

## Ch 11: Respiratory Physiology Instructor Notes

Lecture, part 1

### Respiratory system divided into:

**1) Conduction zone** = how air from environment is “conducted” into lungs.

#### Functions:

- > to conduct air from environment to lungs
- > filter, warm & humidify air.
- > has mucus to trap particles, cilia to move it up and away from lungs. Mucus & particles are “expectorated” (coughed up) and typically swallowed where particles destroyed by stomach acid.

#### Includes:

- > oral & nasal cavities
- > pharynx
- > larynx – where glottis opens into trachea (glottis protected by the epiglottis)
- > trachea
- > primary, secondary, tertiary, and terminal bronchioles.

### **2) Respiratory Zone**

- > respiratory bronchioles are smallest bronchioles branching off the tertiary bronchioles of conducting zone.
- > alveolar sacs = honeycomb-shaped sacs for gas exchange with pulmonary vessels. (about 300 million of them in the lungs!)

### **The capillary plexus of alveoli involves a capillary plexus of:**

**Pulmonary arteries** – carry O<sub>2</sub>-poor blood from pulmonary trunk to the lungs to pick up O<sub>2</sub> and drop off CO<sub>2</sub>. (Remember that arteries ALWAYS go away from the heart, but the pulmonary artery carries O<sub>2</sub>-poor blood, unlike systemic arteries.)

**Pulmonary veins** – carry O<sub>2</sub>-rich blood from lungs back to heart (left atrium). (Remember, veins ALWAYS go towards the heart, but pulmonary veins carry O<sub>2</sub>-rich blood, unlike systemic veins.)

### Types of alveolar cells:

**1) type 1 alveolar cells** – make up the thin wall of alveolar sacs (1 cell layer thick to allow for easy gas exchange)

The alveolar sac is lined by a **thin layer of water** (regulated by ion channels on the surface of the type 1 cells).

This water layer helps gases cross the sac membrane, BUT the water adds **surface tension**. Surface tension of water makes the sacs prone to collapsing (the cell walls could stick to each other) when the sacs get smaller with exhalation, making it difficult for them to inflate with the next inhalation.

**2) type 2 alveolar cells** – secrete surfactant, which decrease the surface tension caused by the water layer and keeps the sacs (and thus the lungs) from collapsing.

### **Membranes (pleura) of the lungs:**

Visceral pleura = membrane covering the lungs

Parietal pleura = membrane lining each pleural cavity containing a lung. This parietal pleura is stuck to the thoracic cage wall by surface tension. Thus, as thoracic cage changes shape with inhalation/exhalation, the plural (lung) cavities change shape with it.

**Intrapleural space** = potential space between the visceral and parietal pleura containing a small amount of lubricating serous fluid (so when pleural membranes move against each other during inhalation/exhalation, they don't build up friction, which would damage the membranes).

There should NEVER be air within the intrapleural space, and the pressure within this space must always be negative. If air ever invades the intrapleural space (such as can happen when the lungs are punctured or damaged so that air escapes from within the lung and into the intrapleural space), a pneumothorax can occur, and the lungs collapse.

**Atelectasis:**

**1) Non-obstructive atelectasis** = seen in premature newborns (< 28 weeks gestation). Their lungs are too immature to produce surfactant, so their alveolar sacs collapse when exhaling. Leads to collapsed lung.

**2) Obstructive atelectasis** = when a foreign body gets lodged within trachea or bronchiole. Air cannot fill alveolar sacs, and they collapse, leading to collapsed lung. Foreign bodies lodged in upper airway (trachea, maybe primary bronchi) can be pushed up by Heimlich maneuver.

**Respiratory Distress Syndromes:****1) Infant respiratory distress syndrome (IRDS)**

> pre-mature babies born with immature lungs that can't produce enough surfactant can suffer from non-obstructive atelectasis and collapsed lung.

> treat with synthetic surfactant until their lungs (type 2 alveolar cells) can make their own.

**2) Acute respiratory distress syndrome (ARDS)**

> see in children and adults

> due to inflammation from many possible causes (e.g. infection, chronic damage from smoking, chronic bronchitis, coronavirus!)

> results in fluid (serum) buildup in alveolar sacs.

> fluid dilutes surfactant, which  $\uparrow$  alveolar surface tension, causing alveoli to collapse (and lung collapse)

> decreased gas exchange makes it very difficult to breath.

