TOPIC 18: RESPIRATORY SYSTEM: MECHANICS

I. Structure of Respiratory system

A. Airways: Tubes that carry air between environment and alveoli (Fig 16.2 & 16.3)
1. nasal passages
2. pharynx (throat)
3. trachea (windpipe); fairly rigid structure (made of cartilage)
    a) larynx (voice box) at entrance to trachea
4. trachea splits into right and left bronchi, which enter right and left lung, respectively. Bronchi are fairly rigid (made of cartilage)
5. bronchi branch into bronchioles, which are smooth muscle instead of cartilage & so are flexible

B. Alveoli: location of gas exchange with blood (Fig 16.2 & 16.3)
1. Clusters of thin walled, inflatable, grapelike sacs at the terminal branches of the bronchioles
2. Walls consist of single layer of Type I alveolar cells
3. Type II alveolar cells secrete pulmonary surfactant which reduces surface tension in alveoli and keeps lungs from collapsing.
4. Surrounded by pulmonary capillaries (Fig 16.5)
5. NOTE: ***thinness*** of walls of each alveolus, and ***huge surface area*** (75 m^2) of all alveoli, greatly ***facilitates diffusion*** of gases.

C. Lungs and Chest cavity (Fig16.2)
1. Two lungs, each supplied by one of the bronchi.
2. Lungs composed of bronchi, bronchioles, and alveoli, plus lots of elastic connective tissue
3. Lungs are smaller than the thoracic cavity, but occupy most of it. Two factors keep lungs close to thoracic wall (Fig 16.8)
    a) Intrapleural fluid is “sticky” in the same way that water is sticky when it holds two thin glass microscope slides together. You can move the slides back and forth against each other, but it is difficult to pull them apart. Likewise, the intrapleural fluid allows movement of lungs along chest wall, but keeps the lungs “stuck” to the chest wall.
    b) The intrapleural pressure is 756 mm Hg and the intra-alveolar pressure is 760 mm Hg when equilibrated with atmospheric pressure. This transmural pressure gradient across the lung wall is crucial in expanding the lung to fill the chest cavity.
4. Rib cage provides bony protection for lungs and heart
5. Diaphragm forms the floor of the chest cavity.

II. Respiratory Cycle (Fig 16.11 & 16.12 & 16.13)

A. Pressure Considerations
1. Air moves from a region of high pressure to low pressure; it flows down a pressure gradient. ***Air flows in and out of the lungs by reversing pressure gradients between lungs and environment!***
2. Important pressures related to respiration

a) Atmospheric (barometric) pressure: pressure exerted by weight of air in atmosphere on objects on earth's surface. At sea level, it is 760 mm Hg.

b) Intra-alveolar pressure (sometimes called intrapulmonary pressure) is the pressure within the alveoli. Whenever intra-alveolar pressure does not equal atmospheric pressure, air will move down its pressure gradient until intra-alveolar pressure equals atmospheric pressure

c) Intrapleural pressure (also called intrathoracic pressure) is the pressure exerted outside the lungs **within** the thoracic cavity. Usually just less than intra-alveolar pressure and atmospheric pressure, averaging about 756 mm Hg. Because thoracic cavity is closed to the outside, air can not move down pressure gradient into thoracic cavity.

B. Respiration works by changing the volume of the chest cavity, which changes the volume of the lungs, which changes the pressure in the lungs, and then air moves along its pressure gradient

C. Before the start of inspiration (taking a breath), respiratory muscles are relaxed, intra-alveolar pressure = atmospheric pressure, and no air is flowing.

D. At onset of inspiration, inspiratory muscles (primarily the diaphragm) contract, which results in enlargement of the thoracic cavity.

E. As the thoracic cavity enlarges, the lungs are forced to expand to fill the larger cavity. As the lungs enlarge, the intra-alveolar pressure drops because the same number of air molecules now occupy a larger lung volume.

F. Because the intra-alveolar pressure is less than atmospheric pressure, air follows its pressure gradient and flows into the lungs until no further gradient exists (ie, the intra-alveolar pressure again equals atmospheric pressure).

G. THUS LUNG EXPANSION IS **NOT** CAUSED BY THE MOVEMENT OF AIR INTO THE LUNGS; INSTEAD, AIR FLOWS INTO THE LUNGS **BECAUSE OF THE FALL IN INTRA-ALVEOLAR PRESSURE** BROUGHT ABOUT BY LUNG EXPANSION!

