Ventilation-Perfusion Ratio

Editing File

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Special Thanks to Hasan Alsughayir for the Sketch <3

Male Dr: Thamir Al-khlaiwi
Female Dr: Felwa Alzaid

Objectives

01 Recognize the high-pressure and the low-pressure circulation supplying the lungs.

02 Identify the meaning of the physiological shunt in the pulmonary circulation.

03 State the different lung zones according to the pulmonary blood flow.

04 Define the V/Q ratio and its regional variation.

05 Explain the clinical significance of the V/Q ratio.

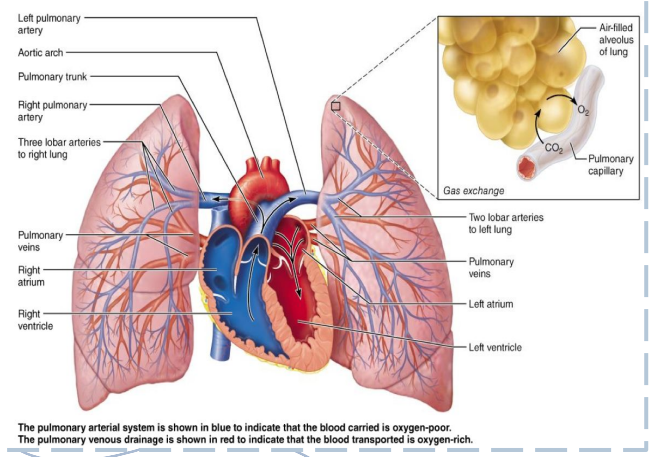
06 Describe the abnormal patterns of the V/Q ratios, shunt and dead space patterns .

Check the description of the vid, there is a mistake in min 26:27

Female Slides Only

Pulmonary Circulations

Starts from Right ventricle -> Pulmonary artery -> arterioles -> Alveolar capillaries (Surrounding the alveolar sac) participating in gas exchange -> The blood will take O2 and remove CO2 -> Then it'll go to venules -> Pulmonary vein which drains into the left atrium. Arteries are Oxygenated while Veins are deoxygenated but it's the other way round in case of pulmonary vessels

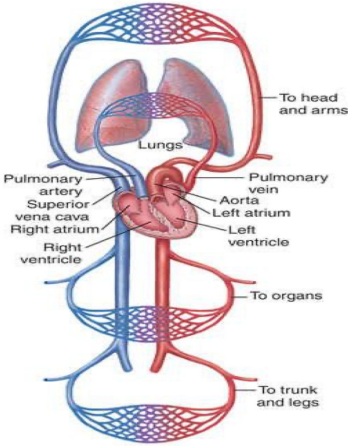


The pulmonary arterial system is shown in blue to indicate that the blood carried is oxygen-poor.
The pulmonary venous drainage is shown in red to indicate that the blood transported is oxygen-rich.

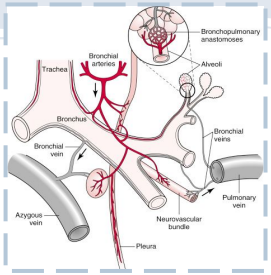
Blood volume of the lungs

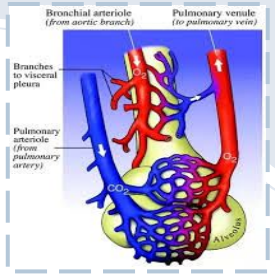
Blood volume of the lungs

- 450 ml
- 9% of total blood volume
- Approximately 70 ml in pulmonary capillaries
- Lungs serve as blood reservoir (100-250 ml)



Pulmonary Circulations





Pulmonary circulations

High-pressure/low-flow circulation

Supplies systemic arterial blood to:

- Trachea
- Bronchial tree (including terminal bronchioles)
- Supporting tissues of lung
- 0uter coats (adventitia) of pulmonary arteries & veins.

- **Bronchial arteries:** branches of thoracic aorta.
  - Supply most of systemic arterial blood at a pressure that is only slightly lower than aortic pressure.

"pressure" here is hydrostatic pressure of blood.

