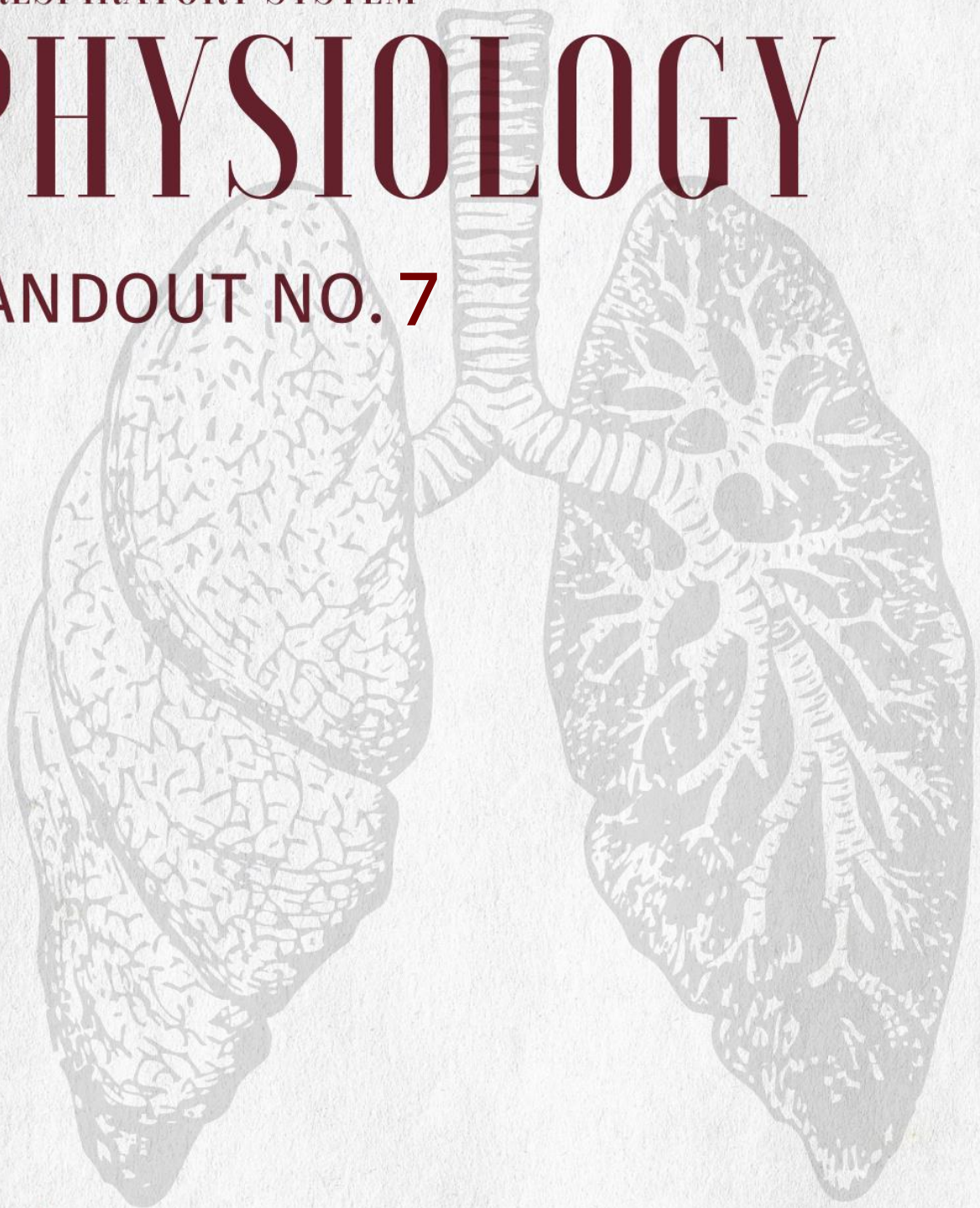
RESPIRATORY SYSTEM

PHYSIOLOGY

HANDOUT NO. 7



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Color code
Slides
Doctor
Additional info
Important

A student's question on the previous lecture: What is the importance of a high V/Q ratio?