H. Deeper inspirations are accomplished by contracting inspiratory muscles more forcefully, and by using accessory inspiratory muscles to enlarge the chest cavity further.

I. At the end of inspiration, the inspiratory muscles relax, the chest cavity returns to original size, and the lungs return to original size. As they do so, the intra-alveolar pressure increases as the same number of air molecules now occupy a smaller volume. The air in the lungs then moves down its pressure gradient and expiration occurs until intra-alveolar pressure equals atmospheric pressure.

J. Although at rest expiration is a passive process, during exercise it is an active process and expiratory muscles (primarily abdominal muscles) contract to decrease the size of the chest cavity during expiration.

III. Airway Resistance (Fig 16.14)

A. Similar to cardiovascular system, resistance plays a role in determining airflow rates. An increase in airway radius decreases resistance and increases airflow rate. A decrease in airway radius increases resistance and decreases airflow rate.

- B. Parasympathetic stimulation causes bronchoconstriction.
- C. Sympathetic stimulation causes bronchodilation.
  - 1. Useful in fight or flight
  - 2. Useful in clinical treatments: administration of epi in a person with bronchial spasms can alleviate the problem.
- D. Matching blood flow and air flow: Need to have a good match between air flow and blood flow in the alveoli to avoid buildup of CO_2 or lack of O_2
  - 1. Large Blood Flow & Small Airflow
    - a) Too much CO_2 in alveolus, too little O_2 for blood to pick up.
    - b) Local control: the buildup of CO_2 and lack of O_2 cause
      - (1) vasoconstriction to reduce blood flow
      - (2) bronchodilation to increase airflow
  - 2. Small Blood Flow & Large Airflow
    - a) Too little CO_2 in alveolus, too much O_2 for blood to pick it all up
    - b) Local control: the lack of CO_2 and buildup of O_2 cause
      - (1) vasodilatation to increase blood flow
      - (2) bronchoconstriction to decrease airflow

IV. Volume, Capacity & Ventilation

- A. Important volumes (given for healthy young males)
  - 1. Max air that lungs can hold: 5700 ml (4200 ml in females)
  - 2. Air still in lungs after normal expiration at rest: 2200 ml
  - 3. Air in lungs after normal inspiration: 2700 ml
  - 4. Tidal volume (volume of air entering / leaving in a breath): 500 ml
  - 5. Air **still** in lungs after MAXIMAL expiration: 1200 ml
- B. Ventilation
  - 1. pulmonary ventilation = tidal volume x respiratory rate
  - 2. resting conditions:
    - a) 500 ml/breath x 12 breaths/min = 6000 ml/min
  - 3. Anatomical dead space: only air that reaches the alveoli is available for gas exchange; the air that stays in conducting airways is useless for gas exchange. This volume, called anatomical dead space, is about 150 ml.
    - a) This means that of the 500 ml of air inspired per breath, only 350 ml is actually used for gas exchange
  - 4. So, what's really important is alveolar ventilation.
    - a) alveolar ventilation = (tidal volume - dead space) x respiratory rate
    - b) (500 ml/breath - 150 ml dead space) x 12 breaths/min = 4200 ml/min
  - 5. Slower deep breaths vs. Rapid shallow breaths
    - a) Table 16.1
    - b) Deep breaths are more effective than rapid shallow breaths.

V. Control of Respiration: Rhythmic breathing pattern

- A. Cardiac vs. Respiratory Systems
  - 1. Recall that the heart is autorythmic, and that input from the nervous system is only required to modify the rate and strength of cardiac contraction. This is NOT the case in the lungs; CNS input is REQUIRED for breathing to occur at all.

B. Area of brain involved in control of rhythmic breathing
   1. Brain Stem
      a) Medullary respiratory center is responsible for
         (1) basic rhythm of inspiration
         (2) origin of nerves that supply the inspiratory muscles for normal breathing
         (3) origin of nerves that supply inspiratory and expiratory muscles used for high rates of ventilation
      b) apneustic and penumotaxic centers in pons of brain stem are positive and negative systems that finely regulate action potentials in inspiratory neurons to ensure smooth breathing

C. Voluntary control
   1. Voluntary control of breathing is accomplished by the cerebral cortex which sends impulses directly to the motor neurons in the spinal cord that supply the respiratory muscles.