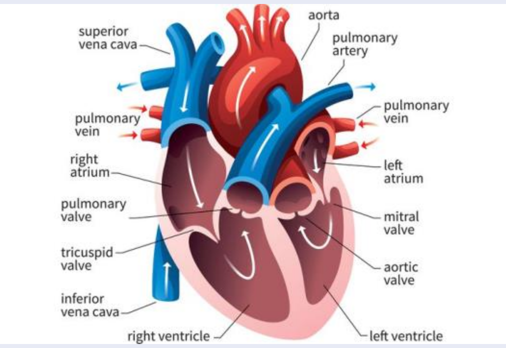
Applied Anatomy & Physiology
-Cardiovascular & Respiratory Systems

The Structure of the Heart

Left	Right
The left side of the cardiac muscle has a thicker muscular wall which can contract with more force to circulate oxygenated blood from the lungs through the large systemic circuit to the muscles and organs	The right side of the cardiac muscle contracts to circulate deoxygenated blood from the body through the pulmonary circuit to the lungs



Cardiac Cycle

The cardiac muscle is myogenic

- **Myogenic** – The capacity of the heart to generate its own electrical impulse, which causes the cardiac muscle to contract

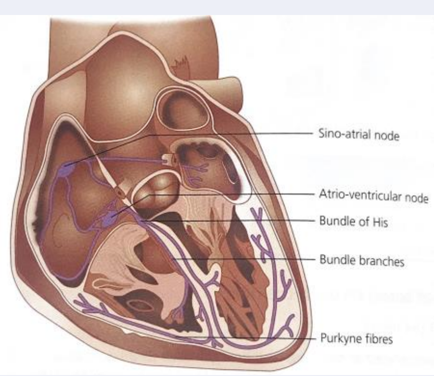
The cardiac cycle refers to the process of cardiac muscle contraction and the movement of blood through its chambers. One complete cardiac cycle represents the sequence of events involved in. Single heartbeat. It is referred to as a cycle as it never stops or tires. At rest, one complete cycle takes approximately 0.8 seconds and has two distinct phases;

- **Diastole** – The relaxation phase of the cardiac muscle where the chambers fill with blood
- **Systole** – The contraction phase of cardiac muscle where the blood is forcibly ejected into the aorta and pulmonary artery

3 Main Vessels

Arteries & Arterioles	Capillaries	Veins & Venules
• Arteries and arterioles carry oxygenated blood away from the heart to the muscles and organs • The main artery is the aorta which carries blood at high pressure directly from the left ventricle • Structure - Larger layer of smooth muscle and elastic tissue to cushion and smooth the pulsating blood flow • The smooth muscle walls also allow them to vasoconstric and vasodilate • Arterioles have a ring of smooth muscle surrounding the entry of a capillary bed called pre-capillary sprinters. These dilate and constrict to control blood flow into the capillaries	• Capillaries bring the blood slowly into close contact with the muscle and organ cells for gaseous exchange • Structure - Capillary walls are 1 cell thick which is thin enough to allow gas, nutrients and waste exchange	• Veins and venules transport deoxygenated blood from the muscles and organs back to the heart • The venules leaving the capillaries reconnect to form veins. The main vein is the vein cava and carries slow moving blood at low pressure back to the right atria • Structure – Thin layer of smooth muscle allowing them to venoconstrict and venodilate to maintain the slow flow of blood towards the heart • Veins have one-way pocket valves which prevent the back flow of blood

- **Once the electrical impulses' journey is complete, the atria and ventricles relax and the heart re-fills with blood. This process signifies one heartbeat.**



The Conduction System

1	Sing-atrial node, located in the right atrial wall, generates the electrical impulse and fires it through the atria walls, causing them to contract.
2	Atrio-ventricular node collects the impulse and delays it for approximately 0.1 seconds to allow the atria to finish contracting. It then releases the impulse to the Bundle of His.
3	Bundle of His, located in the septum of the heart splits the impulse in two ready to be distributed through each separate ventricle
4	Bundle branches carry the impulse to the base of each ventricle
5	Purkyne eyes fibres distribute the impulse through the ventricle walls, causing them to contract

Heart Rate Regulation

The heart is myogenic, the brain controls increasing and decreasing heart rate. The CCC receives information from the sensory nerves which causes the change in HR.

