وَقُل رَّبِّ زِدْنِي عِلْماً

RESPIRATORY SYSTEM

HAYAT BATCH

SUBJECT : Physiology

LEC NO. : 4

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PULMONARY AND ALVEOLAR VENTILATION ($\dot{V}_A$)

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Lecture objectives:

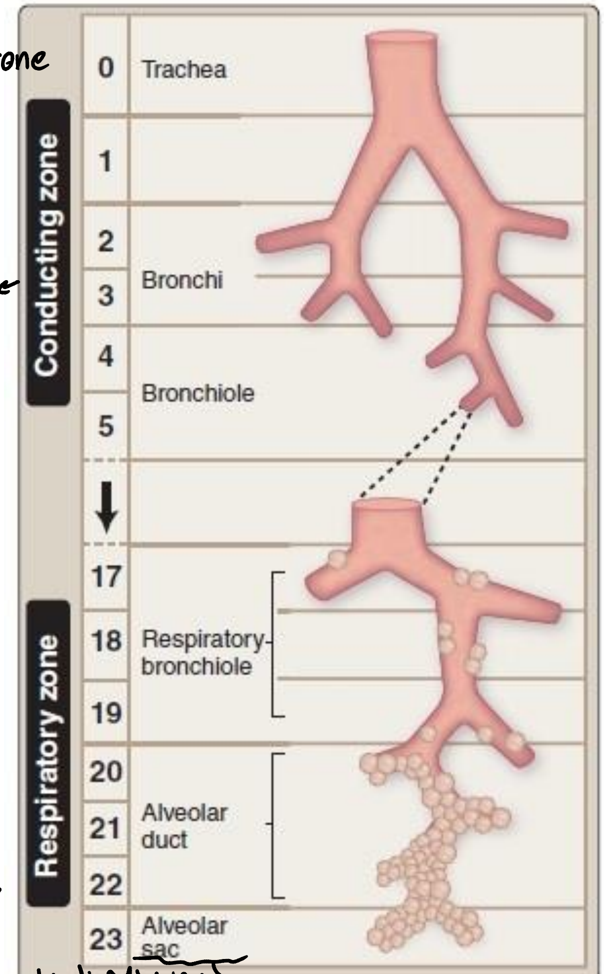
By the end of this lecture the student should be able to:

1. Describe pulmonary and alveolar ventilation.
2. Define and contrast the following terms: anatomic dead space, physiologic dead space, total minute ventilation and alveolar minute ventilation.
3. Define and contrast the relationships between alveolar ventilation and the arterial PCO_2 and PO_2.
4. Predict the effects of alterations of alveolar ventilation on alveolar carbon dioxide and oxygen levels.
5. Describe the effect of dead space on alveolar ventilation.
6. Understand Fowler's method of measuring the anatomic dead space. And calculate the volume of dead space in a lung using the Bohr equation.
7. Describe and explain the mechanism of regional differences in alveolar ventilation in the normal lung.

Alveolar Ventilation ($\dot{V}_A$)

The rate at which new air reaches gas exchange areas (with **pulmonary blood**). These areas include the alveoli, alveolar sacs, alveolar ducts, and respiratory bronchioles.

The total area of the alveolar walls in contact with capillaries in both lungs is about 70 m^2



The **Respiratory zone** houses the blood–gas interface

$V_T = 500L$

150mL stay in conducting zone

350mL reach the respiratory zone (for alveolar ventilation)

Dead space (V_D): The space in the respiratory passages where gas exchange **does not** occur.

(air exchange ما فيها alveoli (لذلك) لا يحدث فيها

1. The **anatomic** dead space: is the volume of gas that occupies the airways, which are called the conducting zone. The conducting zone **does not** participate in gas exchange because of the thickness of the airway walls (nose, pharynx, and trachea).

هي مع فروعها تشكل conducting zone.

