PHYSIOLOGY TEAM 435

5

Effects of exercise on the respiratory system

((الْمُؤْمِنُ الْقَوِيُّ خَيْرٌ ، وَأَحَبُّ إِلَى اللَّهِ مِنْ الْمُؤْمِنِ الضَّعِيفِ ، وَفِي كُلٍّ خَيْرٌ ، احْرِصْ عَلَى مَا يَنْفَعُكَ ، وَاسْتَعِنْ بِاللَّهِ ، وَلَا تَعْجَزْ ، وَإِنْ أَصَابَكَ شَيْءٌ فَلَا تَقُلْ : لَوْ أَنِّي فَعَلْتُ كَانَ كَذَا وَكَذَا ، وَلَكِنْ قُلْ : قَدَرُ اللَّهِ ، وَمَا شَاءَ فَعَلَ ، فَإِنَّ لَوْ تَفْتَحُ عَمَلَ الشَّيْطَانِ))

- Very important
- Extra information
- Terms

Objectives

By the end of this lecture the students should be able to :-

- Describe the effects of moderate and severe exercise on **oxygen consumption and ventilation volumes.**

- Describe the **effects of exercise on arterial PO_2, PCO_2 and H^+ ions.**

- Define the **diffusing capacity of the respiratory membrane**, and its typical values at rest, and explain its changes in exercise.

- Explain **causes of hyperventilation** in exercise.

The respiratory system and exercise

When we exercise more oxygen is needed by the working muscles and more carbon dioxide must be removed from the muscles.

<u>As a result :</u>

- **Increase > The rate of breathing.**
- **Increase > The depth of breathing ,up to vital capacity.**
- **Increase > The blood flow through the lungs or increase the amount of the blood that supply the lungs called “pulmonary perfusion”**
- **Increase > The oxygen taken up and used by the body.**

Oxygen used during exercise can be up to 20 times a person’s normal uptake.

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Effects of exercise on the respiratory system

- The blood gases do not always have to become abnormal for respiration to be stimulated in exercise.

  The gas concentration remains the same but their diffusion increases.
- Instead, respiration is stimulated mainly **by neurogenic mechanisms** during exercise.

Regulation of respiration during exercise

- In strenuous (exhausting) exercise **O_2 consumption** and **CO_2 formation** may increase 20 folds, but alveolar ventilation increases almost exactly in step with increased level of metabolism.
- Therefore the arterial PO_2, PCO_2 (P: partial pressure "NEXT slide") and PH all remain almost exactly normal.

-If we have abnormal blood gases for example, the O2 decreased or CO2,H ions increased that's means there's no regulation of respiration. So, the main goal of respiratory regulation is to maintain these parameters normal whatever's the activity.

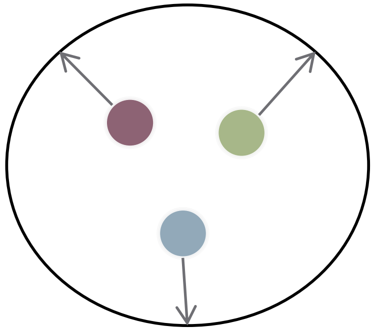
-How can we know that the function of respiratory system changed? The most important parameter is "Alveolar ventilation / min".
= 4200 ml = 4.2L
From 4200ml we need only 250ml of O2 **at rest.**
But, **at exercise** we need the double so, from 4200ml we need 500ml of O2.

- In step means: if I want to increase O2 consumption I have to increase the alveolar ventilation.(علاقة طردية)

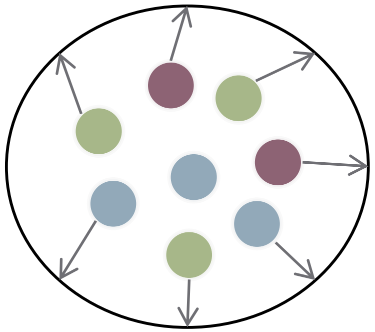
Partial Pressure "EXTRA"

What is the "Pressure"?
Force exerted by gas molecules within a given volume.

What is the "Partial Pressure"?
Portion of the total pressure exerted the presence of a single gas molecules.

