

2.1.1 List the principal structures of the ventilatory system

- The principle structures of the respiratory system are:
 - Nose/Mouth – used for inhalation of oxygen-rich air and expelling carbon dioxide rich air
 - Pharynx - passageway leading from the oral and nasal cavities in the head to the larynx
 - Larynx (voice box) - tubular structure connected to the top of the trachea
 - Trachea (windpipe) - conveys air from the larynx to the two main bronchi, with the lungs and their air sacs as the ultimate destination

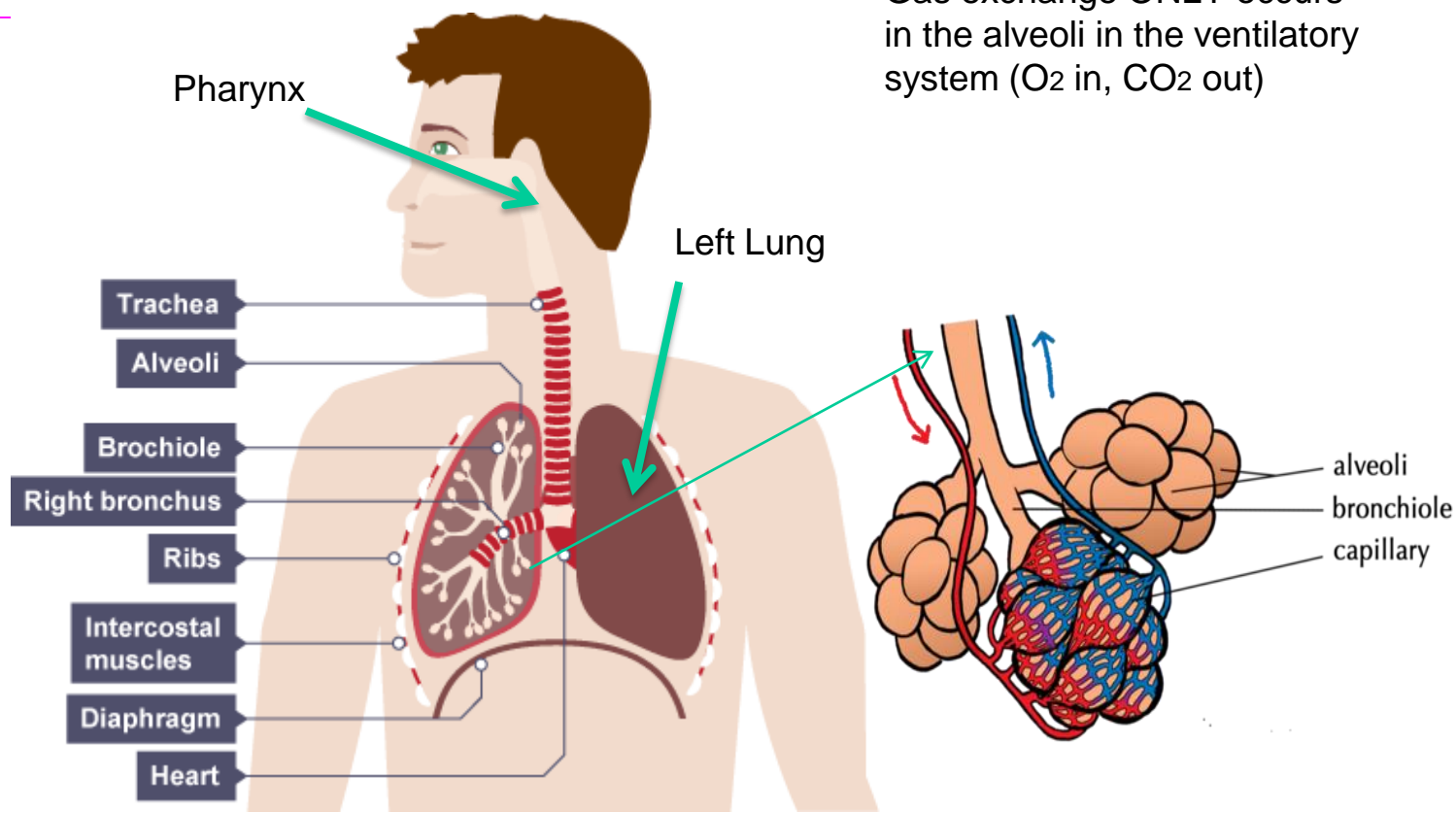
2.1.1 List the principal structures of the ventilatory system

- The principle structures of the respiratory system are:
 - Bronchi (bronchus singular) - airway in the respiratory tract that conducts air into the lungs. Bronchi will branch into smaller tubes that become bronchioles.
 - Bronchioles - any of the minute branches into which a bronchus divides.
 - Lungs - each of the pair of organs situated within the rib cage, consisting of elastic sacs with branching passages into which air is drawn, so that oxygen can pass into the blood and carbon dioxide be removed.
 - Alveoli - any of the many tiny air sacs in the lungs where the exchange of oxygen and carbon dioxide takes place.

2.1.1 List the principal structures of the ventilatory system

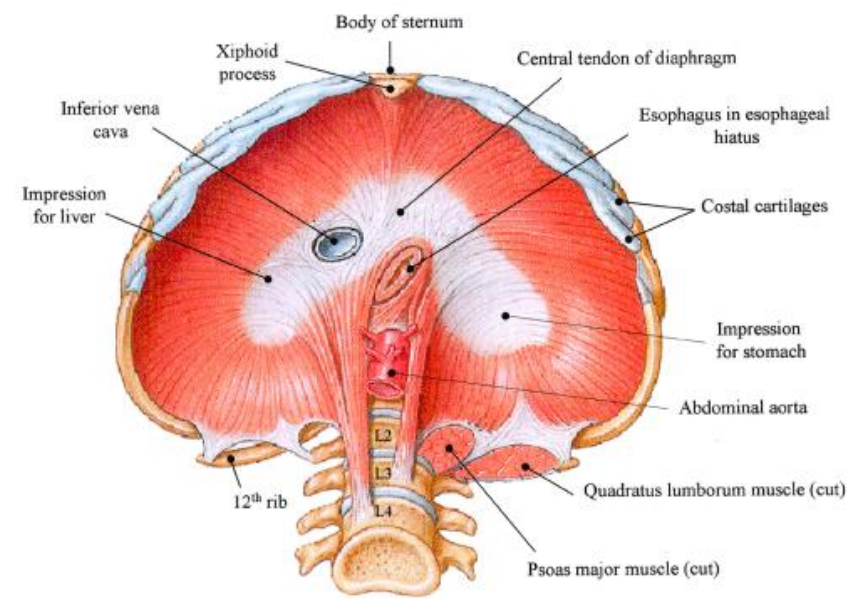
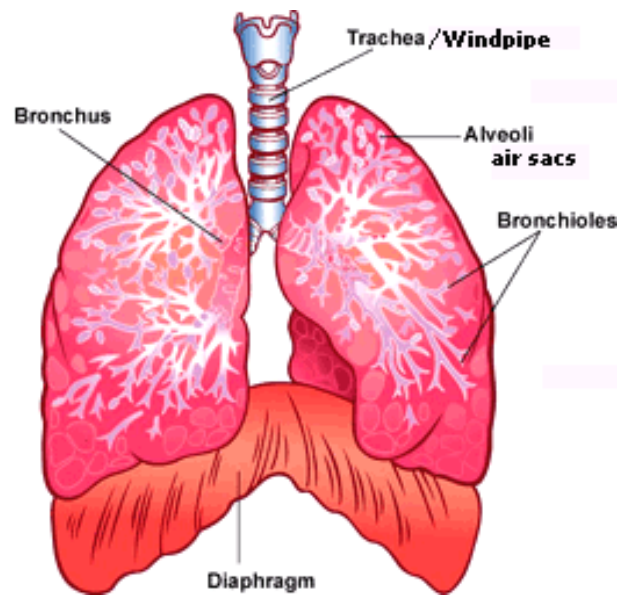
Exercise physiology

Gas exchange ONLY occurs in the alveoli in the ventilatory system (O₂ in, CO₂ out)



2.1.2 Outline the functions of the conducting airways

Diaphragm - a dome-shaped, muscular partition separating the thorax from the abdomen in mammals. It plays a major role in breathing, as its contraction increases the volume of the thorax and so inflates the lungs.



Tricks to preventing or getting rid of a side cramp (of the diaphragm)

Topic 2 Exercise Physiology

Sub-topics

1. Structure & function of the ventilatory system

2. Structure & function of the cardiovascular system

- **Eat mindfully pre-run.** Foods that are higher in fat and fiber take longer to digest. That doesn't mean they are bad foods, but if you eat them within one to two hours before a run, they can cause havoc—creating stomach upset, stitches, and other problems.
- **Invest in a solid warmup.** Going from sitting to running speed can create irregular, rapid-fire breathing patterns, which can translate to you bending over in pain on the side of the road
- **Regulate your breathing.** Match your breathing to your strides—inhaling for two to four strides and exhaling for the same. The faster the pace, the shorter the sequence (fast pace = one or two strides per breath, slower = three or four strides per breath). This can not only prevent stitches, but also improve the efficiency of your oxygen transport.
- **Slow down and exhale to release the stitch.** If you still get another side cramp, implement this strategy and it will go away in seconds (I promise). Slow your pace and exhale as the foot on the opposite side of the cramp strikes the ground. When you exhale, you relax the muscles of your diaphragm. When this happens in unison with your foot striking the ground, the impact forces travel up the body and through your core (your side too) and exacerbate (piss off) the muscles in spasm creating that stitch. When you change the side of the landing forces to the opposite side, the tension causing the stitch releases.

2.1.2 Outline the functions of the conducting airways

Sub-topics

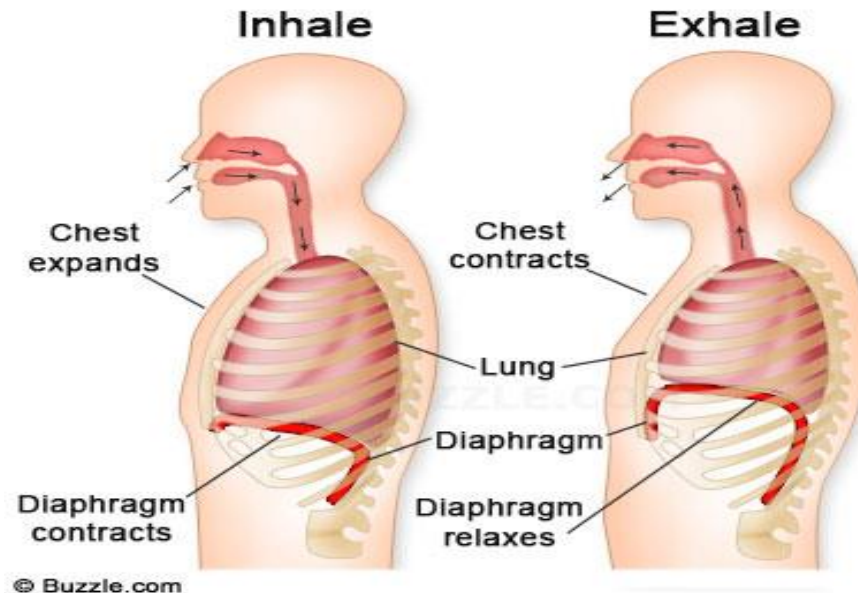
1. Structure & function of the ventilatory system

2. Structure & function of the cardiovascular system

- Breathing based on physics
 - Air flows from areas of high pressure to low pressure
 - Inhalation occurs when the air pressure in the lungs is lower than in the atmosphere
-
- At rest, inhalation caused by diaphragm contraction
 - Diaphragm pulls downward (contracts) and creates a vacuum in the chest cavity by increasing lung volume.
 - Draws air in due to pressure imbalance

2.1.2 Outline the functions of the conducting airways

- The exhalation process is passive (no energy required) because as the diaphragm relaxes it returns to original position, shrinking lung volume and creating greater pressure in the lungs compared to atmosphere.