Low-pressure/high-flow circulation

Supplies venous blood from all parts of the body to alveolar capillaries where oxygen (O_2) is added & carbon dioxide (CO_2) is removed.

- **Pulmonary artery** (receives blood from right ventricle) and its arterial branches carry blood to alveolar capillaries for gas exchange.
- Pulmonary veins then return blood to left atrium to be pumped by left ventricle through systemic circulation.

Physiological Shunt

Female Slides Only

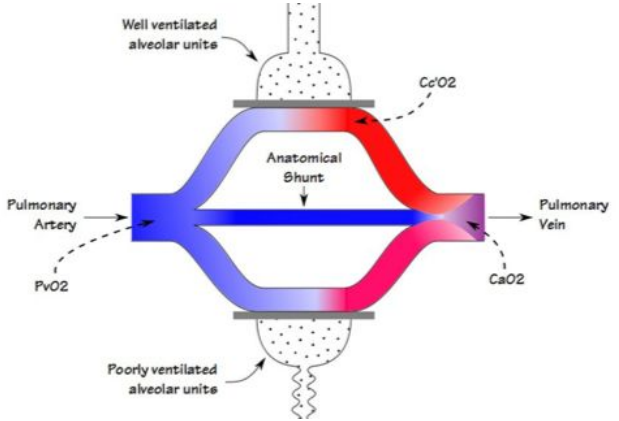
Physiological shunt: A diversion through which the **venous blood** is **mixed** with **arterial blood**

It's the blood the escaped gas exchange and it's 1-2%.

There are only 2 physiological shunts in the body, they're:

1. Flow of **deoxygenated blood** from bronchial circulation into **pulmonary veins** without being oxygenated makes up part of normal physiological shunt.

2. Flow of deoxygenated blood from thebesian veins into cardiac champers directly.



Physiological shunt results in venous admixture (mixing of oxygenated blood with deoxygenated blood).

Physiological shunt: total quantitative amount of shunted blood per minute.

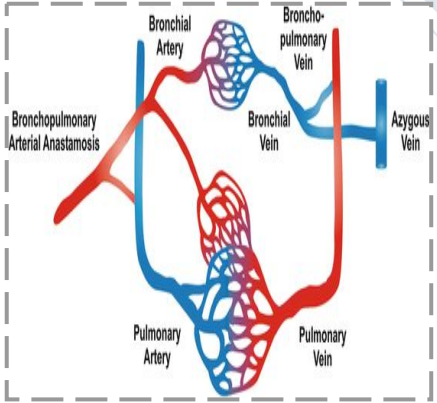
Physiological Shunt

1. The blood that flows to lungs through small bronchial arteries that originate from the systemic circulation amounts to 1 - 2% of the total cardiac output.

2. The bronchial arterial blood is oxygenated blood, supplies the supporting tissues of the lungs, including the connective tissue, septa, and large and small bronchi.

3. After this bronchial blood & arterial blood passes through supporting tissues, it empties into pulmonary veins and enters the left atrium, rather than passing back to the right atrium (shunt blood).

