Ch. 11: Respiratory Physiology

PowerPoint updated 3/2025

Objectives:

1. Review respiratory anatomy.
2. Understand mechanics of breathing, gas pressure vocabulary, and the principles of surface tension, compliance, and recoil.
3. Respiratory disorders and diagnosing them
4. How gas exchange occurs between the alveoli & pulmonary vessels, and between capillaries & tissue.
5. Regulation of breathing (voluntary vs involuntary) and blood pH
6. Hemoglobin & hemoglobin disorders

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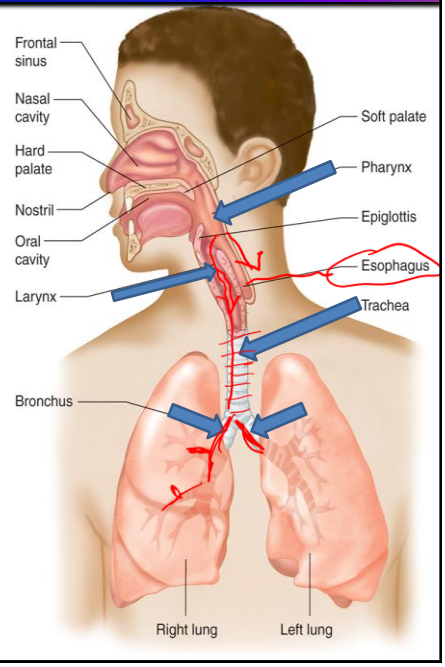
1. Respiratory Anatomy - REVIEW

2 Zones of Respiratory System:
Conduction and Respiratory zones

1) Conduction Zone = from oral/nasal cavities to:

- **Pharynx (throat)**
- **Larynx (voice box)**
- **Trachea**
- **Primary Bronchi**
- **Secondary Bronchi**
- **Tertiary Bronchi**
- **Terminal bronchioles**



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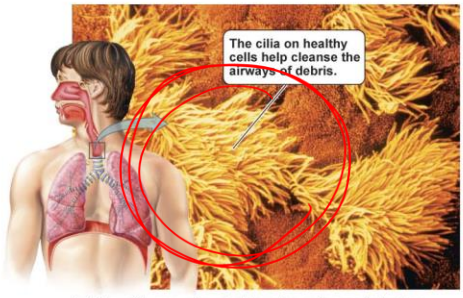
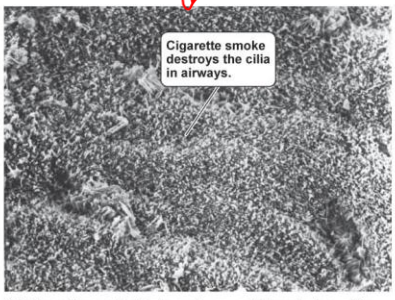
Functions of Conducting Zone:

- Transports air to the lungs.
- Warms, humidifies, filters, and cleans the air.
  - **Mucus** traps small particles, and **cilia** move it away from the lungs.
  - **Expectoration** = coughing up the mucus that trapped debris and pathogens.



(a) The cilia are yellow in this color-enhanced electron micrograph. The cells without cilia secrete mucus.



(b) Cigarette smoke first paralyzes and then destroys the cilia. As a result, hazardous materials can accumulate on the surfaces of the air passageways.

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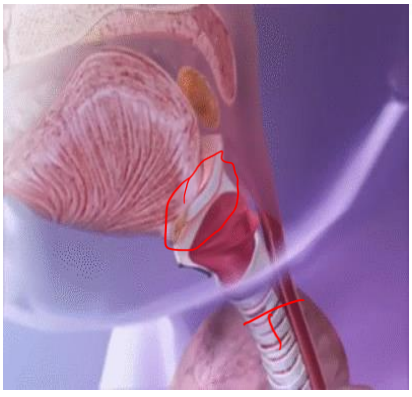
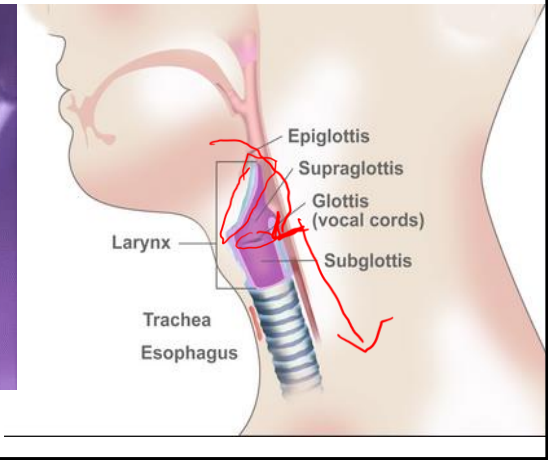
Structures in the larynx

glottis – opening between vocal cords

epiglottis – closes upon swallowing to prevent food from entering



Click **HERE** for GIF



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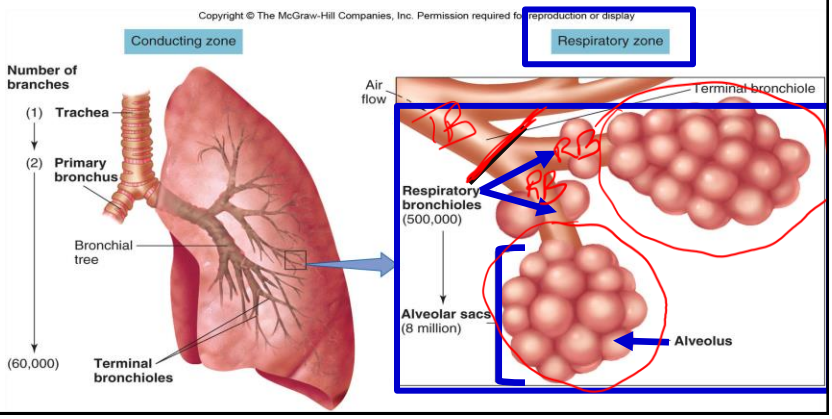
2) Respiratory zone

Respiratory bronchioles = smallest bronchioles, branch from tertiary bronchioles.

Alveolar sacs = honey-comb shaped, 1-cell thick sacs for gas exchange. [~600 mill in lungs!]



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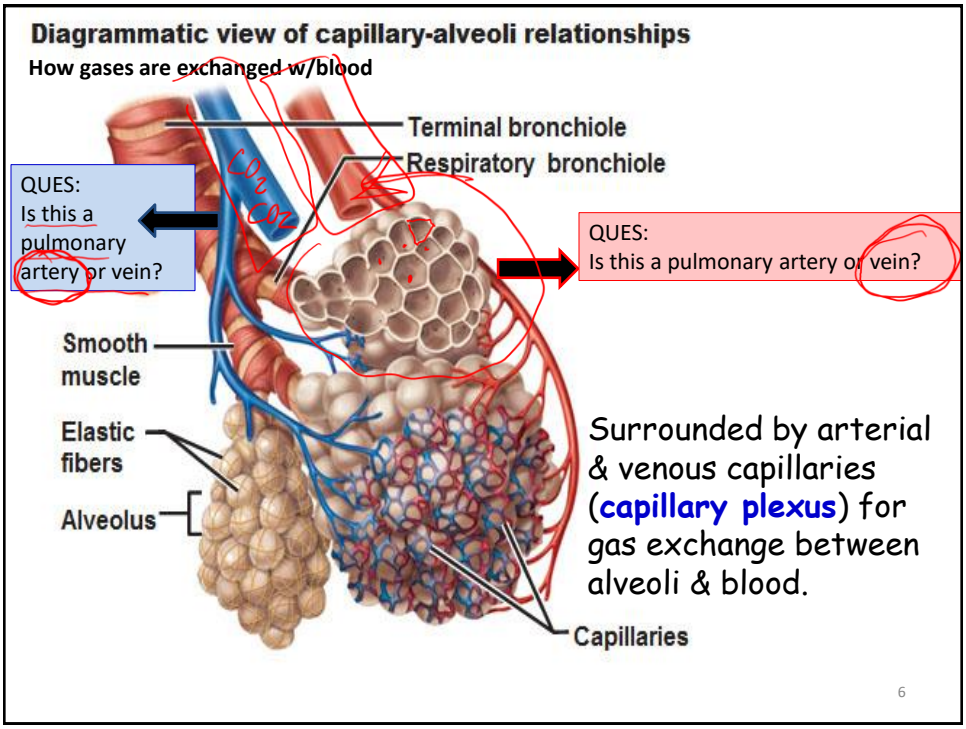

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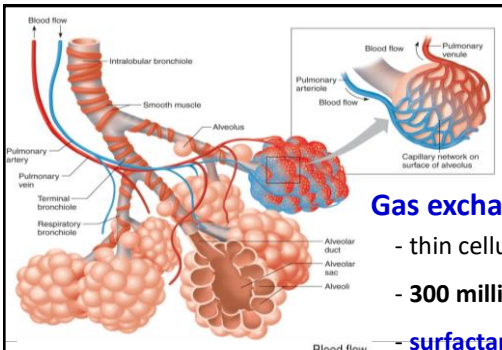
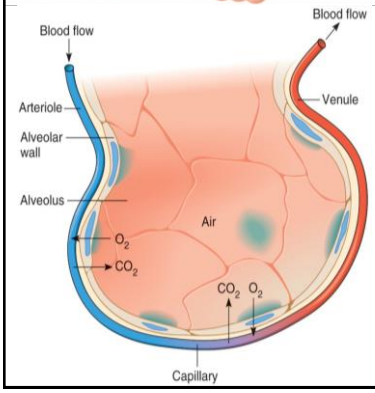


Gas exchange occurs at the Alveoli

- thin cellular walls covered with capillary networks
- **300 million sacs!** - very large surface area
- **surfactant** keeps the alveoli inflated



Click **HERE** for brief video(3 min) showing conduction of air to, and gas exchange at, lung alveoli.