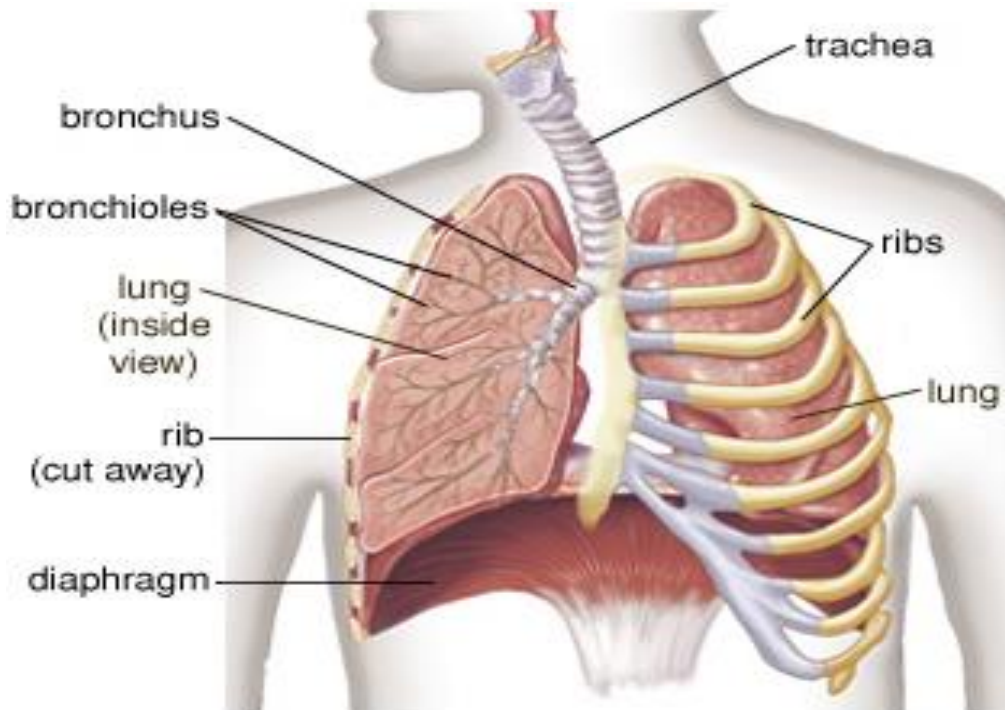


2.1.2 Outline the functions of the conducting airways

Sub-topics

1. Structure & function of the ventilatory system

2. Structure & function of the cardiovascular system



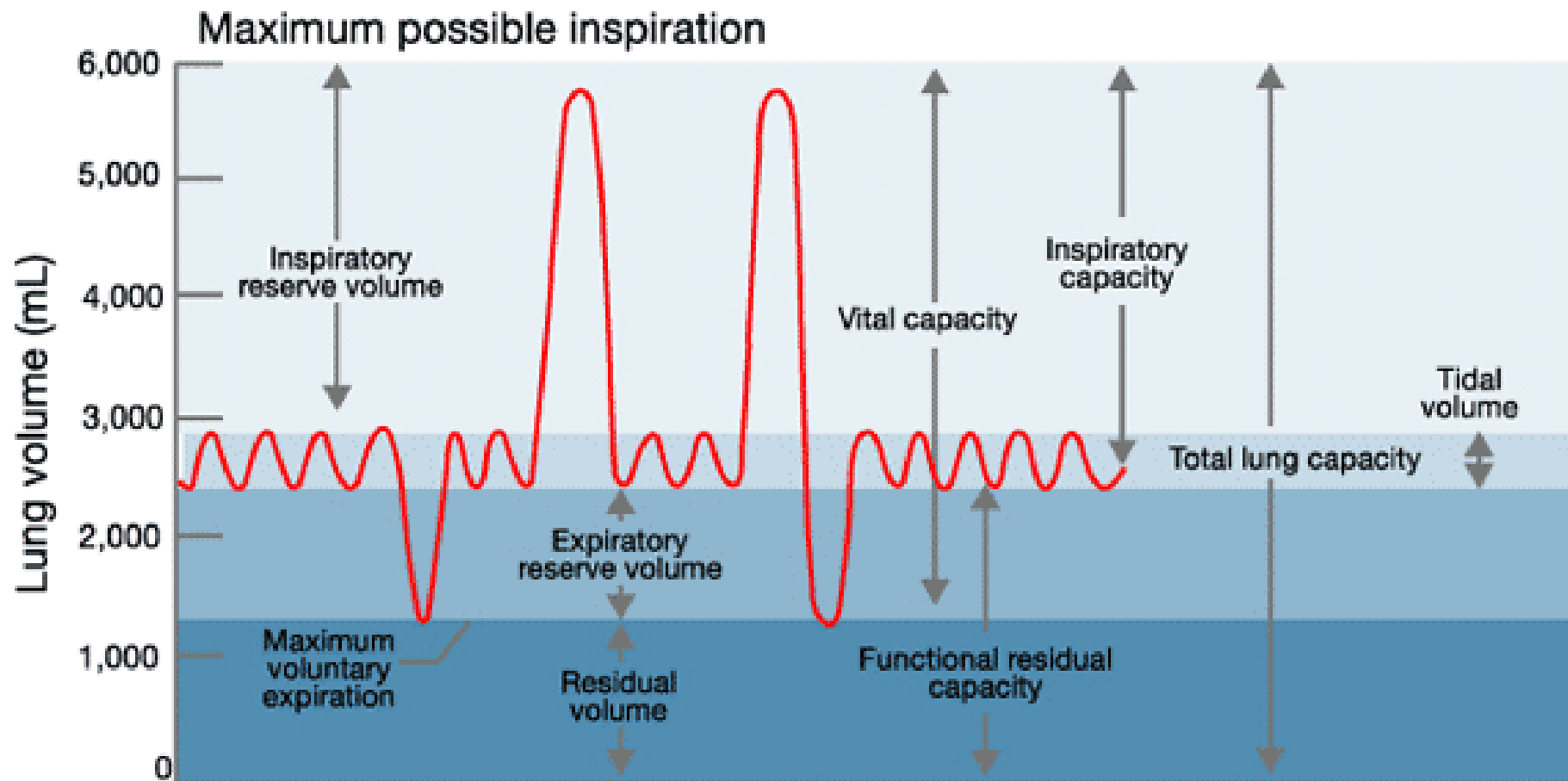
[BREATHING
MOVEMENTS
VIDEO](#)

2.1.2 Outline the functions of the conducting airways

During exercise, more oxygen is needed in the active muscles and more carbon dioxide is being produced.

- More air needs to be inhaled and exhaled at a faster rate
- Additional muscles must be recruited to make this happen - external intercostal muscles (chest muscles), abdominals and even shoulders can assist in increasing lung volume
- Compression also can use the contractions of these muscles to expel air faster thus increasing respiration rate.
- Uses/needs an incredible amount of energy

Lung Volumes and Capacities



2.1.3 Define respiratory terms

Sub-topics

1. Structure & function of the ventilatory system

2. Structure & function of the cardiovascular system

- Atmospheric pressure – pressure exerted by the weight of the atmosphere
- Intra alveolar (intrapulmonary) pressure – pressure of the lungs relative to the atmosphere
- Pulmonary ventilation - is commonly referred to as breathing. It is the process of air flowing into the lungs during inspiration (inhalation) and out of the lungs during expiration (exhalation).
- Total Lung Capacity (TLC) – the amount of gas contained in the lung at the end of a maximal inhalation
- Tidal volume (V_T)– the amount of air moving into and out of the lungs while at rest.

2.1.3 Define respiratory terms

Sub-topics

1. Structure & function of the ventilatory system

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- Vital Capacity (VC) – the greatest volume of gas that, following maximum inhalation, can be expelled during a complete, slow, forced exhalation
- Expiratory reserve volume (ERV) – the additional maximal volume of air that can be **expelled from the lungs** by forced exhalation after normal exhalation (after lowest tidal volume)
- Inspiratory reserve volume (IRV) - the additional maximal volume of air that can be **drawn into the lungs** by forced inhalation after normal inhalation (after highest tidal volume)
- Residual Volume (RV) - **volume** representing the amount of air left in the lungs after a forced exhalation; this **volume** cannot be measured, only calculated.

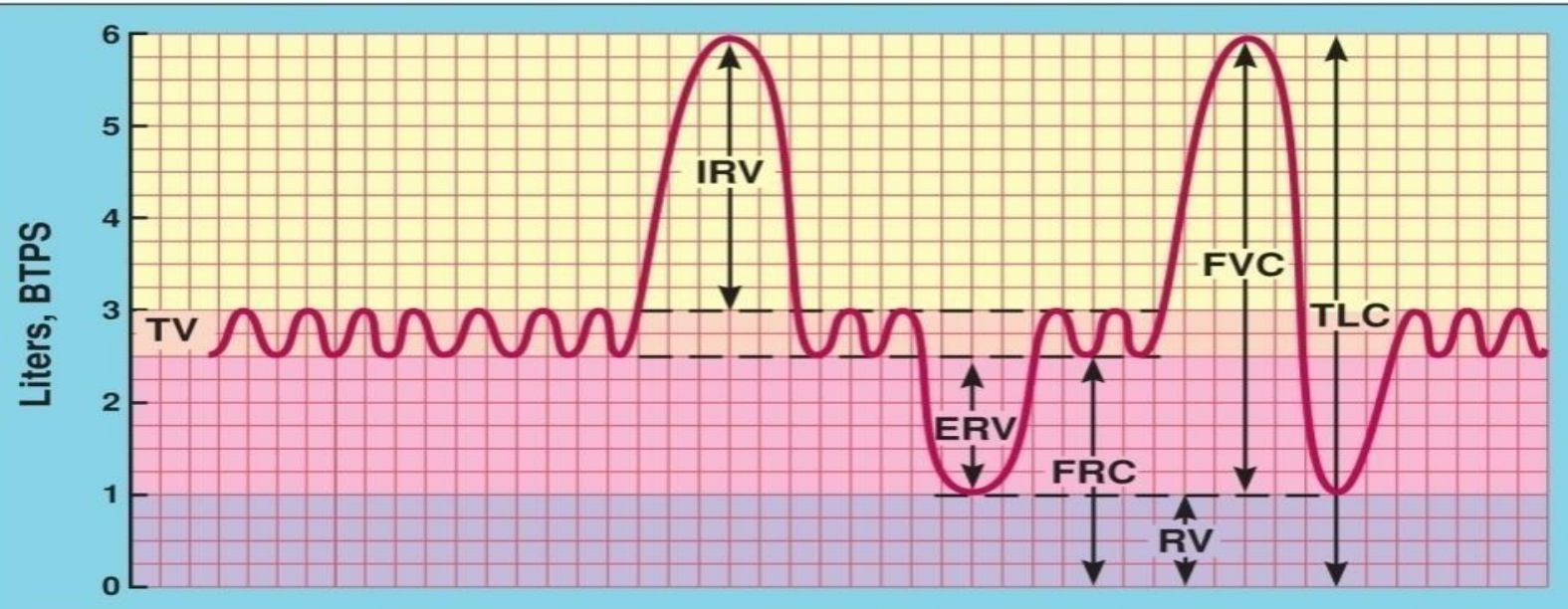
2.1.3 Define respiratory terms

- **Total lung capacity** can be calculated by adding **vital capacity** to **residual volume** of the lungs.
- During normal, quiet respiration, about 500mL of air is inspired. The same amount of air moves out with expiration. This volume of air is called the **tidal volume**.
- When we forcibly take a deep breath, we can take in up to 3100mL above the tidal volume. This additional air is the **inspiratory reserve volume**.