Answer: The V/Q ratio is highest at the lung apex, which means that PO_2 in apical alveoli is elevated. This environment favours the growth of aerobic organisms like TB bacilli. So, any radiographic shadow at the apex suggests tuberculosis, while shadows at the lung base suggest cancer.

• Radiographic abnormalities in the apical regions of the lung often raise suspicion for tuberculosis and warrant further investigation.	• While lung cancer can occur anywhere in the lungs, shadows or lesions at the lung base are more likely to suggest non-infectious pathologies, including cancer, particularly in patients with risk factors like smoking.

Recruitment and distention increase pulmonary blood flow

Pulmonary blood vessels are much more compliant than systemic blood vessels. Also, the system has a remarkable ability to promote a decrease in resistance as the blood pressure rises.

During normal situations, Pulmonary Vascular Resistance (PVR) is usually 1/7th of Total Peripheral Resistance (TPR).

Mathematical explanation:

flow (Q) of 1 which is approximately 5 Liters per minute (L/min)

Q= ΔP/R

$$Q_{\text{Systemic}} = \frac{(P_{\text{Aorta}} - P_{\text{Rt. atrium}})}{TPR} = (100 - 0)/100 = 1 = 5L$$

$Q_{\text{Pulmonary}}$ = 5L (same as Q systemic; closed circulatory system) = 1

PVR (pulmonary vascular resistance) = 12

$$Q_{\text{Pulmonary}} = \frac{(P_{\text{Pulmonary artery}} - P_{\text{lt. atrium}})}{PVR} = (14\text{-}2)/12$$

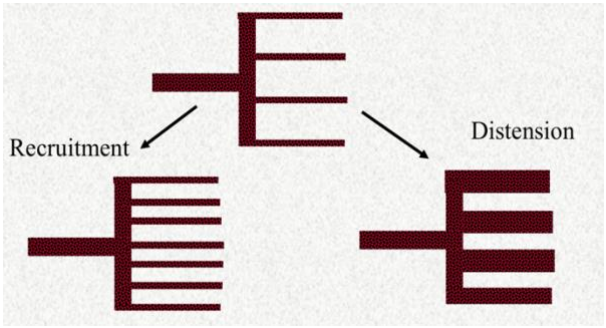
PVR/TPR = 12/100 ≈ 1/7 → (PVR is 1/7 of TPR)

NOTICE that P of the right atrium=0 so the pressure difference in systemic circulation=P in aorta (100-0=100)

While P in the left atrium is slightly higher =2 so the pressure difference in pulmonary circulation is lower than the P of pulmonary artery (14-2=12)

- **Changes during exercise:**

1. **Recruitment**: Increased number of open capillaries (At rest only 1/3 of muscle capillaries are open, but all open during exercise).
2. **Distention:** increased diameter of capillaries

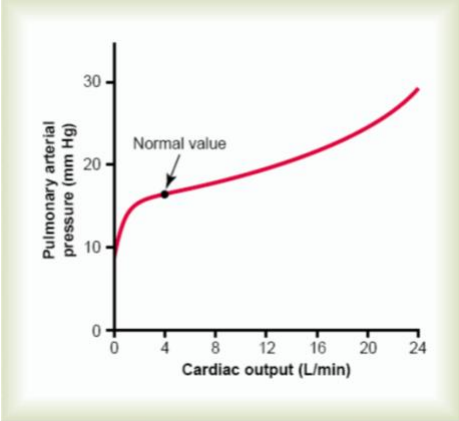


Recall CVS physiology, in a parallel capillary arrangement, increasing the number of capillaries or decreasing the resistance of any existing capillary reduces total resistance.

