Respiratory Fluid Mechanics and Medical Ventilators

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Introduction

• Anatomy and Physiology of Respiratory System
• Spirometer
• The need for artificial respiration
• Polio and Iron lung
• Positive pressure ventilators
• CPAP and PEEP
• Classification of medical ventilators
• The future of ventilators
Respiratory System

A. Nasal cavity
B. Pharynx
C. Larynx
D. Trachea
E. Alveoli
F. Bronchial tree
G. Diaphragm
Upper Respiratory Tract

- Nasal Cavity
- Nasopharynx
- Oral Cavity
- Oropharynx
- Epiglottis
- Laryngopharynx
- Vocal Cords (folds)
- Trachea
- Esophagus
Lower Respiratory Tract

Anterior view

- Larynx
- Trachea
- Visceral pleura
- Parietal pleura
- Pleural cavity
- Right secondary bronchus
- Right primary bronchus
- Right tertiary bronchus
- Right bronchiole
- Right terminal bronchiole
- Carina
- Left primary bronchus
- Left secondary bronchus
- Left tertiary bronchus
- Left bronchiole
- Left terminal bronchiole

Diaphragm
Pressure Changes in Pulmonary Ventilation

1. At rest (diaphragm relaxed)
   - Atmospheric pressure = 760 mmHg
   - Alveolar pressure = 760 mmHg
   - Intrapleural pressure = 756 mmHg

2. During inhalation (diaphragm contracting)
   - Atmospheric pressure = 760 mmHg
   - Alveolar pressure = 758 mmHg
   - Intrapleural pressure = 754 mmHg

3. During exhalation (diaphragm relaxing)
   - Atmospheric pressure = 760 mmHg
   - Alveolar pressure = 762 mmHg
   - Intrapleural pressure = 756 mmHg
Lung Volume and Capacities

At rest: a healthy adult averages 12 breaths per minute
Moving about 500mL of air into and out of the lungs.
The rate of the air moving in and out:
12 breaths/min x 500mL/breaths = 6 L/min

Maximum exercise: a healthy adult averages 60 breaths per minute
Moving about 3000mL of air into and out of the lungs.
The rate of the air moving in and out:
60 breaths/min x 3000mL/breaths = 180 L/min
Spirometer
One of the Applications of Spirometer

- The spirometer is widely used in measuring lung function.
- Eg. Asthma and COPD: Asthma/COPD is a disease of the respiratory system in which the airways constrict and increase airway resistance.
- From spirometer, the stage of patients can be known.
The Need for Artificial Respiration

- COPD
- Asthma
- Pneumonia
- Lung Cancer
- Severe Acute Respiratory Syndrome (SARS)
- Poliomyelitis
- Etc.
Medical Ventilator

• Definition:
  – A flow generator. A machine that generates a controlled flow of gas into a patient’s airways.

• Types:
  – Negative Pressure
  – Positive Pressure
The use of ventilators

• Intensive care
• During surgery
• Home care
• Life support
Poliomyelitis

• Respiratory failure is a consequence of
  ➢ the destruction of motor cells in the spinal cord innervating respiratory muscles
  ➢ neuronal destruction of the respiratory center in the medulla
  ➢ both.
Iron Lung
Iron Lung
Iron Lung

Fig. 1.—The mechanical respirator, showing patient ready to be pushed into the tank. The pumps and manometer for controlling the pressure are shown in the background, to the left.
History of Iron Lung

• Iron Lung was invented by Dr. Philip Drinker and Dr. Louis Agassiz Shaw of Harvard Medical School.

• They injected the cat with the South American arrow-poison curare to produce an effect of extremely relaxed muscles, to the point of respiratory arrest.

• They then placed the cat into the sealed box and used a hand-operated piston to manually control the pressure.

• This experiment was successfully ventilated the cat for a few hours.
From negative pressure to positive pressure
Positive Pressure Ventilator
CPAP & PEEP

- CPAP – Continuous Positive Airway Pressure
- PEEP – Positive End Expiratory Pressure

Elevated baseline airway pressure
Purpose of CPAP:
To avoid low lung volume

• Functional Residual Capacity (FRC)
  – The lung volume after a normal expiration.
  – Equals to the residual volume + expiratory reserve volume.
Classification of machine ventilations

1. Type of Control:
   - Volume Controlled
   - Pressure Controlled
   - Dual Controlled

2. Type of Cycling:
   - Time Cycled
   - Flow Cycled
   - Volume Cycled

3. Triggering:
   - Time, Pressure, or Flow.

4. Breathing:
   - Mandatory, Assisted, or Spontaneous.
Phase 1 – Inhalation. The pressure increases until a peak pressure is reached.

Phase 2 – Pressure drops to a stable level, known as the plateau phase.

Phase 3 – Exhalation. The pressure falls to a residual value.
Three Main Problems with Mechanical Ventilation

- Peak pressure may increase mechanical stress on the lung tissue.

- The residual pressure drops if breathing gas is able to escape through a leak. (constant residual pressure has great clinical significance - PEEP)

- Patient is unable to breathe out during the plateau stage. Natural breathing is considerably impaired during this phase.
Pressure-Controlled Ventilation
pressure limited

- Uses machine ventilation bellows.
- Enables ventilation to be performed with the airway pressure limited to the level of the “working pressure”.
Pressure-Controlled Ventilation with valves and microprocessor

- Substitutes the bellows with modern valves.
- Dynamic gas flow and expiratory valve control.
- Electromagnetic drive mechanism.
Pressure-Controlled Ventilation with open system

- The expiratory valve is controlled with great sensitivity.
- Allows spontaneous breathing.
Volume-Controlled Ventilation
with intermittent mandatory ventilation
Volume Assist Controlled

Assisted breaths are identical to controlled breaths

CPAP/Volume Assist Control
Synchronized Intermittent Mandatory Ventilation

• Another method for spontaneous breathing.
• Allow the patient to breathe spontaneously while also receiving mandatory breaths.
Pressure-Controlled

- The inspiratory flow and flow waveform are determined by the ventilator.
- Requires the clinician to titrate the inspiratory pressure to the measured tidal volume.
- Limits the maximum airway pressure delivered to the lung, but may result in variable tidal and minute volume.

Volume-Controlled

- Requires the clinician to appropriately set the inspiratory flow, flow waveform, and inspiratory time.
- Offers the safety of a pre-set tidal volume and minute ventilation.
- Airway pressure increases in response to reduced compliance, increased resistance, or active exhalation and may increase the risk of ventilator-induced lung injury.
Pressure-Controlled

Volume-Controlled
Volume Controlled + Pressure Controlled

Synchronized Intermittent Mandatory Ventilation with Pressure Support:

Pressure controlled SIMV mode
ICU Ventilators
The Future of Ventilators
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