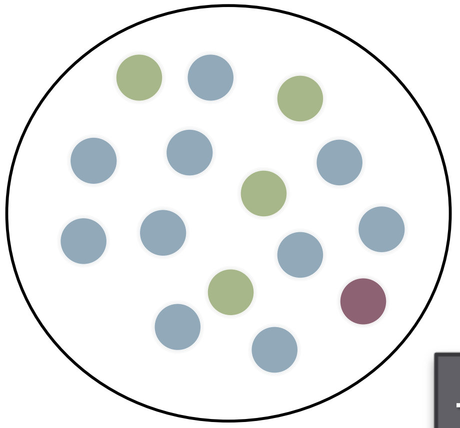


P = 3



P = 8

Less gas molecules > Low pressure.
More gas molecules > High pressure.



Gas	Conc.
N2	79.03%
O2	20.03%
CO2	0.03%

Total ATM P. = PO2+ PCO2+ PN2

PN2 ~ 600.6 mmHg
PO2 ~ 159.1 mmHg
PCO2 ~ 0.3 mmHg

Total Pressure = 760 mmHg

Diffusion capacity of the respiratory membrane

- It is the volume of gas that diffuse through the membrane each minute for a pressure difference of 1mmHg. (To diffuse gases from one side to another require differences in pressure at least 1 mmHg .. Ex, PO2 in alveoli = 20mmHg & PO2 in pulmonary capillaries = 19mmHg (P. Difference = 1)

Diffusion capacity	At rest	During exercise
Oxygen (O_2)	**21ml/min/mmHg** - We know that we need 250ml of O2 / min at rest. So, if we want to consume 250ml of O2 or around it, what's the pressure difference that require? (11 mmHg) -If the oxygen pressure difference across the respiratory membrane is **(11mmHg)** The amount oxygen diffusing through the membrane each minute will be: **(230ml) ⟶ (11x21=230)** **-During rest tissues consume 250ml of O_2 each minute.**	**65ml/min/mmHg** -Diffusion of respiratory membrane will be tripled during exercise. **The reasons of this :** 1- Due to increased number of opened pulmonary capillaries which was dormant[1], thereby increasing the surface area for gas exchange. 2- Increased alveolar ventilation.
Carbon dioxide (CO_2)	**400ml/min/mmHg** It diffuses 20 times greater than oxygen due to greater diffusion coefficient (معامل الانتشار)(More soluble than O2 > More diffusible). The benefit when the CO2 more diffusible than O2! To remove easily and faster from the body.	**1200 to 1300ml/min/mmHg** -Diffusion of respiratory membrane also will be tripled during exercise.

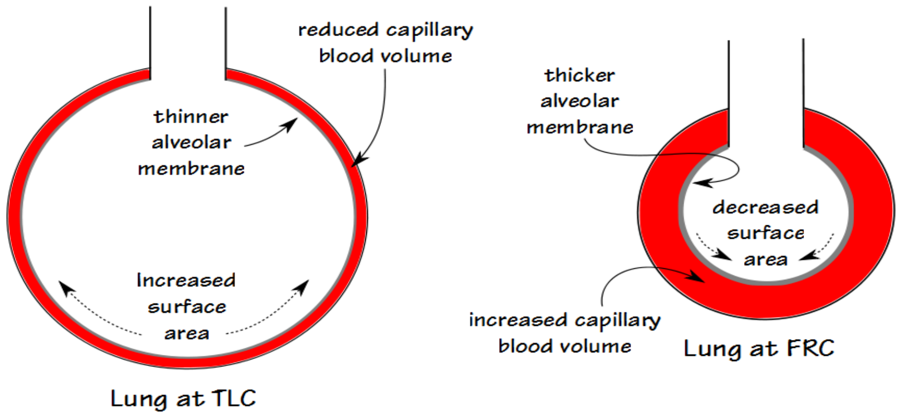
[1]Dormant : having normal physical functions suspended or slowed down for a period of time, as if in a deep sleep.

Diffusion capacity of the respiratory membrane “Extra explanation”

Diffusion capacity of O2 – During exercise

-We can increase surface area of alveoli “More stretched” but, we can’t increase the number of it.
SO, **How can we increase the surface area ?** By increasing the alveolar ventilation / min. Instead of 4.2L take for example 16L.