The functions of the anatomic dead space is to

- warm the inspired gas to the body temperature
- saturate the gas with H_2O vapor (بخار الماء) that will slightly dilute the O_2 and N_2 concentrations and prevent drying of the alveolar surface
- assist in the removal of foreign materials

pressure of gases في الويصلات لا يساوي 760mm (الضغط الجوي) وذلك بسبب دخول ضغط بخار الماء (دح يوخذ حصة)

يعمل طبقة رقيقة من الماء تبطن alveolus

H_2O vapor pressure = 47mm

alveolar pressure = atmospheric pressure − H_2O vapor pressure = 760 − 50 (≈47) = 710

O_2 concentration = 710 × 21% = (< 160)

شعيرات في الأنف والأهداب في القصبات الهوائية ↓ تخلصنا من Foreign particles كبيرة الحجم ↓ particles ولكن الـ عبارة عن دخان و microscopical particles <2 mic الصغيرة لأنها يمكن أن تصل إلى alveoli

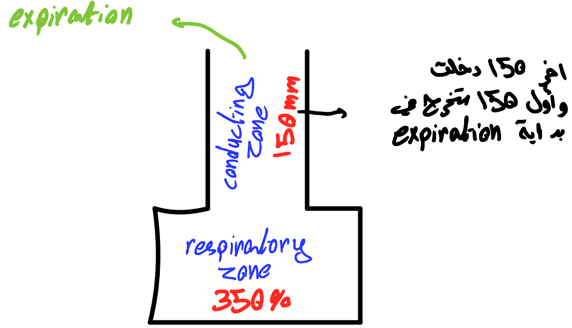
2. The **total (physiologic)** dead space (functional): includes the anatomic dead space and alveolar dead space (alveoli that **do not** receive any blood flow and therefore **do not** participate in gas exchange). It is approximately 2ml/kg or 150 ml in an young adult, roughly a third of the tidal volume. This value increases slightly with age.

ولكن في بعض الأمراض يحصل فرق.

Normally → anatomical dead space = total dead space

physiologic dead space → المنطقة يوصلها هواء ولكن ما بيصير فيها air exchange لأنه لا يصلها blood

Note:



- Air in the dead space is the first part of air to be removed on expiration.
- Normally, the anatomic and physiologic dead spaces are nearly equal, significant difference only occurs in patients with lung diseases because of the increase in alveolar dead space.

← هواء الزفير مفيد في artifichial expiration
حيث أنه يتم اعطاء ① dead space (هواء عادي تركيز O2 فيه 160mm) (في البداية)
ثم يتم اعطاء ② alveolar air

