Chapter 23
Respiratory System

I. Functions of the Respiratory System
A. Respiration
   1. ventilation - mechanical process of moving air in and out of lungs
   2. Gas exchange (oxygen and CO₂)
      a. External respiration - gas exchange between air and blood
      b. Internal respiration - gas exchange between blood and tissue.
B. pH regulation (regulation of CO₂)
C. Olfaction
D. Temperature regulation (Rover and spot)

II. Structures associated with the respiratory system and their functions
A. Nose - nares
   1. Initial filtration of air
   2. Nasal bones, septal cartilage, alar cartilage
B. Nasal cavity
   1. Nasal Septum - divides nasal cavity into 2 lateral halves.
      a. Vomer, ethmoid, septal cartilage
   2. Mucous epithelium (pseudostratified ciliated columnar cells and goblet cells)
   3. Nostril - anterior opening
   5. Conchae
   6. Meatuses
C. Functions of Nasal cavity
   1. Important when mouth is full
   2. Cleans, warms and humidifies air
      a. Filtration:
         (1) hairs (vibrissae) in nose trap / filter large particles of dust.
         (2) conchae increase air turbulence increase chance that particles will
             stick to mucous membrane - mucous is swept backwards and
             swallowed.
      b. Humidification
         (1) moisture from mucous epithelium / excess tears
      c. Warms air.
         (1) nasal cavity is highly vascular
         (2) Prevents damage to lungs.
   3. Olfaction
      a. Olfactory epithelium - upper medial portion of nasal cavity
   4. Resonating chamber for voice
D. Opening into the nasal cavity
1. Paranasal ducts - from paranasal sinuses (frontal, ethmoid, maxillary, and sphenoidal sinuses)
2. Nasolacrimal ducts - (enters below inferior conchae)
3. Auditory (eustation) tubes - middle ear (enters in nasopharynx)

E. Pharynx
1. Common opening to digestive and respiratory system’
2. 3 parts to pharynx
   a. nasopharynx
      (1) Eustatian (auditory) tubes open into nasal pharynx
   b. oropharynx
      (1) soft palate
      (2) uvula
      (3) fauces
   c. laryngopharynx
3. Tonsils - lymphatic tissue - defend body from infection (3 tonsils)
   a. pharyngeal tonsils - nasopharynx
      (1) adenoid - enlarged pharyngeal tonsil
      (2) can interfere with breathing
   b. Lingual tonsil - base of tongue
   c. Palatine tonsil - lateral portion of fauces (opening of oral cavity into oropharynx)

F. Larynx
1. Cartilage (9 segments) of hyaline
   a. thyroid cartilage
   b. arytenoid cartilage (ladle shaped)
   c. cricoid cartilage
2. Epiglottis
   a. Elastic cartilage
   b. swallowing, prevents food from entering larynx
3. Vocal folds
   a. False vocal cords (vestibular folds) - prevent food and liquid from entering larynx.
   b. true vocal cords
      (1) elastic ligaments
      (2) laryngitis - inflammation of larynx
         (a) Cause - viral infection, breathing toxic substances (smoke)
4. Glottis (opening between vocal folds)
5. Function of larynx
   a. Maintain an open passage for air
   b. Prevention of food entering trachea (epiglottis and vestibular fold)
c. Sound production
   (1) Air passing vocal cords causes them to vibrate
   (2) Pitch is regulated by varying the length/tension of the vocal cords.
      (a) Skeletal muscle attaches to cords arytenoid to thyroid cart.
   (3) Amplitude/loudness is regulated by the amount of air going over the cords.
   (4) Sound is modified by the tongue, lips and teeth

G. Trachea
1. Approx. 4 in long and 1 in. In diameter.
2. Hyaline cartilage rings
   a. Protect trachea and maintain open airway.
   b. Fibrous connective tissue posterior
3. Smooth muscle (trachealis)
   a. Narrows the passageway during coughing
4. Pseudostratified epithelium lining with goblet cells
   a. Propel mucus, etc. to pharynx to be swallowed
5. Heimlich maneuver - dislodge foreign object from air passage
6. Intubation
   a. Cricothyrotomy - tube between cricoid and thyroid cart.
   b. Tracheostomy - opening in trachea (covered by thyroid etc.)

