridor suggests upper airway obstruction
- Elevated jugular venous pressure suggests right ventricular dysfunction due to accompanying pulmonary hypertension
- Tachycardia and arrhythmias may be the cause of cardiogenic pulmonary edema

Diagnosis: Laboratory Workup

- ABG
 - Quantifies magnitude of gas exchange abnormality
 - Identifies type and chronicity of respiratory failure
- Complete blood count
 - Anemia may cause cardiogenic pulmonary edema
 - Polycythemia suggests may chronic hypoxemia
 - Leukocytosis, a left shift, or leukopenia suggestive of infection
 - Thrombocytopenia may suggest sepsis as a cause

Diagnosis: Laboratory Workup

- Cardiac serologic markers
 - Troponin, Creatine kinase- MB fraction (CK-MB)
 - B-type natriuretic peptide (BNP)
- Microbiology
 - Respiratory cultures: sputum/tracheal aspirate/bronchoalveolar lavage (BAL)
 - Blood, urine and body fluid (e.g. pleural) cultures

Diagnostic Investigations

- Chest radiography
 - Identify chest wall, pleural and lung parenchymal pathology; and distinguish disorders that cause primarily V/Q mismatch (clear lungs) vs. Shunt (intra-pulmonary shunt; with opacities present)
- Electrocardiogram
 - Identify arrhythmias, ischemia, ventricular dysfunction
- Echocardiography
 - Identify right and/or left ventricular dysfunction

Diagnostic Investigations

- Pulmonary function tests/bedside spirometry
 - Identify obstruction, restriction, gas diffusion abnormalities
 - May be difficult to perform if critically ill
- Bronchoscopy
 - Obtain biopsies, brushings and BAL for histology, cytology and microbiology
 - Results may not be available quickly enough to avert respiratory failure
 - Bronchoscopy may not be safe in the if critically ill

Respiratory Failure: Management

■ ABC's

- Ensure airway is adequate
- Ensure adequate supplemental oxygen and assisted ventilation, if indicated
- Support circulation as needed