- Browne et. al 2001

2.1.3 Define respiratory terms

- We can also forcibly exhale. This is termed the **expiratory reserve volume**.
- Forced Expiratory Volume (FEV) – Test of dynamic lung function
- Even after the expiratory reserve volume is expelled, some air is still trapped in the lungs because of pressure. This is called the **residual volume**.
- This also allows for uninterrupted gaseous exchange during the breathing cycle.



Lung Volume/Capacity	Definition	Average Values (mL)	
		Males	Females
Tidal Volume (TV)	Volume inspired or expired per breath	600	500
Inspiratory Reserve Volume (IRV)	Maximum inspiration at end of tidal inspiration	3000	1900
Expiratory Reserve Volume (ERV)	Maximum expiration at end of tidal expiration	1200	800
Total Lung Capacity (TLC)	Volume in lungs after maximum inspiration	6000	4200
Residual Lung Volume (RLV)	Volume in lungs after maximum expiration	1200	1000
Forced Vital Capacity (FVC)	Maximum volume expired after maximum inspiration	4800	3200
Inspiratory Capacity (IC)	Maximum volume inspired following tidal expiration	3600	2400
Functional Residual Capacity (FRC)	Volume in lungs after tidal expiration	2400	1800

2.1.4 Explain the mechanics of ventilation in the human lungs

1. Structure & function of the ventilatory system

2. Structure & function of the cardiovascular system



Composition of Inhaled & Exhaled Air

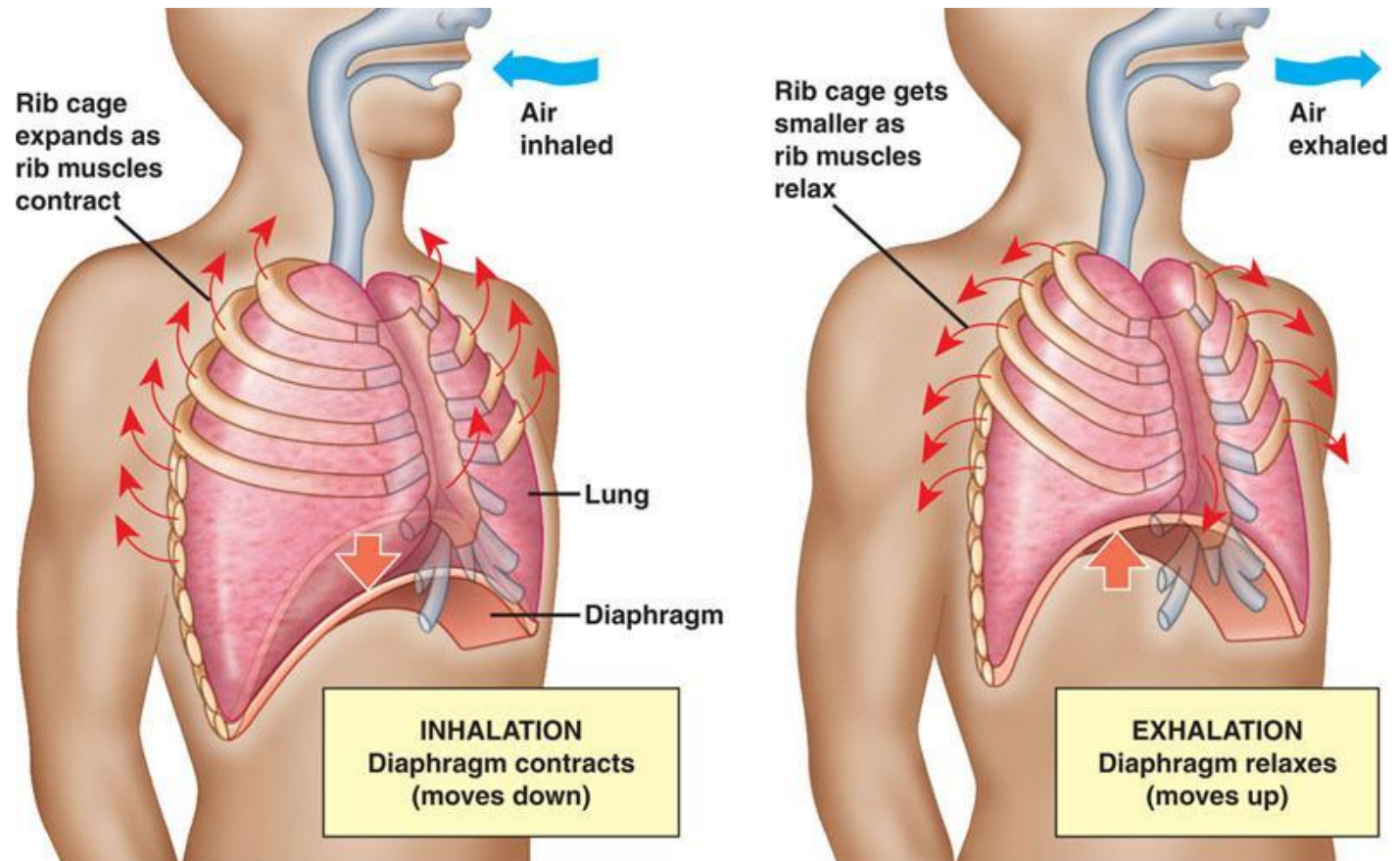
Components of air	Inhaled air	Exhaled air
Oxygen	21%	16%
Carbon dioxide	0.03%	4%
Nitrogen	78%	78%
Water vapour	Varies (depends on the humidity of air)	More (usually saturated)
Dust particles	Varies	Usually none
Temperature (heat)	Varies (follows atmospheric temp.)	Body temperature

2.1.4 Explain the mechanics of ventilation in the human lungs

Sub-topics

1. Structure & function of the ventilatory system

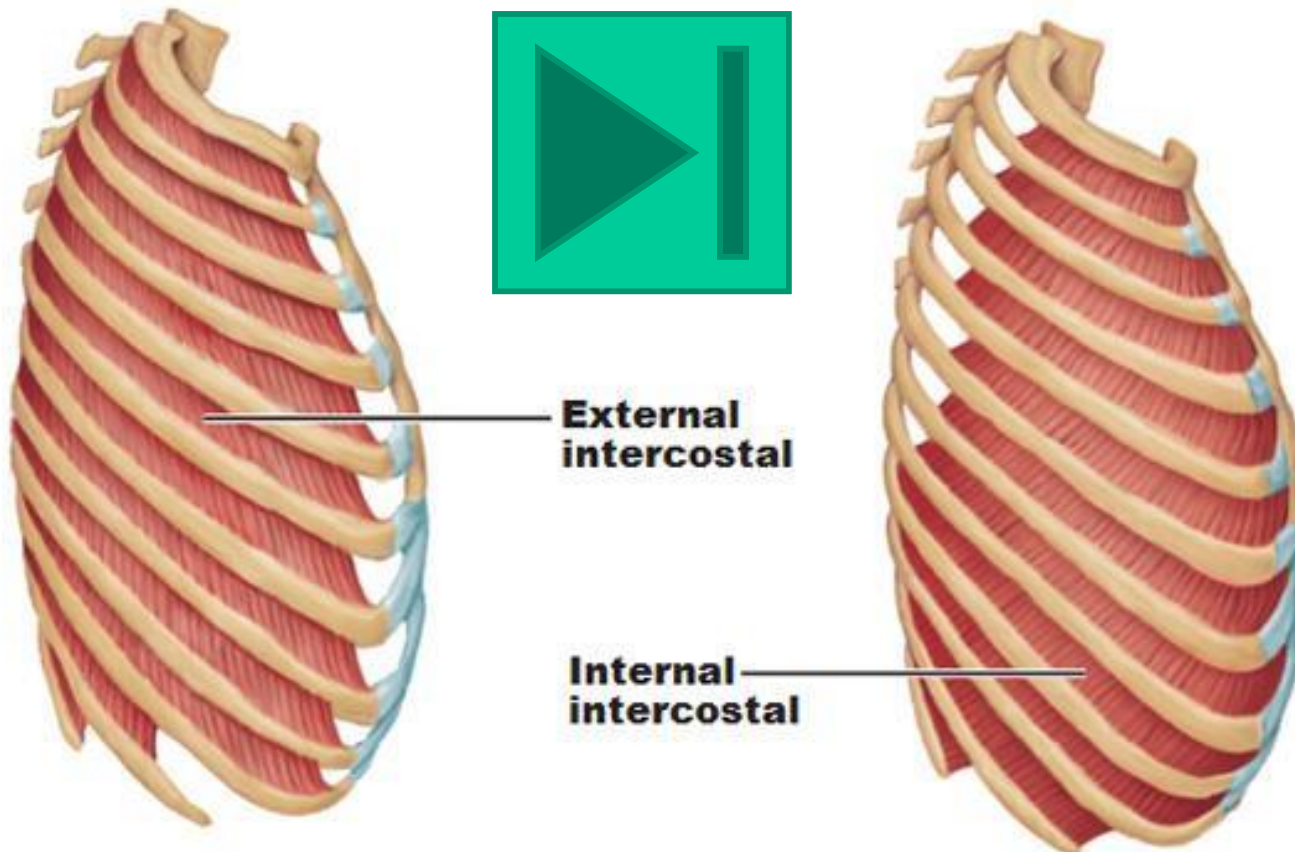
2. Structure & function of the cardiovascular system



2.1.4 Explain the mechanics of ventilation in the human lungs

Sub-topics

1. Structure & function of the ventilatory system
2. Structure & function of the cardiovascular system



2.1.4 Explain the mechanics of ventilation in the human lungs



Sub-topics

1. Structure & function of the ventilatory system

2. Structure & function of the cardiovascular system

Explain how the role between volume and pressure regulates breathing.

Discuss the role of the intercostal muscles.

2.1.4 Explain the mechanics of ventilation in the human lungs

- V_E = volume of air being exhaled per minute
- V_T = tidal volume
- B_f = breathing frequency (breaths per minute)

- $V_E \text{ (L.min}^{-1}\text{)} = V_T \text{ (L.Breath}^{-1}\text{)} \times B_f \text{ (breaths.min}^{-1}\text{)}$

TO DO

Complete the table below that presents some data collected during an exercise test.

