Pulmonary System

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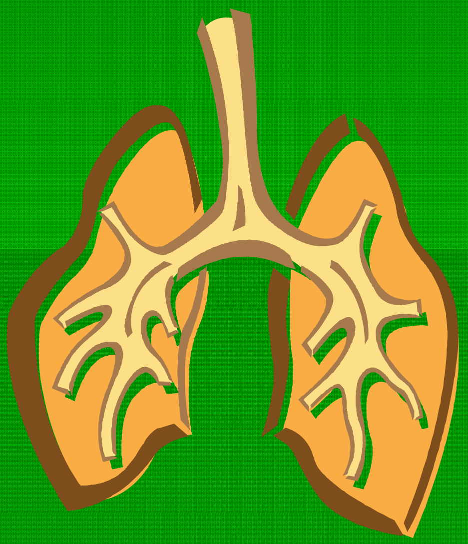
- What is the Function of the Pulmonary System?

Pulmonary Function

- Attain O2 from environment
- Deliver O2 to circulatory system
- Remove CO2 from the body
- Acid-base balance
- Phonation
- Olfaction
- Modification of inspired air
- Pulmonary defense
- Metabolism



PULMONARY FUNCTION

- VENTILATION
  - Moving O_2/CO_2 b/t lungs & environment
- DIFFUSION
  - Moving O_2/CO_2 b/t lungs & capillaries
- TRANSPORT
  - Moving O_2/CO_2 b/t capillaries & tissues
- REGULATION

CONTENTS

- **VENTILATION**
- DIFFUSION
- STRUCTURE & FUNCTION
- PULMONARY FUNCTION TESTS
- MECHANICAL VENTILATION

VENTILATION

What muscles work during normal quiet inspiration?

VENTILATION

- Normal quiet breathing is performed by the diaphragm only.
  - Diaphragm contracts down
  - Lengthens the chest
  - Increases negative pressure
  - Draws air into the lungs

VENTILATION

- What muscles work during normal quiet expiration?

VENTILATION

There are NO muscles that WORK during normal quiet expiration.

Expiration occurs when the diaphragm RELAXES or <u>RECOILS</u> upward

- shortens the chest
- reduces the negative pressure
- expels the air

VENTILATION

What muscles assist with heavy breathing?

VENTILATION

- Rib Cage
  - Natural position: ribs slanted down
  - External intercostal muscles contract→Inspiration
    - Rib cage elevates
    - Pulls the sternum away from the spine
    - Increases the A-P diameter by 20%
  - Internal intercostal muscles contract→Expiration
    - Rib cage depresses
    - Pulls the sternum down
    - A-P diameter decreases

VENTILATION

- Muscles of Heavy Inspiration: Raises the Rib Cage
  - External Intercostals
  - SCM (lifts the sternum)
  - Anterior Serratus (lifts the ribs)
  - Scalene Muscles (lifts 1st two ribs)
- Muscles of Heavy Expiration: Depresses the Rib Cage
  - Abdominal Recti
  - Internal Intercostals

VENTILATION

Muscles can change the shape and therefore the pressure inside the thoracic cavity to assist with breathing

VENTILATION

<u>Pleural Pressure</u>

- Continual suction of excess fluid into lymphatics
- Normally a slightly negative pressure

-5 cm H_20

(The amount required to keep lungs open at the resting level)

- Normal inspiration: ↑ pleural pressure

-7.5 cm H_20

VENTILATION

Alveolar Pressure

Pressure inside the lung alveoli

- With no airflow and open glottis,

  alveolar pressure = atm pressure = 0

- Normal inspiration→ -1 cm H_20
- Normal expiration→ +1 cm H_20

VENTILATION

- Alveolar Pressure change of -1 cm H_20

AND

- Pleural Pressure change of -2.5 cm H_20

→Moves 500 mL air into the lungs

VENTILATION

<u>Transpulmonary Pressure</u>

Alveolar Pressure – Pleural Pressure

Measure of the elastic forces

≈ Recoil Pressure

VENTILATION

What is the measure of how well the lungs expand for the pressure applied?