- **So, what exactly happens to TPR during exercise?**

P= Q*R

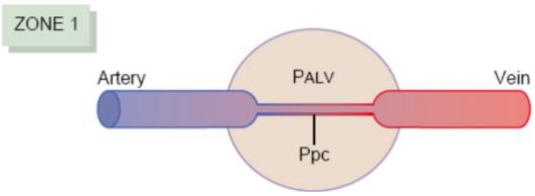
Even though During Exercise, **Q might increase 5 times,** recruitment and distension **decrease pulmonary vascular resistance** (**becomes even less than 1/7th of TPR**), so that the pulmonary **arterial pressure rises only slightly** regardless the intensity of exercise.
(CO increases, so resistance decreases proportionally to counterbalance this increase; ensuring that blood pressure stays within a normal range)



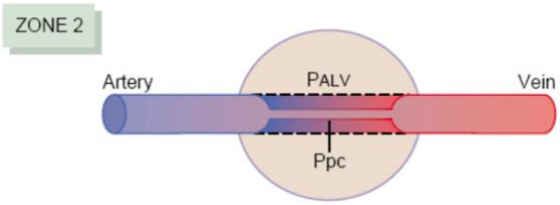
Hydrostatic effects on blood flow

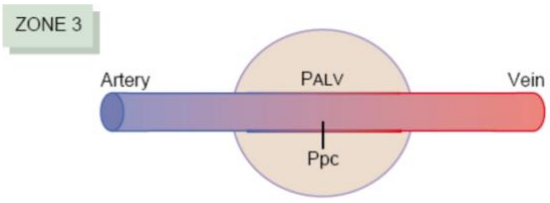
We can divide the lung into three zones based on pressure gradients: 1,2, and 3:

1. **Zone 1:** ***No flow*** *(in systole or diastole)*
    - Alveolar pressure > arterial pressure > venous pressure.
    - Alveolar pressure will close the capillaries around the alveoli
    - No blood flow occurs (e.g., during pathological conditions like severe bleeding where CO is reduced to 3.5 L/min (instead of 5), which is not sufficient for apex perfusion).
    - **Does not exist in normal lungs**.
    - V/Q=∞

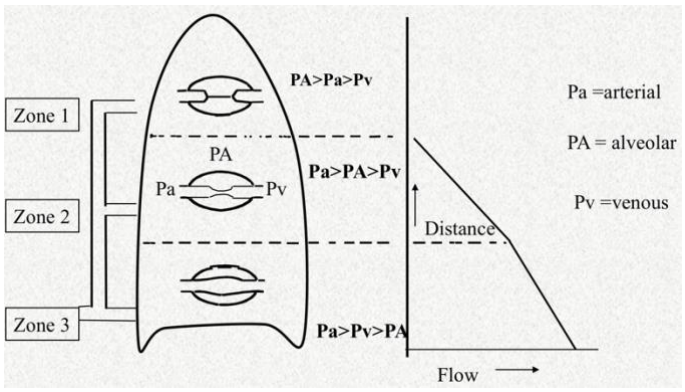


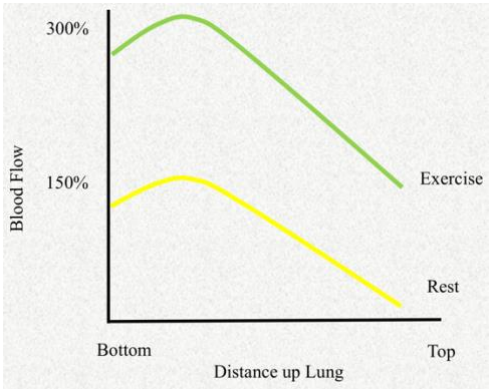
2. **Zone 2:** ***Intermittent flow***
    - Arterial (systolic) pressure > alveolar pressure > venous (diastolic) pressure.
    - **Blood flows during systole but not during diastole.**
3. **Zone 3:** ***Continuous flow***
    - Arterial pressure > venous pressure > alveolar pressure.
    - **Continuous blood flow occurs during both systole and diastole.**





