Chapter 16 The Respiratory System: Pulmonary Ventilation

- Overview of Respiratory Function
- Anatomy of the Respiratory System
- Forces for Pulmonary Ventilation
- Factors Affecting Pulmonary Ventilation
- Clinical Significance of Respiratory Volumes and Air Flows

16.1. Overview of Respiration Function

- The main function of the respiratory system is to deliver oxygen to the cells to fuel cell respiration and remove carbon dioxide from cells.
  - Internal respiration = cellular respiration
  - External respiration = Exchange of oxygen and carbon dioxide between atmosphere and body tissues

Other functions of the respiration
- Acid-base balance regulation
- Vocalization
- Immune
- Water and heat loss
- Increase venous returned via respiratory pump
- Activation of certain plasma protein

Internal Respiration = Cellular respiration (Figure 16.1)
External Respiration Processes (Figure 16.1)

1) ___________ ________________= movement of the air into the lung (inspiration) and out of the lung (expiration)
2) ______ ________between lungs and blood
3) ______ and ____ _______in blood
4) Gas exchange between blood and body tissues

16.2 Anatomy of the Respiratory System

The Components of the Respiratory System (Figure 16.2)
- Upper airways: Air → nasal cavity → pharynx
- The respiratory tract is divided to two zones
  - The ________________ zone and the ________________ zone
    - Pharynx → larynx → trachea → bronchi → lungs (thoracic cavity → bronchioles → alveoli)
  - Lungs are major organs of the respiratory system.
    - Lungs are located inside the air tight chest wall and surrounded by pleura sacs.
    - Intrapleural space filled with 15 ml intrapleural fluid.
Features of the Conducting Zone (Figure 16.3)

- The upper part of the respiratory tract with 150 mL volume = dead space volume
- _______ prevents food from getting to the opening of trachea called glottis
- The epithelium lining in the larynx and trachea contains
  - _______ cells secrete mucus to trap foreign molecules
  - _______ cells move particles toward mouth via mucus escalator
- Accumulation of mucus in airway provide breeding ground for bacterial growth
  - Smoker’s cough: Smoking paralyzes cilia therefore disables mucus escalator. Mucus is coughed out of airways
- At levels below bronchioles, macrophages clean foreign invaders
  - Ciliated cells and goblet cells becomes less abundant
- Cartilage is present in the walls of trachea and bronchi to provide structural support; and it becomes less abundant as the diameter of the bronchi decreases
- Smooth muscle is less abundant in the upper conducting zone. The presence of smooth muscle in the walls of the small bronchioles enables them to adjust the air flow.

Functions of the Conducting Zone

- Air passageway for air from the larynx to the lungs
- Increase air temperature to body temperature
- Humidify air
- Remove impurities

Features and Function of the Respiratory Tract (Figure 16.3)

- The site of gas exchange has maximum surface area and minimum thickness.
- It includes the respiratory bronchioles, terminate in alveoli ducts and leads to alveoli.
- Alveoli are microscopic thin-walled air sacs that provide an enormous surface area for _______ 
  - There are 300 million alveoli in the lungs (tennis court size).
  - Rich blood supply—capillaries form sheet over alveoli
  - Alveolar pores connects alveoli that allows equilibration of air pressure in the lungs
  - Type I alveolar cells make up wall of alveoli. They are made of single layer epithelial cells which form respiratory membrane
  - Type II alveolar cells—secrete _______
  - Alveolar macrophages: removes debris and microbes.

Respiratory Membrane (Figure 16.5 d)

- Contains
  - Capillary _______
o Basement membrane
o Alveolar ________________________

• Is very thin and allows rapid diffusion and is the barrier for diffusion

Pulmonary Disorder
• Emphysema is a chronic, progressive condition that destroys alveolar tissue, resulting in fewer, larger alveoli
  o Reduces surface area for gas exchange & ability of bronchioles to remain open during expiration
  o Collapse of bronchiole during expiration causes air trapping, decreasing gas exchange
  o Commonly occurs in long-term smokers
  o Cigarette smoking stimulates macrophages & leukocytes to secrete protein-digesting enzymes that destroy tissue

16.3 Forces for Pulmonary Ventilation

• Air moves in and out of lungs by bulk flow
• ______________ ______________drives flow: Air moves from high to low pressure

Pulmonary pressures
• Ventilation or breathing is driven by ______ ________
• Inspiration—pressure in lungs < atmosphere
• Expiration—pressure in lungs > atmosphere