VENTILATION

COMPLIANCE

- Normal compliance for the lung =

  200 ml / cm H_20

- Two Factors:
  - Elastic Forces of the Lung Tissue
  - Elastic Forces of the Surface Tension

VENTILATION

- Elastic Forces of Lung Tissue
  - only 1/3 contribution to compliance
  - depends on elastin & collagen fibers in the lung parenchyma

VENTILATION

Elastic Forces of Surface Tension

2/3 contribution to compliance

What is Surface Tension?

Water on the surface sticks together by contracting together

ex: Raindrops

VENTILATION

- What about water in the alveoli??

  The thin layer of water inside the alveoli:
  - contracts together
  - tries to push the air out
  - collapses the alveoli

- Surface Tension ≈ Elastic Force

VENTILATION

- What agent decreases the surface tension inside alveoli??

VENTILATION

Surfactant

- Made by Type II alveolar epithelial cells
- Contains: phospholipids, proteins, ions
- Key Ingredients:
  - Dipalmitoylphosphatidylcholine
  - Apoproteins
  - Calcium ions

VENTILATION

- Dipalmitoylphosphatidylcholine:
  - One portion hydrophilic—spreads over alveolar water
  - One portion hydrophobic—orients toward air in alveoli
  - Does not dissolve in fluid
  - Decreases the normal surface tension by 1/12 to 1/2

VENTILATION

- Apoproteins & Calcium ion
  - Alllow phospholipid to spread faster over alveolar surface.
  - Surfactant not functional without them

VENTILATION

- Surface Tension

Pure Water	72 dynes / cm
Alveoli	50 dynes / cm
Alveoli w/ Surfactant	5-30 dynes / cm

VENTILATION

Factors of Inspiration

- Muscles
- Pleural Pressure
- Alveolar Pressure
- Compliance
- Surfactant

Factors of Expiration

- Collapse Pressure
- Surface Tension
- Recoil Pressure
- Muscles

Measures

- Lung Volumes / Capacities
- Minute Ventilation
- Alveolar Ventilation
- Dead Space

VENTILATION

Collapse Pressure

$$= \frac{2 \times \text{Surface Tension}}{\text{Radius}} = 4 \text{ cm } H_20$$

The smaller the alveolus, the greater the collapse pressure

VENTILATION

In premature babies:

- Alveoli are usually ¼ the normal size
- Surfactant is secreted b/t 6th & 7th gestational month
- Therefore, a premature baby could have a collapse pressure of > 30 mm Hg

- RESPIRATORY DISTRESS SYNDROME OF THE NEWBORN

VENTILATION

- Compliance of Lung-Thorax system is = ½ that of lungs alone (200 ml / cm H_20)

110 ml / cm H_20

Therefore, it takes 2x the energy for normal inspiration

VENTILATION

- Compliance Work
- Tissue Resistance Work
- Airway Resistance Work

VENTILATION

- Compliance Work
  - Overcomes elastic forces
  - $= \frac{\Delta \text{ Volume} \times \Delta \text{ Pressure}}{2}$

VENTILATION

- Tissue Resistance Work
  - Overcomes the viscosity of the lungs
- Airway Resistance Work
  - Overcomes resistance to airflow thru respiratory passageways

VENTILATION

- Usually compliance >> airway > tissue resistance work
- Usually there is no work during expiration…
- Heavy Breathing: ↑↑airway resistance work
- Pulmonary disease: all work ↑
- Fibrosis: ↑ compliance & tissue resistance work
- Airway Obstruction: ↑ airway resistance work
- Asthma: ↑ airway resistance work in expiration > inspiration

VENTILATION

- Measurements
  - Volumes (4)
  - Capacities (4)

VENTILATION

- What are the four lung volumes?