Cardiac Control Centre (CCC)

A control centre in the medulla oblongata responsible for HR regulation

Cardiovascular System

The cardiovascular system refers to the heart (cardiac muscle), blood vessels and the blood they contain. They form a closed system transporting oxygen, nutrients and hormones to every corner of the body and removing waste products as they are produced. The more efficient the cardiovascular system, the greater the capacity to transport oxygen to the muscles and removes waste products

Cardiovascular System	Pulmonary Circuit	Systemic Circuit
The heart, blood vessels and the blood	Carries deoxygenated blood to the lungs and oxygenated blood back to the heart	Carries oxygenated blood to the body and deoxygenated blood back to the heart

Cardiac Output (L/min)
= Heart Rate x Stroke Volume

Cardiac Cycle

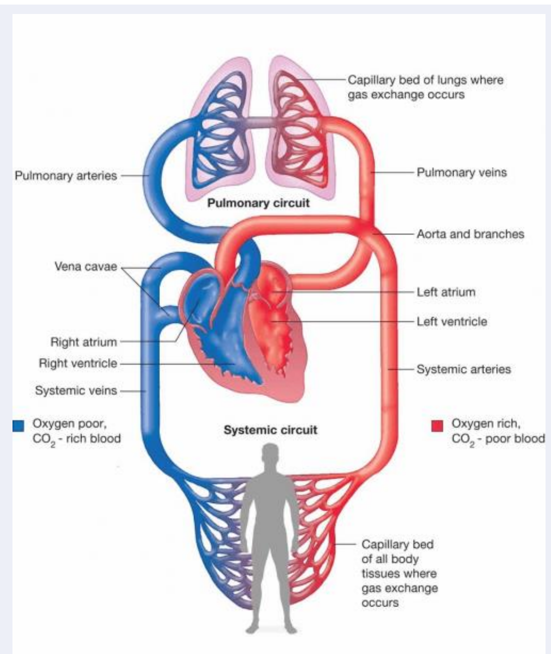
Diastole	Atrial Systole	Ventricular Systole
As the atria and then ventricles relax, they expand drawing blood into the atria The pressure in the atria increases opening AV valves Blood passively enters the ventricles SL valves are closed to prevent blood from leaving the heart	The atria contract, forcing remaining blood into the ventricles	The ventricles contract, increasing the pressure closing the AV valves to prevent back flow into the atria SL valves are forced open as blood is ejected from the ventricles into the aorta and pulmonary artery

Cardiovascular System - Pulmonary

Functions:

- **Transport nutrients such as oxygen and glucose**
- **Protects and fights disease**
- **Maintains the internal stability of the body (homeostasis) and regular temperature**

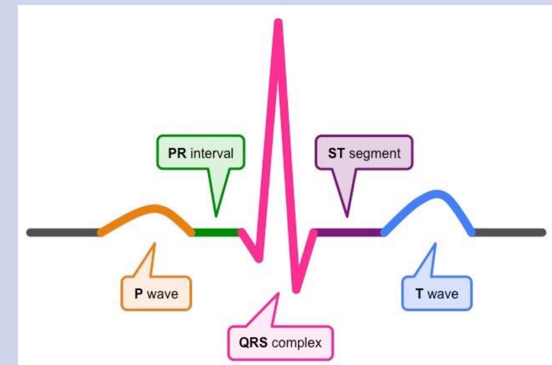
The Heart, Pulmonary and Systemic Circuit



Key Words

- **Diastole** – Relaxation of the atria then ventricles
- **Systole** – Contraction of the atria then ventricles
- **Depolarisation** – The change in electrical charge/decrease (negative)
- **Repolarisation** – The increase in our hearts electrical charge (positive)