- **Normal Conditions: Lungs typically exhibit only zones 2 and 3**. Zone 2 begins approximately 10cm above the heart's mid-level (at the apex of the lung), with the remainder of the lung in zone 3 (all the lower area of the lungs).
  In a supine position during sleep, gravity's effects on blood flow are less pronounced, and the lung zones are more evenly distributed compared to standing or sitting.
- **Exercise**: Blood flow becomes uniform across the lung, making **the entire lung zone 3.**





Blood flow

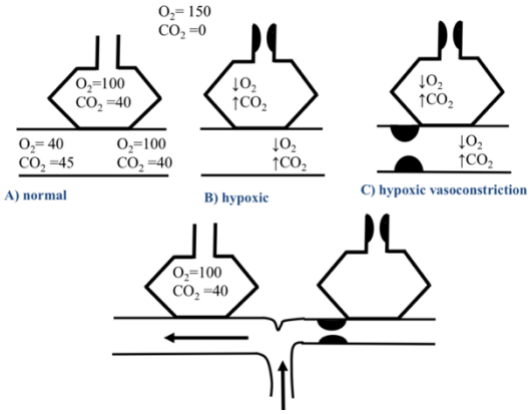
At the apex:

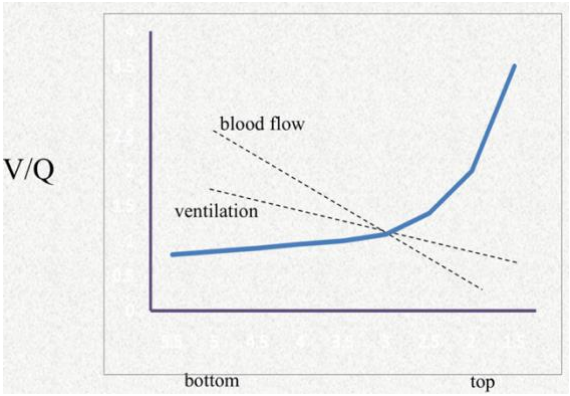
$$\frac{V\downarrow}{Q\downarrow\downarrow\downarrow} = \uparrow\left(\frac{V}{Q}\right)$$

- **Normal**: Venous blood PO2=40, PCO2=45; after gas exchange, PO2=100, PCO2=40.
- **Hypoxic:** Airway obstruction reduces PO2 and increases PCO2.
- **Hypoxic Vasoconstriction: Ventilation is lower at the apex** than the base. **Gravity influences perfusion not ventilation, causing it to dominate at the lung base** (both V and Q are lower at the apex)**.** But the V/Q ratio at the base is <1 and higher at the apex. (The **steeper perfusion curve** (below) compared to the ventilation curve makes the decrease in perfusion at the apex much more than the decrease in ventilation resulting in a higher V/Q ratio at the apex)

  This makes the apex more susceptible to have wasted ventilation in some pathological conditions

- at some point, in the lungs, the V/Q ratio will be = 1

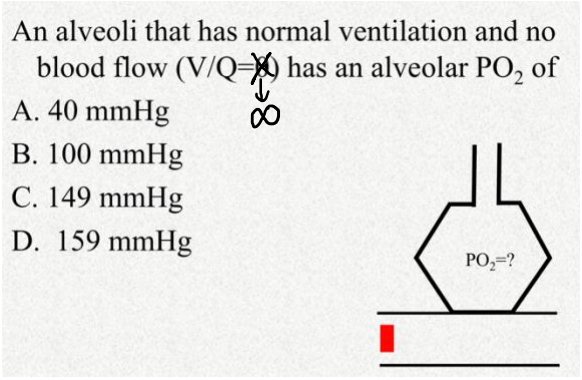




- **If there is no diffusion impairment, then the PO_2 and PCO_2 between an alveolus and end capillary blood are usually the same.**

  $P_{A\,(alveolar)}O_2 - P_{a(arterial)}O_2$ = zero, or less than 5.