VENTILATION

- Tidal Volume (TV or V_T)
  - Normal breath 500 ml
- Inspiratory Reserve Volume (IRV)
  - Maximum Inspiration p V_T 3000 ml
- Expiratory Reserve Volume (ERV)
  - Maximum Expiration p V_T 1100 ml
- Residual Volume (RV)
  - Air left in lungs p ERV 1200 ml

VENTILATION

What are the four lung capacities?

VENTILATION

- Capacities are combos of lung volumes

- <u>Inspiratory Capacity (IC)</u>
  - V_T + IRV 3500 ml
- <u>Functional Residual Capacity (FRC)</u>
  - ERV + RV 2300 ml
- <u>Vital Capacity (VC)</u>
  - IRV + V_T + ERV 4600 ml
- <u>Total Lung Capacity (TLC)</u>
  - IRV + V_T + ERV + RV 5800 ml

VENTILATION

- Minute Ventilation (V_E) = V_T x RR

  Normal = 6 L / min

- Alveolar Ventilation (V_A)
  - Normal tidal volume gets most of the air only to the terminal bronchioles
  - The velocity of the air molecules moving a short distance to the alveoli occurs by diffusion
  - Rate at which new air reaches respiratory bronchioles

VENTILATION

- Alveolar Ventilation

  $= RR \times (V_T - V_D)$

  Normal = 4200 ml / min

  One of the major factors determining concentration of O_2 and CO_2 in the alveoli

VENTILATION

- Dead Space (V_D)
  - <u>Dead Space Air</u>
    - Air that stays in the nose, pharynx, trachea, terminal bronchioles
  - <u>Dead Space</u>
    - Respiratory passages where no gas exchange occurs
    - Normal V_D is 150 ml (increasing with age)

VENTILATION

- Anatomic Dead Space
  - Volume of the respiratory passages not in the gas exchange areas
- Physiologic Dead Space
  - Additional volume of air in gas exchange areas that are not functional

VENTILATION

What conditions can increase the physiologic dead space?

VENTILATION

- Things that decrease perfusion:
  - Pulmonary Embolus
  - Pulmonary HTN
  - Decreased Cardiac Output
  - High PEEP
  - ARDS

  - Causes high P_aCO_2

VENTILATION

- Alveolar Ventilation

$$= RR \times (V_T - V_D)$$

Normal = 4200 ml / min

One of the major factors determining concentration of O_2 and CO_2 in the alveoli

VENTILATION

Factors of Inspiration

- Muscles
- Pleural Pressure
- Alveolar Pressure
- Compliance
- Surfactant

Factors of Expiration

- Collapse Pressure
- Surface Tension
- Recoil Pressure
- Muscles

Measures

- Lung Volumes / Capacities
- Minute Ventilation
- Alveolar Ventilation
- Dead Space

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- **DIFFUSION**
- STRUCTURE & FUNCTION
- PULMONARY FUNCTION TESTS
- MECHANICAL VENTILATION

DIFFUSION

- Gas Exchange between alveoli and capillaries
- Hydrostatic Pressure difference between the apex and the base of the lung

$\approx$ 23 mm Hg difference

DIFFUSION

Three Zones of Blood Flow

- ZONE 1—No Flow: $P_A > P_a$
- ZONE 2—Intermittent Flow: SBP > P_A but DBP < P_A
- ZONE 3—Continuous Flow: $P_a > P_A$

DIFFUSION

- Exercise increases blood flow to the top of the lung ~ 700-800% and to the bottom of the lung ~200-300% creating equalization.
- The entire lung becomes Zone 3 blood flow

DIFFUSION

- V/Q Ratio
  - Usually 0.8 to 1.2
  - If V/Q ratio increases: (vice versa)
    - There is more O2 in the alveoli that are not delivered to the blood volume
    - $\uparrow P_AO_2$ and $\downarrow P_ACO_2$
- Shunt
  - Perfused, but not ventilated
  - Mixed venous blood from the right heart shunted to the left heart without gas exchange
  - Not correct by administration of oxygen