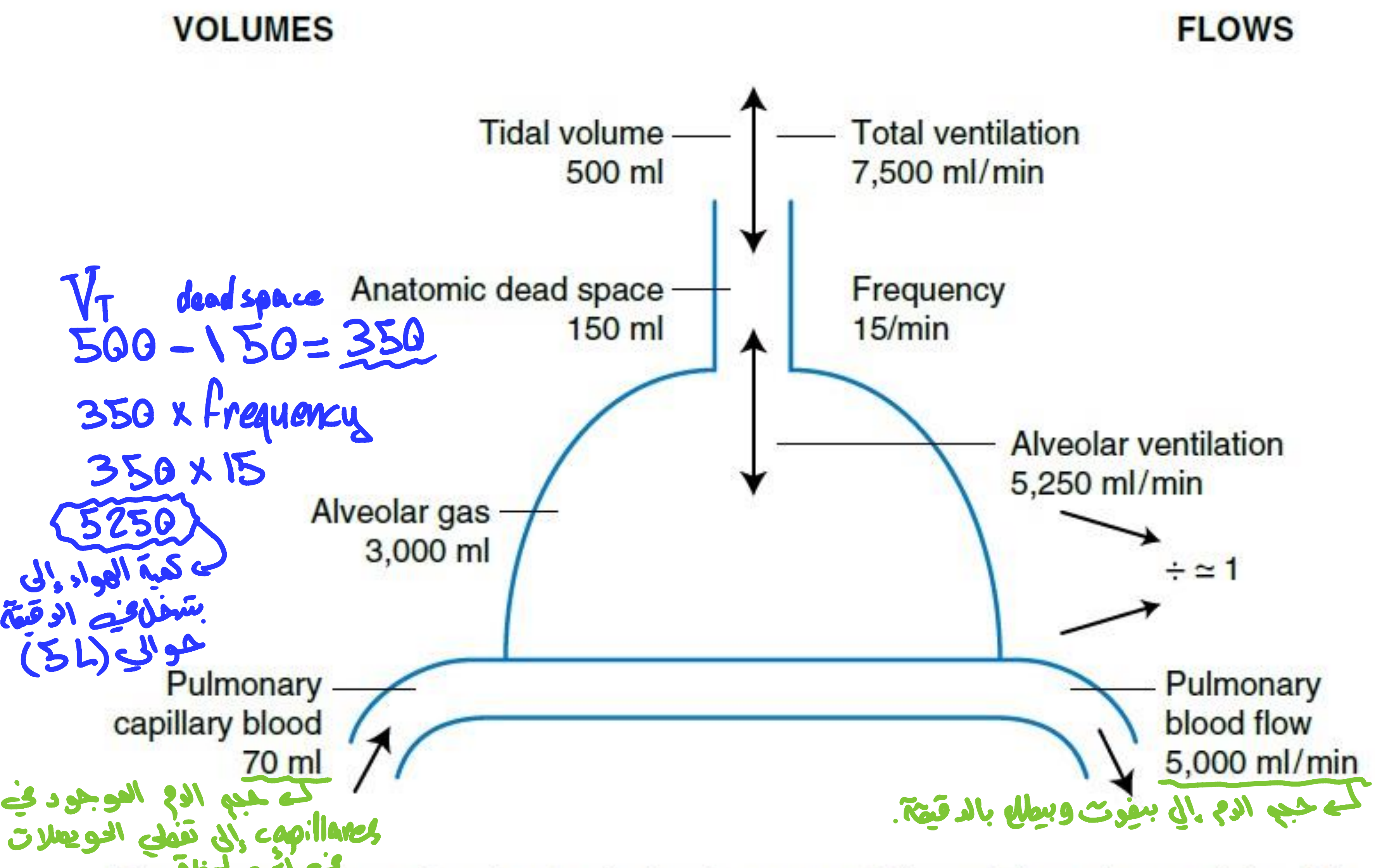


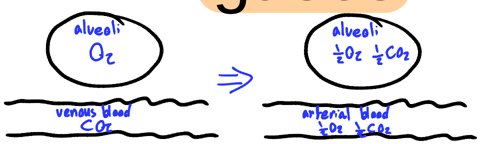
Diagram of a lung showing typical volumes and flows. There is considerable variation around these values depending on the size and gender of the patient.

Methods of measuring the total dead space:

measure all total dead space

(pure air)(dead space)150mL
(أُخذ منها O2 واضاف إليها CO2) إلى جاي من الحويصلات إلى تم فيها التبادل الغازي) 350mL
mixing ⇐ تركيز CO2 ميكون أقل من تركيز CO2 في الحويصلات لأنه تم تخفيفه بـ150mL
في حال طلع expired V_T في كيس (على سبيل المثال)

1. Bohr's method: depends on determining CO_2 tensions in the mixed expired and alveolar gases.



$$V_D = VT.\left(1 - \frac{P_{ECO2}}{P_{ACO2}}\right)$$

يتم معرفته من خلال تركيز CO2 في الدم الشرياني
حيث انه يساوي تركيز CO2 في الحويصلة الهوائية

V_D = Volume of dead space

V_T = Tidal Volume

P_{ECO_2} = CO_2 tension in mixed expired gas

P_{ACO_2} (alveolar) = CO_2 tension in alveolar gas = P_{aCO_2} (arterial) in healthy individuals

Note: Bohr's method measures the volume of the lung that does not eliminate CO_2 (i.e. physiologic dead space) if P_{aCO_2} is used.

Methods of measuring the total dead space:

measure of anatomical dead space only.

2. Fowler's method: uses expired N_2 as an indicator. The subject inspires a single deep breath of 100% oxygen, and then the expired N_2 is measured during the subsequent full expiration through a rapidly recording nitrogen meter.

$$V_D = \frac{\text{Gray area} \times V_E}{\text{Pink area} + \text{Gray area}}$$