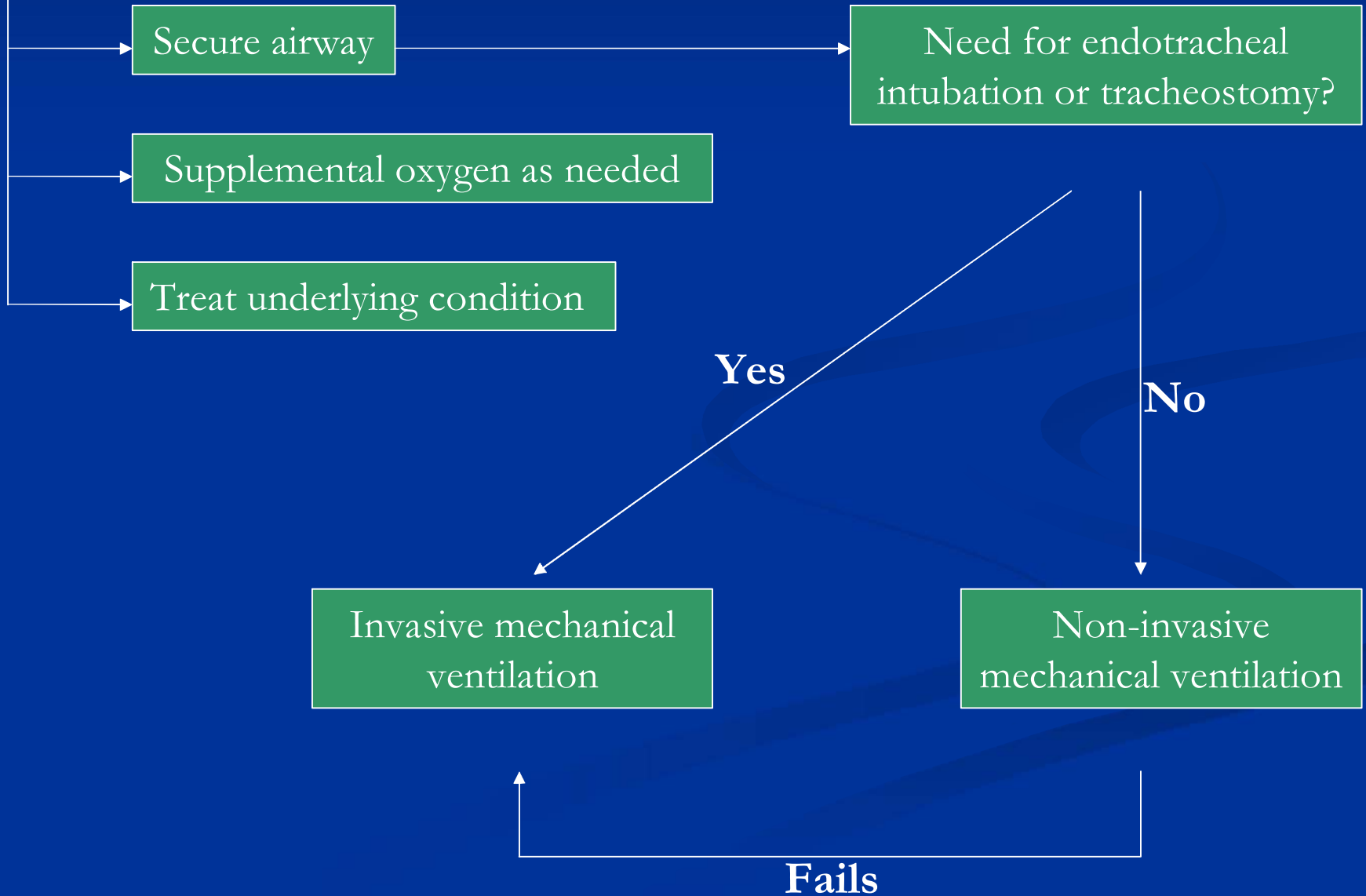
Respiratory Failure: Management

- Treatment of a specific cause when possible
 - Infection
 - Antimicrobials, source control
 - Airway obstruction
 - Bronchodilators, glucocorticoids
 - Improve cardiac function
 - Positive airway pressure, diuretics, vasodilators, morphine, inotropy, revascularization

Respiratory Failure: Management

- Mechanical ventilation
 - Non-invasive (if patient can protect airway and is hemodynamically stable)
 - Mask: usually orofacial to start
 - Invasive
 - Endotracheal tube (ETT)
 - Tracheostomy – if upper airway is obstructed

Respiratory Failure



Indications for Mechanical Ventilation

- Cardiac or respiratory arrest
- Tachypnea or bradypnea with respiratory fatigue or impending arrest
- Acute respiratory acidosis
- Refractory hypoxemia (when the P_aO_2 could not be maintained above 60 mm Hg with inspired O_2 fraction $(F_I O_2) > 1.0$)
- Inability to protect the airway associated with depressed levels of consciousness

Indications for Mechanical Ventilation

- Shock associated with excessive respiratory work
- Inability to clear secretions with impaired gas exchange or excessive respiratory work
- Newly diagnosed neuromuscular disease with a vital capacity $<10-15$ mL/kg
- Short term adjunct in management of acutely increased intracranial pressure (ICP)

Invasive vs. Non-invasive Ventilation

- Consider non-invasive ventilation particularly in the following settings:
 - COPD exacerbation
 - Cardiogenic pulmonary edema
 - Obesity hypoventilation syndrome
 - Noninvasive ventilation may be tried in selected patients with asthma or non-cardiogenic hypoxemic respiratory failure

Goals of Mechanical Ventilation

- Improve ventilation by augmenting respiratory rate and tidal volume
 - Assistance for neural or muscle dysfunction
 - Sedated, comatose or paralyzed patient
 - Neuropathy, myopathy or muscular dystrophy
 - Intra-operative ventilation
 - Correct respiratory acidosis, providing goals of lung-protective ventilation are met
 - Match metabolic demand
 - Rest respiratory muscles