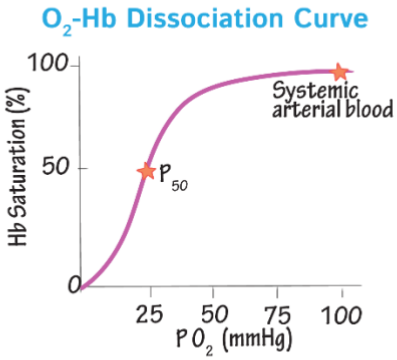
- Question:
- (Edit: V/Q=∞)



- Answer: C

But why is PO2a 95 instead of 100?

1) **Venous admixture:** the arterial and mixed venous oxygen content estimate 2% of the blood in the bronchial circulation never touches the alveoli, it bypasses the capillary from the pulmonary artery directly to the pulmonary vein, which is known as the **physiological shunt**. (Part of the deoxygenated blood is passing the lung without gas exchange and oxygenation)
2) **Inadequate V/Q ratio:** nonuniform. It is:
   -High in the apex
   -Low in the base
   Note that the hyperventilated region does not compensate for the hypoventilated region. As the shape of oxygen-hemoglobin curve is sigmoidal.



The point is in linear curves, compensation is a logical solution. However, in sigmoidal curves the saturation level is reached at a certain PO2, and **any further increase in pressure won't affect the concentration of O2.**

Basically saying, if the PO2 in the hyperventilated region reached 130 mmHg, only 100 mmHg would be mixed with the hypoventilated region (90 mmHg), with the remaining 30 mmHg being considered excess. (this is hypothetical to help understand the concept)

To explain this, understanding the following is crucial:

[O2] in blood is found in

A- **Dissolved in plasma (1.5%)** = PO2 * solubility of O2
100*0.003 = 0.3 ml/ dl

B- **HbO2 (98.5%)**, **depends on Hb concentration**, each 1g of Hb contains 1.34ml O2. (each heme carries 1 O2 molecule)
The normal Hb concentration being:
14-16 in males (consider it 15, 15*1.34 =20ml of O2)

So, the total [O2] in blood is 20+0.3= 20.3 ml/dl

When increasing PO2 beyond 100mmHg, the [O2] dissolved in plasma is **increased** minutely (0.3 to 0.4), the [O2] bound to Hb **isn't affected** as it is already saturated. In the sigmoidal curve, we note that when PO2=100, the saturation is about 98.5, if the pressure were to be duplicated (PO2 =200) the saturation would rise to 99. With that in mind, **O2 saturation occurs approximately at PO2=100**.

Logically speaking, the 2 factors above are expected to lower the mixed arterial PO2 and increase mixed arterial PCO2. However, PCO2 isn't affected (=40mmHg), this is because:

1. Unlike PO2, the PCO2 curve is linear.
2. If CO2 slightly increases in blood (it can be as little as 1mmHg), the **respiratory centers will be stimulated, and hyperventilation occurs.**

Hyperventilation's function is to washout excess CO2 till it returns to the normal levels in the body (PCO2=40 mmHg)

- **The respiratory centers are also important in detecting hypoxia**
- Remember, the body tissues require an overall 5 ml of O2 uptake

- **Referring to the oxygen-hemoglobin saturation curve:**
- At **PO2=100, 98.5%** saturation, 20 ml of O2 available in the blood flow.
- At **PO2=60, 90%** saturation, 18 ml of O2 is available in the blood flow.
  The respiratory centers remain inactivated at these levels as they are in a safe margin for tissue uptake.
- At **PO2<60**, the **respiratory centers respond to low PO2 in the blood to prevent or correct hypoxemia**.
- This response is attributed to the sigmoidal curve, as the curve is steep below 60 mmHg, and causes rapid decrease of saturation. (remember the curve for the lung compliance where the phase 2 is the easiest to change, and phase 3 is more difficult, here the curve prior to PO2 of 60 is similar to phase 2, beyond 60 is similar to phase 3 of the curve) Note that it isn't always 100% accurate.