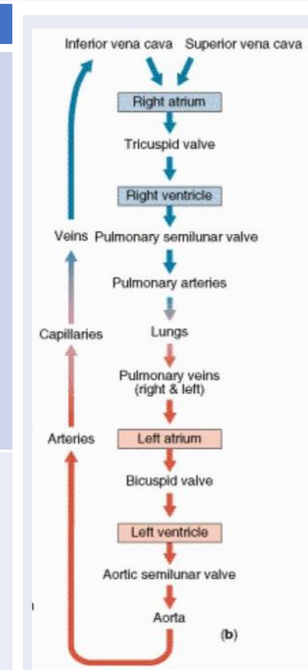
Electrocardiogram (ECG or EKG)



- An electrocardiogram (ECG or EKG) records the electrical signal from your heart to check for different heart conditions.
- **P Wave-** Depolarisation of atria in response to SA node triggering
- **T Wave-** Ventricular repolarisation
- **PR Interval-** Delay of AV node to allow filling of ventricles
- **QRS Complex-** Depolarisation of ventricles, triggers main pumping contractions
- **ST Segment-** Beginning of ventricle repolarisation, should be flat

Path of Blood Through the Heart

Left Side	Right Side
Blood is oxygenated at the lungs and brought back to the left atria through the pulmonary vein. Oxygenated blood moved from the left atria, through the left av valve (bicuspid) into the left ventricle to be forced out of the left side of the heart into the aorta. The aorta carries this oxygenated blood to the muscles and organs.	Deoxygenated blood from the muscles and organs arrives, back at the right atria through the vena cava. It moves from the right atria, through the right AV valve (tricuspid) into the right ventricle to be forced out of the right side of the heart not the pulmonary artery. The pulmonary artery carries the deoxygenated blood to the lungs.

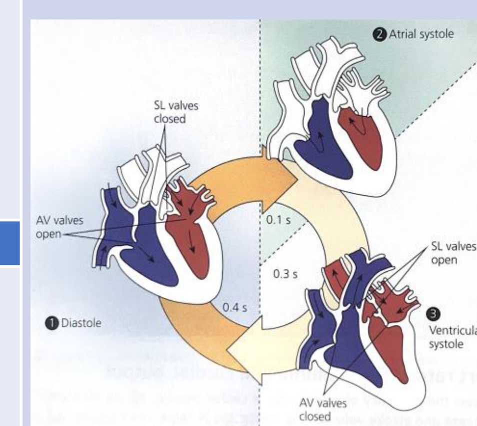


Conduction	This Causes...	Event	Effect
• No electrical impulse	• Diastole	• Cardiac muscle relaxes	• SL valve close, atria fill with blood opening the AV valves
• SA node fires an electrical impulse through the atria walls to the AV node. Av node delays the impulse	• Atrial systole	• Atrial muscle contraction	• AV valves are forced open and the blood is pushed into the ventricles until the atria finish contracting
• Bundle of his splits and passes the impulse through 2 branches to the purkyne fibres in both ventricle walls	• Ventricular systole	• Ventricular muscle contracts	• AV valves close and blood is pushed into the arteries, forcing SL valves open until the ventricles finish contracting

Atria Diastole	Ventricular Diastole
- The upper chamber of the heart are filled with blood - The body via the vena cava to the right atrium - The lungs via the pulmonary artery	- High pressure forces the atrioventricular valves open and ventricular diastole now takes place

Atrial Systole	Ventricular Systole
- The atrial contraction ensures that all the blood is ejected into the ventricles	- Ultimately the ventricular pressure overcomes that in the aorta and the pulmonary artery

The Stages of the Cardiac Cycle



Stroke Volume

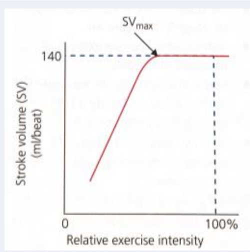
The volume of blood ejected from the left ventricle per beat (resting SV, approximately 70ml)

Stroke volume increases in proportion to exercise intensity until a plateau is reached at approximately 40-60% of working capacity (sub-maximal exercise)
SV plateaus because there is not enough time for the ventricles to completely fill with blood during the diastolic phase