4. The flow into left atrium and left ventricular output are about 1 - 2% greater than that of right ventricular output.



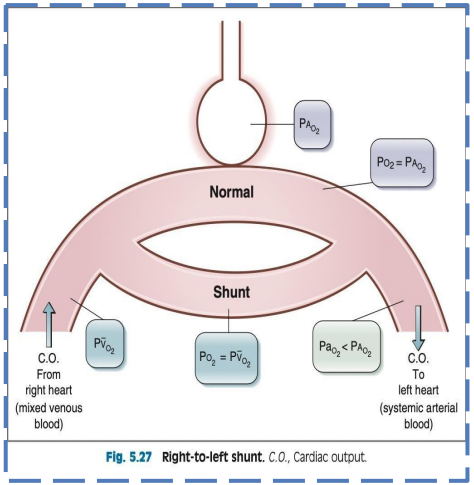
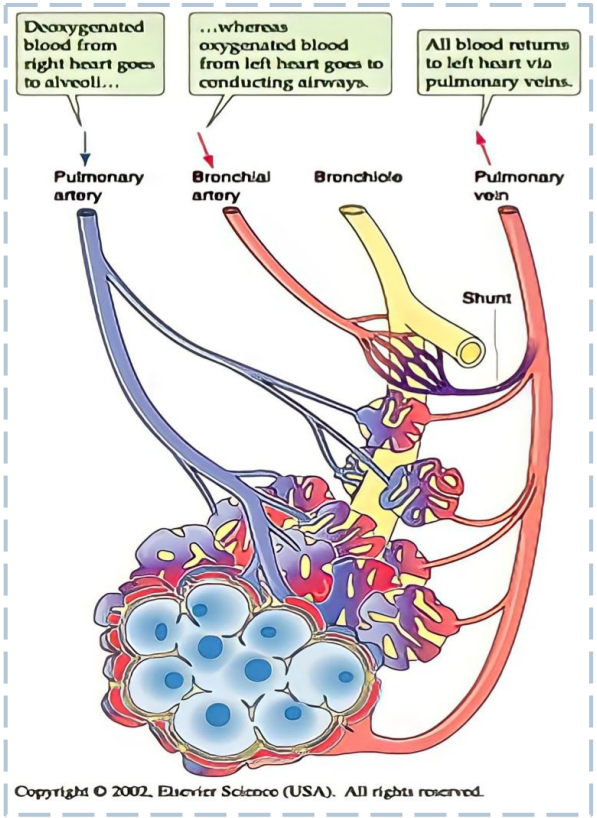


Fig. 5.27 **Right-to-left shunt.** *C.O.*, Cardiac output.

Shunts

Male Slides Only

Shunt	A portion of the pulmonary blood flow that bypasses the alveoli (no gas exchange).
Physiological Shunt	Bronchial blood flow & coronary blood flow (2%) bypasses the alveoli.
Abnormal shunt	Example: **right to left shunt:** • Will not be treated by high O_2 supply. • Useful diagnostic tool.

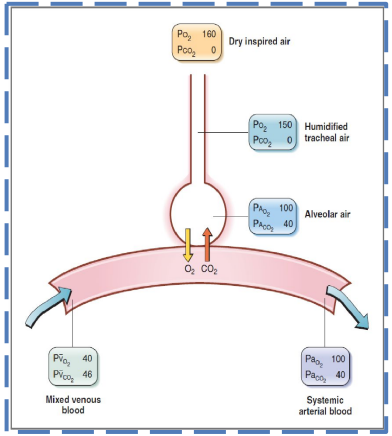


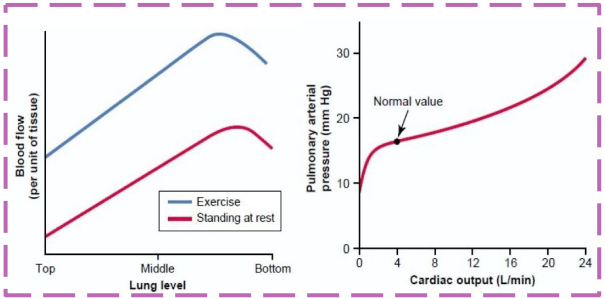
Regulation of Pulmonary Blood Flow

Male Slides 1,2,3,4,5

6–Female Slides

1. The major factor regulating pulmonary blood flow is the partial pressure of O_2 in alveolar gas, PA_{O2}.
2. Decreases in PA_{O2} → pulmonary vasoconstriction.
   (Adaptive mechanism: blood flow is directed away from poorly ventilated region)
3. If PA_{O2} is reduced below 70 mmHg → vasoconstriction occurs.
4. High altitude: PA_{O2} is reduced which produced → global vasoconstriction.
5. Fetal pulmonary blood flow circulation is about 15% of cardiac output; due to global vasoconstriction.
6. Factors regulating pulmonary blood flow:
   - Cardiac output (Increases blood flow).
   - Decreased alveolar oxygen (Decreases blood flow; for gas exchange it's like a reflex).
   - Chemical factors,vasoconstrictor or dilator.(Constrictor decreases blood flow, Dilator increases blood flow).
   - Hydrostatic pressure (Next slide).
   - Physical activity (Increases blood flow).