- At **PO2= 40**, **75%** saturation,**15 ml** of O2 is available.
  This is logical, as the arterial PO2= 100 mmHg (100% saturation), contains 20 ml of O2, where 25% will be used up in the tissues before returning the remaining 75% in the venous circulation, in which PO2=40 mmHg.
  So again:

  The **arteries**: PO2 =100, 100% saturation, 20 ml of O2

  Tissue uptake= 5 ml of O2

  The **veins**: PO2 =40, 20-5ml =15 ml of O2, 15/20=75% saturation of O2
- At **PO2=26**, **50% saturation**, AKA **P50** (partial PO2 when 50% is saturated)

The Dr emphasized that it is important to understand how to calculate saturation

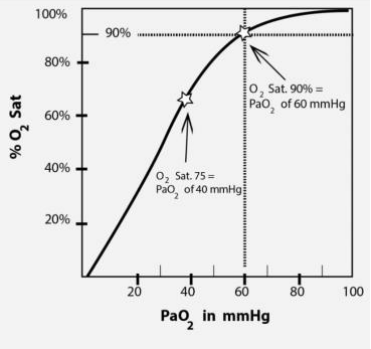
So, a quick recap:

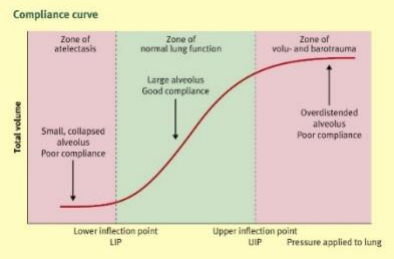
PO2=100 arterial pressure

PO2=60 curve shifts to steep part

PO2=40 venous pressure

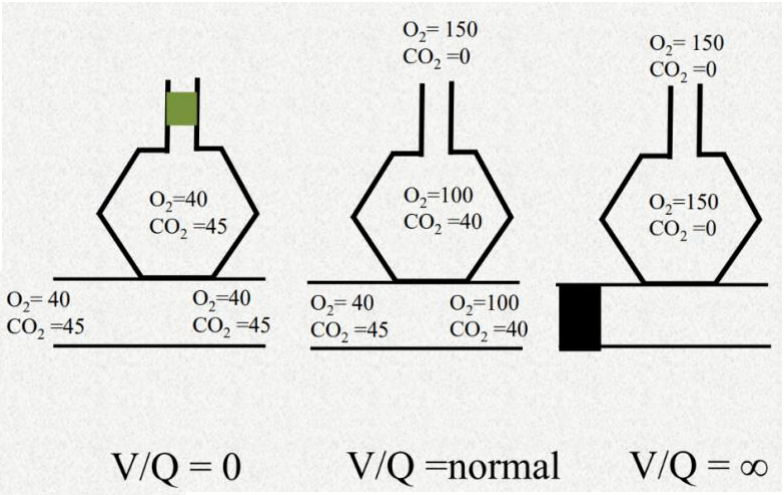
PO2=26 P50

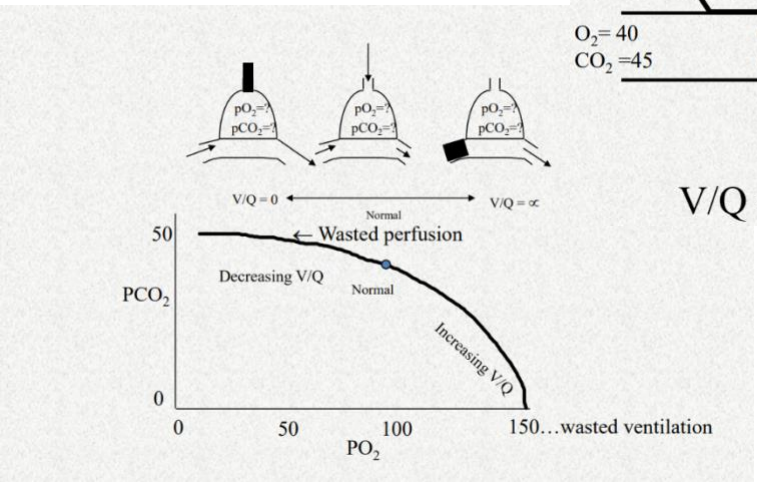




Note the different pressures measured in alveoli according to V/Q

(remember, a V/Q of 0 means no ventilation, ∞ means there is no perfusion)





Abnormal VA/Q in the Upper and Lower Normal Lung

•Upper part of the lung

– Less blood flow and less ventilation; but blood flow is considerably less than ventilation.