-During increase the alveolar ventilation we increase the number of pulmonary capillaries. **How?**
By opening the dormant “sleeping” capillaries around the alveoli. **Why do we increase the number of pulmonary capillaries ?**
When the surface area of alveoli increased will press on the capillaries and decrease its volume. So, increase the number of capillaries to make the gas exchange more effective. “Image”



Diffusion capacity during exercise

- During exercise the **oxygen requirement** increases **20 times** and **cardiac output** increases and so the time blood remained in the pulmonary capillaries becomes less than half normal despite the fact that additional capillaries open up, but the blood is almost **completely saturated with oxygen** when it leaves the pulmonary capillaries.

- Differences between diffusing capacity at resting and the state of maximal exercise make the blood flow through many of the pulmonary capillaries and **providing greater surface area through which oxygen can diffuse into the pulmonary capillary of blood**.

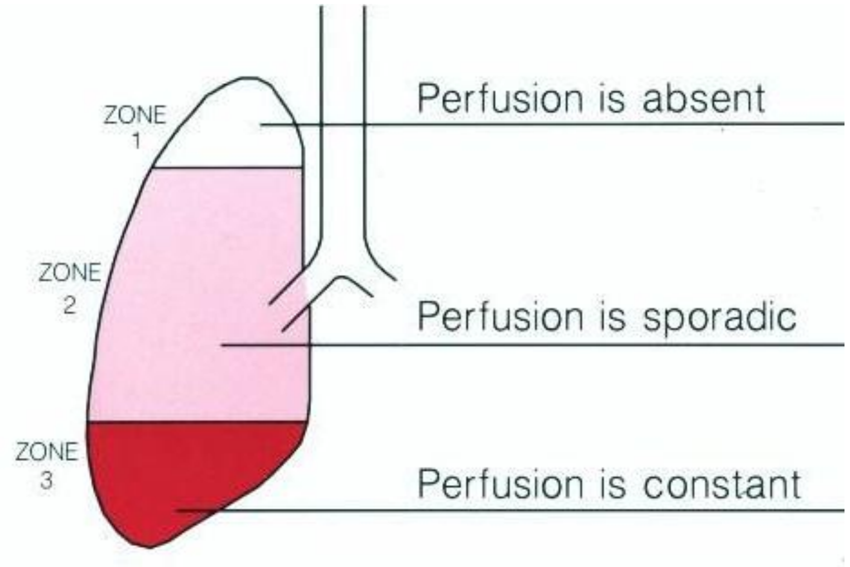
During exercise:

•Need more O2 > Increase "Cardiac Output" > Increase blood flow to lungs > Decrease time of pulmonary capillaries that required in gas exchange to "Half normal" > Faster Oxygenated blood "Fully saturated with O2"

-Less Time > Faster oxygenated.
-MoreTime > Slower oxygenated.