Effect of exercise on pulmonary blood flow and on mean pulmonary arterial pressure caused by increase cardiac output.

Effect of Hydrostatic Pressure on Regional Pulmonary Blood Flow

1. Hydrostatic pressure is affected by gravity.

2. The lowest point in the lungs is normally about 30 cm below the highest point (Between the apex and base), this represents a 23mm Hg pressure difference, about 15 mm Hg of which is above the heart and 8 below it.

3. Gravitational effect → pulmonary arterial pressure in uppermost portion of the lung of a standing person is ~15 mmHg less than pulmonary arterial pressure at the level of the heart. The Pressure in the lowest portion of lungs is ~8 mmHg greater.

4. Pressure differences have profound effects on blood flow through different areas of lungs → the effect determines blood flow per unit of lung tissue at different levels of lung in upright person.

5. In the standing position at rest, there's little flow in the top of the lung. In supine position, blood flow is nearly uniform.

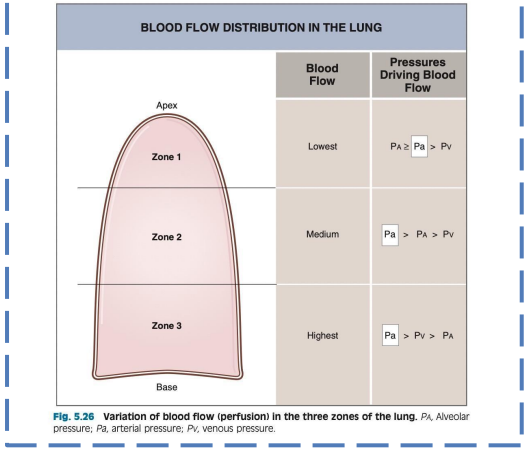


Fig. 5.26 Variation of blood flow (perfusion) in the three zones of the lung. *PA*, Alveolar pressure; *Pa*, arterial pressure; *Pv*, venous pressure.

Ventilation/Perfusion Ratio (V/Q)

A little math
won't kill you :3

V/Q is the ratio of **alveolar ventilation** to the **pulmonary blood flow** per minute**, it functions in determining the oxygenation level of the body:**

-The alveolar ventilation(V) **at rest** is **4200 ml/min (4.2 L/min)**
-The pulmonary blood flow **at rest** (perfusion - Q)**:** equal to right ventricular output per minute is **5000 ml/min (5 L/min)**

When the tidal volume and cardiac output are normal, the alveolar ventilation is about 80% of the pulmonary blood flow.

Because of this ratio, the gas exchange process through the respiratory membrane is almost optimal.

-Alveolar PO_2=104 mmHg
-Alveolar PCO_2=40 mmHg

V/Q = (4200 ml/min)/(5000 ml/min) = 0.84 (this is the normal average V/Q ratio across all lung areas)

The perfusion isn't equal across different parts of the lung due to the effect of gravity. When the perfusion increases, the ratio decreases, and when the perfusion decreases, the ratio increases. (لانه المقام)

This slide will be explained in detail in the next 4 slides, I recommend coming back here after reading them.

Ventilation (V)

Ventilation is the movement of air into and out of the lung, it can be calculated by the tidal volume (minus the anatomical dead space because we're talking about **alveolar** ventilation) multiplied by the respiratory rate. (basically: amount in each breath * how often you breathe)

In normal cases 12/min (respiratory rate) * 350ml (tidal volume - dead space (next slide)) = **4200 ml/min**

-the right lung is slightly better ventilated than the left lung. There is, however, some differences in ventilation between erect and lateral (منسدح على جنب) positions.

In an erect position

-the bases of the lung are a little bit better ventilated. (but doesn't affect V/Q much)

-The weight of the lung helps improving the compliance of the dependent lung (lower part) while stretching the non-dependent (upper part), this is only significant at low inspiratory flow rates.