> patients might need to be put on mechanical ventilator until problem can be treated (anti-inflammatory steroids, get fluid out of lungs)

> patient with fluid in alveolar sacs prone to pneumonia (infection in lungs) because bacteria thrive in warm, humid environments. Bacteria produce toxins, which can get into bloodstream and cause sepsis. Risk of death.

**Coronavirus can cause ARDS** (<https://health.clevelandclinic.org/heres-the-damage-coronavirus-covid-19-can-do-to-your-lungs/>)

- 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 fluid within the alveoli of the lungs is prone to bacterial infection. This is called **pneumonia**.

**Mechanics of Respiration:**

**1) Air always moves across membranes from areas of high gas pressure to areas of low pressure.** (almost like diffusion)

Atmospheric air pressure is constant (at low altitude  $\sim$  760 mmHg)

Air pressure within lungs (intrapulmonary) depends of volume of thoracic cavity.

**2) Air pressure in lungs (a closed chamber) changes with volume of that chamber (Boyles law)**

As volume of chamber  $\uparrow$ , the air pressure within  $\downarrow$ .

As volume of chamber  $\downarrow$ , the air pressure within  $\uparrow$ .

*What changes the volume of the lungs during breathing? Movement of the diaphragm!*

> **When diaphragm contracts, it moves downward:**

This pulls thoracic cage DOWN &  $\uparrow$  its volume, which  $\uparrow$  lung volume, and this  $\downarrow$  **intrapulmonary air pressure (-3 mmHg below atmospheric pressure)**

> **When diaphragm relaxes, it moves upward:**

This pulls thoracic cage UP &  $\downarrow$  its volume, which  $\downarrow$  lung volume, and this  $\uparrow$  **intrapulmonary air pressure (+3 mmHg above atmospheric pressure)**

**Gas pressure vocabulary:**

**Intrapulmonary pressure** = pressure of air (gases) inside lungs

> during inhalation it is -3 mmHg lower than atmospheric pressure (due to action of diaphragm)

> during exhalation it is +3 mmHg above atmospheric pressure (due to action of diaphragm)

**Intrapleural pressure** = pressure of air between the pleural membranes (it should always be negative, and even more negative than the intrapulmonary pressures)

> during inhalation it is -6 mmHg lower than atmospheric pressure.

> during exhalation it is -3 mmHg above atmospheric pressure

**\* 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. \***

**Pneumothorax = collapse of the lung(s) due to air entering the intrapleural space (either from trauma or lung disease)**

Air from the lungs filling the intrapleural space builds up pressure and that pressure presses into the lung, collapsing it. Treatment = put in chest tube to drain out the air in the intrapleural space.

Lecture, part 2

**Important Properties of the lungs:**

**1) Surface tension** = pressure within the alveoli from thin layer of water lining the sacs. Makes alveoli vulnerable to collapse when they get smaller during exhalation.

**2) Compliance** = the stretchiness of the lungs allowing them to expand when air enters during inhalation.

> more lung compliance = greater capacity to expand & fill with air (this is good)

> less lung compliance = lower capacity to expand & fill with air. (this is bad – lung disease)

**3) Recoil** (or elasticity) = tendency of lungs (and alveolar sacs within) to bounce back to normal size during exhalation. (Allows air to evacuate from lungs).

**Smoking, emphysema, and loss of alveolar recoil.**

> Smoking introduces chemical particles into alveolar sacs, from which they cannot leave.

> Foreign material causes body to mount immune response with inflammation.

- Chronic smoking leads to **chronic alveolar inflammation**.
- Chronic inflammation causes the alveolar sacs (and lungs) to thicken with fibrous scar tissue, and this is called **pulmonary fibrosis**. Pulmonary fibrosis reduces compliance (ability of sacs & lungs to inflate with air)
- Chronic inflammation also **causes alveolar walls to degrade**, leaving large pockets of air space. This causes “*air trapping disease*” and it **reduces recoil** (the ability of alveolar sacs & lungs to recoil back to normal shape during exhalation. Thus alveolar sacs don’t empty completely during exhalation, leaving less space for “fresh air” (full of O<sub>2</sub>) to fill the alveolar sac during the next inhalation. The result = less O<sub>2</sub> gets into the alveoli. Gas exchange decreases dramatically.

> This is why emphysema is called an air trapping disease.

**Factors that affect lung compliance:**

**1) Factors increasing compliance** = surfactants

**2) Factors decreasing compliance:**

> many, many things! Anything that causes chronic inflammation.

(smoking, inhaling small particles of sand, glass, stone, asbestos, allergens)

> chronic inflammation of the bronchioles is called **bronchitis**.