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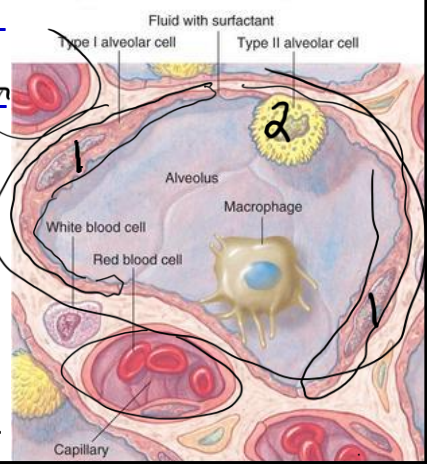
2 Types Alveolar Cells:

Type 1 Alveolar Cells = make up alveolar walls, which are 1-cell layer thin.
It's 97% of total lung surface area where most gas exchange occurs.

Type 2 Alveolar Cells = Secrete Surfactant, which ↓ surface tension

Surfactant = from thin film of water on alveolar wall.



So when you exhale and alveolar sac shrinks, the walls don't stick together, causing collapsed alveoli (collapsed lungs!).

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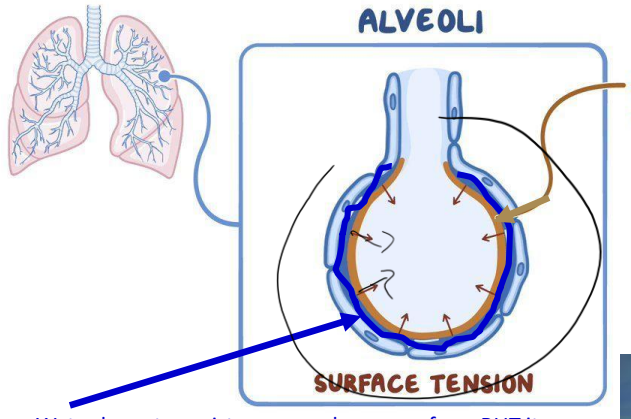
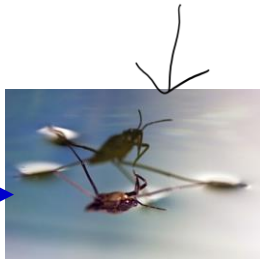
Effect of surface tension and surfactant in alveolar sacs.



Water layer to moisten gas exchange surface, BUT it introduces problem of **surface tension.**



Click **HERE** for 4 min video explaining.

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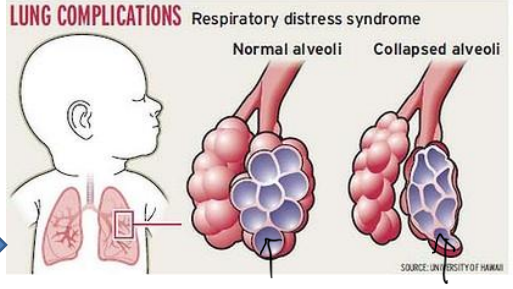
Why is surfactant important?

Non-obstructive Atelectasis =
not enough surfactant in alveolar sacs, and they collapse with exhalation.

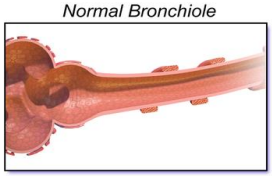
Leads to collapsed lungs.

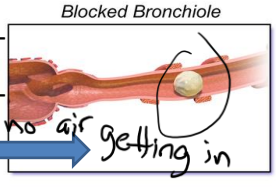


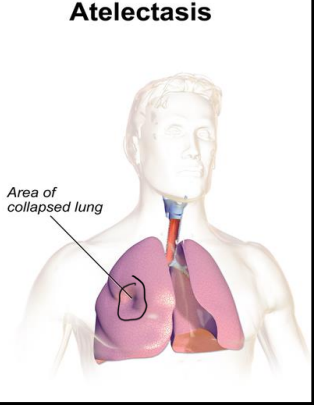
Not to be confused with

Obstructive Atelectasis =
foreign body blocking airway. Alveolar sacs collapse because no air getting in

Leads to collapsed lungs.







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Surfactants ↓ intra-alveolar pressure & prevent collapse

Infant Respiratory Distress Syndrome (IRDS)

- Surfactant is produced > 28 weeks (7-8 months)
- Babies are born < 28 wks - not enough surfactant. High surface tension inside alveoli, results in collapsed alveoli, which collapses lung (non-obstructive atelectasis)
- Tx = synthetic surfactant delivered into baby's lungs & mechanical ventilator until Type 2 alveolar cells can make surfactant.

Adult

Acute Respiratory Distress Syndrome (ARDS)

- Due to inflammation from infection (septic shock)
- Results in protein (serum) secretion in lungs.
- Fluid dilutes surfactant, ↑ surface tension, alveoli collapse,
- could cause lung collapse (non-obstructive atelectasis)

COVID causes ARDS! Click HERE to read more.

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Coronavirus (COVID) and ARDS

- Alveolar sac walls are very thin to allow for easy gas exchange.
- **Chronic inflammation of any kind**, which can occur with COVID-19, **leads to thickening of the alveolar walls,** making gas exchange difficult. (A patient with ARDS will have low oxygen levels – lower than the normal of 95% oxygen saturation of their arterial blood.)
- The **inflammation also causes serum buildup within the alveolar sacs**, which further decreases gas exchange.
- The increased fluid within the alveoli of the lungs is prone to **bacterial infection. This is called pneumonia**.

Click **HERE** for YouTube video explaining this, and respiratory treatment discoveries that decrease mortality of patients put on ventilators.

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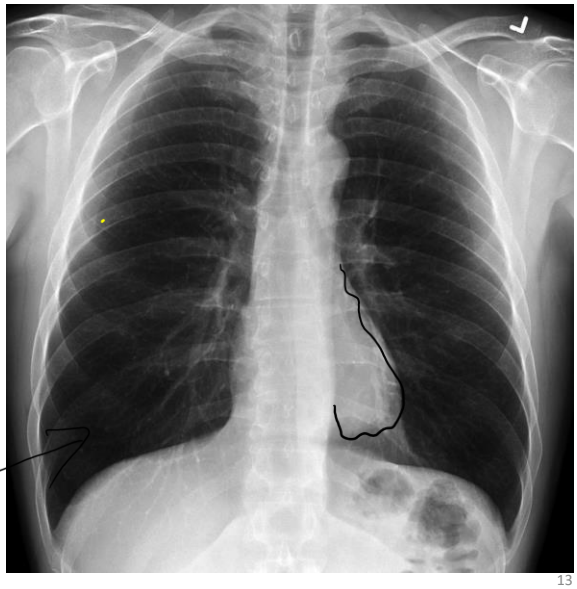
Radiograph of healthy lungs

The black areas show air spaces. A normal x-ray of the lungs looks like this. There should be no white spots.



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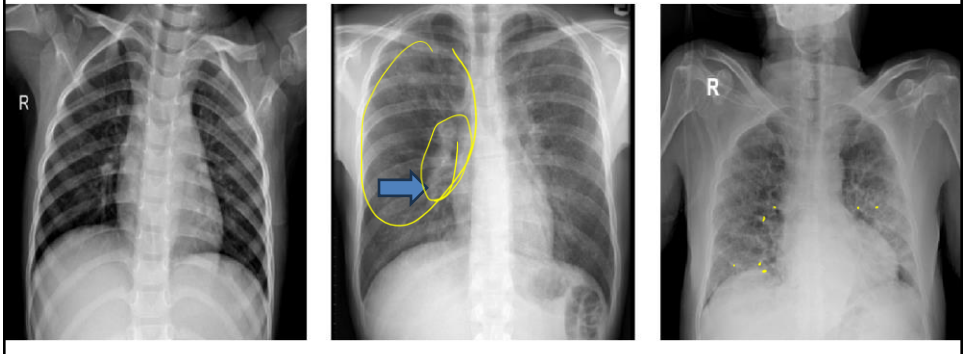
Radiograph of lungs with **pneumonia & COVID-19**



(a) Normal (b) Pneumonia (c) COVD-19

The arrow points to white spots, which are fluid pockets within the alveolar sacs that have become infected with bacteria.