DIFFUSION

- Similar molecular weights b/t O_2 and CO_2
- Diffusion rate of O_2 in the gaseous phase is 1.2 x that of CO_2
- Diffusion rate of CO_2 in the liquid phase is 20 x that of O_2
- CO_2 diffuses until the partial-pressure gradient is equalized
- O_2 diffuses into the blood combining with Hb maintaining the original partial-pressure gradient to saturate all the Hb

DIFFUSION

- Fick's Law
  - Rate of Gas Diffusion =
    Area x Gas Diffusion Coefficient x Pressure Gradient / Barrier Thickness
  - $V_{gas} = \frac{A \times D_{gas} \times \Delta P}{T}$

DIFFUSION

- Easier to measure diffusion capacity of Carbon Monoxide than Oxygen:
  - DL_{CO}
  - Divide uptake of CO by measure P_aCO
  - Based on
    - Diffusing Capacity of Alveolar-Capillary Membrane
    - Hb-CO reaction
    - Pulmonary Capillary Blood Flow

DIFFUSION

- O2 content of blood

$$C_aO_2 = (Hb \times 1.34 \times O_2sat) + 0.0003\ P_aO_2$$

DIFFUSION

- Oxyhemoglobin Dissociation Curve

O_2 % saturation vs P_aO_2

Function of Hb's changing affinity for O_2

Normal p50 = 50% O_2sat ~ 27 mmHg

DIFFUSION

- Right Shift:
  - Low pH
  - High temperature
  - High pCO_2
  - High levels of 2,3-DPG (↓ affinity of Hb for O_2)
  - High ATP

  - Encourages O_2 offloading making it more available for tissue

DIFFUSION

- Alveolar gas equation
  - $P_AO_2 = P_IO_2 – P_ACO_2/0.8 + F$
- A-a gradient equation
  - $P_{(A\text{-}a)}O_2 = P_AO_2 – P_aO_2$

DIFFUSION

- Causes of Hypoxemia
  - V/Q mismatch (most common)
  - Shunt
  - ↓ P_AO_2
  - Hypoventilation
  - ↑ Diffusion gradient

CONTENTS

- VENTILATION
- DIFFUSION
- **STRUCTURE & FUNCTION**
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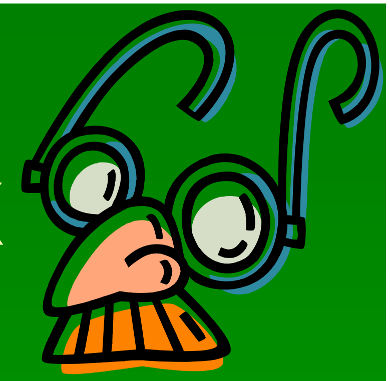
Airways--Nasopharynx



- 10,000 L of Toxic, Infected, Irritating Air
- Functions:
  - Filter
  - Humidify
  - Warm
- SNIFFING: abrupt inspiration allowing olfactory system to detect hazard before full breath

Airways—Tracheobronchial Tree

- 23 Generations of airway branching
  - Conducting Zone: 1-16 generations
  - Transition Zone: 17-19 generations
  - Respiratory Zone: 20-23 generations

- Anatomic Dead Space =
  - Conducting Zone of the airway
  - Nasopharynx, Larynx, Trachea

Tracheobronchial Tree

- Three groups of histology / function
  1. Trachea, major lobar, and segmental bronchi
  2. Membranous and terminal bronchioles
  3. Respiratory bronchioles, alveolar ducts, and alveolar air sacs

Tracheobronchial Tree

- Trachea, Major Lobar Bronchi & Segmental Bronchi
  - Cartilaginous Walls
  - Ciliated, Pseudostratified, Columnar Epithelium
  - Mucus-secreting goblet cells
  - <u>MUCOCILIARY ESCALATOR</u>
  - Submucosal glandular cells secrete lactoferrin (bacteriostatic agent)

Tracheobronchial Tree

- Membranous and Terminal Bronchioles
  - No cartilage
  - Large amt of smooth muscle & elastic fibers
  - Neuroendocrine (APUD) cells
    - Serotonin, Dopamine, Norepinephrine, VIP
  - Mast cells
  - Autonomic Nervous System