Four primary pressures (Figure 16.8)
• Atmospheric Pressure ($P_{atm}$) = the pressure of air in the atmosphere
  o 760 mm Hg at sea level
  o Decreases as altitude increases
  o Increases under water
  o Other lung pressures given relative to atmospheric (set $P_{atm} = 0$ mm Hg)
• Intra-alveolar Pressure ($P_{alv}$)
  o $P_{alv}$ = pressure of air within the alveoli
  o $\Delta p$ between $P_{alv}$ and $P_{atm}$ drives ventilation
  o Varies with phase of respiration
    ▪ During inspiration = negative
    ▪ During expiration = positive
    ▪ At rest, $P_{alv} = P_{atm} = 0$ mmHg
• Intrapleural Pressure ($P_{ip}$) = Pressure inside pleural space
  o Always negative under normal conditions due to elasticity in lungs and chest wall
    ▪ Always less than $P_{alv}$
    ▪ Varies with phase of respiration
    ▪ At rest, -4 mm Hg, keeps lungs inflated
    ▪ Opposing pulls on intrapleural space
Surface tension of intrapleural fluid hold wall and lungs together
  - Pneumothorax (Figure 16.9)
    - Caused by the puncture of the chest wall
    - $P_{ip} = P_{atm} = 0$
    - Air in the intrapleural space causes the lung to recoil and collapse

- Transpulmonary Pressure = $P_{alv} - P_{ip}$
  - Distending pressure across the lung wall
  - Increase in transpulmonary pressure
    - Increase distending pressure across lungs
    - Lungs (alveoli) expand, increasing volume

**Mechanics of Breathing**
- Describes mechanisms for creating pressure gradients (force for flow)
- Accomplished by alternately increasing & decreasing volumes of thorax & lungs
- Flow Rate

  $\frac{P_{atm} - P_{alv}}{R}$

  Flow rate =---------------------------

  $R$

  - Atmospheric pressure constant (during breathing cycle)
  - $R$ = resistance to air flow
  - Resistance related to radius of airways and mucus
  - Therefore, changes in alveolar pressure creates and changes pressure gradients
  - Forces for Air Flow

- Boyle’s Law: pressure is inversely related to volume
  - Thus, can change alveolar pressure by changing its volume

  $\frac{nRT}{V}$

  - $N$: is the quantity of gas (mole)
  - $R$: universe gas constant
  - $T$: absolute temperature

- Figure 16.10 Changes in $P_{alv}$ and Breathing Volume
- Determinants of intra-alveolar pressure
  - Quantity of air in alveoli
  - Volume of alveoli
    - Lungs expand—alveolar volume increases $\rightarrow P_{alv}$ decreases $\rightarrow$ pressure gradient drives air into lungs
    - Lungs recoil—alveolar volume decreases $\rightarrow P_{alv}$ increases $\rightarrow$ pressure gradient drives air out of lungs

- Figure 16.13 Volume and Pressure Changes
  - During inspiration, decreased $P_{ip}$ makes transplumary pressure increase therefore lung expand
• Muscles of Respiration during Quiet breathing
  • Quiet inspiration
    o Inspiratory muscles: _______ and _______ __________ increase volume of thoracic cavity
  • Quiet expiration
    o When inspiratory muscles stop contracting, recoil of lungs and chest wall to original positions decreases volume of thoracic cavity
    o __________ caused by the relaxation of inspiration muscles
• Active Expiration
  o Active expiration requires expiratory muscles
    ▪ Internal intercostals
    ▪ Abdominal muscles
    ▪ Contraction of expiratory muscles creates greater and faster decrease in volume of thoracic cavity
• Muscles of Respiration during Deep Breathing
  o Muscles of deep inspiration: sternocleidomastoid, scalenes; external and parasternal intercostals and diaphragm
  o Muscles of deep expiration: internal intercostals; external and internal abdominal oblique; transversus abdominus and rectus abdominis

• Figure 16.12 Events in the process of inspiration

16.4. Factors Affecting Pulmonary Ventilation
• Factors affect pulmonary ventilation: lung compliance and airway resistance

Lung Compliance = \( \Delta V / \Delta (P_{alv} - P_{ip}) \)
  o Larger lung compliance
    ▪ Easier to inspire
    ▪ Smaller change in transpulmonary pressure needed to bring in a given volume of air
• Factors Affecting Lung Compliance
  o Elasticity: More elastic \(\rightarrow\) less compliant
  o Surface tension of lungs
    ▪ Greater tension \(\rightarrow\) less compliant
    ▪ Surface Tension in Lungs
      ➢ Thin layer fluid lines alveoli
      ➢ Surface tension due to attractions between water molecules
      ➢ Surface tension = force for alveoli to collapse or resist expansion
    ▪ To Overcome Surface Tension
      ➢ Surfactant: Secreted from type II cells begin in late fetal life.
      ➢ Surfactant = detergent that decreases surface tension and it prevents surface tension from collapsing alveoli
      ➢ Surfactant increases lung compliance and makes inspiration easier
      ➢ Surfactant consists of phospholipids
      ➢ Premies are often born with immature surfactant system (= Respiratory
Distress Syndrome or RDS) and have trouble inflating lungs
In adults, septic shock may cause acute respiratory distress syndrome (ARDS)
which decreases compliance & surfactant secretion