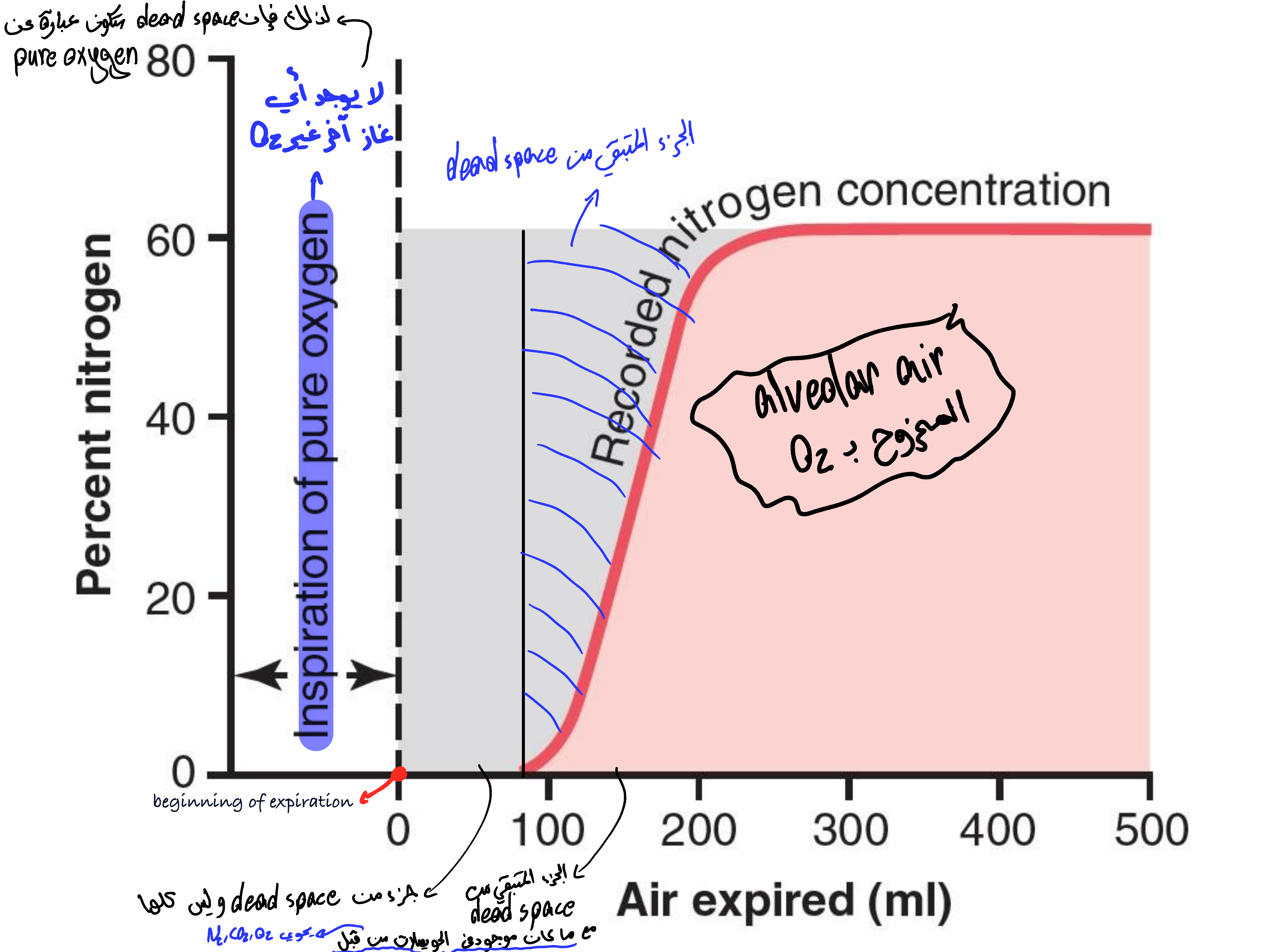
In Normal person

Measurement of Bohr's method = Measurement of Fowler's method

V_D = The volume of dead space gas

V_E = The total volume of expired air

Note: Fowler's method reflects the morphology of the lung (i.e. anatomic dead space).