Diffusion capacity during exercise

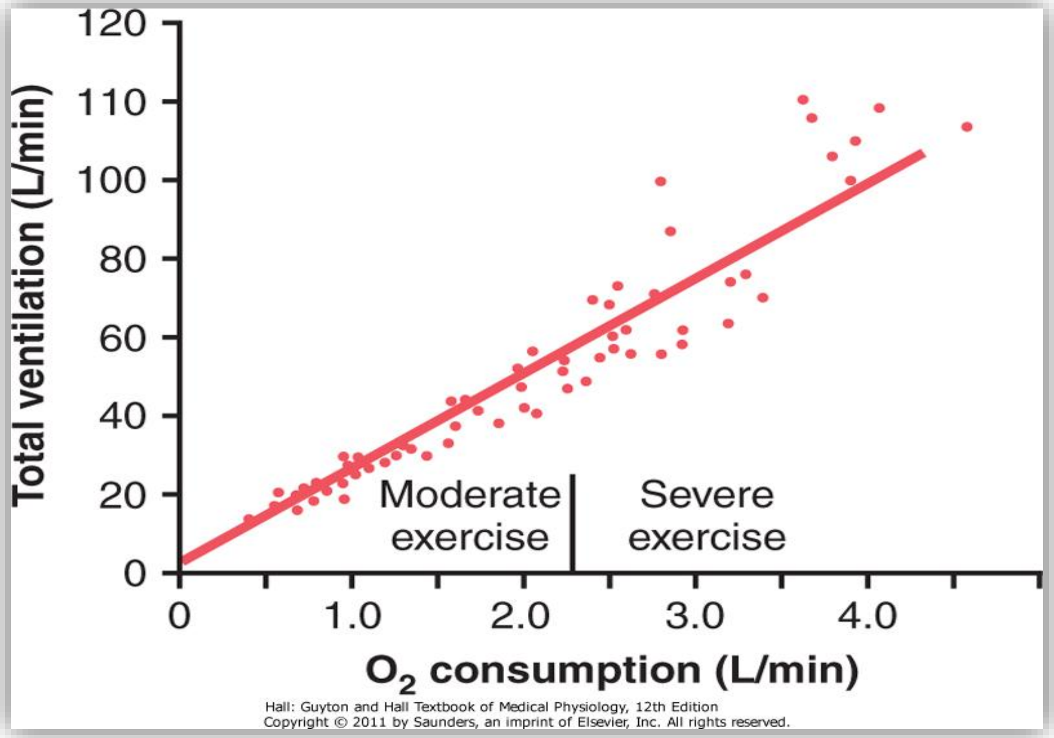
- **The reasons for this are:**
- The diffusing capacity for oxygen increases almost <u>three folds</u> during exercise, this results mainly from increasing numbers of capillaries participating in the diffusion, and a <u>more even V/Q ratio all over the lung</u>.
  That means, the value of V/Q is Same in whole lungs.
  V/Q : it is the ratio of alveolar ventilation to pulmonary blood flow per minute.
- At rest the blood normally stays in the lung capillaries about <u>three times</u> as long as necessary to cause full oxygenation. Therefore, **even with shortened time of exposure in exercise, the blood is still fully oxygenated or nearly so.**



V/Q ratio:
- V= Ventilation/min (4.2L/min)
- Q= Cardiac Output/min. "The blood flow to lungs per min" (5 L/min)
- **Average V/Q = 4.2/5 = 0.8 L/min**
- **At Rest ..** The V/Q ratio at the apex of lung different from the base, due to the gravity. Because the apex is above the heart and blood goes to it against the gravity has low amount of blood flow than at the base.
- <u>V/Q Low at Apex of lung(Zone 1)</u>
- <u>V/Q High at Base of lung(Zone 3)</u>
- **During exercise ..** V/Q ratio in Apex & Base "SAME"

Relation between oxygen consumption and total pulmonary ventilation at different levels of exercise

- There is a linear relation between both **oxygen consumption** (VO_2 max) and **total pulmonary ventilation** increased about 20-folds between the resting state and maximal intensity of exercise in the well-trained athlete.



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Causes of hyperventilation in exercise

At maximal effort :

- Pulmonary ventilation at maximal exercise 100-110L/min
- Maximal breathing capacity 150-170L/min
- Maximal breathing capacity is about 50 % greater (70% in some references) than the actual pulmonary ventilation during maximal exercise.
- to giving athletes extra ventilation (Causes of hyperventilation):

Examples:
1. exercise at high altitudes.
2. exercise under very hot conditions.
3. abnormalities in the respiratory system.

Maximal breathing capacity (MBC) is a test used in the clinical sections to see the volume of gas that can be breathed in 15 seconds when a person breathes as deeply and quickly as possible.

- Respiration is stimulated mainly by neurogenic mechanisms during exercise.
- Stimulation results from direct stimulation of the respiratory center by the same nervous signals that are transmitted from the brain to the muscles
- An additional part is believed to result from sensory signals transmitted into the respiratory center from the contracting muscles and moving joints.

Effects of exercise on arterial PO2, PCO2 and H+ ions.

1. (LT) is strongly correlated with Ventilatory Anaerobic Threshold (VAT) The term VAT actually refers to the onset of exercise induced hyperventilation during effort.
2. This increase in is a homeostatic response to deal with the consequences of the excess lactate production which can dissociate to release H+ ions from lactic acid into the blood stream.
3. The H+ ions are buffered by bicarbonate and release CO_2 .
4. This buffering of lactic acid results in extra CO_2 production over that produced by aerobic metabolism and increases the arterial CO_2 partial pressure ($PaCO_2$)
5. The increase in $PaCO_2$ stimulates excess ventilation that follows on from the lactate threshold.