> chronic bronchitis can cause narrowing of the bronchioles, called **bronchoconstriction**.

> chronic inflammation of the alveolar sacs can lead to **pulmonary fibrosis**, which ↓ compliance (see above)

### **Respiratory Disorders Classified as Restrictive or Obstructive:**

- 1) **Restrictive disorder** = when lung tissue is damaged (lungs are stiffened or respiratory muscles weakened)
  - > Ex. Pulmonary fibrosis
- 2) **Obstructive disorder** = when lung tissue is normal, but resistance to air flow is increased (airways narrowed)
  - > Ex. Asthma (have bronchoconstriction)
  - > COPD (which includes emphysema & chronic bronchitis – both of which can cause bronchoconstriction)
  - > Cystic fibrosis

### **Restrictive respiratory disorder – Pulmonary fibrosis**

Many causes! From breathing in fine particles or chemicals, which get trapped in alveolar sacs, cause chronic inflammation, which leads to scar tissue. Decreases compliance!

- > **Silicosis** = fibrosis from inhaling fine particles of glass, rock, or sand.
- > **Anthracois** = fibrosis from inhaling fine particles of coal. (Coal miners disease)
- > **Mesothelioma** = fibrosis form inhaling asbestos
- > **Smoking** = fibrosis from inhaling chemicals in cigarette smoke.

### **Obstructive respiratory disorders:**

**Asthma** – bronchiole smooth muscle over-reacts (to allergen)

- > obstructive disorder due to inflammation & mucus secretion narrows bronchioles.

*Question: What drug would you use to treat severe bronchoconstriction in an asthmatic?*

Answer: albuterol (a  $\beta_2$  agonist), which causes bronchodilation.

### **COPD (chronic obstructive pulmonary disease)**

- > chronic inflammation of alveolar sacs
- > narrowed bronchioles due to inflammation
- > mucus in airways and bronchioles – from goblet cells
- > formation of scar tissue (pulmonary fibrosis) – thus, COPD starts out as obstructive but can become restrictive

**Emphysema** – see Pg 3 above

**Cystic fibrosis** =genetic disorder affecting Cl<sup>-</sup> ion channels on alveolar cell membranes. Cause water layer to become viscous mucus.

- > Results in mucus buildup, which dilutes surfactant (will  $\uparrow$  surface tension & intra-alveolar pressure)
- > Alveoli more prone to collapse
- > reduces available alveolar space for gas exchange (because filled with mucus)
- > warm and humid environment leads to bacterial growth (pneumonia)

### **Additional respiratory vocabulary**

- > **apnea** = absence of breathing
- > **dyspnea** = difficulty/labored/painful breathing
- > **eupnea** = normal breathing
- > **hyperventilation** = rapid breathing (can cause respiratory alkalosis, rise in blood pH)
- > **hypoventilation** = lower than normal breathing or holding breath (can cause respiratory acidosis)

**Gas exchange at lungs & body tissues:**

Gas always moves passively across membranes, from area of high gas (O<sub>2</sub>/CO<sub>2</sub>) pressure to areas of low pressure. (kind of like diffusion). The difference in gas pressures on either side of a membrane is called a **pressure gradient**.

**Gas exchange within lungs (between alveoli & pulmonary vessels).****O<sub>2</sub>:**

Within alveoli PO<sub>2</sub> = 105 mmHg, which is higher than PO<sub>2</sub> in pulmonary arteries (40 mmHg), so O<sub>2</sub> will move from the alveoli (where it's high) to the pulmonary vessel (where it's low).

**CO<sub>2</sub>:**

Within alveoli, PCO<sub>2</sub> = 40 mmHg, which is lower than PCO<sub>2</sub> in pulmonary arteries (46 mmHg), so CO<sub>2</sub> will move from pulmonary artery into alveoli. CO<sub>2</sub> is released during next exhalation.

**Gas exchange with tissues and systemic vessels:****O<sub>2</sub>:**

Within systemic arterial capillary PO<sub>2</sub> = 100 mmHg, which is higher than in tissues (PO<sub>2</sub> < 100mmHg), so O<sub>2</sub> moves from arterial capillary into tissues.

**CO<sub>2</sub>:**

Within the tissues PCO<sub>2</sub> = >40 mmHg, which is higher than in the capillary (PCO<sub>2</sub> = 40 mmHg), so CO<sub>2</sub> moves from the tissues into the capillary.