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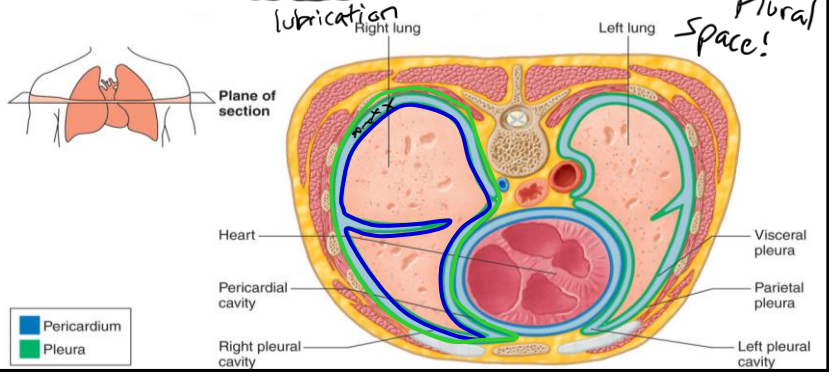
Thoracic cavity: Anatomy REVIEW!

Membranes of the lungs:

Visceral pleura = membrane covering the lungs.

Parietal pleura = membrane lining the pleural cavity containing containing each lung.
- *Parietal pleura held tight against thoracic wall by surface tension of water layer.*
- *As thoracic cage changes volume (w/ breathing) so do the lungs.*

Intrapleural space = empty space between the 2 pleura. Never should be air in intrapleural space!
- *The 2 pleura pressed together w/serous fluid between them.* lubrication



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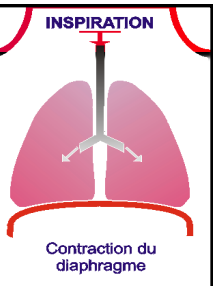
2. Mechanics of Respiration



1) Air moves across membranes from high to low pressure

- **Atmospheric air pressure = constant (760 mmHg)**
- **Lung air pressure depends on volume of thoracic cavity**

2) Air pressure in lungs (closed chamber) changes with volume of chamber

"Boyle's Law" = as volume of closed chamber ↑, air pressure within ↓

as volume of closed chamber ↓, air pressure within ↑

Translates to lung volume & air pressure within lungs ("intrapulmonary pressure") (within lungs)

When diaphragm contracts, thoracic volume ↑, lung volume ↑, & intrapulmonary pressure ↓

When diaphragm relax, thoracic volume ↓, lung volume ↓, & intrapulmonary pressure ↑

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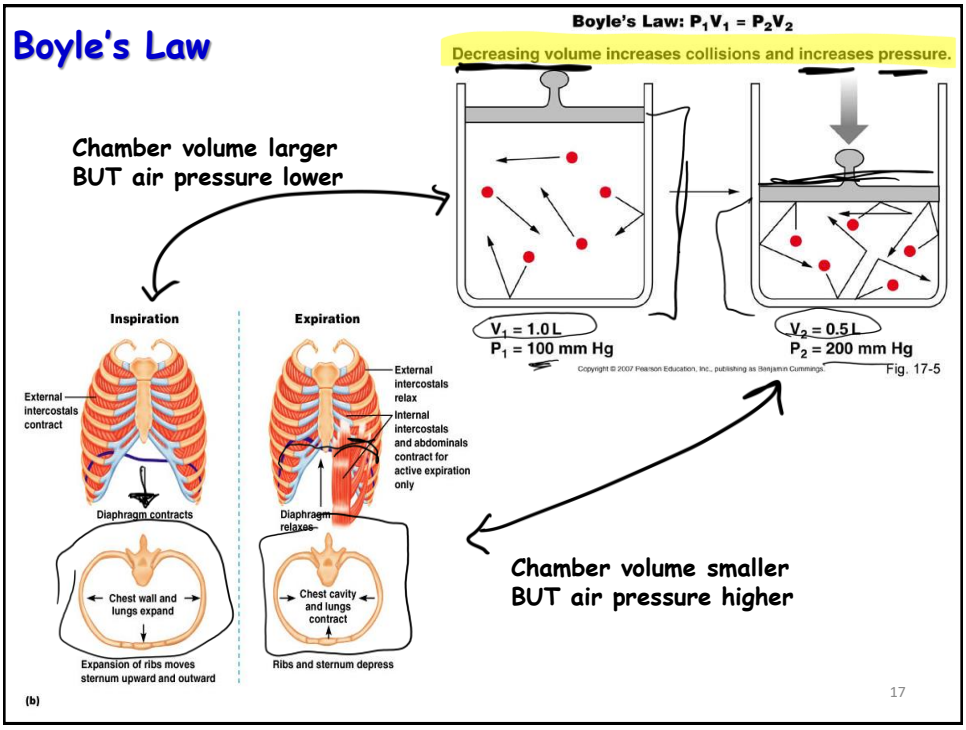

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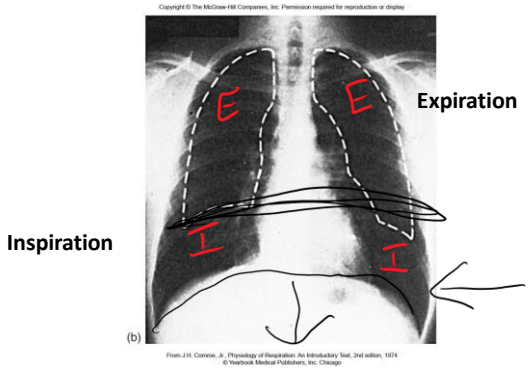
Diaphragm contracts, lung volume ↑, intrapulmonary pressure ↓

Diaphragm relaxes, lung volume ↓, intrapulmonary pressure ↑



Click **HERE** (40 sec) for brief video showing how respiratory muscles change lung volume, and air pressure, during inhalation & exhalation.18

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Gas Pressure Vocabulary:

Intrapulmonary pressure = pressure of air within lungs (P_{O2} or P_{CO2})

- *During inhalation* – is lower than atmospheric pressure **(-3 mmHg)**
- *During exhalation* – is above atmospheric pressure **(+3 mmHg)**

Intrapleural pressure = pressure between parietal & visceral plura. Should always be negative air pressure.

- *During inhalation* – is lower than atmospheric **(-6 mmHg)**
- *During exhalation* – is still lower atmospheric **(-3 mmHg)**

****** intrapleural pressure should ALWAYS be negative. If air enters this space, the lung can detach from thoracic wall, trapped air puts pressure on lung, & lung can collapse. *****

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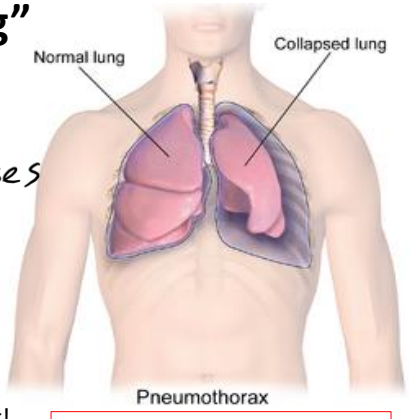
Causes of a collapsed lung"

"Pneumothorax" = ↑ air within intra plural space, causes collapsed lung.



Result = can't expand lungs to get air to enter! Lung collapses.

Click **HERE** for 3 min YouTube video of pneumothorax.

Treatment = chest tube. Click **HERE**

2nd pneumothorax YouTube video where doctors demonstrate with a set of lungs wrapped in a bag to simulate air invading the space between visceral parietal pleura. (As air escapes punctured lung, it fills the space making the bag expand and the lung collapse 20

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CLINICAL APPLICATIONS

If air enters the intrapleural space and thereby raises the intrapleural pressure, the difference in pressure between the inside of the lungs (intrapulmonary pressure) and the outside of the lungs (intrapleural pressure) is abolished. As a result, the lung is no longer stuck to the thoracic wall; this is like releasing a stretched rubber band, and the lung's elastic recoil causes it to collapse. The condition of air entering the intrapleural space and causing the collapse of a lung is known as a **pneumothorax**. Fortunately, a pneumothorax usually causes only one lung to collapse, because each lung is contained in a separate pleural compartment.

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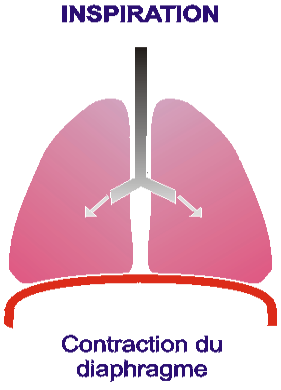
Important properties of the lungs:

A) Surface tension = pressure resulting from thin film of water lining alveoli that resists their expansion. Makes alveoli want to collapse with exhalation.

B) Compliance = lungs expand when stretched (when thoracic volume ↑).
- more lung compliance = greater capacity for "stretchiness"
- less lung compliance = less capacity for "stretchiness"

C) Elasticity/**Recoil** = tendency of lungs to return to normal shape after stretching. *(I use the word recoil, because it avoids confusion with the "stretch" of compliance.)*(When thoracic volume ↓, lungs volume also ↓ parietal pleura keeps lungs "stuck" to thoracic wall).



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B) Lung compliance

Factors that increase compliance:

- **pulmonary surfactants**
- **Emphysema =** destruction of alveolar walls leading to air-trapping. Loss of recoil. You can't get air out of sacs.