An increase ventilation rate > Increase gas exchange ensure that there is neither :
1- Decrease in arterial PO_2.
2- Increase in arterial PCO_2.

Exercising → hyperventilation → Lactic acid formation → Release of H+ in blood stream → Buffering H+ by bicarbonate → Release of CO_2 → Increase arterial PCO_2

In conclusion the result of that is two sources of CO_2 that increases the PCO_2:
1. Normal metabolic process.
2. Excessive production of CO_2 from Kreps cycle during anaerobic effort.

Causes of intense ventilation during exercise

Neural signals from the motor areas of the brain to the respiratory center.

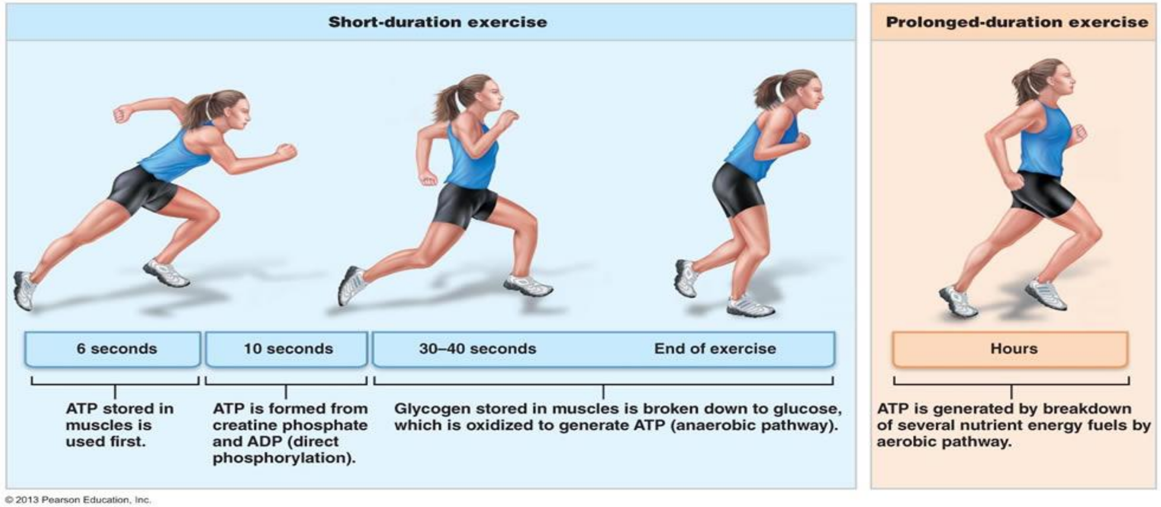
Body temperature (hypothalamus).

The joint proprioceptors.

Possibility that the neurogenic factor for control of ventilation during exercise is a learned response.

Energy sources

1. Phosphocreatine →Creatine + PO3
   8 to 10 seconds
2. Anaerobic Glycogen →Lactic acid
   1.3 to 1.6 minutes
3. Aerobic system
   Unlimited time (as long as nutrients last)



The Aerobic system :

Clucose
Fatty acids
Amino acids

+O2 > CO2 +H2O + ATP + Urea

The phosphagen energy system :

- The combined amounts of cell ATP and cell phosphocreatine are called the phosphagen energy system.
- These together can provide maximal muscle power for 8 to 10 seconds, almost enough for the 100-meter run.
- Thus, the energy from the phosphagen system is used for maximal short bursts of muscle power.

Oxygen Consumption and Pulmonary Ventilation in Exercise

-Normal oxygen consumption for a young man at rest is about 250 ml/min.