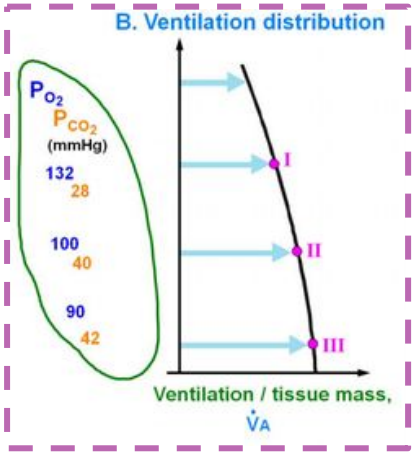
- The V/Q ratio in the bases is ~0.6.
- The V/Q ratio in the apices is > 3.

Females' Slides

In a lateral position

-The dependent lung (closer to gravity) is better ventilated in a normally breathing patient

-The non-dependent lung is better ventilated in a ventilated patient. (under anesthesia)



Male Slides Only

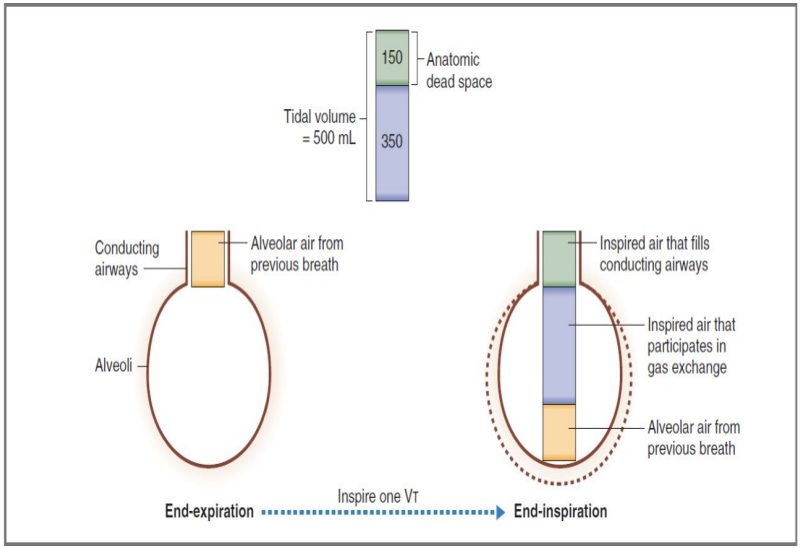
Dead Space

Dead space refers to the amount of air that doesn't participate in the gas exchange process. It is classified into three types:

-**Anatomical dead space:** the amount of air in the conducting zone, it is about one-third of the tidal volume **(150ml)**. During expiration, the air in it gets exhaled first.

-**Functional dead space:** the amount of air in malfunctioning alveoli due to collapse or obstruction.

-**Physiological dead space:** the total amount of dead space. (anatomical + functioning) (its value should be around that of anatomical dead space in a healthy individual)



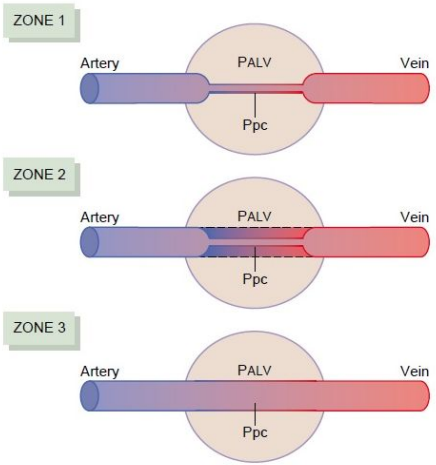
Perfusion (Q)

Trust me!!