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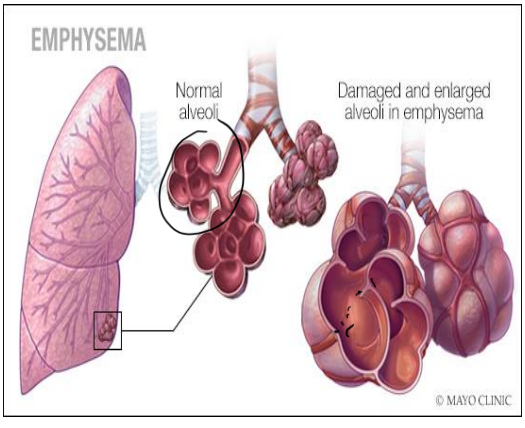
Smoking, Emphysema, and increased lung compliance

Smoking causes particles to settle into alveoli (where they never leave & cause chronic inflammation). The inflammation damages & destroys alveolar walls, leading to large air spaces within alveoli (thus **emphysema** is called an **air trapping disease**).



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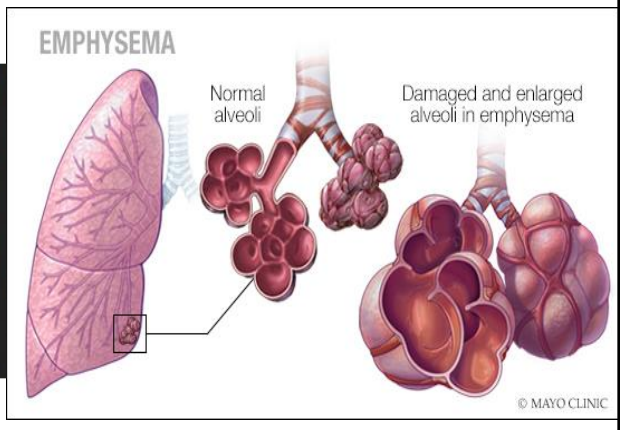
In a study published in the *American Journal of Respiratory and Critical Care Medicine*, the UNC scientists found that the lungs of **vapes** – like the lungs of smokers – have elevated levels of protease enzymes, a condition known to cause emphysema in smokers. The researchers also found that the nicotine in vaping liquids is responsible for the increase in protease enzymes.



https://808novape.org/scientists-show-how-vaping-induces-reactions-in-lungs-that-can-lead-to-disease/

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For Ex. - Lung damage from smoking causes chronic bronchitis and formation of scar tissue (pulmonary fibrosis). *Click image for YouTube video demonstrating scarring of the lungs from smoking. (This will freak you out!)*

Comparison between normal lungs with smoker's lung

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B) Lung compliance

Factors that decrease compliance:

- many, many things!
- Anything that causes chronic inflammation can lead to ↓ compliance

↑ scar tissue, which is not flexible.

Example: **pulmonary fibrosis**.

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Review

- **The respiratory system**
  - **The conduction & respiration zones**
- **Airway, lung, and thoracic cavity anatomy**
- **Alveoli (gas exchange, surfactant, factors that affect intra-alveolar surface tension and pressure)**
- **Mechanics of breathing (Boyle's law and respiratory muscles), muscles of respiration.**
- **Gas pressure vocabulary, and pneumothorax,**
- **Important properties of the lungs**
  - **Surface tension, compliance, & recoil.**
  - **Factors that affect compliance: emphysema & pulmonary fibrosis**

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3. Respiratory Disorders

Restrictive Disorder = Lung tissue is **damaged**. Lungs are stiff, or respiratory muscles are weak. Have difficulty filling lungs with air.

Example: **Pulmonary fibrosis (also decreases compliance)**
Pulmonary sarcoidosis
Lung cancer
IRDS and ARDS

Obstructive Disorder = Lung tissue is normal, for time being, but resistance is increased (airways are narrowed) so air tends to remain in lungs even after exhaling.

Examples: **Asthma, COPD**, **Emphysema**, **Cystic fibrosis, Chronic bronchitis, and sleep apnea**

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Restrictive Respiratory Disorders *following slides updated 3/26/25*

- **Pulmonary fibrosis =** Scar tissue in lungs.

HAS MANY CAUSES

> **Breathing in small particles that accumulate in & irritates the lungs:**

Ex: Silicosis = breathing in fine dust of stone, sand, soil & other substance

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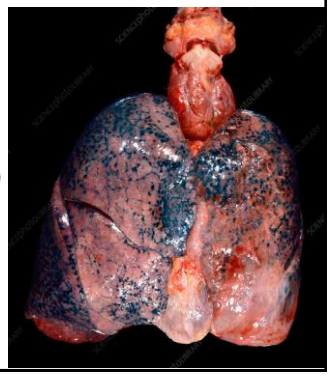
Restrictive Respiratory Disorders

- Pulmonary fibrosis = Scar tissue in lungs.

HAS MANY CAUSES

> **Breathing in small particles that accumulate in & irritates the lungs:**

Ex: Anthracosis (black lung disease) = Breathing in coal dust (coal miner's disease)



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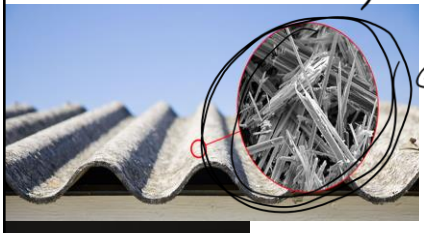
Restrictive Respiratory Disorders

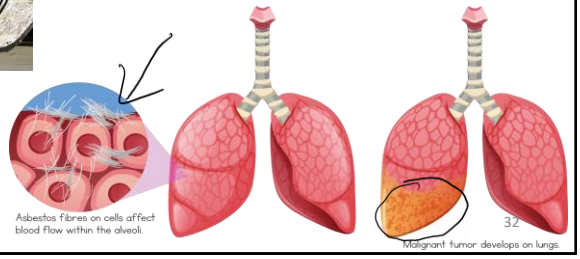
- Pulmonary fibrosis = Scar tissue in lungs.

HAS MANY CAUSES

> **Breathing in small particles that accumulate in & irritates the lungs:**

Ex. Mesothelioma – lung cancer from breathing in asbestos insulation.





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Restrictive Respiratory Disorders

- **Pulmonary fibrosis** = Scar tissue in lungs.

HAS MANY CAUSES

> **Breathing in small particles that accumulate in & irritates the lungs:**

Ex. Smoking - Cigarettes have chemicals and foreign particles that you breathe in.

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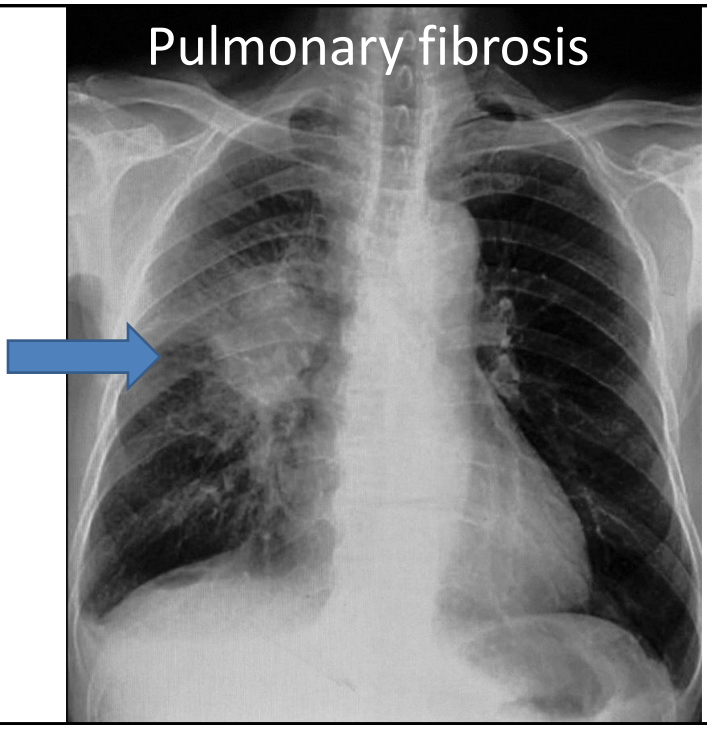
Pulmonary fibrosis



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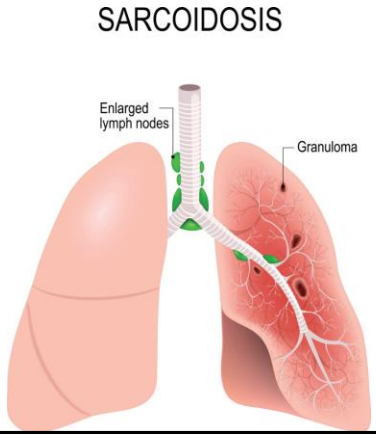
Restrictive Respiratory Disorders

- Pulmonary sarcoidosis = rare condition that causes formation of small patches of swollen tissue (granulomas). ~200,000 cases / year in US.