H. Bronchial tree - Conducting Zone
1. Bronchi - primary, secondary, tertiary
   a. Carina - strong cough reflex, foreign objects that pass don't generally cause coughing
2. Bronchioles
   a. Cartilage rings replaced by plates and gradually disappear
   b. Amount of smooth muscle increases.
3. Terminal Bronchioles
   a. No cartilage only smooth muscle
   b. Asthma- constriction of smooth muscle primarily in terminal bronchioles

I. Respiratory Zone -
1. Respiratory bronchioles - limited gas exchange
2. Alveolar ducts - branching hallways.
3. Alveolar sacs - simple cuboidal epi.
4. Alveoli -
   a. Type I alveolar cells (simple squamous epithelium, gas exchange)
   b. Type II alveolar cells (simple cuboidal epithelium, septal cells)
      (1) Secrete surfactant
         (a) lipoprotein molecule
         (b) reduces surface tension of water by preventing formation of
hydrogen bonds in alveoli (water wants to form a droplet without surfactant.)
(c) Lack of surfactant (esp. Premature babies < 7 months) hyaline membrane disease or respiratory distress syndrome (RDS) or infant RDS
  i) lungs tend to collapse
  ii) inadequate ventilation - labored breathing (fatigue)
  iii) treated by oxygen pressure (inflates lungs) and artificial surfactant.
  iv) Treat mother with glucocorticoids - precursor to surfactant.
  v) 65,000 premature babies / year in U.S.
     a) 10% die. Surfactant reduced this number by 1/2.

c. Elastic fibers surround each alveoli
   (1) expand during inspiration, recoil during exhalation.
d. Debris removed by macrophages.

J. Lungs.
  1. Lobes
     a. right = 3 lobes
     b. left = 2 lobes - smaller than right.
  2. Base, apex, costal surface.
  3. Hilum - entry of bronchi, blood vessels, lymphatic vessels
  4. Mediastinum - Middle wall of thoracic cavity - separate pleural cavities
     a. Filled with heart, trachea, blood vessels, etc.
  5. Pleura
     a. Visceral pleura (on surface of lung)
     b. Parietal pleura (lines thoracic cavity)
        (1) intrapleural “space”
        (2) Pleural cavity
        (3) pleural fluid
           (a) lubrication,
           (b) hydrogen bonding between pleural membranes (fluid and glass)
        (4) Pleurisy - inflammation of the pleura

III. Mechanics of Breathing
A. Inspiration
  1. Ventilation - process of moving air into and out of the lungs.
     a. **Flow** requires a pressure gradient
     b. \[ F = \frac{P_1 - P_2}{R} \]
        \[ F = \text{flow}, \quad P = \text{pressure at one point}, \quad R = \text{resistance}. \]
c. Air moves through tubes because of pressure difference.
d. Flow of air decreases as the resistance increases.
   (1) Resistance increases as the radius (r) of the passageway decreases.
      (a) small change in radius results in a large change in resistance \( R = 1/r^4 \).
   (2) Asthma - constriction of bronchioles
   (3) Emphysema - obstruction of bronchioles due to inflammation or collapse.

2. **Barometric Air Pressure** \( (P_B) \) Atmospheric pressure outside of the body is assigned a value of 0.
a. Atmospheric pressure at sea level (760 mmHg or 760 Torr)
b. ~640 mmHg at our altitude

3. Pressure - volume relationships (Boyle’s law) - inverse proportion relationship
a. \( P = 1/V \) or \( V = 1/P \)
b. \( P = nRT \)
   \( P = \) pressure, \( n = \)gram moles of gas, \( R = \) gas constant, \( T = \) temp, \( V = \) volume
   
   c. \( n, R \) and \( T \) are all considered constant within the body.

4. Movement of Air in and out of body
a. Increased thoracic vol \( \rightarrow \) decreased intrathoracic pressure (less than atmospheric pressure) and air rushes in to fill the void.

5. Muscles of inspiration
a. Diaphragm (phrenic nerve)
b. External intercostals (intercostal nerves) - pull ribs up and out.
c. Sternocleidomastoid, scalenus, petroalis minor

6. Mechanism of inspiration
a. Contraction of muscle of inspiration
b. Decreased intrathoracic / pleural pressure
   \( (1) \) The lungs expand because they adhere to the thoracic wall
   \( (2) \) a decrease in pleural pressure causes the alveoli to expand.
   \( (3) \) The greater the difference in pressure between the pleural cavity and the alveoli the greater is the force of expansion
   
c. Atmospheric pressure forces air into lungs.