**Airway Resistance**
- As airways get smaller in diameter they increase in number, keeping overall resistance low
- Pressure gradient needed for air flow thus low~1 mm Hg
- An increase in resistance makes it harder to breathe
- Pressure gradient needed for air flow > 1 mm Hg

*Effects of Airway Resistance Increase (Figure 16.14)*

*Factors Affecting Airway Resistance*
- Passive forces on the airway
  - Changes in transpulmonary pressure during respiratory cycle
  - Tractive forces (pulling action of tissues surrounding the airway)
  - Both decrease resistance during inspiration and increase resistance during expiration
- Contractile activity of smooth muscle
- Mucus secretion

*Role of Bronchiolar Smooth Muscle in Airway Resistance*
- Bronchoconstriction—smooth muscle contracts causing radius to decrease therefore increases the resistance
- Bronchodilation—smooth muscle relaxes causing radius to increase, hence decreases resistance

*Contractile state of bronchiolar smooth muscle under extrinsic and intrinsic controls*

*Extrinsic Control of Bronchiole Radius*
- Sympathetic: relaxation of smooth muscle: Bronchodilation
- Parasympathetic: contraction of smooth muscle: Bronchoconstriction
- Hormonal control: epinephrine : bronchodilation

*Intrinsic Control of Bronchiole Radius*
- Histamine—bronchoconstriction
  - Released during asthma and allergies
  - Also increases mucus secretion
- Carbon dioxide—bronchodilation

*Pathological States that Increase Airway Resistance*
- Asthma is caused by spastic contractions of bronchiolar smooth muscle. It is treated by corticosteroid and other bronchodilators.
- Chronic obstructive pulmonary diseases (COPD)

16.5 Clinical Significance of Respiratory Volumes and Air Flows

Lung volumes and capacities
- Pulmonary function tests
- Alveolar ventilation
- Spirometry (Figure 16.15) measures lung volumes and capacities
- Spirometry measurements (Figure 16.16)
Lung volumes and lung capacities: The total volume contained in the lung at the end of a maximal inspiration is subdivided into volumes and subdivided into capacities.

Lung volumes
- Tidal volume (VT): 500 mL - the amount of air inspired or expired with each normal (resting) breath
- Inspiratory reserve volume (IRV): 3000 mL, after breathing in, volume you can still inspire additionally
- Expiratory reserve volume (ERV): 1000 mL, maximum expiration, after normal expiration, additional volume you can still expire
- Residual volume (RV): 1200 mL the volume left after ERV. This cannot be measured by a spirometer, it is measurable by helium dilution method

Lung capacities
- Total lung capacity (TLC) is the volume of air contained in the lungs after a maximal inspiration. TLC = VT + ERV + IRV + RV
- Inspiratory capacity (IC) is the maximum volume of air can be inspired from the end of a rest expiration. IC = VT + IRV = 3500 mL
- Vital capacity (VC) = maximum volume expired after maximum inspiration. VC = VT + IRV + ERV = 4500 mL
- Functional residual capacity (FRC) = volume remaining after a normal expiration. FCR = ERV + RV = 2200 ml

Obstructive Pulmonary Diseases
- Associated with increased airway resistance
Residual volume increases (harder to expire)
- Functional residual capacity increases
- Total lung capacity increases

**Pulmonary Function Tests** (Figure 16.17):
- Forced Expiratory Volume (FEV) = percentage of FVC that can be exhaled within certain time frame
- FEV₁ = percent of FVC that can be exhaled within 1 second
- Normal FEV₁ = 80%
  - If FVC = 4000 ml, should expire 3200 ml in 1 sec
  - FEV₁ < 80% indicates obstructive pulmonary disease

- **Restrictive Pulmonary Diseases**
  - More difficult for lungs to expand
  - Total lung capacity decreases
  - Vital capacity decreases

- **Minute Ventilation (VE)** = Total volume of air entering and leaving respiratory system each minute
  - Minute ventilation = V̇T x RR
  - Normal respiration rate (RR) = 12 breaths/min
  - Normal tidal volume V̇T = 500 mL
  - Normal minute ventilation = 500 mL x 12 breaths/min = 6000 mL/min

- **Anatomical Dead Space**
  - Air in conducting zone does not participate in gas exchange
  - Thus, conducting zone = anatomical dead space
  - Dead space approximately 150 mL

- **Dead Space and Ventilation** (Figure 16.19)

**Alveolar Ventilation (V̇A)**
- Volume of air reaching the gas exchange areas per minute
  - Alveolar ventilation = (V̇T x RR) - (DSV x RR) = 4200 mL/min = (500 mL/breath x 12 breaths/min) - (150 mL/breath x 12 breaths/min)

- Table 16.1