HAS MANY CAUSES

> **Breathing in bacteria, viruses, or chemicals that irritates the lungs:**



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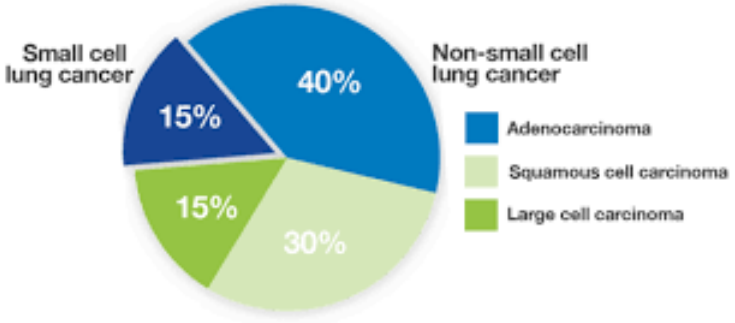
Restrictive Respiratory Disorders – Lung cancer

Main Types:

Non-small cell lung cancer (85% of all lung cancers in this group)

1. Adenocarcinoma (~40 of lung cancers)
2. Squamous cell cancer (~ 30% of lung cancers)
3. Large cell carcinoma (~15% of lung cancers)

Small cell lung cancer (~15% of all lung cancers)



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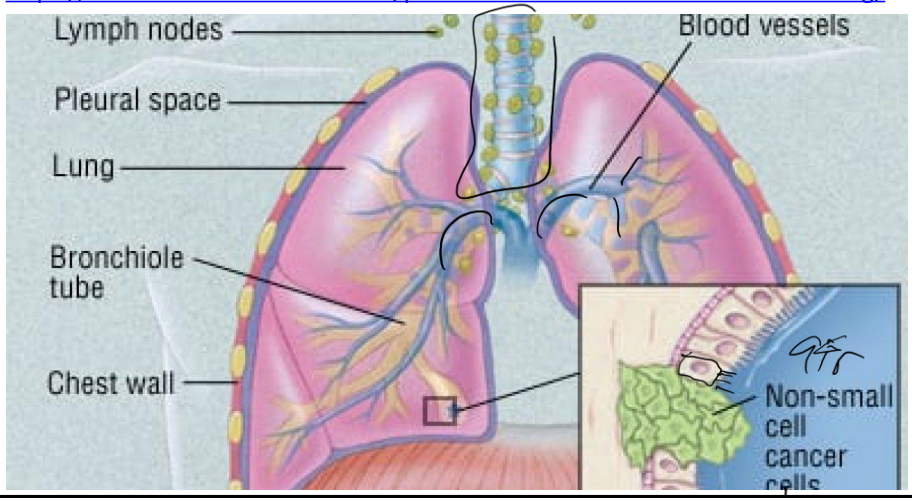
Respiratory Illnesses – Lung cancer

Non-small cell lung cancer

very treatable!

1. Adenocarcinoma. This is the most common type (40% of all lung cancers), and starts in the mucus making gland cells in the lining of your airways. More likely to be localized to one area.

https://www.2minutemedicine.com/patient-basics-adenocarcinoma-of-the-lung/



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Respiratory Illnesses – Lung cancer

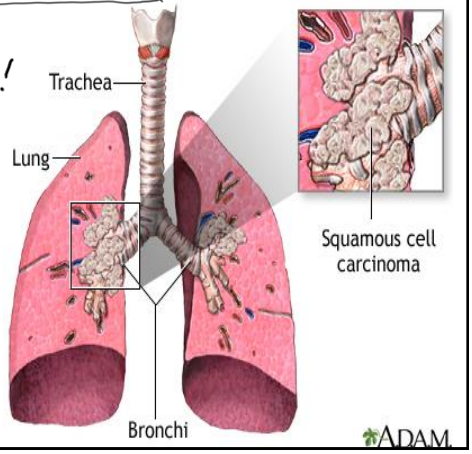
Non-small cell lung cancer

1. Adenocarcinoma. This is the most common type and starts in the mucus making gland cells in the lining of your airways.

2. Squamous cell cancer. 2nd most common lung cancer. Cancer of squamous cells lining the inside of the airways (bronchi) in the lungs. They are often linked to a history of smoking. Tends to be slow growing cancer.

Catch it early!

https://www.cancer.org/cancer/lung-cancer/about/what-is.html



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Respiratory Illnesses – Lung cancer

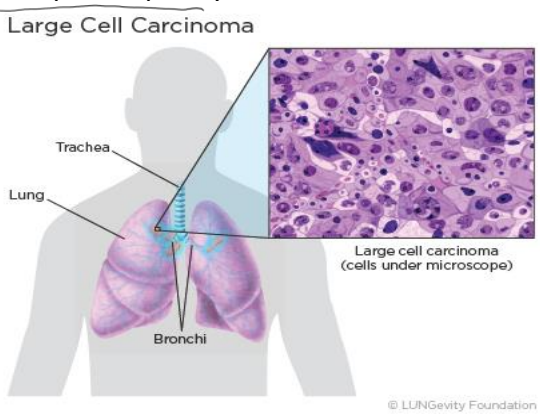
Non-small cell lung cancer

1. Adenocarcinoma. This is the most common type and starts in the mucus making gland cells in the lining of your airways.

2. Squamous cell cancer. This type develops in the flat cells that cover the surface of your airways. ...

3. Large cell carcinoma: Large cell carcinoma can appear in any part of the lung. It tends to grow and spread quickly, which can make it harder to treat.

https://www.cancer.org/cancer/lung-cancer/about/what-is.html



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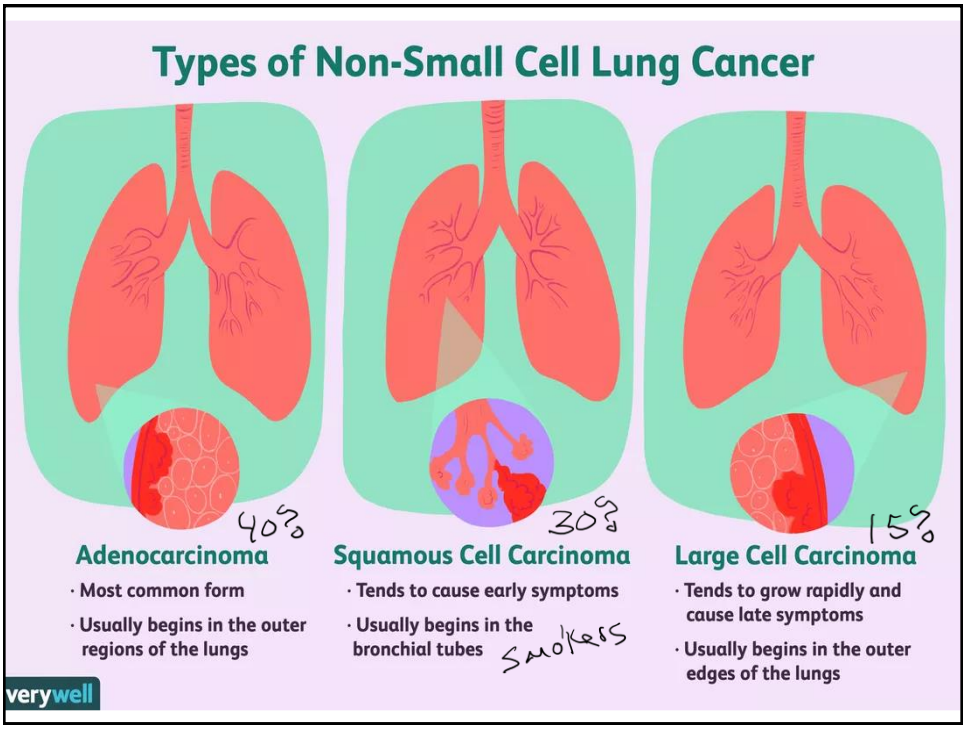

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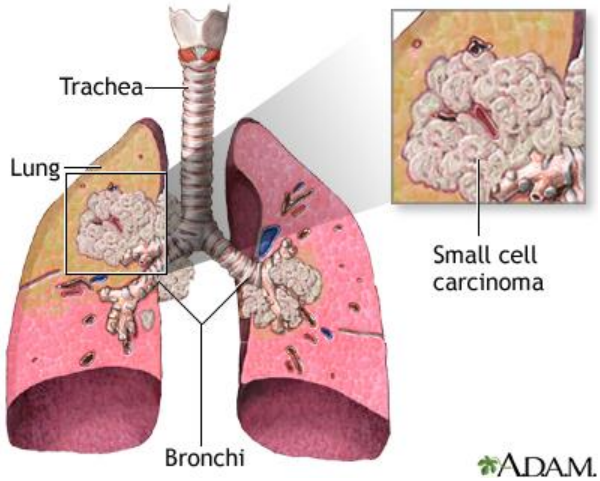
Small Cell Lung Cancer (SCLC): is the most aggressive form of lung cancer. It usually starts in the breathing tubes (bronchi) in the center of the chest. Although the cancer cells are small, they grow very quickly and create large **tumors**



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5-year relative survival rates for non-small cell lung cancer

These numbers are based on people diagnosed with NSCLC between 2009 and 2015.

SEER stage	5-year relative survival rate
Localized	61% (has not spread from original spot)
Regional	35% (has spread from original spot, but not metastasized)
Distant	6% (has metastasized)
All stages combined	24%

5-year relative survival rates for small cell lung cancer

These numbers are based on people diagnosed with SCLC between 2009 and 2015.

SEER stage	5-year relative survival rate
Localized	27% (has not spread from original spot)
Regional	16% (has spread from original spot, but not metastasized)
Distant	3% (has metastasized)
All stages combined	6%

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Restrictive Disorder = Lung tissue is damaged. Lungs are stiff, or respiratory muscles are weak.