EXERCISE INTENSITY DURING RUNNING AT PROGRESSIVELY FASTER SPEEDS							
	Rest	8 km.h ⁻¹	10 km.h ⁻¹	12 km.h ⁻¹	14 km.h ⁻¹	16 km.h ⁻¹	18 km.h ⁻¹
V_T [L.br ⁻¹]	0.67	2		3.3	3.6		4
B_f [br.min ⁻¹]	12		22.3	24.2		30	38
\dot{V}_E [L.min ⁻¹]	8	40	58		98	115	

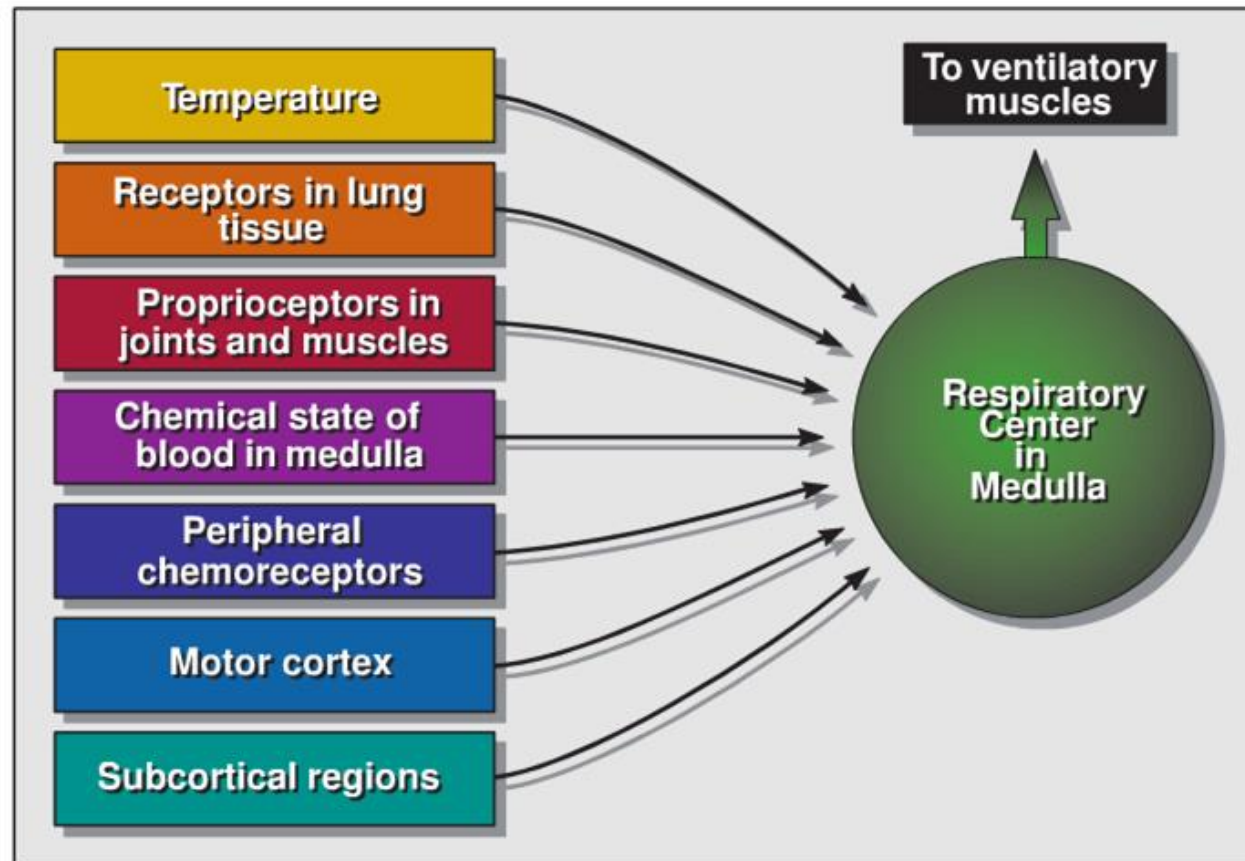
↑ Table 2.1: Comparison of \dot{V}_E , V_T and B_f values at rest and during incremental exercise

As exercise intensity increases, how is the increased ventilation achieved?

2.1.5 Describe the nervous and chemical control of ventilation during exercise

- Ventilation increases in response to increasing intensity of exercise
- The main objective is to maintain resting oxygen and carbon dioxide levels in blood
- This is achieved by increasing breathing rate and depth of breathing
- **Regulation of breathing is quite complex and no single factor is responsible.** Carbon dioxide levels in the blood is commonly thought to be the main driving factor.

2.1.5 Describe the nervous and chemical control of ventilation during exercise



2.1.5 Describe the nervous and chemical control of ventilation during exercise

Receptors in lung tissue

Inspiration is activated via the respiratory center in the medulla of the brain

The lungs inflate because motor neurons activate the diaphragm and the external intercostal muscles.

Inflation of the lung tissue stimulates **stretch receptors** in the bronchioles that inhibit inspiration and stimulate expiration. (don't want to stretch too much)

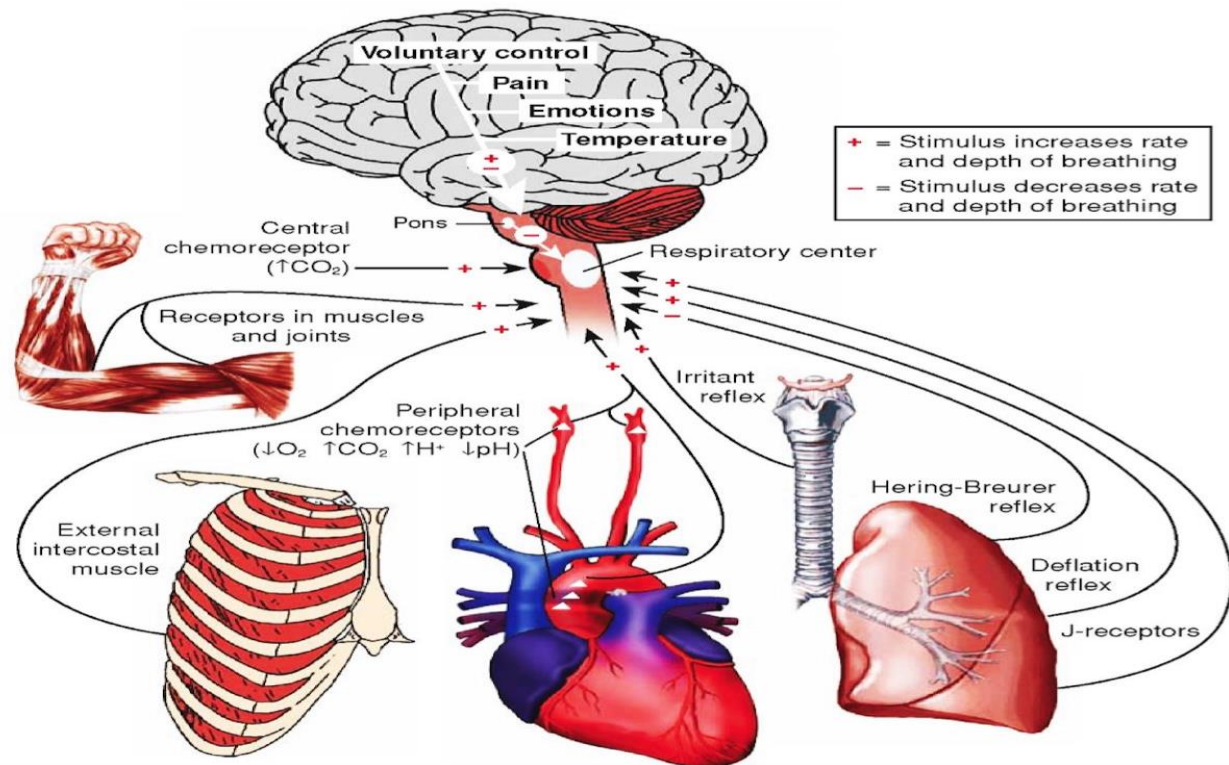
Expiration begins with a recoil of the stretched lung tissue and the inspiratory muscles are stimulated to relax. The internal intercostals muscles will be stimulated while inspiratory muscle activation is inhibited.

2.1.5 Describe the nervous and chemical control of ventilation during exercise

Sub-topics

1. Structure & function of the ventilatory system

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2.1.5 Describe the nervous and chemical control of ventilation during exercise

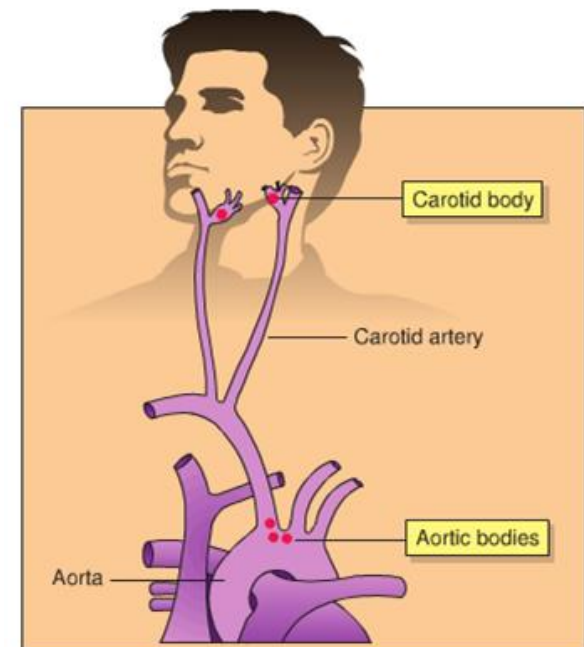
Chemical state of blood in medulla

- The chemical state of blood regulates pulmonary ventilation at rest and exercise.
- Variations in PO_2 , O_2 , CO_2 acidity and temperature activate sensors in the brain (medulla) and arterial system to adjust ventilation and maintain blood chemistry within narrow limits.

PO_2 = partial pressure of oxygen.

- It is the individual **pressure** exerted independently by a particular gas within a mixture of gasses.

Peripheral chemoreceptors



Sub-topics

1. Structure & function of the ventilatory system

2. Structure & function of the cardiovascular system

2.1.5 Describe the nervous and chemical control of ventilation during exercise

- When we exercise, we experience an increase in depth and rate of respiration to meet the increased oxygen requirement.
- The increase in respiration often precedes the actual increased oxygen requirement!!! What?!?!
- There are at least 2 components to this increase in respiration that precedes the increased oxygen requirement.
 - 1) The first component is "anticipation of exercise" and may involve activation of the sympathetic nervous system in order to prepare the body for activity

Proprioceptors in joints and muscles

Exercise physiology

Topic 2
Exercise
Physiology

2.1.5 Describe the nervous and chemical control of ventilation during exercise

Sub-topics

1. Structure & function of the ventilatory system

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2) The second component involves activation of stretch receptors (proprioceptors) in skeletal muscle and joints.

- Increased activity of stretch receptors is detected by the medulla and results in increased rate and depth of respiration.

- The effect is very rapid and shows the value of stretching/warming up before exercise (ie. in addition to heating up muscles and connective tissues and reducing stretch-related injuries).

- This allows the body to properly prepare for exercise and helps control breathing, heart rate, temperature, etc.

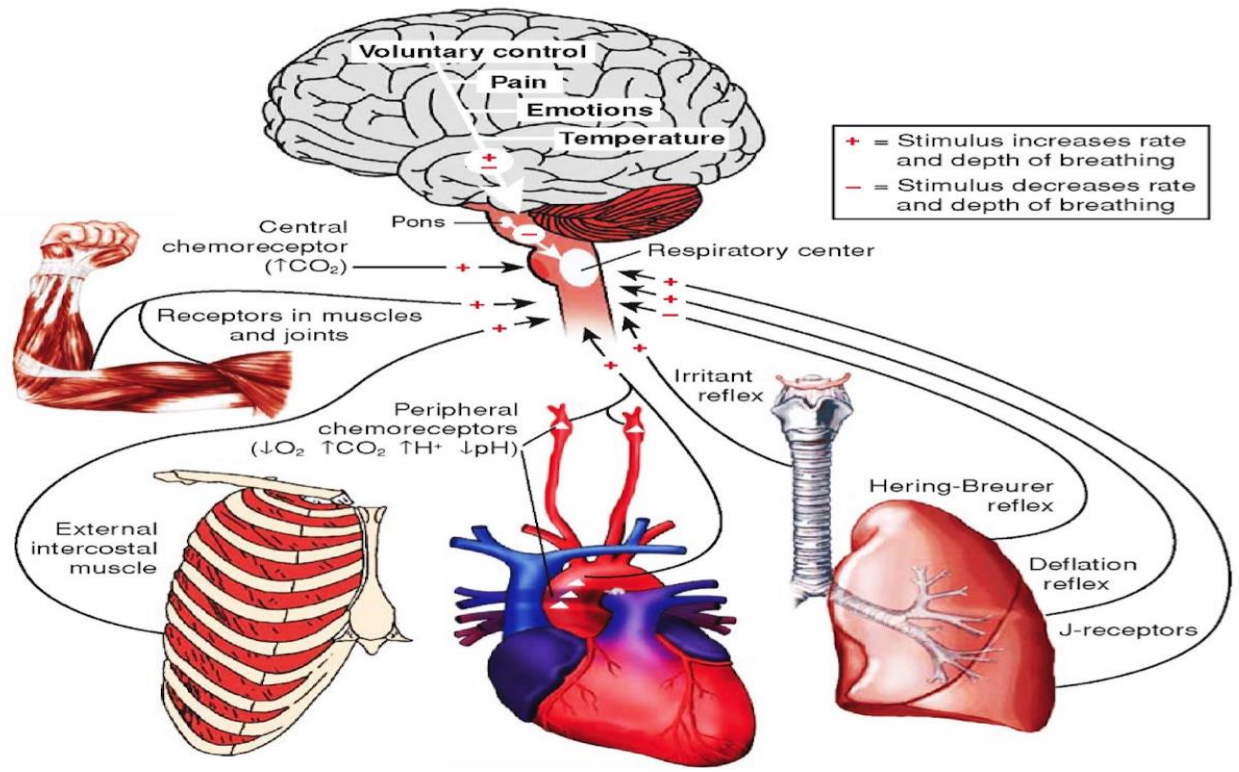
Proprioceptors in joints and muscles

Exercise physiology

2.1.5 Describe the nervous and chemical control of ventilation during exercise

1. Structure & function of the ventilatory system

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2.1.5 Describe the nervous and chemical control of ventilation during exercise