Percent nitrogen
80
60
40
20
0
Inspiration of pure oxygen
Recorded nitrogen concentration
0
100
200
300
400
500
Air expired (ml)
لذلك فإن dead space ستكون عبارة عن pure oxygen
لا يوجد أي غاز آخر غير O2
الجزء المتبقي من dead space
alveolar air الممزوج ب O2
beginning of expiration
جزء من dead space وليس كلها
يحتوي N2, CO2, O2
الجزء المتبقي من dead space
مع ما كان موجود في الحويصلات من قبل

Measurement of Alveolar Ventilation (V_A)

To measure the volume of new air that participates in the exchange of O_2 and CO_2 per minute the following equation is used;

$$\dot{V}_A = f.(V_T - V_D)$$

- With a respiratory rate of 12-15 /min, $\dot{V}_A$ is about 4200-5000 ml/min.
- * Adequate alveolar ventilation is critical because it determines O_2 and CO_2 tensions in the lungs.

⇐ لذلك فإن alveolar ventilation هو الي رح يحدد تركيز O_2 و CO_2 في alveoli لأنه لو ventilation زاد فإن تركيز O_2 في الحويصلة رح يزيد وتركيز CO_2 رح يقل لأنه زاد طرد CO_2 من الحويصلات
ولكن لو ventilation قل فإن تركيز CO_2 رح يزيد في الحويصلات (لأن طرده من الحويصلات قل) وتركيز O_2 قل
← التغيير في ventilation رح يغير تركيز الغازات في الدم ورح يأثر على عمل الجسم كله.

alveoli رح يوصلها الهواء
← يوخذ منها O_2 إلى الدم ويطرح CO_2 بشكل مستمر

Regional differences in ventilation

In upright position

← نجعل الشخص يتنفس هواء مع مخليط من zenon
← غاز نبيل مشع

← نضع Radiation counters خلف الشخص حتى تقيس radioactivity

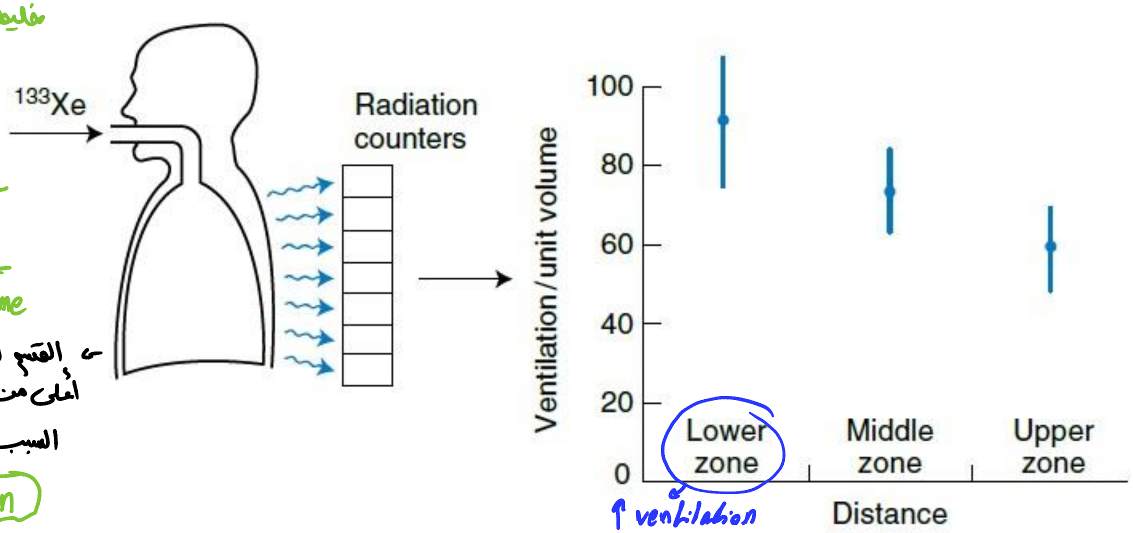
← المنطقة إلي فيها zenon كثير رح تعطي Radioactivity عالية.

← تم تسجيل Radioactivity عند lower zone أعلى من upper zone

← القسم العلوي من الرئتين يستلم هواء أعلى من القسم السفلي
السبب هو Gravity

In supine position

← منطقة الظهر تستلم هواء أعلى من المنطقة العلوية القريبة من الصدر



Measurement of regional differences in ventilation with radioactive xenon. When the gas is inhaled, its radiation can be detected by counters outside the chest. Note that the ventilation decreases from the lower to upper regions of the upright lung.