Stroke volume is dependant on 2 factors;
- Venous return
- Ventricular elasticity and contractility

Stroke volume is able to increase due to the following
- Increased venous return, during exercise venous return increase, meaning there is a greater volume of blood returning to the heart and filling the ventricles. This is sue to the squeezing action of muscular contraction around the veins known as the muscle pump.
- The Frank-Starling mechanism increased venous return which ends to an increased SV, due to an increased stretch on the ventricle walls, and therefore the force of contraction. The lower the heart rate, the more time available to maximise this effect, hence why we see greater exercising Stroke Volume in trained athletes

Stroke volume reaches a plateau during sub-maximal intensity due to
- increased heart rate towards maximal intensities does not allow enough time for the ventricles to completely fill with blood in the diastolic phase, this limits the Frank-starling mechanism.



Stroke volume response to increasing exercise intensity

Frank-Starling Mechanism

Increased venous return leads to an increased stroke volume, due to an increased stretch of the ventricle walls and therefore force of contraction

Autonomic Nervous System

Involuntarily regulates heart rate and controls the firing of the SA node

Sympathetic Nervous System	Parasympathetic Nervous System
• Part of the autonomic nervous system responsible for increasing heart rate, specifically during exercise	• Part of the autonomic nervous system responsible for decreasing heart rest, specifically during recovery
Vasodialate	**Vasoconstrict**
Widening of the arteries, arteriolar and pre-capillary sphincters	Narrowing of arteries, arteriolar and pre-capillary sphincters
Blood Pooling	**Active Recovery**
Accumulation of blood in the veins due to gravitational pull and lack of venous return	Low intensity activity post exercise to maintain elevated heart and breathing rate

Venous Return

The return of the blood to the right atria through the veins

This is the volume of blood returning to the heart, the greater the return of blood to the heart the greater the volume of blood available in the ventricles for ejecting

Venous return is overcome in a number of ways
- Muscle Pump (contraction of veins)
- Inspiration / Expiration – Respiratory Pump
- Pocket Valves
- Smooth Muscle
- Gravity

- The heart can only pump out as much blood as it receives, so cardiac output is dependent on venous return. A rapid increase in venous return enables a significant increase in stroke volume and therefore cardiac output

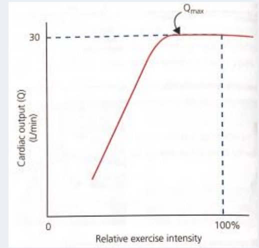
Muscle Pump

The muscles surrounding the veins expand and contract, pressing on veins ad causing a pumping effect. This muscle action is particularly important in maintaining venous return during exercise

Cardiac Output

The product of HR and SV and therefore its response to exercise is a combination of the two

This increases in line with exercise intensity and plateaus during maximal exercise. In recovery, there is a rapid decrease followed by a slower decreases to resting levels



Cardiac output response to increasing exercise intensity

Cardiac Hypertrophy

The more efficient the cardiac muscle, the greater volume of blood can be ejected per beat, and therefore the heart rate and volume

Effects of exercise on the Cardiovascular System
- Increase in heart rate
- Increase in stroke volume
- Increase in cardiac output

	Heart Rate	Stroke Volume	Q
Untrained	70-72 bpm	70 ml	5 l/min
Athlete	50 bpm	100 ml	5 l/min
Untrained	**Rest**	**Sub-Maximal**	**Maximal**
HR	70-72 bpm	100-130 bpm	220-age
SV	70 ml	100-120 ml	100-120 ml
Q	5 l/min	10-15 l/min	20-30 l/min
Trained	**Rest**	**Sub-Maximal**	**Maximal**
HR	50 bpm	95-120 bpm	220-age
SV	100 ml	160–200 ml	160-200 ml
Q	5 l/min	15-20 l/min	30-40 l/min

Ventricular Elasticity and Contractility

This is the degree of street has in the cardiac muscle fibre

The greater the stretch the greater the force of contraction = increase SV. The ejection fraction is the % of blood ejected from the ventricle during VS.