- Carbon dioxide (CO_2) diffuses through the alveolar walls much more easily than oxygen
- CO_2 is produced by muscles then sent into bloodstream. CO_2 reacts with carbonic anhydrase & H_2O (enzyme to speed up reactions) in red blood cells (RBC's) and forms carbonic acid
- After being further reduced, it is now bicarbonate (HCO_3^-) which dissolves in blood plasma (discussed in a few slides). Blood pH drops and sensors force us to breathe.
- This is necessary to transport CO_2 out of the body because we don't want gases in the bloodstream
- All of these reactions are reversed in the lungs so we can transfer and exhale CO_2 from our bodies

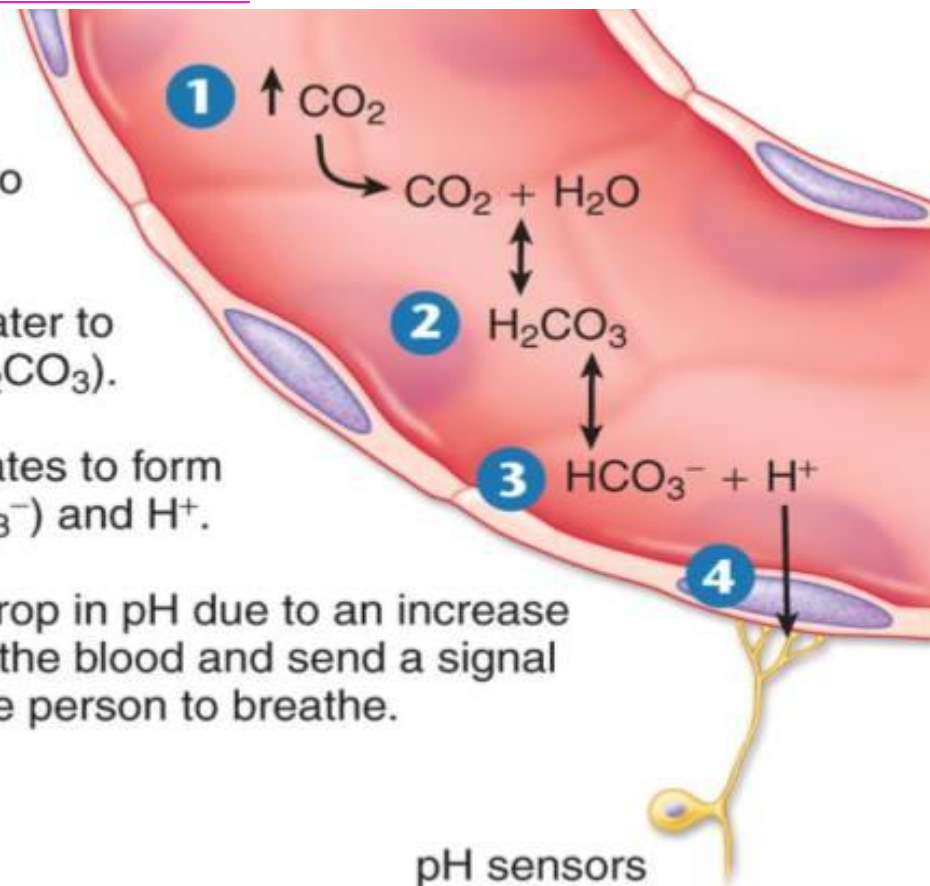
2.1.5 Describe the nervous and chemical control of ventilation during exercise

Sub-topics

1. Structure & function of the ventilatory system

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- 1** Holding one's breath causes levels of CO_2 to rise in the blood.
- 2** CO_2 combines with water to form carbonic acid (H_2CO_3).
- 3** Carbonic acid dissociates to form bicarbonate ion (HCO_3^-) and H^+ .
- 4** pH sensors detect a drop in pH due to an increase in H^+ concentration in the blood and send a signal to the brain, forcing the person to breathe.



2.1.5 Describe the nervous and chemical control of ventilation during exercise

Sub-topics

1. Structure & function of the ventilatory system

2. Structure & function of the cardiovascular system

- As it is, carbon dioxide excretion is far more easily hindered than is oxygen absorption.
- **Thus breathing is governed not by oxygen, but the carbon dioxide content of the blood.**

2.1.5 Describe the nervous and chemical control of ventilation during exercise

Sub-topics

1. Structure & function of the ventilatory system

2. Structure & function of the cardiovascular system

- HYPERVENTILATION
- An increase in ventilation above what is required
- Exhale too much CO₂ and inhale too much O₂
- Leads to an increased blood pH
- Typically caused by a state of panic, dizziness, tingling in the lips, hands or feet, headache, weakness, fainting and seizures are common



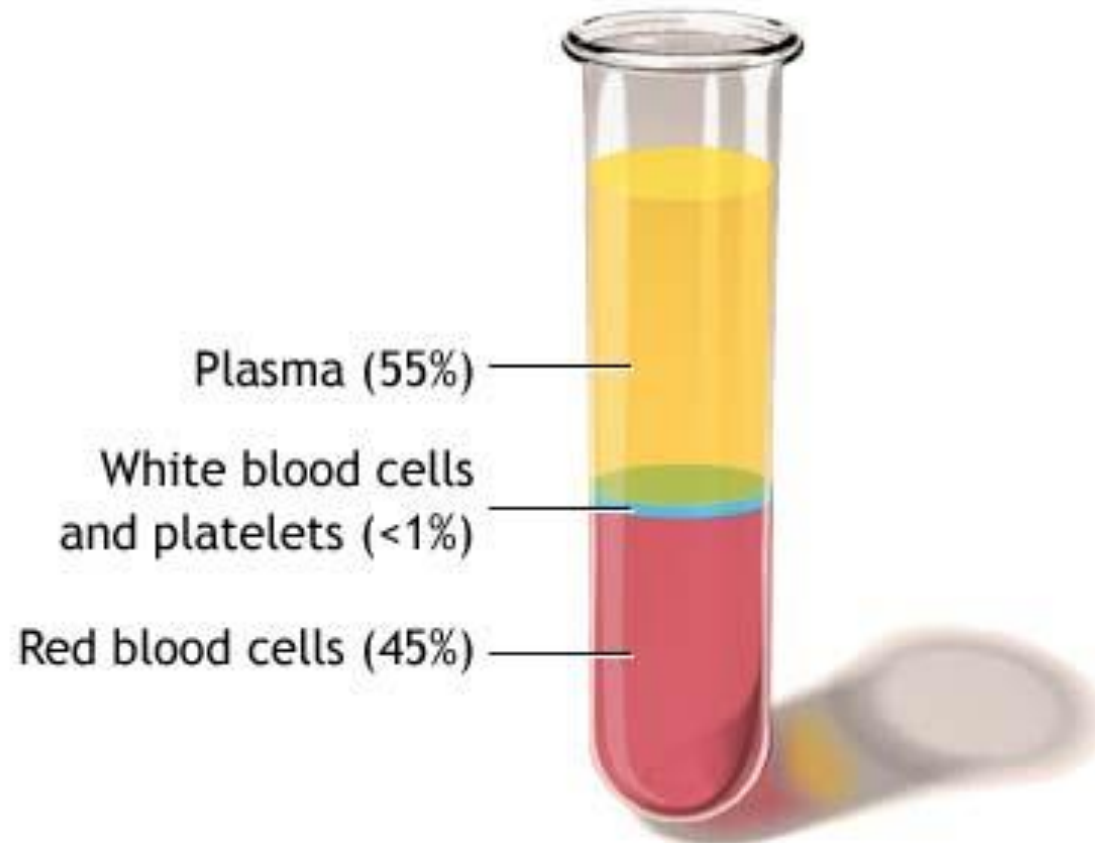
[Hyperventilation video](#)

2.1.6 Outline the role of hemoglobin in oxygen transportation

Sub-topics

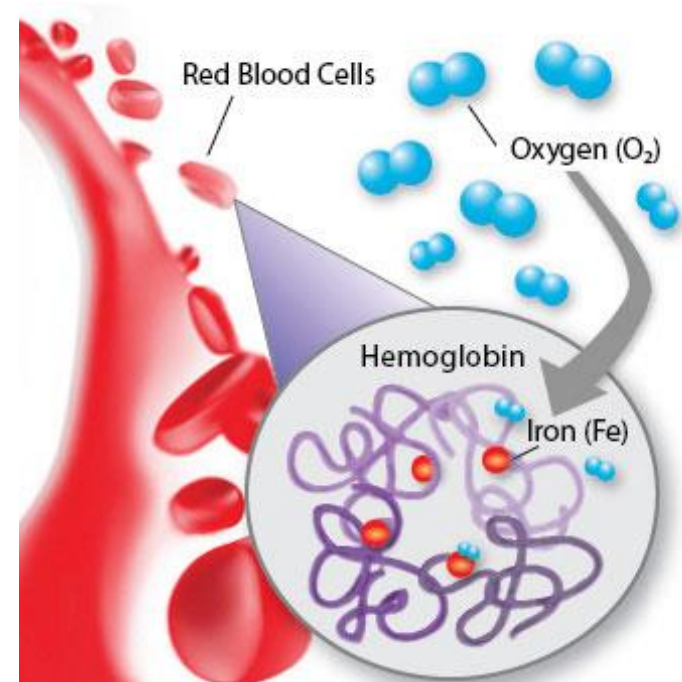
1. Structure & function of the ventilatory system

2. Structure & function of the cardiovascular system



2.1.6 Outline the role of Hemoglobin oxygen transportation

- Hemoglobin is the iron containing oxygen transport protein in the red blood cells.
- It transports oxygen from the lungs to the rest of the body, such as the muscles, where it releases it's oxygen.
- Each molecule of hemoglobin can carry 4 oxygen molecules
- It can also carry CO₂ as carboaminohemoglobin back to the lungs for diffusion and expiration.



2.1.6 Outline the role of hemoglobin in oxygen transportation

Sub-topics

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- Oxygen at the lungs is collected mostly by red blood cells (~95%) where they combine with hemoglobin to form oxy-hemoglobin (O_2 saturated hemoglobin) and the rest (~5%) diffuses into blood plasma (O_2 has low solubility)
- This oxygen dissolved in the plasma determines the movement of oxygen from cells into the blood (pressure gradient)
- Plasma PO_2 determines the loading of hemoglobin at the lungs and the unloading of oxygen at the cells
- When there is low PO_2 , hemoglobin gives up its oxygen to the plasma (it now becomes part of the blood) which increases the PO_2 of the blood in relation to surrounding cells. Oxygen moves from the blood to the cells.
- At rest only 25% of the oxygen content of blood is used with rest remaining in circulation.