**B. Expiration (exhalation)**
1. Intrathoracic pressure will exceed atmospheric pressure
2. Passive breathing (at rest)
a. Elastic recoil (elastic C.T. in lungs and chest wall)
   \( (1) \) The tendancy for the lungs to recoil increases as the lungs are stretched. (Similar to rubber band)
(2) elastic recoil causes the alveoli to collapse,
  (a) decrease in alveolar volume  
  (b) increase in alveolar pressure  
  (c) air flows out.
(3) collapse is caused by elastic fibers in alveolar walls.
  b. Abdominal pressure (recoil as diaphragm relaxes)

3. Active or Forced expiration
  a. Elastic recoil
  b. Internal intercostals - pull ribs down and in.
  c. Abdominal muscles (increase abdominal pressure)

IV. Measuring Lung Function

A. Used to assess lung function.
  1. Used to diagnose disease, or track recovery form disease.

B. Compliance: Measure of the ease with which the lungs and thorax expand.
  1. Greater compliance - easier it is for a change in pressure to cause expansion of the lungs and thorax.
  2. Lower compliance - harder to expand lungs and thorax
     a. Low compliance causes a marked increase in total amount of energy required for ventilation.

3. Factors that affect compliance:
  a. Deposition of inelastic fibers in the lung
     (1) Pulmonary fibrosis -
         (a) Replacement of lung tissue with fibrous connective tissue
         (b) Causes by exposure to asbestos, coal dust.
     (2) Cystic fibrosis
         (a) genetic disease which causes thick mucous build up in the lungs
         (b) due to decrease Cl- ion diffusion out of tissue. Tissue becomes dehydrated.
  b. Collapse of alveoli
     (1) respiratory distress syndrome - collapse of alveoli due to increases surface tension (lack of surfactant) -
     (2) pulmonary edema - increased water in lungs causes collapse of alveoli
     (3) Emphysema -
         (a) destruction of lung elastic tissue and alveolar walls reduces elastic recoil.
         (b) edema of tissue usually due to smoking
         (c) excessive coughing to remove mucous causes the alveolar walls to break down.
c. Increased resistance to air flow caused by airway obstruction
   (1) Asthma, bronchitis - constriction of bronchioles which increases resistance to air flow.
   (2) Kyphosis or scoliosis - deformities of thoracic wall that reduce the ability of the lung to increase size.

C. Pulmonary Volumes and capacities
   1. Spirometry - process of measuring volumes of air that move in and out during respiration
   2. Measured Volumes:
      a. Tidal
      b. Inspiratory reserve
      c. Expiratory reserve
      d. Residual
   3. Pulmonary capacities: sum of two or more volumes.
      a. Inspiratory capacity
      b. Functional residual capacity
      c. Vital capacity
      d. Total lung capacity
   4. Factors that effect respiratory volumes and capacities include:
      a. Age, gender, body size, physical condition.
         (1) Female vital capacity is ~25% less than male.
         (2) Thin people have a greater capacity than obese people
         (3) Athletes - 30-40% increase
         (4) Compliance factors also effect capacities
   5. Forces expiratory vital capacity
      a. Measures rate at which air can be expired
         (1) Decreased by:
            (a) pulmonary fibrosis - inability of lungs to deflate
            (b) Kyphosis, scoliosis - decreased ability of thoracic cavity to compress
            (c) Asthma, ephysema - airway obstruction.
   6. Minute Respiratory ventilation
      a. Respiratory rate: number of breaths / minute
         (1) ~12 breaths / minute
      b. Minute ventilation = resp. rate X tidal volume.
         (1) 12 breaths/min X 500 ml = 6 liters / min.
c. Dead space - volume of air not used for respiration.
   (1) **Anatomic dead space** - nasal cavity, pharynx, larynx, trachea, bronchi, bronchioles and terminal bronchioles. (~150 ml)
   (2) **Physiologic dead space** = anatomic dead space + volume in alveoli in which gas exchange is less than normal.
      (a) i.e decreased surface area in emphysema due to deterioration of alveolar walls.

d. Alveolar ventilation:
   (1) Inspired air fills the dead space first before reaching the alveoli.
   (2) \( V_A = f (V_T - V_D) \)
      (a) \( V \) - ventilation, \( A \) - alveolar, \( T \) - tidal vol., \( D \) - dead space.
      (b) frequency

V. **Gas Exchange**

A. Between alveoli and blood

B. **Partial pressure**: measure of the concentration of gases
   1. Components of air (Dry):
      a. Nitrogen: 79%
      b. Oxygen: 21%
      c. \( \text{CO}_2 \): .04%
      d. \( \text{H}_2\text{O} \): 6% if humidified