Example: **Pulmonary fibrosis**

Obstructive Disorders = Lung tissue is normal, but resistance is increased (airways are narrowed)

Examples: **Asthma**

COPD = Chronic Obstructive Pulmonary disease

- which includes **emphysema** &
- **chronic bronchitis**)

✓ **Cystic fibrosis**

✓ **Chronic bronchitis**

✓ **Sleep apnea (updated 3/25)**

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Asthma

= narrowing of bronchioles in response to allergens or other irritants.

Muscles around the bronchioles are hyper-excitable

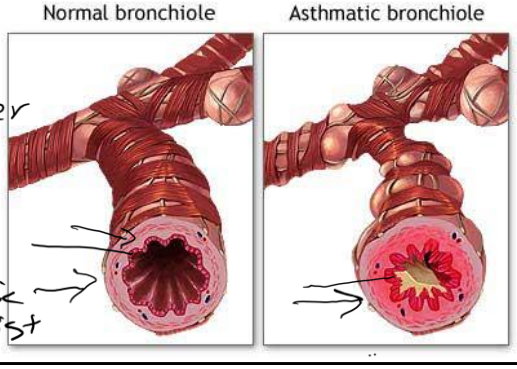
- Is an obstructive disorder due to bronchiole inflammation, mucous secretion, & narrowing of airways (**bronchoconstriction).**

Question:

What drug would you give as a treatment to dilate the bronchioles?

rescue inhaler

Albuterol
β_2 adrenergic agonist



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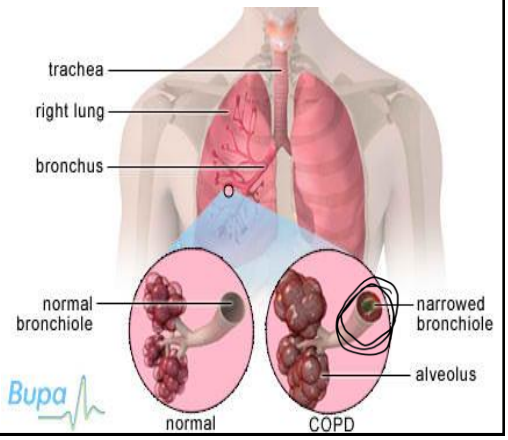
Chronic Obstructive Pulmonary Disease (COPD)

Chronic inflammation of airways alveolar tissue
- narrows airways & destroys alveolar walls
- proliferation of mucus-secreting goblet cells
- development of scar (fibrous) tissue = **pulmonary fibrosis**
- **Obstructive disorder –** due to mucus buildup and narrowed airways.

permanent
cancer risk



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PHYSIOLOGY IN HEALTH AND DISEASE

People with pulmonary disorders frequently complain of **dyspnea**, which is a feeling of "shortness of breath." The dyspnea, wheezing, and other symptoms of **asthma** are produced by increased resistance to airflow through the bronchioles (asthma is an obstructive pulmonary disorder, as discussed previously). The increased resistance to air flow is caused by bronchoconstriction and inflammation that may be provoked by allergic reactions (chapter 11).

Asthma may be treated on a sustained basis with glucocorticoid drugs (related to cortisol) that inhibit inflammation, thereby preventing or reducing the severity of "attacks." New drugs (such as Singulair) that block the action of leukotrienes, a type of regulatory fatty acid (related to prostaglandins) that promote asthma, are now also available for this purpose. Acute asthma attacks are commonly treated with inhaled drugs (such as Albuterol) that stimulate the β_2-adrenergic receptors (a type of receptor for epinephrine and norepinephrine; see chapter 6) that promote dilation of the bronchioles.

Alveolar tissue is destroyed in **emphysema**, resulting in fewer but larger alveoli (see fig. 12.8). The loss of alveoli reduces the ability of the bronchioles to remain open during expiration, causing *air trapping* during expiration when the bronchioles collapse. The most common cause of emphysema is cigarette smoking, which indirectly causes different protein-digesting enzymes to destroy the lung tissue. The loss of alveoli and air trapping reduces gas exchange, so that people with emphysema have difficulty in both oxygenating the blood and eliminating carbon dioxide. Because of this, people with emphysema must often breathe from an oxygen tank.

Chronic obstructive pulmonary disease (COPD) is characterized by chronic inflammation with narrowing of the airways and destruction of the alveolar walls. Included in the COPD category is *emphysema* and *chronic obstructive bronchiolitis*, which refers to fibrosis and obstruction of the bronchioles. The condition results in a faster age-related decline in the FEV_1 (discussed previously). COPD differs from asthma in that, unlike asthma, COPD is not reversible with the use of a bronchodilator such as Albuterol. Also unlike asthma, COPD is not helped much by inhaled glucocorticoids (drugs related to hydrocortisone). The vast majority of people with COPD are smokers, and stopping smoking once COPD has begun does not seem to stop its progression. In addition to the pulmonary problems directly caused by COPD, this condition increases the risk of pneumonia, pulmonary emboli (traveling blood clots), and heart failure. Patients with COPD may develop *cor pulmonale*—pulmonary hypertension with eventual failure of the right ventricle. COPD is now the fifth leading cause of death in the United States, and scientists have estimated that by 2020 it will become the third leading cause of death worldwide.

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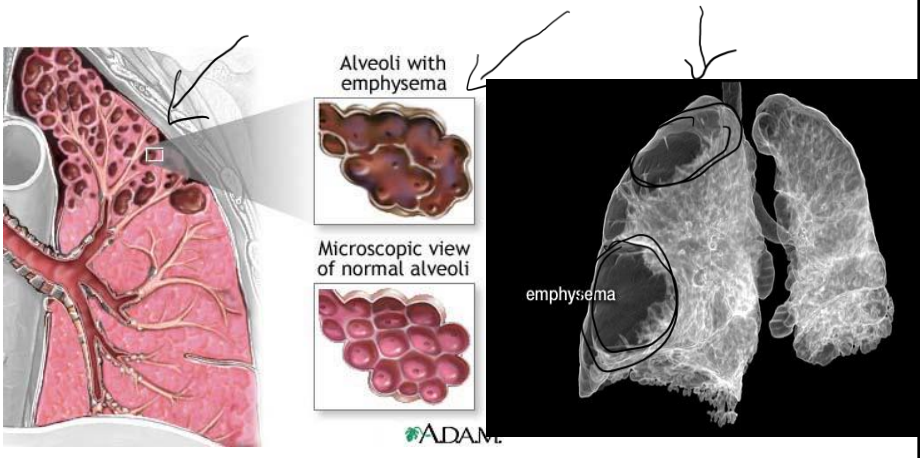
Emphysema

Chronic destruction of alveolar tissue (walls between alveoli lost)
- reduces area for gas exchange
- alveoli expand easily, but can't empty easily (air-trapping disorder)
- **obstructive disorder**



http://www.nlm.nih.gov/medlineplus/ency/images/ency/fullsize/17055.jpg

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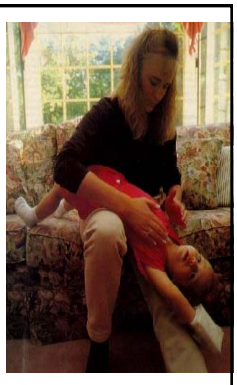
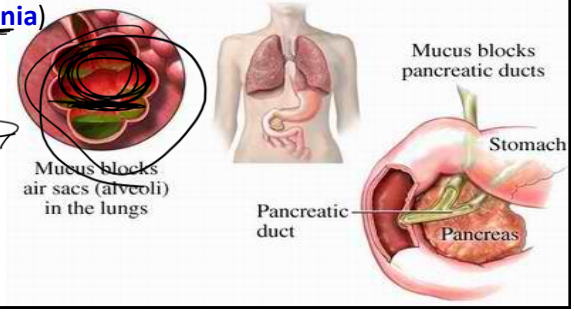
Cystic Fibrosis

- Genetic disorder affecting Cl- channels on alveoli membrane. **Obstructive disorder**



Results in buildup of mucus within alveoli causing:
- Dilutes surfactant
- ↓ decreased functional alveolar size
- ↑ surface tension & intra-alveolar pressure
  (~~harder for alveoli to expand~~)
- ↓ with gas exchange
- Warmth & moisture (mucus) aids bacterial growth.
  (Vulnerable to **pneumonia**)



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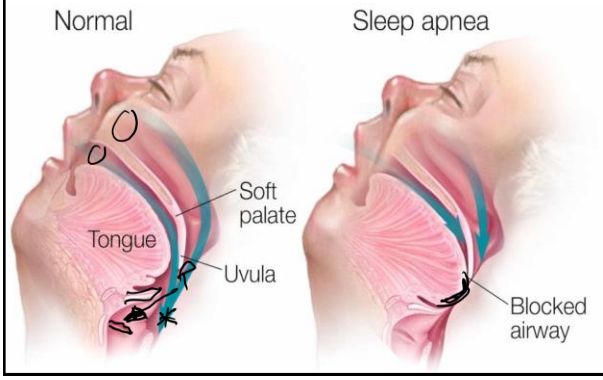
Sleep apnea *(added slide)*

Sleep apnea = prone to tissue blocking airway & stop breathing repeatedly during night.