2.1.6 Outline the role of hemoglobin in oxygen transportation

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Diffusion - The passive movement of molecules or particles along a concentration gradient, or from regions of higher to regions of lower concentration in relation to surface area – Ficks Law

Gas concentration reflects the amount of gas in a given volume, (determined by the gas' partial pressure and solubility)
Partial pressure = percentage concentration x total pressure of gas mixture i.e. PCO_2 and PO_2

Gas pressure represents the force exerted by the gas molecules against the surfaces they encounter i.e. breathing

2.1.7 Explain the process of gaseous exchange at the alveoli

Fick's Law

Fick's law is used to measure the rate of diffusion.

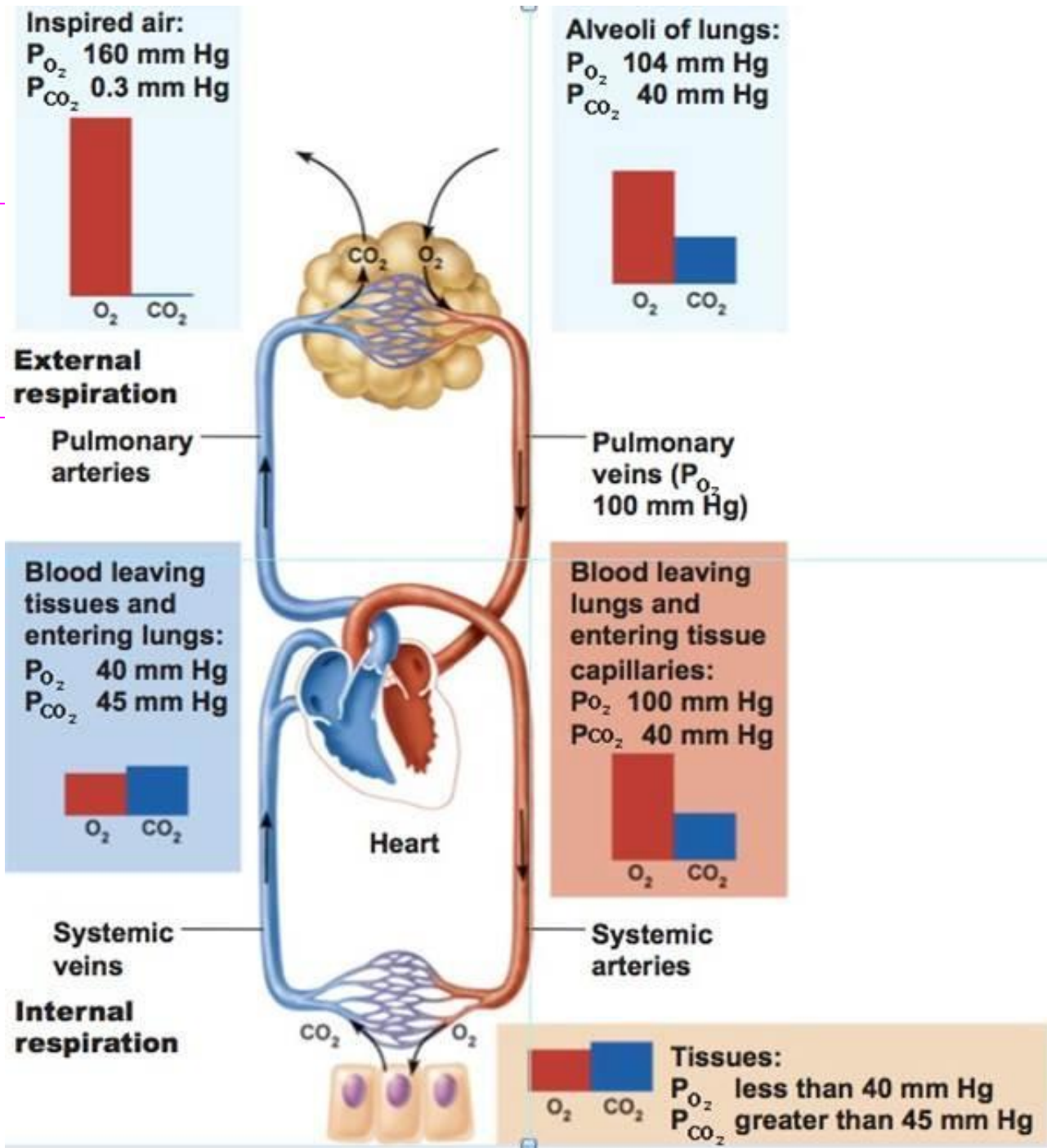
It states that:

$$\text{Rate of diffusion} \propto \frac{\text{Area of diffusion surface} \times \text{Difference in concentration}}{\text{Thickness of surface over which diffusion takes place}}$$

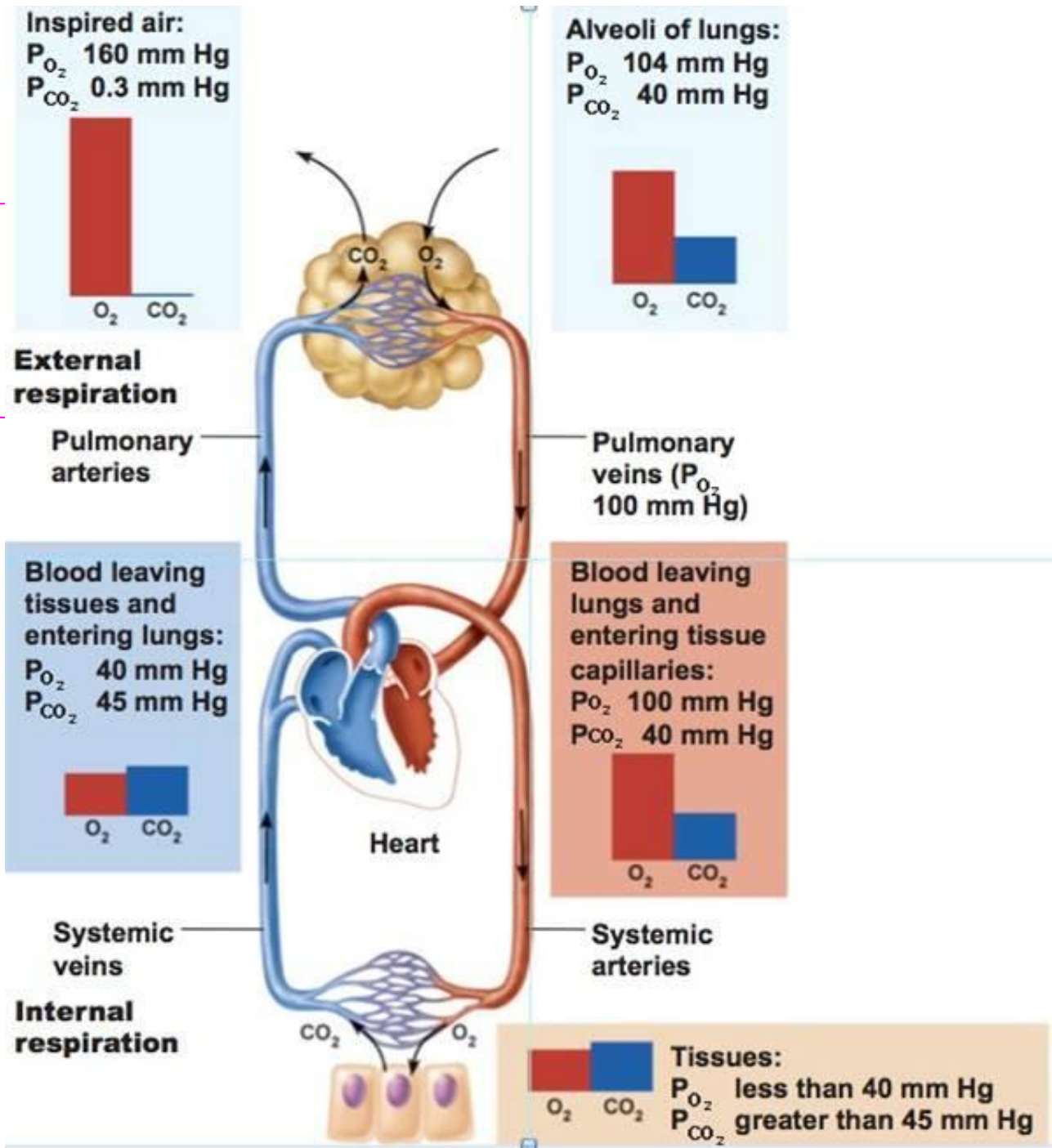
The larger the area and difference in concentration and the thinner the surface, the quicker the rate.

So, for example, in the lung the surface area is made very large by the presence of many alveoli. The difference in concentration is maintained by breathing, which brings in air with a high oxygen concentration and removes the air with a high carbon dioxide concentration and by a good blood supply. The capillaries surrounding the alveoli take away the oxygenated blood and replace it with blood with a high carbon dioxide concentration. The walls of the alveoli are only one cell thick, so the surface across which diffusion occurs is thin and the rate is high

- 1. Structure & function of the ventilatory system
- 2. Structure & function of the cardiovascular system



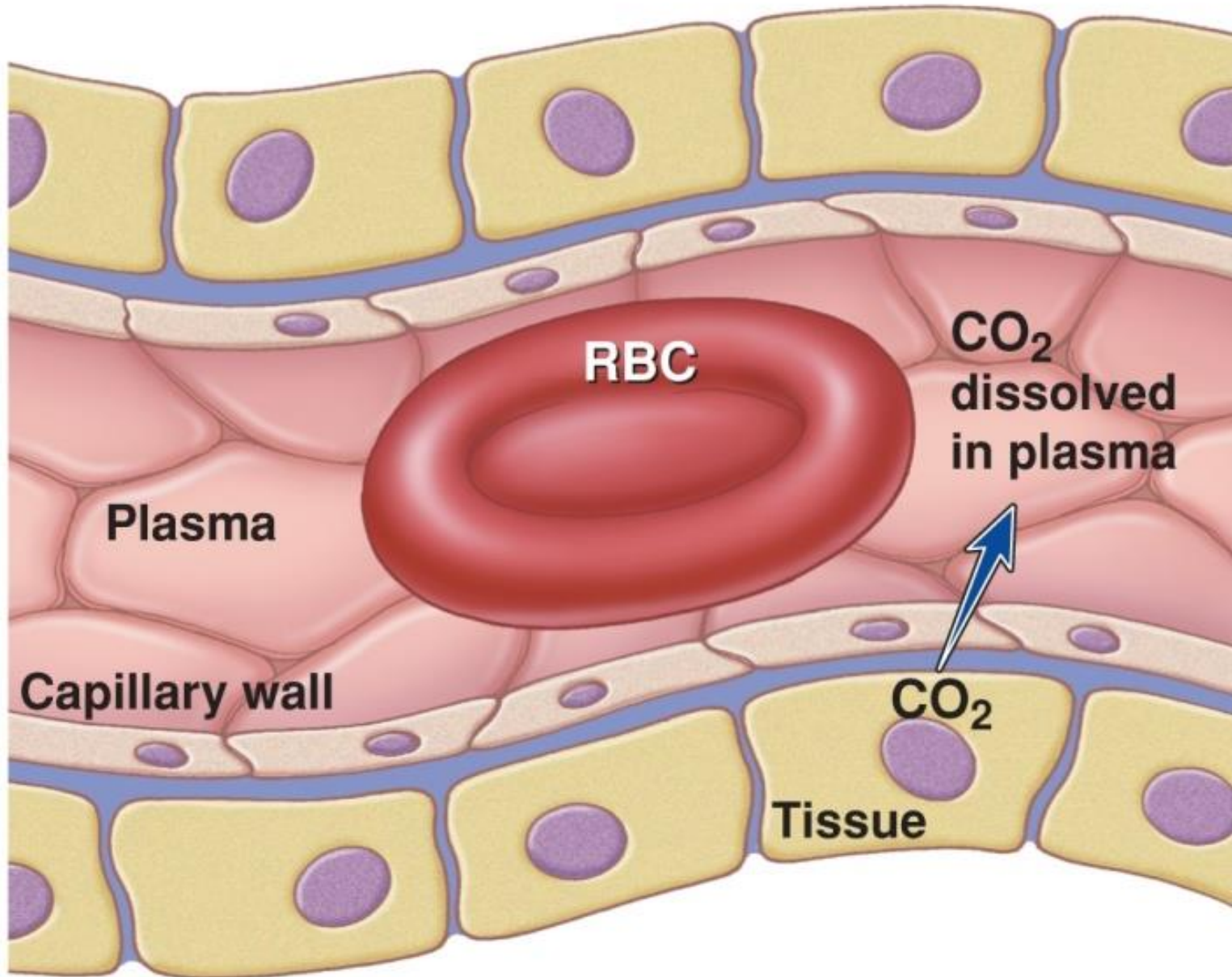
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2.1.5 Describe the significance of carbon dioxide in the control of pulmonary ventilation