C. Diffusion of Gas through a membrane
   1. Respiratory membrane: 300 million alveoli, diameter .25 mm
   2. Alveolus is surrounded by a network of capillaries
      a. Air is separated from pulmonary capillaries by a thin respiratory membrane.
      b. Respiratory membrane consists of:
         (1) Thin layer of fluid lining alveolus
         (2) alveolar epithelium (sse)
         (3) basement membrane
         (4) thin interstitial space
         (5) basement membrane of capillary
         (6) capillary endothelium.
   3. Factors that influence the rate of gas diffusion across respiratory membrane
      a. Thickness of Respiratory membrane
         (1) Increased thickness decrease rate of diffusion
         (2) Inflammation of lungs increases thickness
            (a) tuberculosis, pneumonia,
      b. Diffusion Coefficient
         (1) measure of how easily a gas diffuses through a liquid or tissue
         (2) \( \text{CO}_2 \) diffuses through the resp. memb. 20 times easier than \( \text{O}_2 \).
(3) Oxygen capacities are diminished by Disease: Oxygen therapy
c. Surface Area
(1) Surface area of normal lung ~ 70 m².
(2) Decreases of 1/3 may effect normal breathing
   (a) Causes:
      i) removal of lung, cancer, tuberculosis, degeneration of
         alveolar walls,
      ii) conditions that cover the alveoli with fluid - pneumonia,
         pulmonary edema,
d. Partial pressure difference.
   (1) difference of gas across the respiratory membrane is the difference
      between the PP of gas in alveoli compared to PP of gas in capillary
      (a) Gas moves from area of greater PP to lesser PP.
      (b) PO₂ is greater in alveoli
      (c) PCO₂ is greater in blood
      (d) result: O₂ in, CO₂ out.

VI. Oxygen and CO₂ transport in the blood
A. O₂ and CO₂ diffusion gradients-
   1. Oxygen diffuses into the blood and CO₂ diffuse into the alveoli because of
      differences in PP.
   2. As a result of diffusion the PO₂ in the blood is equal to the PO₂ in the
      alveoli and the P CO₂ in the blood is equal to the PCO₂ in the alveoli.
   3. The PO₂ of blood in the pulmonary veins is less than in the pulmonary
      capillaries because of mixing with shunted blood from bronchi and
      bronchioles.
   4. Oxygen diffuses into the tissue and CO₂ diffuse out of the tissue becasue of
      differences in partial pressure.
   5. As a result of diffusion, the PO₂ in the blood is equal to the PO₂ in the tissue
      and the PCO₂ in the blood = the P CO₂ in tissue.
B. Hemoglobin and Oxygen transport
   1. 98.5% of the oxygen transported in the blood is transported by hemoglobin
   2. Saturation of hemoglobin (occurs when all of the hemoglobin is bound to
      oxygen)
   3. Oxygen - Hemoglobin dissociation curve. (At rest and during exercise)
      Figure 23.16 and 23.17
      a. 104 mmHg (PO₂ in pulmonary cap.) = 98% saturation of Hemoglobin
      b. 80 mmHg = 95% saturation
      c. 40 mmHg (tissue level at rest) = 75% saturation (23% released)
      d. 25 mm Hg (exercising muscle level) = 25% saturation (73% released)
e. When oxygen needs of the tissue increase, blood $PO_2$ decreases and more oxygen is released from hemoglobin for use by the tissue.

4. Other factors that influence the oxygen-hemoglobin dissociation curve.
   a. pH - (Christian) Bohr effect
      (1) Decrease in pH causes Hb oxygen saturation to go down.
      (a) $H^+$ binds to Hb changing the configuration causing increased release of oxygen from Hb
      (b) pH near working muscles will be lower due to lactic acid buildup etc. - resulting in increase oxygen release.
   b. $CO_2$
      (1) Increase in $CO_2$ causes a decrease in Hb binding ability of oxygen.
      (2) Occurs because of $CO_2$ effect on pH
      (3) $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$
      (a) $H_2CO_3$ - carbonic acid
      (b) $HCO_3^-$ - bicarbonate
      (4) At tissue the $CO_2$ level is high causing a decrease in the binding affinity of Hb for oxygen
      (a) result: more $O_2$ is released in tissue
      (5) At lung $CO_2$ decreases resulting in an increase in the binding affinity for $O_2$
      (a) result: more $O_2$ is taken up.
   c. Temperature
      (1) Increased temperature cause decreased $O_2$ binding.
      (a) increased temp = increased metabolism = increased $O_2$ consumption = increased $O_2$ release in tissue
   d. Shift in the dissociation curve.
      (1) As Hb affinity for $O_2$ decreases it causes a shift in the dissociation curve to the right
      (2) Exercise
         (a) **Tissue**: ↑$CO_2$, ↓acids (↓pH), ↑temp causes a shift in the oxygen dissociation curve to the right releasing more oxygen at the same partial pressure.
         (b) **Lungs**: ↓$CO_2$, ↑acids (↑pH), ↓temp shifts the curve to the left.
      (3) At rest there are 5 ml $O_2$ / 100ml blood transported to tissue.
         (a) Cardiac output of 5000 ml / min. = 250 ml $O_2$/min. to tissue.
      (4) Exercise results in a 15 fold increase
         (a) 3X due to increase in $O_2$ release at tissue
         (b) 5X due to increased cardiac output
         (c) results in the ability to carry 3750 ml $O_2$ / min
         (d) Train athletes may carry as much as 5000 ml $O_2$ / min
C. Transport of Carbon Dioxide