Perfusion (or pulmonary blood flow) refers to **the cardiac output of the right ventricle per minute.** It can be calculated by the stroke volume multiplied by the heart rate. It is normally around **5000 ml/min.**

The pulmonary circulation is a low-pressure (high flow) circulation. Gravity can affect its pressure, making the bases more perfused than the apices, this creates 3 zones of uneven pulmonary blood flow in the lungs:

Zone 1	Zone 2	Zone 3
Alveolar air pressure is higher than the pressure of both the arterioles and venules, resulting in little to no flow of blood during all portions of the cardiac cycle (alveolar air pressure > systolic pressure > diastolic air pressure)	Alveolar air pressure is higher than the pressure of venules but less than that of the arterioles, resulting in an intermittent flow of blood during peaks of pulmonary arterial pressure (systolic pressure > alveolar air pressure > diastolic air pressure)	Alveolar air pressure is less than the pressure of both the arterioles and venules, resulting in a continuous flow of blood (systolic pressure > diastolic air pressure > alveolar air pressure)



Zones Cont.

Normally, the lungs has only the pattern of flow of zones 2 and 3. (2 at the apices and 3 at the lower areas of the lungs)

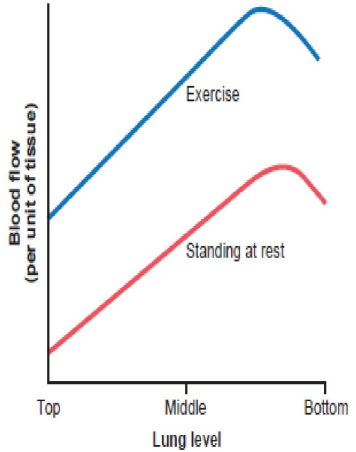
Standing position at rest (erect): little flow in the top of the lung but about five times as much flow in the bottom. (V/Q ratio is **0.6 at the bases** and **3 at the apices** because the apices are more ventilated than perfused and the bases are more perfused than ventilated, remember?)

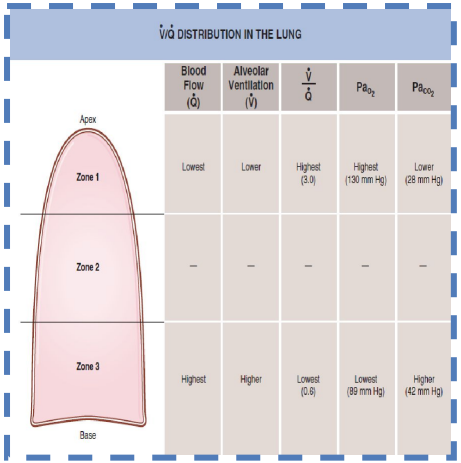
During exercise lying flat, the V/Q ratio becomes **homogeneous** (more balanced) among different parts of the lungs.

The blood flow in all parts of the lung increases during exercise.

A major reason for increased blood flow is that the pulmonary vascular pressures rise enough during exercise to convert the lung apices from a zone 2 pattern into a zone 3 pattern.

You can now reread that slide again to fully understand, click "that"





Abnormalities in V/Q Ratio

Changes in either the ventilation or perfusion (or both) can alter the ratio. This is also called a V/Q ratio mismatch, which happens when air or blood flow (usually) decreases. This can cause **hypoxia.** Causes of V/Q mismatch include COPD, pneumonia, asthma, pulmonary edema, chronic bronchitis, and airway obstruction.

Airway obstruction (as in COPD, asthma, or mucus plug) is an example of abnormal (decreased) ventilation causing a shunt of blood. (blood goes without being oxygenated)

Blockage of blood supply (as in pulmonary embolism is an example of abnormal (decreased) perfusion creating dead space. (air does not participate in gas exchange)

With decreasing alveolar ventilation, the V/Q ratio decreases until it becomes zero making the venous blood (which should have oxygenated blood) pass without being oxygenated and have PO2=40 mmHg & PCO2=45 mmHg (shunt), the alveoli will then have the same pressure of these gases. (because they can't be ventilated)

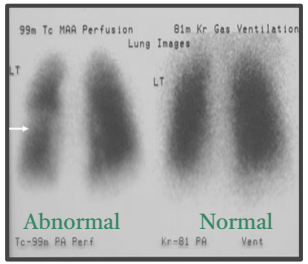
With decreasing perfusion, the V/Q ratio increases until it becomes infinity making the air get wasted and unable to exchange gases (dead space) because there is no blood flow to exchange gases with (Obviously) and the alveoli will have PO2=149 mmHg & PCO2=0 mmHg, similar to that of the conducting zone (not 104 and 40 don't mix them up!)