– Therefore, V/Q is 3.4 times higher than the normal value

– This causes a moderate degree of physiologic dead space.

• The bottom of the lung

– Slightly too little ventilation in relation to blood flow

– Va/Q as low as 0.6 times the normal value.

– A small fraction of the blood fails to become normally oxygenated, and this represents a physiologic shunt.

– Assuming perfusion is adequate … **hyperventilation** makes alveolar air like atmospheric air …. **Hypoventilation** makes alveolar air like venous blood

Abnormal VA/Q in the Upper and Lower Normal Lung

• Physiologic shunt

– V/Q ration is less than normal bcs of low ventilation

• Physiologic dead space…alveolar wasted volume

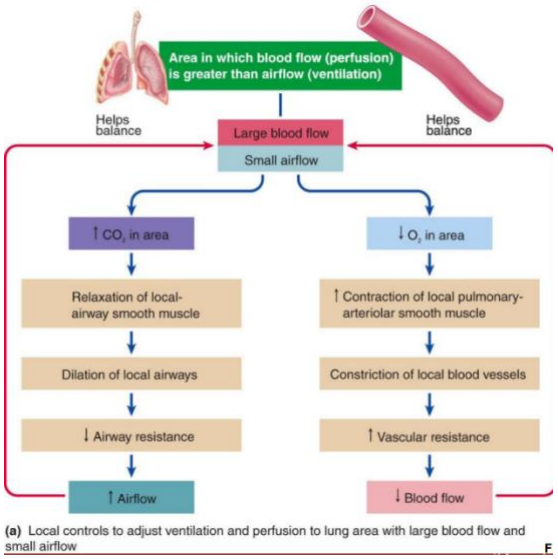
– V/Q > normal

• Abnormalities

– Upper lung **V/Q =3**

– Lower lung **V/Q =0.5**

A) When **V/Q < 1**, blood Flow (q) is high in relation to Ventilation(v)

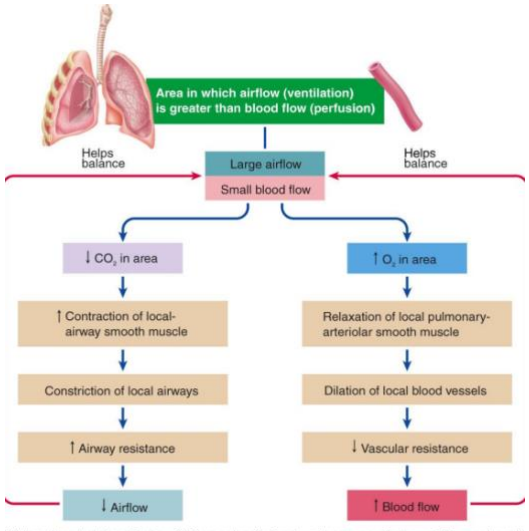


(a) Local controls to adjust ventilation and perfusion to lung area with large blood flow and small airflow

➢ Hypoxia in pulmonary artery is a strong vasoconstrictor, when there is low oxygen in the surrounding alveoli, there is no need for the supplied blood. On the contrary, systemic hypoxia is a strong vasodilator to increase the blood supplied in order to increase the supplied oxygen.

➢ The goal is to increase airflow to achieve adequate ventilation (relaxation of the airway smooth muscle), and to decrease perfusion to prevent wasted perfusion (vasoconstriction).

B) When **V/Q >1**, High ventilation in relation to perfusion



(b) Local controls to adjust ventilation and perfusion to a lung area with large airflow and small blood flow

➢ The goal is to decrease airflow to achieve balance (so the contraction of the airway smooth muscle), and to increase perfusion to prevent hypoxia (vasodilation).