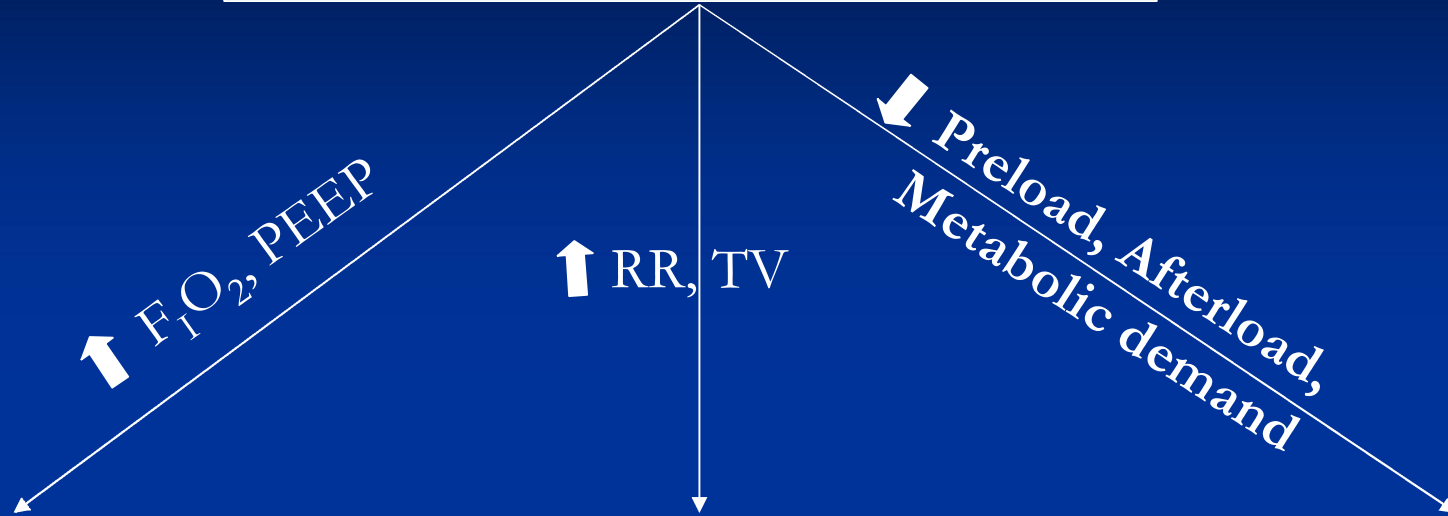
Goals of Mechanical Ventilation

- Correct hypoxemia
 - High $F_{I}O_2$
 - Positive end expiratory pressure (PEEP)
- Improve cardiac function
 - Decreases preload
 - Decreases afterload
 - Decreases metabolic demand

Permissive Hypercapnia

- Ventilation strategy that allows $P_a\text{CO}_2$ to rise by accepting a lower alveolar minute ventilation to avoid specific risks:
 - Dynamic hyperinflation (“auto-peep”) and barotrauma in patients with asthma
 - Ventilator-associated lung injury, in patients with, or at risk for, ALI and ARDS
- Contraindicated in patients with increased intracranial pressure such as head trauma

Mechanical Ventilation



Correct Hypoxemia

Enhance Ventilation *

Optimize cardiac function

Correct respiratory acidosis*

Assistance for neural and/or muscle dysfunction

Hyperventilation may be used as a short term adjunct to treat acutely elevated ICP

Meet increased metabolic demand

* Avoid ventilator induced lung injury and dynamic hyperinflation

Other Issues to Consider When Initiating Mechanical Ventilation

- Do not wait for frank respiratory acidosis especially with evidence of:
 - Inability to protect airway
 - Persistent or worsening tachypnea (respiratory rate >35 /minute)
 - Respiratory muscle fatigue
- Always consider risks and benefits of initiation and continuation of mechanical ventilation

Other Issues in Intubated & Mechanically Ventilated Patients

- Always elevate the head of the bed $>30^\circ$ and use ulcer and DVT prophylaxis, unless contraindicated
- Use lung protective ventilation strategy for patients with Acute Lung Injury (TV ~ 6 ml/kg ideal body weight, Plat pressure < 30 cmH₂O)
- Modify ventilator settings primarily to achieve patient-ventilator synchrony. If this fails, use the least amount of sedation required to achieve comfort and avoid unnecessary neuromuscular blockade

Other Issues in Intubated & Mechanically Ventilated Patients

- Monitor patient comfort, gas exchange, mechanics, and ventilator waveforms daily, or more frequently if indicated
- When minimal settings are required for oxygenation ($F_I O_2 < 55\%$, $PEEP < 8$) and patient is hemodynamically stable, perform a spontaneous breathing trial daily

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