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
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 (PaO2 <60 at sea level):** *Failure of oxygen exchange*
  - Increased shunt fraction \(\frac{Q_S}{Q_T}\)
    - Due to alveolar flooding
    - Hypoxemia refractory to supplemental oxygen

- **Type II or Hypercapnic (PaCO2 >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 O2 (SvO2)

- **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

- Secure airway
- Supplemental oxygen as needed
- Treat underlying condition

Need for endotracheal intubation or tracheostomy?

- Yes
  - Invasive mechanical ventilation
  - Fails

- No
  - Non-invasive mechanical ventilation
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 ($F_1O_2>1.0$))
- 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 $F_1O_2$
  - 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
- Meet increased metabolic demand
- Hyperventilation may be used as a short term adjunct to treat acutely elevated ICP

* 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° 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 cmH$_2$O).

- 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 ($F_1O_2 < 55\%$, PEEP $< 8$) and patient is hemodynamically stable, perform a spontaneous breathing trial daily.
References

References