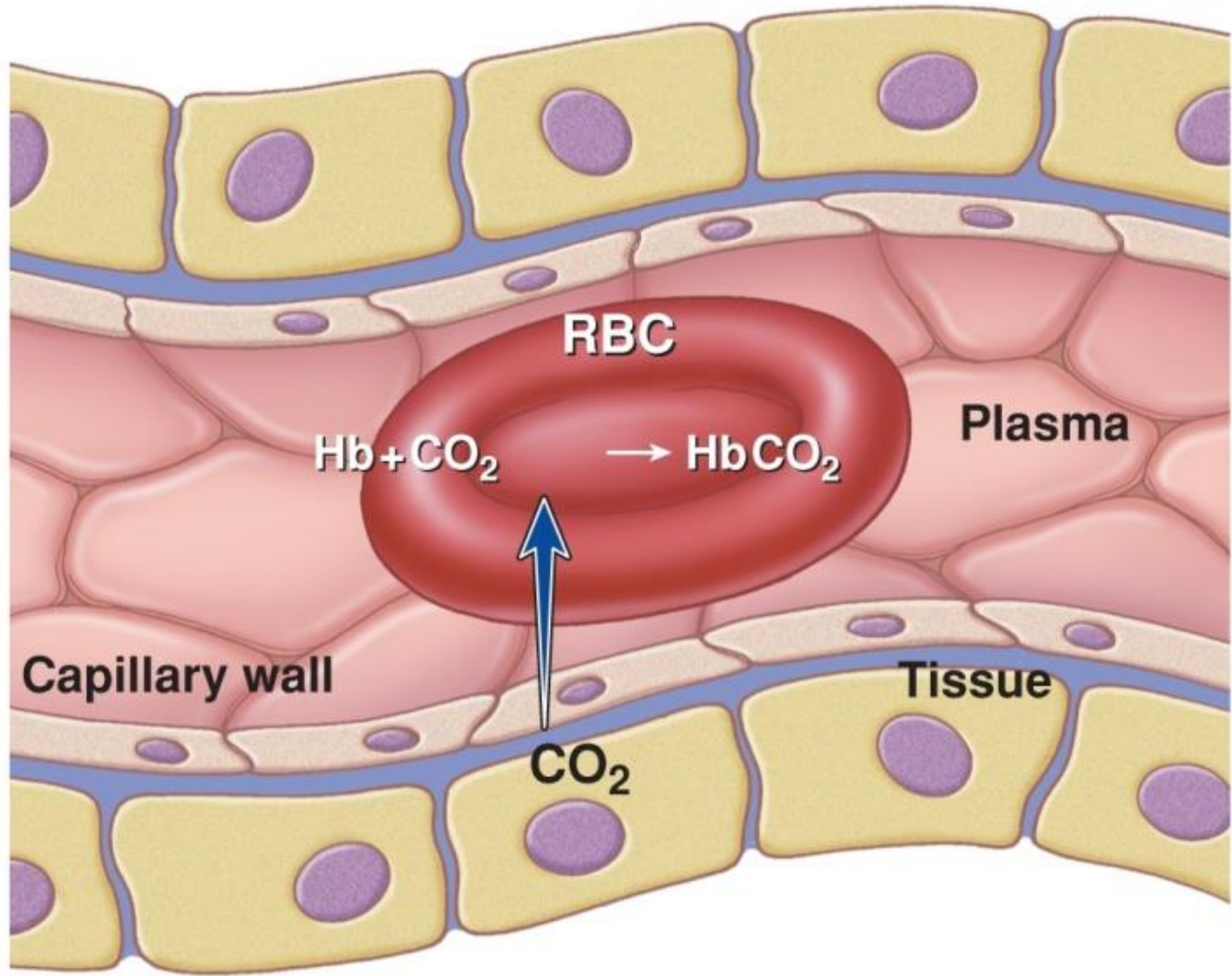
- Physical solution in plasma (7%–10%); establishes the PCO_2 of the blood
- Loose combination with Hb (20%)
- Combined with water as bicarbonate (70%)

A CO_2 dissolved in plasma

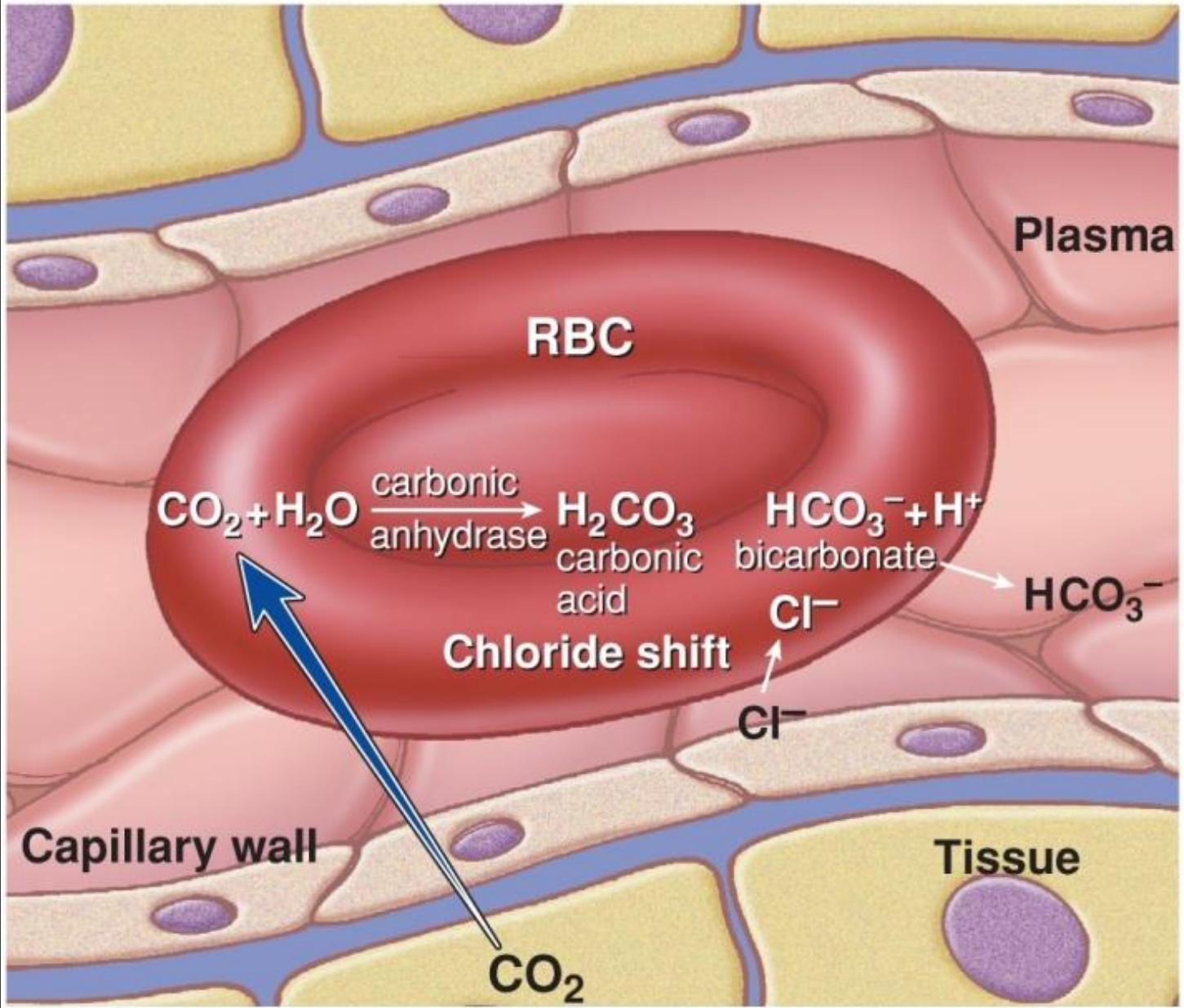


20% = Carboaminohaemoglobin

B CO₂ chemically bound to hemoglobin



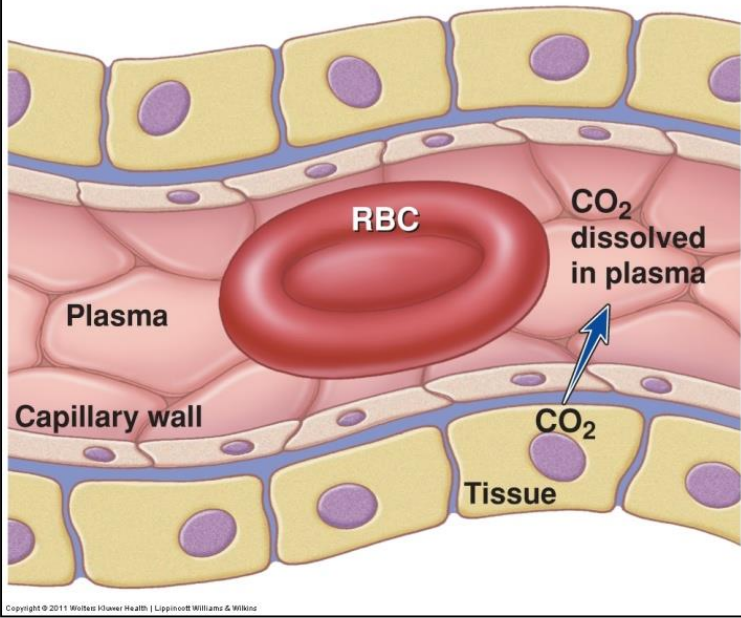
C CO_2 combined with water as bicarbonate



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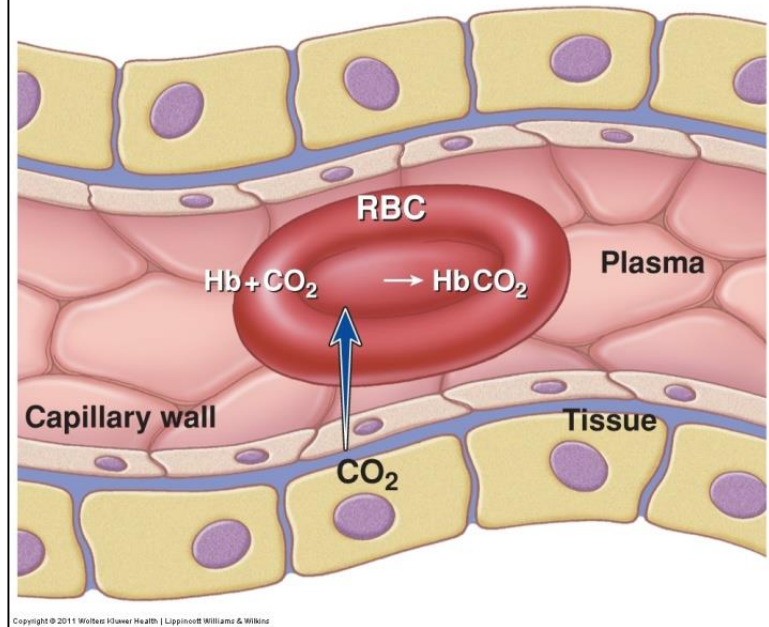
- CO₂ combines with water in the red blood cell to form Carbonic acid ($\text{CO}_2 + \text{H}_2\text{O} = \text{H}_2\text{CO}_3$)
- Carbonic acid ionises into Hydrogen ions (H⁺) and bicarbonate ions (HCO₃⁻)
- At the lungs, as blood PCO₂ lowers Hydrogen ions and Bicarbonate ions recombine to form carbonic acid which in turn is broken down to CO₂ and water