1. 3 ways CO₂ is transported
   a. **7% is transported free in the plasma**
   b. **23% is transported with blood proteins** such as hemoglobin
      (1) Hb that has released O₂ has a greater binding affinity for CO₂
          (Haldane effect)
   c. **70% is transported as bicarbonate (HCO₃⁻)**
      (1) CO₂ + H₂O ↔ H₂CO₃ ↔ HCO₃⁻ + H⁺
          (a) H₂CO₃ - carbonic acid
          (b) HCO₃⁻ - bicarbonate
          (c) *Catalyzed by carbonic anhydrase.
      (2) Chloride shift -
          (a) HCO₃⁻ - is exchanged for Cl⁻ maintaining an electrical ion
              (charge) balance.
          (b) Hb binds to H⁺ preventing large swings in pH.
          (c) Result of the Cl⁻ shift is that CO₂ is transported as HCO₃⁻ in
              the blood.
      (3) Tissue: CO₂ is taken up by RBC and converted to HCO₃⁻ and
          HCO₃⁻ is exchanged for Cl⁻ and HCO₃⁻ is transported in the plasma
          to the lungs
      (4) Lungs: CO₂ leaves RBC, carbonic acid decrease and HCO₃⁻
          combines with H⁺ (released from Hb) to make more carbonic acid
          and Cl⁻ ions are exchanged for more HCO₃⁻ to maintain the
          electrical balance of the cell.

VII. Control of Ventilation

A. Anatomy of ventilation control

1. Ventilation is controlled by neuronal nuclei within the **pons and medulla**
2. **Medullary respiratory center**
   a. **Dorsal resp group**
      (1) most active during inspiration
      (2) stimulates the diaphragm (ext. intercostals)
   b. **Ventral resp. group**
      (1) active during both inspiration and expiration
      (2) simulates ext. and int. intercostals and abdominal muscles.
3. **Pontine respiratory group**
   a. Plays a role in switching between inspiration to expiration

B. Rhythmic ventilation

1. **Starting inspiration**: Medulla monitors blood gas levels, blood temp. and
   muscle movements and receives input from cortex for voluntary control of
resp. and emotions which effect respiration.

a. Medulla combines input from all of these source to determine when inspiration should begin.

2. **Increased inspiration**: (2 sec) causes more and more neurons to be activated sending more stimulation to the medulla as the lungs expand.

3. **Stopping inspiration**: (3 sec) when input from stretch receptors in the lungs reaches a threshold level the neurons in the medulla that stimulate inspiratory muscles are inhibited and the muscles relax resulting in expiration. (Hering - Breuer Reflex - prevents over inflation of lungs)

### C. Modification of Ventilation

1. **Cerebral control**
   a. We can consciously control the rate and depth of respiration
   b. Conscious control will be overridden when CO₂ levels drop (Holding your breath)
   c. Hyperventilation: decreases CO₂ levels causing vasodilation of peripheral vessels and a decrease in blood pressure resulting in a dizzy giddy feeling as blood flow to the brain decreases.
   d. Strong Emotions - hyperventilation, sobs and gasps of crying.

2. **Chemical control**
   a. Respiratory centers monitor blood O₂, CO₂, and pH.
   b. Chemoreceptors.
      1. ventral resp centers of medulla
      2. carotid and aortic bodies

3. **Other factors that affect ventilation**
   a. Higher center of the brain (voluntary control of breathing)
   b. Emotional stimuli - act through the limbic system
   c. Peripheral chemoreceptor
   d. Central chemoreceptors
   e. Hering- Breuer reflex (stretch receptors in the lungs prevent over inflation)
   f. Proprioceptors in muscle and joints
   g. Receptors for touch, pain, temperature.
   h. Centers in the medulla determine basic rhythm