*Just look at the PO<sub>2</sub> and PCO<sub>2</sub> numbers, find where it's higher and lower, and then you know which way to gases will cross membranes (always high to low).*

**Voluntary & Involuntary Regulation of Respiration:**

**1) Voluntary breathing** – is controlled by primary motor cortex in frontal cerebral lobe.

**2) Involuntary breathing** – is controlled primarily by the **medulla** oblongata's respiratory center, which controls respiratory rate.) The medulla controls the pons, which has 2 centers: the apneustic & pneumotaxic centers.

**Negative feedback regulation of blood pH if blood pH drifts outside of normal range (7.35 – 7.45):**

**If blood pH becomes acidic** (e.g. you are hypoventilating, or have metabolic acidosis)

Sensors = chemoreceptors in the aortic arch & carotid arteries sense it, signal medulla

Integrating center = medulla's respiratory center

Effector = diaphragm (and other respiratory muscles) increase minute ventilation. (Minute ventilation = respiratory rate X respiratory depth)

Effect = you blow out extra CO<sub>2</sub> (an acidic molecule), which brings blood pH back up to normal.

**If blood pH becomes alkaline** (e.g. you are hyperventilating or have metabolic alkalosis)

Sensors = same

Integrating center = same

Effector = same, BUT have decreased minute ventilation

Effect = you retain a little CO<sub>2</sub>, which brings blood pH back down to normal

**Blood pH is based primarily on a respiratory component and metabolic component:**

**1) Respiratory component** & how much CO<sub>2</sub> is retained or eliminated.

If you hyperventilate – you lose too much CO<sub>2</sub> (acid) and your blood pH rises (called **respiratory alkalosis**)

If you hypoventilate – you retain too much CO<sub>2</sub> and your blood pH drops (called **respiratory acidosis**)

**2) Metabolic component** – depends on what your body is metabolizing.

If you have a lot of acidic molecules in your blood (e.g. ketones, lactic acid, fatty acids, amino acids) or your kidneys don't retain enough alkaline buffer, called bicarbonate, your blood pH drops (called **metabolic acidosis**).

If you lose a lot of acids (chronic vomiting) or have too much bicarbonate in your blood, your blood pH rises (called **metabolic alkalosis**)

## Hemoglobin

- > **Hemoglobin** is a respiratory pigment associated with our RBCs. Each RBC has 280 molecules of hemoglobin, and each hemoglobin can bind with 4 O<sub>2</sub> molecules. (You do the math – that's A LOT!)
- > Hemoglobin that is maximally bound with O<sub>2</sub> is called **oxyhemoglobin**
- > Hemoglobin that is low in O<sub>2</sub> (because it just released it at tissues) is called **deoxyhemoglobin**

## Hemoglobin Disorders:

**1) Carboxyhemoglobin** is hemoglobin that is bound with carbon monoxide (CO) gas rather than O<sub>2</sub>. Hemoglobin preferentially will bind to CO over O<sub>2</sub> if CO is present. CO is an odorless, colorless gas. Carboxyhemoglobin doesn't have the oxygen that our tissues need, so they are starved for oxygen (hypoxia). CO poisoning is deadly. Is why we have CO detectors in the house.

**2) Methemoglobin** = a form of hemoglobin in which the iron component is ferric (abnormal) rather than ferrous (normal). Methemoglobinemia = **methemoglobin** in the blood. Problem is that methemoglobin won't release O<sub>2</sub> at the tissues (it holds onto it). Tissues starved for O<sub>2</sub> (hypoxia)

**Blue baby syndrome** is when babies turn blue because their formula was made with water containing nitrate. This will cause formation of methemoglobin.

**3) Neonatal jaundice** = when babies turn blue shortly after birth. Their liver is not quite mature yet.

- > when a baby is born, there is a switch from having RBCs with hemoglobin F (fetal) to hemoglobin A (adult).
- > the old RBCs with hemoglobin F are destroyed and the yellow pigment bilirubin rises in the blood.
- > the liver is supposed to filter out & remove this bilirubin, but an immature liver cannot, so bilirubin rises in the blood and the baby becomes jaundiced.
- > treatment = use blue lights to break down bilirubin

**4) Sickle cell anemia** = homozygous recessive condition in which the body produces hemoglobin S rather than hemoglobin A.

- > RBCs carrying hemoglobin S tend to become sickled in shape
- > sickled RBCs tend to clump together and form clots (thrombus)
- > formation of clots increases risk of an embolism
- > embolism can lead to ischemic events.