A CO₂ dissolved in plasma



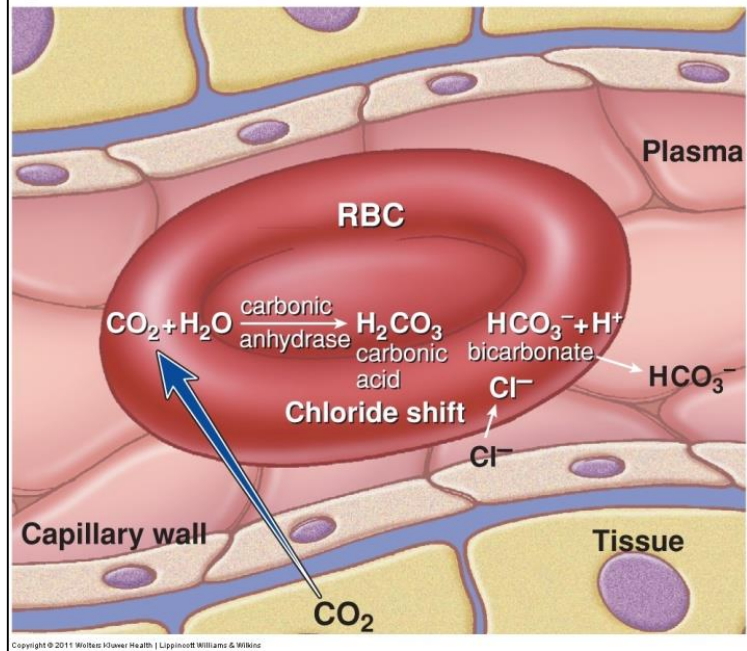
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B CO₂ chemically bound to hemoglobin



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C CO₂ combined with water as bicarbonate



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2.1.5 Describe the significance of carbon dioxide in the control of pulmonary ventilation

- 1. List two functions of the ventilatory system**
- 2. List 2 factors that determine lung filling.**
- 3. List an average tidal volume for men and women.**
- 4. List the average vital capacity for men and women.**
- 5. Compute V_E for an individual with a tidal volume of 0.6 L and a breathing rate of 15 breaths per minute.**
- 6. List 2 ways oxygen transports in blood.**
- 7. Name 3 factors that regulate pulmonary ventilation**
- 8. Why do some swimmers hyperventilate on the starting blocks?**
- 9. Use Ficks law to explain the efficiency of the alveoli**
- 10. Explain how training improves the efficiency of the respiratory system**

2.1.5 Describe the significance of carbon dioxide in the control of pulmonary ventilation

- 1. List two functions of the ventilatory system**
- 2. List 2 factors that determine lung filling.**
 - Magnitude of inspiratory movements
 - Pressure gradient between air inside and air outside the lung
- 3. List an average tidal volume for men and women.**
 - 0.4l – 1l
- 4. List the average vital capacity for men and women**
 - Men 4-5litres women 3-4litres
- 5. Compute V_E for an individual with a tidal volume of 0.6 L and a breathing rate of 15 breaths per minute.**
 - $9.0 \text{ L}\cdot\text{min}^{-1} = 15 \times 0.6 \text{ L}$

2.1.5 Describe the significance of carbon dioxide in the control of pulmonary ventilation

1. List 2 ways oxygen transports in blood.
2. Name 3 factors that regulate pulmonary ventilation
 - Lung and muscle stretch receptors
 - Chemoreceptors in the aorta, brain and neck
3. Why do some swimmers hyperventilate on the starting blocks?
4. Use Ficks law to explain the efficiency of the alveoli

$$\text{Rate of diffusion} \propto \frac{\text{Area of diffusion surface} \times \text{Difference in concentration}}{\text{Thickness of surface over which diffusion takes place}}$$

1. Explain how training improves the efficiency of the respiratory system

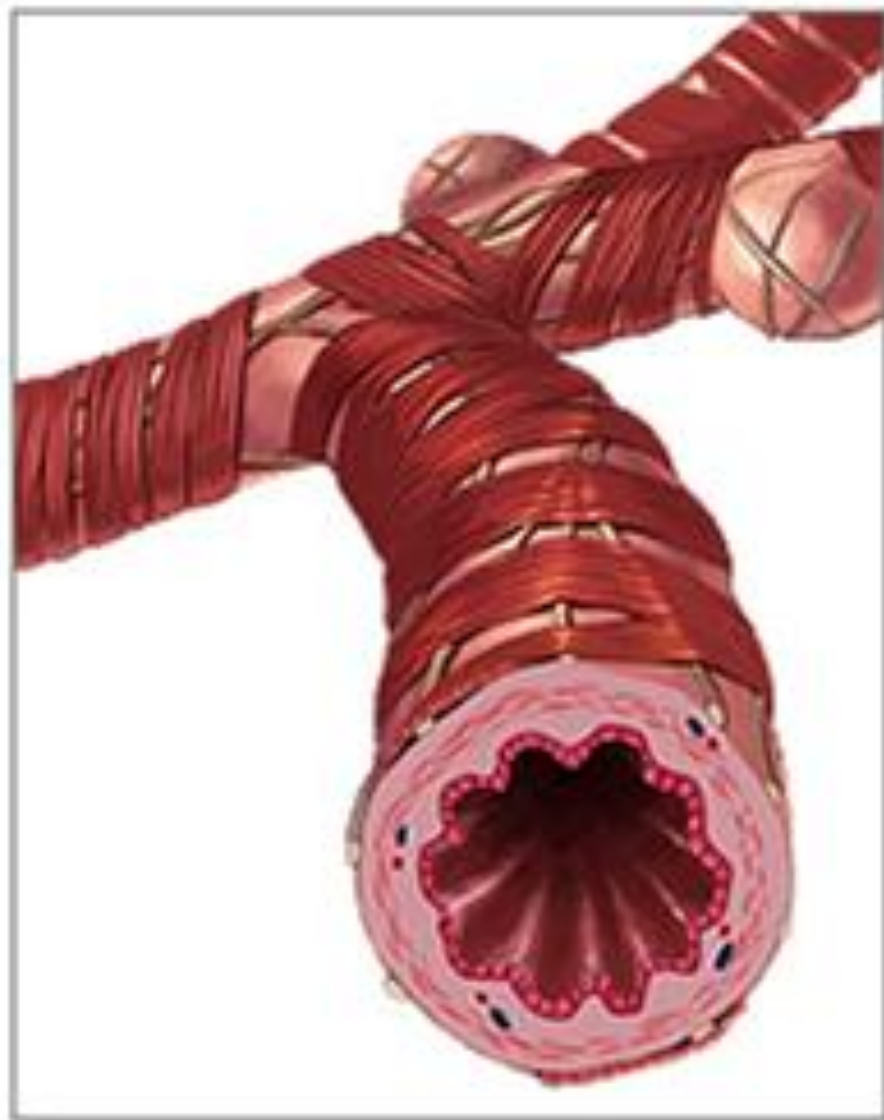
Normal bronchi



Bronchitis



Normal bronchiole



Asthmatic bronchiole





Alveoli with emphysema

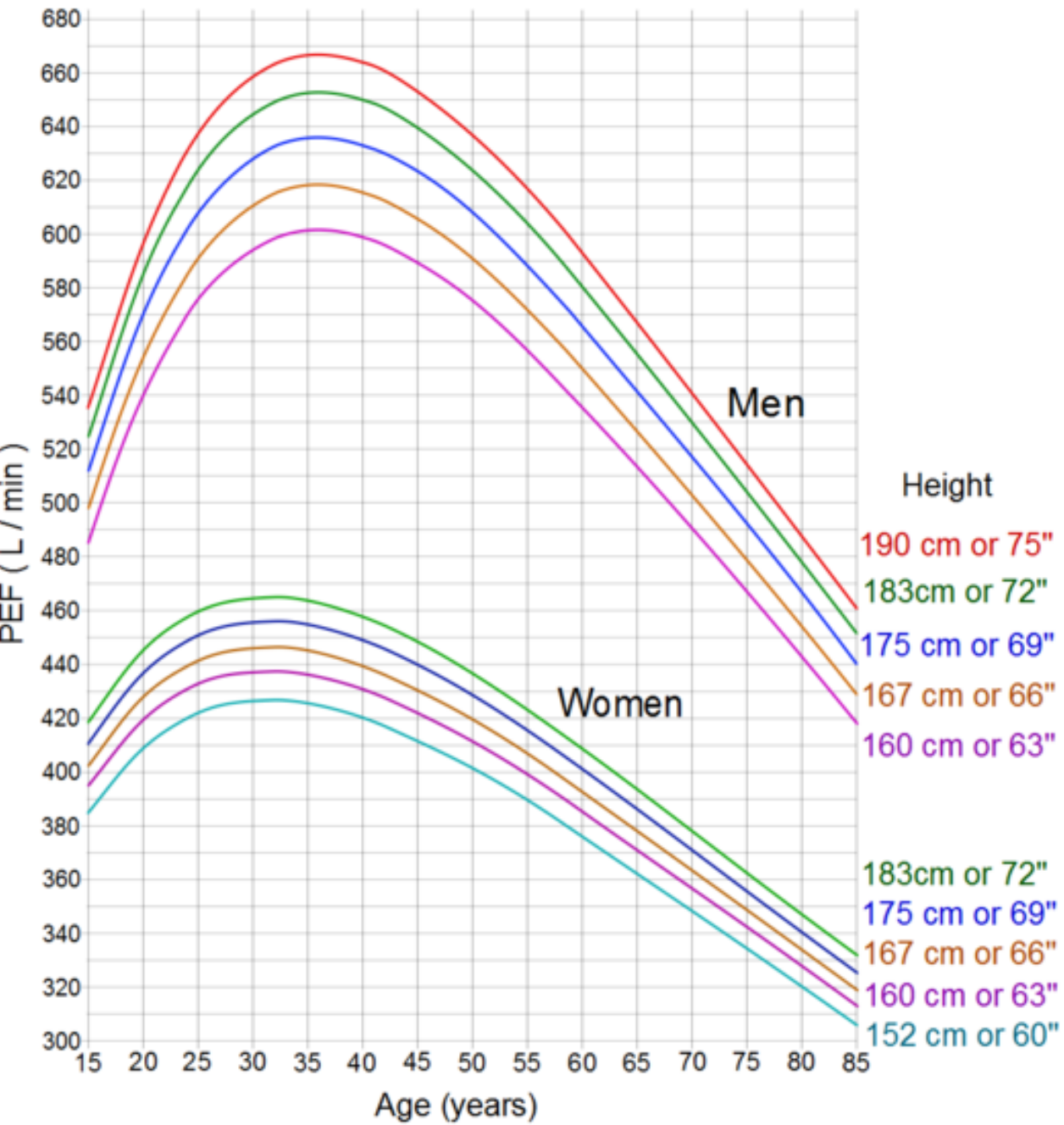


Microscopic view of normal alveoli



Normal values for peak expiratory flow (PEF)

EN 13826 or EU scale



Holding breath activities (ethics be careful)