Tracheobronchial Tree

- Mast cells
  - Histamine, Lysosomal Enzymes, Leukotrienes, Platelet-Activating Factor, Chemotactic Factors, Serotonin
  - Bronchoconstriction
  - Anaphylactic Reactions
  - Immune/Inflammatory Responses of the lung
  - Cardiopulmonary Reflexes

Tracheobronchial Tree

- Autonomic Nervous System
  - Vagus→Bronchoconstriction,
    Glandular Secretion
  - SNS→Bronchodilation
    Inhibit Glandular Secretion
  - α-receptors: Bronchoconstriction
  - β-receptors: Bronchodilation
  - Circadian Rhythm of Bronchial Smooth Muscles by PSNS: bronchoconstriction in the a.m., bronchodilation in the p.m.

Tracheobronchial Tree

- Bronchodilators
  - SNS
  - β-receptors
  - ↑CO_2
  - ↓O_2
- Bronchoconstrictors
  - PSNS
  - α-receptors
  - thromboxane (plts)
  - histamine (mast cells)
  - cool temperature
  - arterial chemoreceptors
  - ↓CO_2

Tracheobronchial Tree

- Respiratory Bronchioles & Alveoli
  - Kohn pores
  - Clara cell
  - Type I pneumocytes
    - 95% simple squamous layer on alveolar surface
    - Primary diffusion surface
  - Type II pneumocytes
    - Cuboidal cells
    - Surfactant
    - Regeneration of Type I pneumocytes
  - Alveolar Macrophage

Chest Wall

- Bony thoracic cage for protection
- Accessory muscles of respiration
- Maintains negative intrathoracic pressure by the intrinsic outward elastic recoil of the curved ribs

Pleura

- Parietal Pleura
  - Corpuscular sensory endings
  - Free somatic nerve endings
  - Primary Function: absorption via lymphatics
- Visceral Pleura
  - PSNS, SNS innervation
  - Primary Function: lubrication
    - Microvilli produce hyaluronic acid-glycoprotein
- Pleural Fluid
  - Typical Volume = 5-15 ml
  - Typical Turnover = 1-2 L / day

Pulmonary Vasculature

- Pulmonary arteries
  - Entire right ventricle output of mixed venous blood
  - Distensible, low-pressure system
  - SNS—vasoconstriction
  - PSNS—vasodilation
  - Branches follow the airways into alveolar-capillary units for gas exchange

Pulmonary Vasculature

- Inspiration increases total pulmonary vascular resistance
- Resistance is the result of passive forces
  - Distension
  - Recruitment—opening of new, previously closed capillaries from increased perfusion pressure overcoming the critical opening pressure

Pulmonary Vasculature

- Vasoconstrictors
  - Histamine
  - Thromboxane
  - Hypoxia
  - Hypercapnia
  - Prostagladins F & E
- Vasodilators
  - Isoproterenol
  - Acetylcholine
  - PGE_1
  - PGI_2

Pulmonary Vasculature

- Bronchial Arteries
  - Supplied from the aorta, intercostal arteries
  - Oxygenated arterial blood
  - Systemic pressure
- Venous Drainage
  - Bronchial unsaturated blood drains to
    - Azygous-hemiazygous veins
    - Pulmonary veins (anatomic right-to-left shunt)

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- MECHANICAL VENTILATION

PULMONARY FUNCTION TESTS

- Static Lung Volumes
  - Decreased in restrictive lung dz
  - Increased RV, FRC, TLC in obstructive dz (air trapping on expiration)
- Dynamic Lung Characteristics
  - FEV_1 Decreased in COPD
  - FVC
  - FEV_1/FVC Decreased in COPD, Nl/Increased in Restrictive Dz

Pulmonary Function Assessment

- Forced Vital Capacity (FVC)
  - Assessment of muscle strength & airway resistance
  - Measures ability for deep breathing & coughing postoperatively
- Forced Expiratory Volume (FEV)
- FEV_1/FVC
  - Abnormal if < 0.7
  - Increased risk for major surgery if < 0.5