With ventricular elasticity at rest 60% of blood is ejected, increasing to 85% during exercise

Recovery

Chemoreceptors increased O2 and decreased lactic acid, proprioceptors decreased motor activity, baroreceptors decrease vessel walls

Pocket Valves

The blood in the veins can only move towards the heart; it cannot fall back to where it came from. This is because at regular intervals there are semi lunar pocket valves situated in large veins. They prevent blood from flowing away from the heart.

Respiratory Pump

Muscles around the thoracic and abdominal regions cause changes in pressure. Change in pressure allows the veins in this region to compress, causing blood to be 'sucked' through them. During inspiration and expiration, a pressure difference between the thoracic and abdominal cavity is created, squeezing the blood back to the heart. As exercise increases respiratory rate, the respiratory pump is maximised

Smooth Muscle

The layers of smooth muscle in the vein wall vasoconstrict to create venom Otto tone which aids the movement of blood

Gravity

Blood from the upper body, above the heart is helped to return by gravity

Heart Rate Regulation

The control centre stimulates the sympathetic nerves located in the walls of the blood vessels. The sympathetic nerves cause the arteriolar and pre-capillary sphincters to vasoconstriction (narrow) and vasodilator)expand) decreasing blood flow to non essential areas and increasing blood flow to the working muscles

The CCC interprets the information received and will either increase or decrease the stimulation of the SA node. The sympathetic nervous system causes an increase in heart rate by releasing adrenaline and noradrenaline, sending stimulation to the SA node via the accelerator nerve. The parasympathetic nervous system reduces the heart rate by inhibiting these actions via the Vagus nerve.

There are 3 main sources that determine the action of the Cardiac Control Centre (CCC), these are known as control mechanism…

Neutral Control

- **Chemoreceptors** located in the muscles, aorta and carotid arteries inform the CCC of chemical changes in the blood stream, such as increased levels of CO2 and lactic acid
- **Proprioceptors** located in the muscles, tendons and joints, detect increases and deceases in blood pressure and send an impulse to the control centre located in the medulla oblongata
- **Baroreceptors** located in the blood vessel walls inform the CCC of increased blood pressure, detect increase in muscle movement, joint and tendon activity

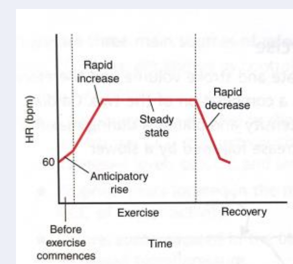
Intrinsic Control

- Temperature changes will affect the viscosity (thickness) of the blood and speed of nerve impulse transmissions
- Venous return changes will affect the stretch in the ventricle walls, force ventricular contraction and therefore stroke volume

Hormonal Control

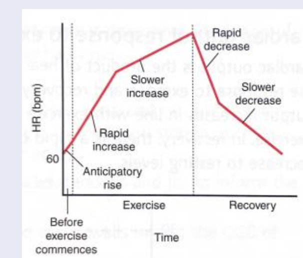
- Adrenaline and noradrenaline are released from the adrenal glands increasing the force of ventricular contraction and increasing the spread of electrical activity through the heart
- Increase heart rate
- Constrict some blood vessels causing blood to be redistributed to where it is needed
- Stimulate the breakdown of glycogen providing more fuel for the muscles

Sub-Maximal



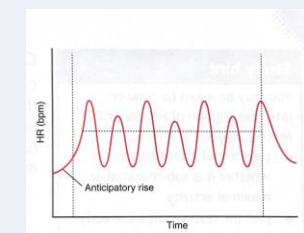
HR response to sub-maximal (aerobic) exercise
e.g running

Maximal



HR response to maximal (anaerobic) exercise
e.g rowing

Fluctuating



Heart rate response to fluctuating intensities of exercise
e.g netball

Sub-Maximal

Exercise is low to moderate intensity within the performers aerobic capacity to below the below the anaerobic threshold
e.g a slow 10K

During sustained sub-maximal intensity exercise, heart rate can plateau (level out) as we reach a comfortable, steady state. This plateau represents the supply meeting demand for oxygen delivery and waste removal.

