Mechanics of Ventilation

- Functional Anatomy of the Lung

![Diagram of the Lungs with labels for various anatomical parts.]
(a) Diagram of a portion of a lobule of the lung
(a) Transverse section of an alveolus showing its cellular components

(b) Details of respiratory membrane
Mechanics of Ventilation

- Anatomic Dead Space – area within the respiratory tract in contact with surfaces where gas exchange cannot take place
Mechanics of Ventilation

- Air Conditioning Functions of Lungs
  - Warm and moisten air
  - Why do dogs pant? Why don’t dogs hyperventilate when panting?
  - Problems with patients on respirators
    - Upper airway is bypassed, preventing moisturizing, bubble oxygen through water before entering the patient

- Removal of Dust
  - Mucociliary System
    - Ciliated epithelial cells
    - Goblet cells
    - Submucosal cells
  - Mucous secretion regulated by parasympathetic system (acetylcholine) - Atropine used prior to surgery to act as an antagonist to acetylcholine
  - Alveolar macrophages (dust cells)
Mechanics of Ventilation

• Structural Changes in Restrictive and Obstructive Lung Disease
  
  - Restrictive Lung Diseases – problem with lungs or chest wall, stiff or chest wall deformed making it difficult to inflate the lungs, airways are normal

• Interstitial Fibrosis
  
  - Chronic inflammation in the space located at the respiratory membrane results in fibrosis, and later scar tissue, examples
    
    » Silica exposure
    » Asbestos exposure

• Chest Wall Deformities
  
  - Abnormal curvature of the spine
    
    » Kyphosis
    » Scoliosis
    » Obesity

Mechanics of Ventilation

- Obstructive Lung Diseases – airways are blocked or resisted, limiting air flow through these passages

  - Chronic Bronchitis

    - Upon chronic insult, goblet cells proliferate at the expense of fewer ciliated cells
    - Submucosal glands hypertrophy
    - Secretions accumulate and form blockages
    - With stagnant secretions bacteria multiply, causing inflammation
      » Coughing
      » Expectorating large amounts of mucous
    - May present as a “blue-bloater”
Mechanics of Ventilation

CLINICAL MANIFESTATIONS

- Excess body fluids
- Chronic cough
- Shortness of breath on exertion
- Increased sputum
- Cyanosis (late sign)
Mechanics of Ventilation

- Asthma
  - Bronchial smooth muscle cells constrict
  - Edema forms in bronchioles
  - Episodes of wheezing and shortness of breath
  - Can be of two types
    » Can be either allergic (extrinsic)
      
      Pollen
      molds
      Animal dander
    
    » Can also be nonallergic (intrinsic)
      
      Infection
      Emotional upset
  
- Treat with bronchodilators and anti-inflammatories
Mechanics of Ventilation

- **Emphysema**
  - Result of alveoli losing their elasticity, lungs enlarge but cannot deflate – alveoli merge with a loss in surface area
    - Extra air trapped in alveoli and large air pockets called bullae
    - Cause of elastic breakdown not really known
      - rare cases where individual inherits a deficiency of alpha1-antitrypsin, result cannot breakdown elastase (released by macrophages in lung) and elastic fibers are destroyed
    - To really diagnose should use a biopsy to see if the removed lung tissue floats
    - Diagnosis typically clinical for irreversible changes seen in pulmonary function tests
  - Patient may present as a “pink-puffer”
Mechanics of Ventilation

CLINICAL MANIFESTATIONS

- Use of accessory muscles to breathe
- Pursed-lip breathing
- Minimal or absent cough
- Leaning forward to breathe
- Dyspnea on exertion (late sign)
Mechanics of Ventilation

- Chronic Obstructive Pulmonary Disease (COPD)
  - A combination of emphysema and chronic bronchitis
  - Typically associated with cigarette smoking
  - Damage cannot be reversed
  - Acute inflammation can be treated
    » Antibiotics
    » Bronchodilators
    » Nebulizer to liquefy secretions
    » Deep suctioning to remove secretions
Structural Changes in Restrictive and Obstructive Diseases

A. Normal

Airways

Alveolus

B. Interstitial Fibrosis

Normal

Fibrous tissue

C. Asthma

Muscle spasm and edema

Normal

D. Chronic Bronchitis

More goblet cells, fewer ciliated epithelial cells, enlarged sub-mucus glands.

More mucus, stagnant mucus, chronic infection

E. Emphysema

Loss of elastic support

Loss of alveolar septa and capillaries

Air trapping

F. Chronic Obstructive Pulmonary Disease (COPD)
Mechanics of Ventilation

- REVIEW LUNG VOLUMES AND CAPACITIES ON YOUR OWN – PG. 563
Mechanics of Ventilation

- Lung Volumes in Obstructive and Restrictive Lung Diseases

  • Lung volumes change with age
    - Residual volume increases with age, ratio of RV/TLC, typically 0.2
  • Emphysema – RV/TLC can be 0.5 or higher

<table>
<thead>
<tr>
<th>LUNG VOLUMES AND CAPACITIES</th>
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<tbody>
<tr>
<td>RV</td>
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<tr>
<td>+ERV</td>
</tr>
<tr>
<td>FRC</td>
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<td>IC</td>
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<tr>
<td>VC = IC + ERV = 4 L</td>
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<tr>
<td>TLC = FRC + IC = 5 L</td>
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Mechanics of Ventilation

- With loss of elasticity lungs cannot deflate fully
  
  » Chest appears enlarged (barrel chest)
  » Lung x-ray appears clear
  » Diaphragm pushed downward

- Restrictive Lung Disease
  
  - RV, FRC, and TLC are decreased
Mechanics of Ventilation

- With scaring of the lungs
  - Lung compliance decreases
    - rapid, shallow breaths
  - Reduced vital capacity
    - also seen when lung tissue removed, displaced lung tissue (tumors, cysts, pneumothorax)
    - seen whenever muscles of maximal inspiration and/or inspiration are impaired (Guillain-Barre syndrome, myasthenia gravis)
    - congestive heart failure

- Dead Space Ventilation (physiological dead space)
  - The result of impaired blood perfusion to the alveoli
  - As physiological dead space increases much of each breath is unproductive
  - When $V_D/V_T$ is about 0.5 then assisted breathing is required
• Ventilatory Apparatus
  – Inspiration

• Normal
Mechanics of Ventilation

- Abnormal Inspiration

**Normal Exercise**
- Chest wall
- Diaphragm
- Air flow
- Pressure: 760 mmHg in mouth, 715 mmHg in alveoli
- Large pressure gradient from mouth to alveoli results in rapid air flow.