Treatment: Continuous positive airway pressure (CPAP) machines



CPAP

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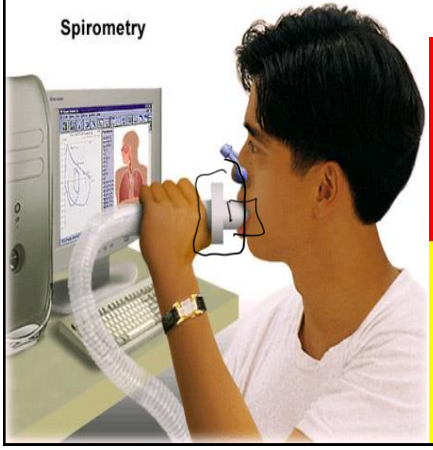
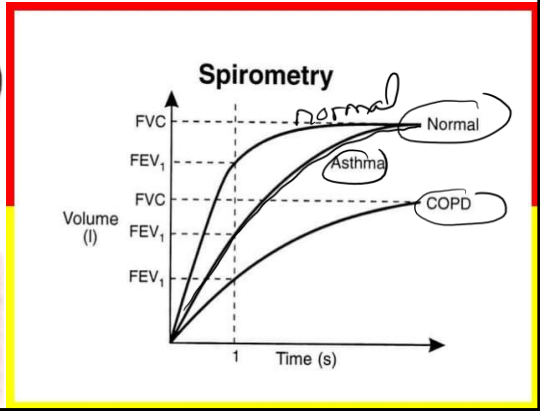
3. Respiratory Disorders – diagnosing them

- **Spirometry**: air movement during respiration recorded on a spirogram.
  - Measures lung volumes and capacities
  - Can diagnose restrictive and obstructive lung disorders





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Additional Respiratory Vocabulary *(I moved this slide up)*:

Apnea = absence of breathing

Dyspnea = labored or difficult breathing

Eupnea = normal breathing at rest

- **Hyperventilation** = excessively rapid ventilation (will decrease alveolar CO2)
- **Hypoventilation** = low ventilation (will increase alveolar CO2)

✓**Pneumothorax** = presence of gas in intrapleural space causing lung collapse

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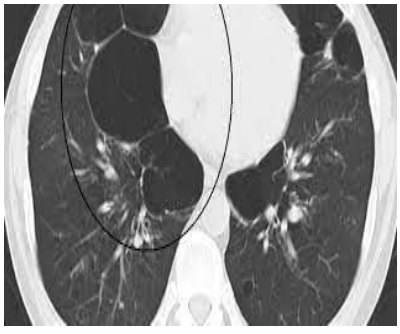
3. Respiratory Disorders – diagnosing them

- Spirometry
- **Lung X-ray**
- **Lung CT scan**



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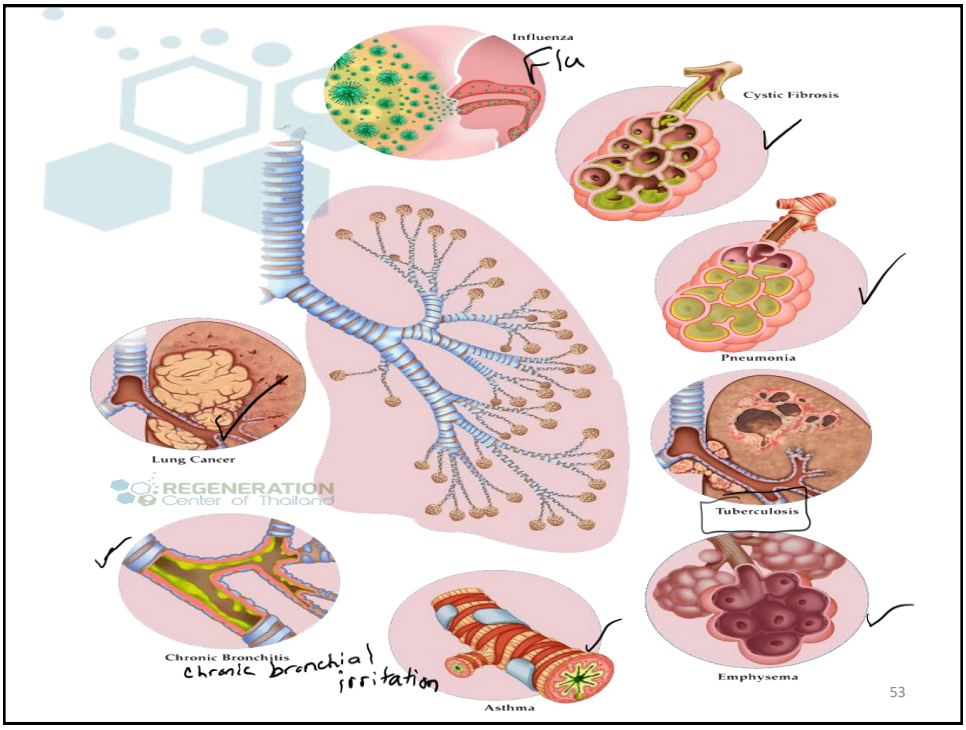

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Review

Respiratory Disorders & diagnosing them

- **Restrictive**
  - **pulmonary fibrosis**
  - **silicosis, mesothelioma**
  - **pulmonary sarcoidosis**
  - **Lung cancer**
    - **Non-small cell lung cancer**
      - » Adenocarcinoma, squamous cell carcinoma, large cell carcinoma
    - **Small cell lung cancer**
- **Obstructive**
  - **Asthma**
  - **COPD**
  - **Emphysema**
  - **chronic bronchitis**
  - **cystic fibrosis**
  - **Sleep apnea**

Spirometry

Additional respiratory vocabulary

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4. Basics of Gas Exchange at Lungs and at Body Tissues

Gas exchange between 2 structures is dependent on pressure gradient of dissolved O2 & CO2

* Gas moves from side with higher pressure (from dissolved gases) to side with lower pressure & visa versa

*Gas wants to move "downhill" from high to low pressure!

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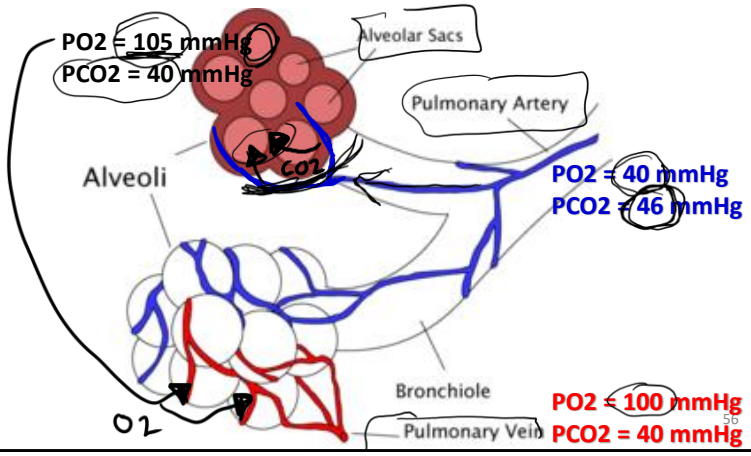
Gas exchange between lung alveoli & pulmonary vessels:

> Alveolar PO2 = 105 mmHg, higher than that in pulmonary arteries (40 mmHg)

> Alveolar PCO2 = 40 mmHg, lower than that in pulmonary arteries (46 mmHg)



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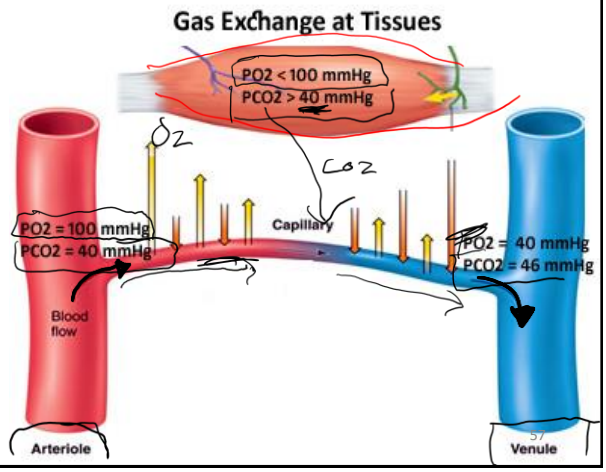
Gas exchange between systemic capillaries & tissues:

> Tissue PO2 (<100 mmHg) = lower than O2-rich arterial blood (100 mmHg)

> Tissue PCO2 (>40 mmHg) = higher than that in arterial blood (40 mmHg)



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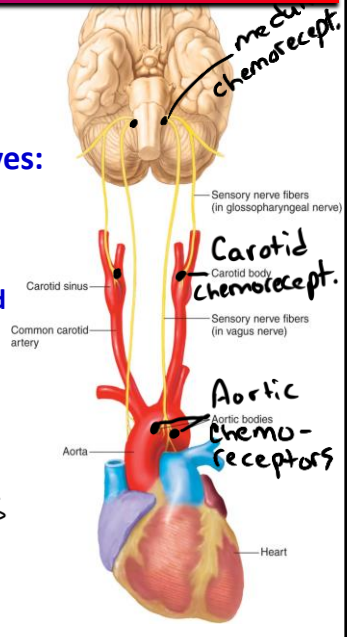
5. Regulation of Respiration – regulation of blood O2 & CO2

Autonomic motor control breathing involves:

Sensors of pH = Chemoreceptors:

- **Aorta & carotid artery chemoreceptors (called peripheral chemoreceptors)**
  - sense blood O2 and CO2 levels
- **Medulla chemoreceptors (called central chemoreceptors)**
  - sense CSF O2 and CO2 levels



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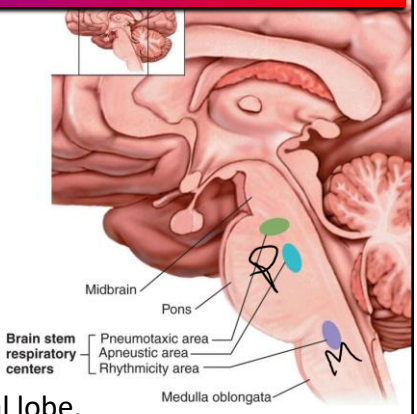
5. Regulation of Respiration – regulation of blood O2 & CO2



Motor neurons from 3 brain areas control breathing muscles:

1) Voluntary Breathing
= primary motor cortex of frontal cerebral lobe.