- In upright position, ventilation per unit volume is greatest near the bottom of the lung and becomes progressively smaller toward the top.
- In the supine position, this difference disappears, with the result that apical and basal ventilations become the same. However, the ventilation of the lowermost (posterior) lung exceeds that of the uppermost (anterior) lung.
- The lower regions of the lung are better ventilated (alveoli expand more) than the upper regions because of the **effects of gravity on the lung**.

Alveolar O_2 and CO_2 tensions

← الجسم يحاول يحافظ على نسبة CO_2 = 40mm
ونسبة O_2 = 100mm
← الحفاظ على نسبة CO_2 أهم من O_2

1. Alveolar CO_2 tension (**P_{ACO_2}**) is equal to arterial CO_2 tension because of the high diffusibility of CO_2. It is about 40 ± 4 mmHg. Regulation of this tension is <u>very important</u>.

   CO_2 يتكون من body metabolism ويتم طرحه في الحويصلات
   ← كمية ما يطرح في الحويصلات يعتمد على ما يتم من metabolism

   - With constant rate of CO_2 production, there is **inverse relationship** between alveolar ventilation and P_{aCO_2}. If alveolar ventilation is halved, P_{aCO_2} will double. So;
   - **Hyperventilation** (with constant rate of CO_2 production) → **Hypocapnia** (↓alveolar CO_2 tension) → **Respiratory alkalosis**

     ← lung تحافظ على acid-base balance
     التخلص من جزيء CO_2 = التخلص من جزيء H

   - **Hypoventilation** → **Hypercapnia** (↑alveolar CO_2 tension), which if it exceeds 45 mmHg → **Respiratory acidosis**. Hypercapnia can lower the O_2 tension in the alveoli by displacing the O_2.

     ← يزيد كمية الهواء الي بتدخل الحويصلة (with constant production of CO_2)

السبب هو زيادة ventilation

↑CO_2 ⇐ السبب هو زيادة metabolism

Note: It is important to differentiate between ***Hyperventilation*** and ***Hyperpnea***. Hyperpnea is increased alveolar ventilation with <u>no change</u> in P_{aCO_2} as in exercise and fever. This is due to increased CO_2 production by metabolism.

↑ metabolism → ↑ CO_2 in alveoli
⇓
↑ ventilation (hyperpnea) ← مترتبة على زيادة metabolism

Alveolar O_2 and CO_2 tensions

(CO2 يحل مكان O2) ↑O2 ← ↓CO2 ← ↑ventilation

2. Alveolar O_2 tension (**P_{AO_2}**). Inspiration brings fresh air into the alveoli, which normally maintains the alveolar O_2 tension at about 100 mmHg.

   An increase in alveolar ventilation → P_{aO_2} will increase in non-linear relationship, as more oxygen is removed from the alveolar gas per unit time than CO_2 is added.

   P_{AO_2} is affected by;

   كل ما يزيد CO2 في الحويصلة بيقل O2 والعكس صحيح

   - Alveolar CO_2 tension
   - Changes in barometric pressure
   - Fraction of O_2 inspired

   In hight altitude ⇓ ↓ atmospheric pressure (يقل O2 الداخل)

   عند تنفس هواء نسبة O2 فيه أقل من 21% ⇒ مثل في حالة الحريق حيث ان نسبة O2 أقل من 21% فالموت يكون نتيجة الاختناق