During sub-maximal exercise we see…
- An initial anticipatory rise in heart rate prior to exercise due to the release of the hormone adrenaline
- A rapid increase in HR at the start of exercise to increase the blood flow and oxygen delivery in line with exercise intensity
- A steady state HR throughout the sustained intensity exercise as oxygen supply meets demand
- An initial rapid decrease in HR as recovery is entered and the action of the muscle pump reduces
- A more gradual decrease in HR to resting levels

Maximal

Exercise is at a high intensity above a performers aerobic capacity, which will take a performer to exhaustion
e.g 100m sprint

During maximal intensity exercise, heart rate does not plateau as exercise intensity continues to increase. There is a growing demand for oxygen and waste removal which HR must continually strive to meet.

HR Regulation in Response to Exercise	HR Regulation in Response to Recovery
Neural Control Chemoreceptors; increased CO2 and lactic acid levels Proprioceptors; increased motor activity Baroreceptors; increased stretch on vessel walls **Intrinsic Control** Increased temperature & venous return **Hormonal Control** Sympathetic release of adrenaline and noradrenaline	**Neural Control** Chemoreceptors; increased O2 and decreased lactic acid Proprioceptors; decreased motor activity Baroreceptors; decreased stretch on vessel walls **Intrinsic Control** Decreased temperature & venous return **Hormonal Control** Parasympathetic inhibition of adrenaline and noradrenaline
CCC in medulla oblongata	CCC in medulla oblongata
Sympathetic nervous system increases stimulation of the SA node via the accelerator nerve to increase HR. Greater force of ventricular contraction increases SV. HR X SV = CO increased	Parasympathetic nervous system decreases stimulation of the SA node via the vagus nerve to decrease HR. Reduced force of ventricular contraction reduces SV slowly. HR X SV = CO decrease

Redistribution of Cardiac Output

Cardiac output at rest is approximately 5 l/min. This can rise to more than 20 l/min during intense exercise. The difference in cardiac output from rest to exercise is not only in volume; where the blood is sent to also changes dramatically

At rest, our body primarily serves to digest, filter and excrete. Therefore, the vast majority of the oxygen and nutrient-rich blood is required around the organs

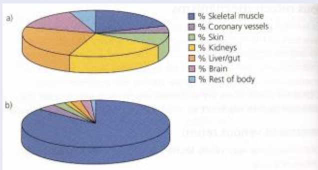


Figure 1.2.17 Distribution of cardiac output: a) at rest, and b) during exercise

Changes in Blood Flow from Rest to Maximal Exercise

Organ	At Rest (cm^3)	% Blood Flow	Maximum Effort (cm^3)	% Blood Flow
Skeletal Muscle	1000	20	26000	88
Coronary Vessels	250	5	1200	4
Skin	500	10	750	2.5
Kidneys	1000	20	300	1
Liver/Gut	1250	25	375	1.25
Brain	750	15	750	2.5
Whole Body	5000	100	30000	100

Vascular Shunt Mechanism

The redistribution of cardiac output around the body from rest to exercise which increases the percentage of blood flow to the skeletal muscles

Arterioles

Blood vessels carry oxygenated blood from the arteries to the capillary beds, which can vasodialate and vasoconstrict to regulate blood flow

Arterioles lead to capillary beds, which serve to bring the blood in close contact with organ and muscle cells. These capillaries are the site for oxygen and nutrient exchange with CO2 and waste products

Blood flow into the capillary beds is controlled by pre- capillary sphincters at the entrance to the capillary bed;
- They can constrict, which limits blood flow through the capillary bed
they can dilate, which maximises blood flow into the capillary bed

Pre-Capillary Sphincters

Rings of smooth muscle at the junction between arterioles and capillaries, which can dilate or constrict control blood flow through the capillary bed