When the V/Q equals either 0 or ∞, there will be **no gas exchange** in the affected alveoli.

I know! anything divided by zero should by undefined, but what can we do :(

Clinical Applications

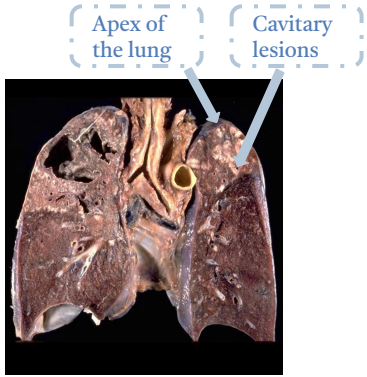
In chronic smokers with emphysema, COPD :there is an obstruction of airways and destruction of alveolar septa with patent alveoli ; these people have areas of serious physiological shunt and other areas of serious physiological dead space. Both of these conditions decrease the effectiveness of lungs as gas exchange organs to as little as 10% of normal.



Ventilation - Perfusion Lung Scan

COPD is the **most common** cause of pulmonary disability today .

In tuberculosis, Mycobacterium tuberculosis LOVES oxygen and target apices where the alveolar air resembles the atmosphere. In advanced cases, lung tissue is destroyed, and large avascular cavities develop making the infection difficult to treat; multiple drugs must be given together for a long period to fully eradicate tubercular organisms from the tissue.



Postmortem specimen showing apical lung lesions caused by tuberculosis.

Take home messages: don't smoke maybe? (or vape for that matter) <3

MCQs

Q1: Which of the following is/are abnormal shunt ?			
A- Bronchial blood flow	B- Coronary blood flow	C- Right to left shunt	D- A & B
Q2: A 44-years old woman, came to the hospital with chest pain. They did a lung examination and found low alveolar capillary pressure. also, it's less than alveolar air pressure. at which zone do they examine her lung?			
A- zone 1	B- zone 2	C- zone 3	D- alveoli
Q3: if the Pa_{O2} is decrease to 65 mmHg , What would occur ?			
A- global vasoconstriction	B- vasoconstriction	C- global vasodilation	D- vasodilation

1-C 2-A 3-B

MCQs

Q4: In an asthma attack, what can we expect to happen the V/Q ratio?			
A-Increases	B-Decreases	C-Doubles	D-Does not change
Q5: If V/Q=0, what will the alveolar pressure of oxygen be?			
A-40 mmHg	B-104 mmHg	C-149 mmHg	D-160 mmHg
Q6: Where does Mycobacterium tuberculosis typically establish itself?			
A-alveoli	B-bronchioles	C-bases of lungs	D-apices of lungs

4-B 5-A 6-D

SAQs

Q1: Describe the shunt and mention the types of shunt with examples

Q2: Differentiate between the blood flow in the 3 types of zones.

Q3: List 3 causes of V/Q ratio mismatch.

A1: slide 7

A2: Slide 13

A3: COPD, pneumonia, asthma, pulmonary edema, chronic bronchitis, and airway obstruction.

Ahmad Addas

Abdulmohsen Alrahaimi

Abdulaziz Nasser

Abdullah Almarwan

Saud Alsaeed

Abdullah Almutlaq

Talal Alrobaian

Khalid Al Tameem

Zyad Alshuhail

Abdulaziz Alobathani

Moath Alabdulsalam

Ibrahim Albabtain

Omar Alattas

Khalid Alkanhal

Leena Shagrani

Marwah Fal

Ghala Alyousef

Rimaz Alhammad

Basma Al-ghamdi

Aljoharah Alyahya

Samiyah Sulaiman

Noreen Almarabah

Aram Alzahrani

Lina Aljameel

Layal Alkhalifah

Hessa Alamer

Aleen Muneif

Farah Aldriweesh

physiology.444ksu@gmail.com