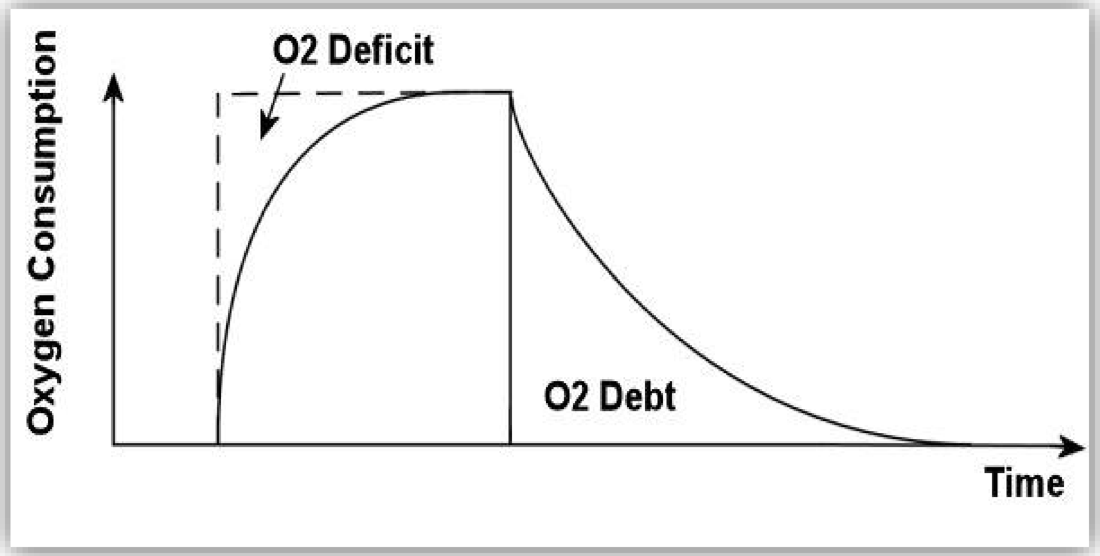
-However, under maximal conditions, this can be increased to approximately the following average levels:

	ml/min
Untrained average male	3600
Athletically trained average male	4000
Male marathon runner	5100

OXYGEN DEBT

“Recovery Oxygen Uptake”

- Oxygen Debt Is the Extra Consumption of Oxygen After Completion of Strenuous Exercise (about 11.5 liters)
- You will develop oxygen debt after about 5 minutes or more of constant exercise.
- This is the point when the exercise becomes ANAEROBIC (without the use of oxygen) and which has to be paid back.
- If the exercise is just AEROBIC (with oxygen) there will be no oxygen debt.



-**Deficit** = The decreased O2 during exercise.
-**Debt** = The increased O2 After exercise.

O2 Debt Greater then O2 Deficit. **WHY?**
To restore the functions in the body to normal as at rest.
After a strenuous exercise there are four tasks that need to be completed:
1-Replenishment of ATP.
2-Removal of lactic acid.
3-Replenishment of myoglobin with oxygen.
4-Replenishment of glycogen.
The need for oxygen to replenish ATP and remove lactic acid is referred to as the "Oxygen Debit" or "Excess Post-exercise Oxygen Consumption"

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Summary of respiratory responses to exercise.

EXTRA

Parameter	Response to exercise
O_2 consumption	↑
CO_2 production	↑
Ventilation rate	↑
Arterial PO_2 and PCO_2	No change
Arterial PH	-No change during moderate exercise - ↓ During strenuous exercise
Venous PCO_2	↑
Pulmonary blood flow and cardiac output	↑
V/Q ratio	More evenly distributed throughout the lung
Physiologic dead space	↓

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Video

- Partial Pressure:
https://www.youtube.com/watch?v=yiaZ8-aMT_A

Quiz

https://www.onlineexambuilder.com/lecture-5/exam-57743

SAQ's

Q/ In strenuous exercise, oxygen consumption and carbon dioxide formation can increase as much as 20-fold. Alveolar ventilation increases almost exactly in step with the increase in oxygen consumption.
Describe what happens to the mean arterial oxygen tension (PO_2), carbon dioxide tension (PCO_2) and pH in a healthy athlete during strenuous exercise?

A/ the arterial PO_2, PCO_2 and PH all remain almost exactly normal

Physiology Team

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- Abdullah Aljaafar
- Adel Alshihri
- Abdulmajeed Alotaibi
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THANK YOU FOR CHECKING OUR WORK

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