PULMONARY FUNCTION TESTS

- Requirement for thoracic surgery
  - Predicted post-op values
    - FEV_1 > 0.8 (>40% predicted)
    - DL_{CO} > 11-12 ml/min/mmHgCO (>50% predicted)
    - FVC > 1.5 L
  - Pre-op values
    - $PCO_2 < 45$
    - $PO_2 > 50$
    - VO_2 max < 10
  - V/Q scan for lung contribution to FEV_1 if < 2L

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MECHANICAL VENTILATION

- Indications
  - Dysfunction:
    - CNS
    - Chest Wall
    - Airway
    - Respiratory Muscles
    - Alveoli

MECHANICAL VENTILATION

- CNS dysfunction
  - GCS < 8 for airway protection
    - Narcotic Overdose
    - Closed Head Injury
- Chest Wall dysfunction
  - Flail chest
  - Open PTX
  - Marked Scoliosis

MECHANICAL VENTILATION

- Airway Dysfunction
  - Facial Trauma
  - Anaphylaxis
  - Foreign Body / Mass
- Respiratory Muscle Fatigue / Disease
- Alveolar Dysfunction
  - Pulmonary Edema
  - Pneumonia

MECHANICAL VENTILATION

- Also
  - PaCO2 > 45
  - PaO2 < 55 (w/ supplemental oxygen)
  - RR > 35

  - Always accepted criteria: clinical judgment

MECHANICAL VENTILATION

- Modes
  - Assist Control (AC)
  - Intermittent Mandatory Ventilation (IMV)
  - Pressure Support (PS)
  - Pressure Control (PC)

MECHANICAL VENTILATION

- AC
  - Volume given at preset intervals
  - Patient breath triggers volume delivery
- IMV
  - Volume given at preset intervals
  - Patient breath not mechanically supported
  - Synchronous setting prevents stacking
- PS
  - Positive pressure with each patient effort
  - Volume depends on PS, patient effort, compliance
- PC
  - Peak pressure, inspiratory time, RR are set
  - Volume depends on compliance
  - Good for ARDS to decrease barotrauma

MECHANICAL VENTILATION

- PEEP (Positive End-Expiratory Pressure)
  - Increases FRC
  - Improves compliance
  - Best way to improve oxygenation
- Pressure Support
  - Decreases Work of Breathing

MECHANICAL VENTILATION

- To decrease P_aCO_2:
  - Increase Tidal Volume
  - Increase Respiratory Rate
- To increase P_aO_2:
  - Increase PEEP
  - Increase F_iO_2

MECHANICAL VENTILATION

- Complications
- Too much PEEP
  - Decrease Preload
  - Decrease CO
  - Decrease Renal Blood Flow & UOP
  - Increase PVR
- Too much Oxygen
  - Oxygen radical toxicity if F_iO_2 > 60-70% for > 24 hours
- Barotrauma
  - Plateau pressure > 30, Peak pressure > 50

MECHANICAL VENTILATION

- Complications
- ET Tube
  - Tracheal Stenosis
  - Laryngeal Injury
  - Tracheomalacia
  - Tracheo-innominate Fistula
- Infection
  - Sinusitis
  - Pneumonia

MECHANICAL VENTILATION

- Weaning Parameters
- Settings:
  - FiO2 < 35%
  - PEEP 5
  - PS 5
  - RR < 24
- ABG:
  - pH 7.35-7.45
  - pO2 > 60
  - pCO2 < 50
- Measurements:
  - V_E < 10 L / min
  - V_T > 5 mL / kg
  - VC > 10 mL / kg
  - Neg Insp Force > 20 cmH20
- Vital Signs:
  - HR < 120
  - O2 Sat > 93%
- Misc:
  - Off pressors
  - Follows commands
  - Can protect airway

CONCLUSION

- VENTILATION
- DIFFUSION
- STRUCTURE & FUNCTION
- PULMONARY FUNCTION TESTS
- MECHANICAL VENTILATION