At rest, a high percentage of cardiac output is distributed to the organs, whereas a very low percentage is distributed to the muscles
This happens because…
- **Arterioles** to the organs vasodilate, increasing blood flow, while arterioles to the muscles vasoconstrict to limit blood flow
- **Pre-Capillary Sphincters** dilate, opening up the capillary beds to allow more blood flow to the organ cells, while constricting, closing the capillary beds to the muscle cells

During exercise roles reverse. Arterioles and pre-capillary sphincters serving the capillary beds surrounding the muscle cells dilate, maximising blood flow, nutrient and gaseous exchange, whole constricting to the organs

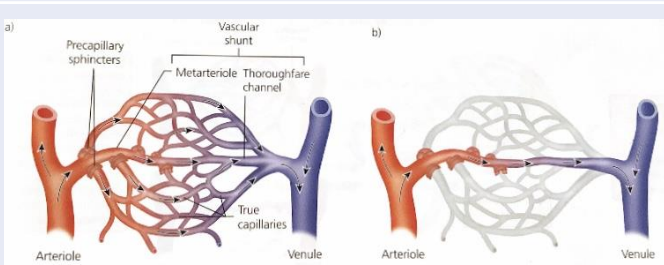


Figure 1.2.18 A capillary bed serving the organs: a) at rest, where the pre-capillary sphincters are open and blood flows through capillaries, and b) during exercise, where the pre-capillary sphincters are closed and blood flow bypasses the capillary bed

Vasomotor Control

The control centre in the medulla oblongata responsible for cardiac output distribution

The smooth muscle in the walls of arterial blood vessels is always in a slight state of constriction, known as vasomotor tone. However, when sensory information is received, the VCC alters the level of stimulation sent to the articles and pre-capillary sphincters at different sites in the body

Vasomotor Tone

The partial state of smooth muscle constriction in the arterial walls

The VCC receives information from…
- Chemoreceptors regarding chemical changes such as CO2 and lactic acid rising during exercise
- Baroreceptors regarding pressure changes on the arterial walls

In receipt of sensory information, sympathetic stimulation will be wither increased or decreased to alter the level of vasoconstriction of the arterioles and pre-capillary sphincters
- Sympathetic stimulation increases to vasoconstrict arterioles and pre-capillary sphincters to limit blood flow to an area such as the muscles at rest
- Sympathetic stimulation decreases to vasodilate arterioles and pre-capillary sphincters to increase blood flow to an area, such as the muscles during exercise

The Respiratory System

Consists of the nose, a series of airways, lungs and respiratory muscles that work together as the mechanism for breathing and gaseous exchange

The Respiratory System has 2 main functions;

Pulmonary Ventilation	Gaseous Exchange
• The inspiration (breathing in) and expiration (breathing out) of air	A) External respiration; the movement of oxygen into the blood stream and carbon dioxide into the lungs B) Internal respiration; the release of oxygen to respiring cells for energy production and collection of waste products

The cardiovascular system provides the link between these 2 processes by transporting the deoxygenated blood to the lungs to become re-oxygenated

Response by the respiratory and cardiovascular system do not work in isolation. The demands of exercise cause changes in both systems and one cannot work without the other

An increase in breathing rate means more oxygen is inhaled and can only benefit the body if heart rate increases too to pump to working muscles

Oxygen (O_2)

Oxygen is transported by the blood either…

- Combines with haemoglobin (Hb) in the red blood cells (>97%)
- Dissolved in the blood plasma (<3%)

Blood consists of 45% cells and 55% plasma

Oxygen is the essential gas required for aerobic energy production in muscle cells

The greater efficiency of inspiration, transport and use of O_2 the greater our aerobic capacity

The ability of haemoglobin to bind to O_2 is influenced by the partial pressure of oxygen

Carbon Dioxide (CO_2)

Carbon Dioxide (CO_2) – The waste product of aerobic energy production in muscle cells

CO_2 can be transported in 3 ways…

- Dissolved in water and carried as carbonic acid (70%)
- Carried in haemoglobin – Hb + CO_2 = $HbCO_2$ (23%) (cardaminohaemoglobin)
- Dissolved in blood plasma (7%)