2) Involuntary Breathing (integrating center) =

- Medulla – respiratory center regulates respiratory rate.
- Pons – apneustic center (stimulate inhalation)
  – pneumotaxic center (inhibit inhalation)

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5. Regulation of Respiration – regulation of blood pH

Normal Blood pH = 7.35 – 7.45
Blood pH maintained by buffering CO_2 with HCO_3-

Blood with high CO2 or H+ content = acidic (acidosis)
Blood w/lower CO2 or high HCO3- content = alkaline (alkalosis)

Blood pH (Acid/Base balance) based primarily on blood CO2 content and metabolic activities in body:

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Minute ventilation = the depth and rate of breathing.
per minute.

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Hypoventilation
not ventilating well
CO_2 is acidic

- What happens to minute ventilation **after hypoventilation**?

Holding breath increases CO2 in blood (respiratory acidosis)

Stimulus = high blood CO2 . ↓ blood pH = acidosis

Sensors = chemoreceptors in aortic arch & carotid arteries

Integrating center = medulla oblongata (respiratory center), which stimulates increased minute ventilation. ↑ CO_2 exhaled removing acid from blood

Effectors = respiratory muscles cause increased minute ventilation. More CO2 exhaled

Effect = blood pH increases back to normal

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over-ventilation.

- What happens to minute ventilation **after hyperventilation**?

Rapid breathing decreases CO2 in blood (causes respiratory alkalosis)

↑ blood pH

Stimulus = low blood CO2

Sensors = chemoreceptors in aortic arch & carotid arteries

Integrating center = medulla oblongata (respiratory center)

Effectors = respiratory muscles cause decreased minute ventilation. Less CO2 exhaled.

Effect = blood pH decreased back to normal

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Review

- **Gas exchange at tissues & at alveoli of lungs Depends on differences in partial pressures of O_2 and CO_2**
- **Regulation of breathing (voluntary vs involuntary)**
  - **Primary motor cortex (voluntary)**
  - **Medulla & Pons (involuntary)**
- **Acid / Base imbalance**
  - **Respiratory Acidosis & alkalosis**
  - **Changes to minute ventilation to fix blood pH**

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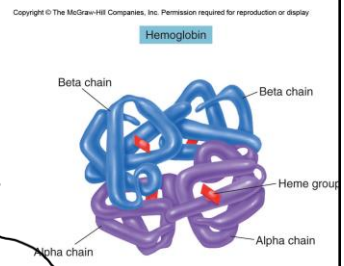
6. Hemoglobin & Hemoglobin Disorders

Hemoglobin =

- **4 protein chains w/4 iron-containing heme (pigments)**
- **Each heme group binds with 1 O2 molecule**
- **Each RBC has ~280 million hemoglobin molecules (each RBC can carry ~billion O2 molecules! (4 X 280 million)**
- **Hemoglobin bound to O2 = "oxyhemoglobin" (Arterial blood 97% saturated w/oxyhemoglobin = bright red)**
- **Hemoglobin lacking O2 = "deoxyhemoglobin" (venous blood dull red or maroon)**



pulse ox; meter

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Hemoglobin Disorders:

Carbon Monoxide = odorless, color-less gas that has greater binding to hemoglobin than to oxygen. Thus, carbon monoxide gas outcompetes O2 for binding sites on hemoglobin, creating **carboxyhemoglobin** on RBCs. Known as "carboxyhemoglobinemia"

Result : **Carboxyhemoglobin doesn't deliver O2 to cells, and carbon monoxide can't be used in ETC to make ATP**

> Hypoxia – tissues starved for O2

> Death *(CDC says 400 people die/year of this in US)*

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CLINICAL APPLICATIONS

Carboxyhemoglobin is hemoglobin with its heme groups bound to carbon monoxide instead of oxygen. Because the bond that hemoglobin forms with carbon monoxide is 210 times stronger than the bond it forms with oxygen, carbon monoxide tends to displace oxygen and remain bound as it goes through the circulation, thereby reducing the oxygen carried by the blood. Carboxyhemoglobin has a cranberry juice color, compared to the tomato juice color of oxyhemoglobin. The body actually produces a tiny amount of carbon monoxide, and so there is always some carboxyhemoglobin; however, according to federal standards, active nonsmokers should not have more than 1.5% carboxyhemoglobin. Higher percentages of carboxyhemoglobin constitute **carbon monoxide poisoning**. Nonsmokers living in certain smoggy cities can have 3% carboxyhemoglobin levels, whereas smokers there may have 10% or more carboxyhemoglobin. Much higher percentages can be produced by smoke inhalation or suicide attempts, and may cause death. People with carbon monoxide poisoning are often given hyperbaric oxygen therapy (previously described).

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Hemoglobin Disorders contin…

Methemoglobinemia = disorder in which hemoglobin's iron (a component of heme) is "ferric" rather than "ferrous".

> this hemoglobin called **methemoglobin** (pronounce as "met-hemoglobin")
> Methemoglobin has ↓ ability to release (unload) O2 at tissues.
> Tissues chronically O2-starved.
> Patients are hypoxic & BLUE!

"**Blue baby syndrome**" = babies turn blue (hypoxia) from drinking milk made w/nitrate contaminated water. Nitrate causes formation of methemoglobin.

CDC says ~3,000 cases in babies/year in US

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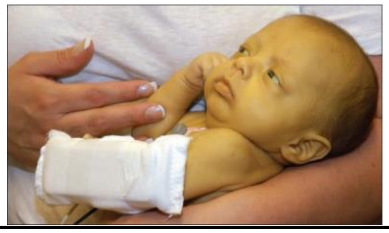
Hemoglobin Disorders contin…

Neonatal jaundice At birth switch from **hemoglobin-F** (fetal) to **hemoglobin-A** (adult)

- Body removes RBCs with hemoglobin f.
- Liver removes biliruben from destroyed hemoglobin f.
- Liver sometimes not mature enough to remove biliruben.
- Bilirubin builds up (*hyperbilirubinemia*)
- Baby turns yellow. (*affecting about 60% of term and 80% of preterm babies*)

Treatment:

"blue light exposure" – breaks bilirubin down to water-soluble form excreted by kidneys.



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CLINICAL APPLICATIONS

The fetus has a different form of hemoglobin (called **hemoglobin F**) than its mother, who has adult hemoglobin (**hemoglobin A**). The reason that the fetus has a different form of hemoglobin than its mother is because hemoglobin F has a stronger affinity for oxygen than does hemoglobin A, causing oxygen to move from the mother's to the fetus's blood. Hemoglobin F has a higher affinity for oxygen because it can't bind to 2,3-BPG, which works to reduce the bond strength for oxygen in the mother's red blood cells. The fetus stops producing hemoglobin F and begins producing hemoglobin A at about week 38 of pregnancy. When the fetus switches from hemoglobin F to hemoglobin A, it destroys its old red blood cells and converts the heme groups into bile pigment, or *bilirubin* (chapter 14). Too much bilirubin can cause *jaundice* (a yellowing of the skin and mucus membranes), and jaundice produced for this reason is called **physiological neonatal jaundice**. Putting the babies under blue light converts the bilirubin into a more water-soluble derivative that they can excrete in the urine.

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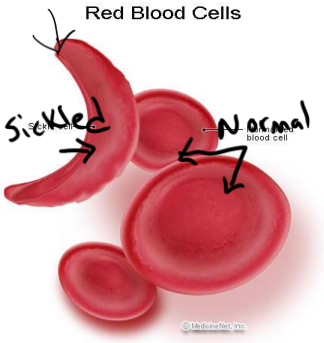
Hemoglobin Disorders contin…

Sickle Cell Anemia = homozygous recessive condition in which body produces RBCs with **hemoglobin-S** rather than **hemoglobin-A.**

sickle cell is from 1 amino acid substitution (valine for glutamic acid) on hemoglobin.



- Hemoglobin-S turns RBCs into sickle-shape.
- Sickled RBCs carry less O2 (cause hypoxia)
- Sickled RBCs tend to form clots (thrombus)
- Patients more prone to embolism.
- More prone to ischemic events.

CDC says 100,000 people in US, and globally millions of people, living with sickle cells dz.

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Review

- **Hemoglobin O_2 transport:**
  - **Oxyhemoglobin & deoxyhemoglobin**
  - **Abnormal hemoglobin (carboxyhemoglobin, methemoglobin)**
  - **Neonatal jaundice**
  - **Sickle cell**

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