**Asthma**
- Chest wall
- Diaphragm
- Air flow
- Pressure: 760 mmHg in mouth, 710 mmHg in alveoli
- Increased airway resistance limits flow despite large pressure gradient.

**Intercostal Fibrosis**
- Chest wall
- Diaphragm
- Air flow
- Pressure: 760 mmHg in mouth, 750 mmHg in alveoli
- Decreased alveolar compliance limits development of pressure gradient and air flow.
Mechanics of Ventilation

• Problems with Inspiration
  
  – Increased intra-abdominal pressure
    
    » Pregnant woman
    » Cirrhosis of the liver and ascites
  
  – Paralysis of diaphragm (Paradoxical Movement of the Diaphragm)
Mechanics of Ventilation

- Flail Chest Injury
Mechanics of Ventilation

- Expiration – typically passive

**A. QUIET EXPIRATION**
- Airways: 760 mmHg
- Diaphragm: 760 mmHg
- Chest wall: 760 mmHg

**B. FORCED EXPIRATION**
- Airways: 760 mmHg
- Diaphragm: 760 mmHg
- Chest wall: 760 mmHg

Alveoli that have been stretched on inspiration are allowed to recoil.

Contraction of abdominal muscles forces the diaphragm upward, increasing intrathoracic and alveolar pressure and moving gases from the lungs to the atmosphere.
Mechanics of Ventilation

- **Case Study – Asthma**
  - Patient – Mrs. S., 30’s
  - Sitting on edge of chair rocking back and forth attempting to gain air
  - Nostrils flared
  - Muscle in neck tightened upon each breath
  - Supraclavicular and suprasternal spaces pulled inward
  - Skin was white, lips, cheeks and fingernail beds bluish
  - Commented, “I can’t...catch my breath..I can’t breath,” in a whisper
Mechanics of Ventilation

- Audible wheezing noises upon breathing
- Respiration rate 24 b/min
- Heart rate over 100 b/min, faded upon inspiration
- Recommended that she relax and try to breath slowly,
- With this she passed out and stopped breathing
- CPR was initiated
- Emergency crew arrived with an emergency medical kit
- Epinephrine was administered immediately, 1 mg
- With additional CPR she began breathing on her own
Mechanics of Ventilation

- Intubated and respirated using an Ambu-bag
- Still unconscious, pupils not dilated
- Brought to ICU, more later

• Case Discussion

- Why was she using her neck muscles to breathe and why were her nostrils flared?
  • Utilizing all accessory muscles of inspiration
    - Muscles of inspiration are used to enlarge the thoracic cavity, Boyle's Law
    - Normally a drop of 2 mmHg is sufficient to inhale, Mrs. S required a much greater drop because of her severe asthma attack
      » Bronchiole constriction
      » Edema
  • Nostrils flared to increase air flow into the respiratory system
Mechanics of Ventilation

- Why were the spaces above her clavicles retracted, and why did her pulse fade upon inspiration?

  - SuprACLavicular Spaces
    - Being unsupported they tend to “collapse” when intrathoracic pressures decrease to the extent observed here

  - Pulse Fade – what effect does the enlarged thoracic cavity have on the heart and large heart blood vessels?
    - Decreases their pressure
      » Pulsus Paradoxus – a drop in BP, >10 mmHg, upon inspiration (also seen in cardiac tamponade)
      » In this case a sign of severe respiratory distress

- Why were her lips and nail beds bluish?

  - Cyanosis – occurs when more than 5 gm of unoxygenated Hb is present in arterial blood
Mechanics of Ventilation

- Why could she only whisper intermittently and why was she wheezing?
  
  • Whisper
    
    - Decreased velocity of air flow upon expiration over the vocal cords
  
  • Wheezing
    
    - Increased velocity of air past narrow bronchiole lumen

- Why encourage her to breath more slowly?
  
  • When excited breaths become quick and shallow, not the most efficient mechanism for breathing efficiently
Mechanics of Ventilation

- Why did she lose consciousness?
  - Purpose of breathing
    - At rest to supply the body with the 250 ml of O$_2$ it needs per minute
    - With Mrs. S.’s labored breathing she has increased her CO in an attempt to supply the muscles of respiration with additional O$_2$
    - With increased metabolism Mrs. S.’s muscles were also producing large amounts of CO$_2$
  - Oxygenation
    - Brain cells are especially sensitive to lack of oxygen
      » Respond after 10 seconds
      » Die after 5 minutes, demonstrates the need for rapid CPR
    - Pupil diameter used to assess brain damage
    - Without O$_2$ ATP synthesis decreases greatly affecting the sodium potassium pump
Mechanics of Ventilation

- Removal of CO$_2$
  
  - Why didn’t Mrs. S. regain consciousness upon the administration of O$_2$ in ICU?
    
    » High levels of CO$_2$ acts like an anesthetic
    
    » Although her levels of O$_2$ were being restored, her levels of CO$_2$ were actually increasing