   P_{AO_2} can be calculated using the ***Alveolar Gas Equation***

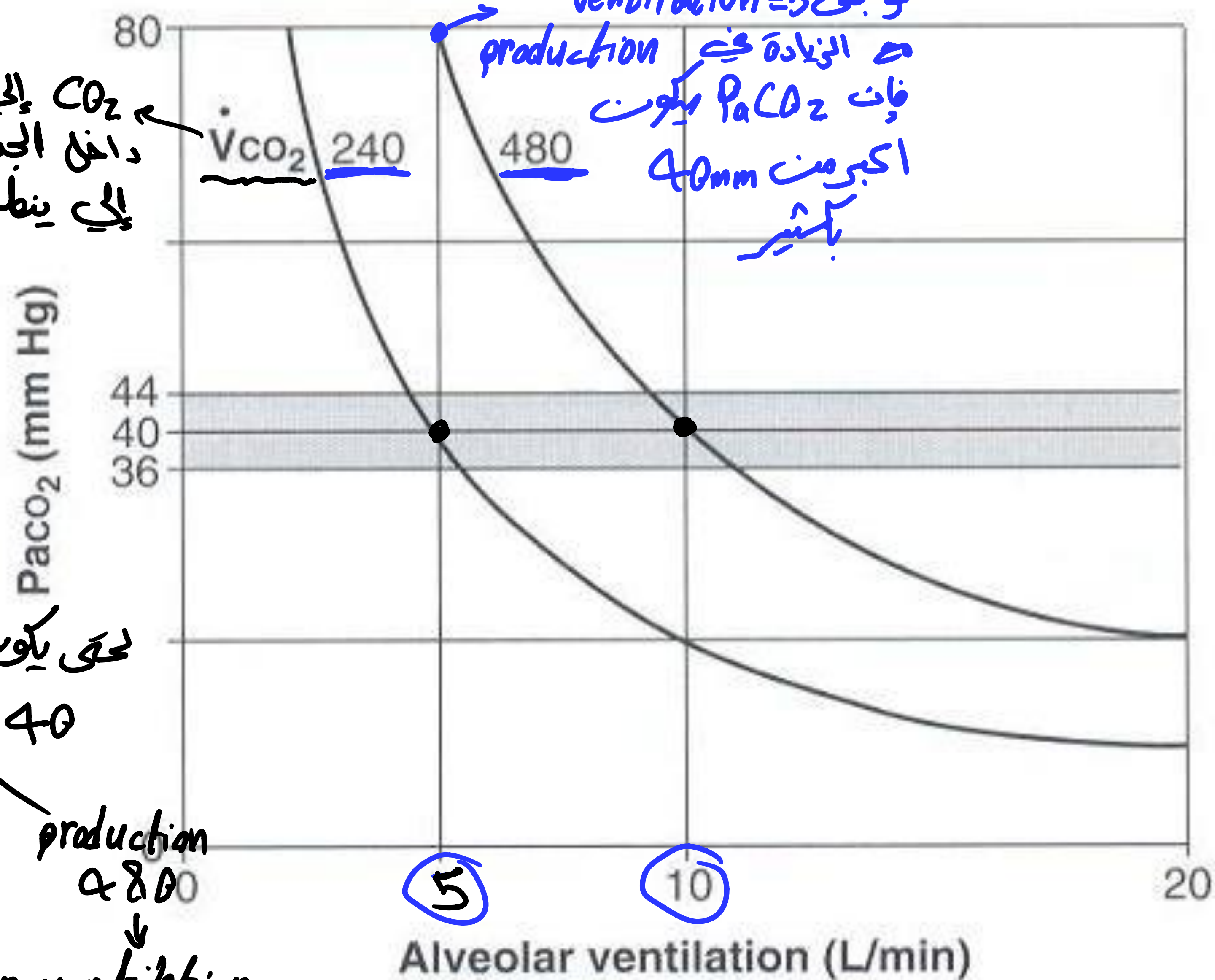
نسبة O2 في الهواء الداخل — ضغط بخار الماء

$$P_{AO_2} = F_I O_2 (P_{atm} - P_{H_2O}) - \frac{P_{aCO_2}}{R}$$

F_IO_2 = Fraction of oxygen in the inspired gas

R = 0.8 (respiratory exchange ratio)

Note: Water vapor pressure at body temperature of 37°C is 47 mmHg regardless of the external barometric pressure.



CO2 إلي يتكون داخل الجسم وهو نفسه إلي ينطرد

لو بقى ventilation = 5 مع الزيادة في production فإن PaCO2 يكون أكبر من 40mm بكثير

لحتى يكون PaCO2 = 40

production 240 → ventilation 5

production 480 → ventilation 10.

V_{CO2} = amount of carbon dioxide eliminated in ml/min

Test Question:

Respiratory dead space:

A. Saturates inspired air with water vapor before it reaches the alveoli.

B. Removes all particles from inspired air before it reaches the alveoli.

C. Decreases when blood catecholamine levels rise.

D. Decreases during a deep inspiration.

E. Increases during a cough.