Oxygen is the essential gas required for aerobic energy production in muscle cells

The greater efficiency of inspiration, transport and use of O_2 the greater our aerobic capacity

Haemoglobin

An iron rich globular protein in red blood cells which can chemically combine with 4 oxygen molecules to form oxyhaemoglobin

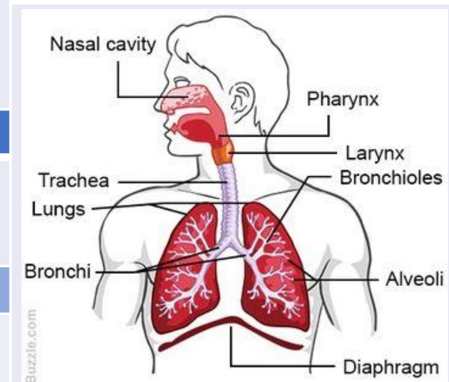
When 4 oxygens are bonded to haemoglobin, it is 100% saturated, with fewer oxygens it is partially saturated. Oxygen binding occurs in response to the high PO_2 in the lungs

Oxyhaemoglobin - When oxygen binds to haemoglobin

Deoxyhaemoglobin - Haemoglobin that is not bound to oxygen

Lung Volume	Definition	Average Value at Rest	Change During Exercise
Tidal Volume	Volume of air inspired or expired in one breath	500 ml	Increases
Inspiratory Reserve Volume	The amount of extra air inhaled above tidal volume during a forceful breath in	3000ml males 2100ml females	Decreases
Expiratory Reserve Volume	The extra volume of air that can be expired from the lungs	1900 – 3300 ml	Small Decrease
Residual Volume	The volume of air remaining in the lungs after maximum forceful expiration	1– 1.2 l	Stays the same
Minute Ventilation (VE = TV x f)	The volume of air inspired or expired per minute	6 – 7.5 l/min	Increases to 35 – 40 breaths per minute

The Respiratory System



Definition

The network of organs and tissues that help you breathe
Consisting of the lungs, blood vessels and your airways

Mechanics of Breathing

	Muscles	Movement of the Ribs and Sternum	Volume of the Thoracic Cavity	Pressure in the Lung Tissue
Inspiration (Rest)	External intercostals, diaphragm contract	Up and out	Increases	Decreases
Inspiration (Exercise)	External intercostals, diaphragm, sternocleidomastoid, pectoralis minor contract	Up and out further	Increases more than at rest	Decreases more than at rest
Expiration (Rest)	External intercostals, diaphragm relax	Down and in	Decreases	Increases
Expiration (Exercise)	Internal intercostals, Rectus abdominis	Down and further in	Decreases	Increases

Four steps for learning the mechanics of breathing…

1 – Muscles create movement
2 – Which changes the volume
3 – Which changes the pressure (MMVP)

All gasses move from an area of high pressure to an area of low pressure

Inspiration and expiration at rest is referred to as a 'quiet' process and is hard to see visually. As taught in CPR first aid, it is often easier to feel whether someone is breathing by placing the cheek above the nose and mouth of a casualty rather than watching for the rise and fall of the chest.

The muscles involved in the mechanics of breathing:

- **Inspiration**
  - Rest: external intercostals and diaphragm (contract)
  - Exercise: in addition, sternocleidomastoid and pectoralis minor (contract).
- **Expiration**
  - Rest: external intercostals and diaphragm (relax)
  - Exercise: in addition, internal intercostals and rectus abdominis(contract).

Mechanics of Inspiration at Rest

Inspiration is an active process. There are two muscles largely responsible for inspiration at rest, which contract to increase the volume of the thoracic cavity…
1 - The external intercostals, which lie between each rib, contract lifting the rib cage and sternum up and out
2 - The diaphragm, which lies underneath the lungs and separates the thoracic and abdominal cavity, contracts and flattens.

As the external intercostals and diaphragm contract, the volume inside the thoracic cavity and space inside the lungs increases. This lowers the pressure below the atmosphere outside the body. All gases move from an area of high to low pressure, so air rushes into the lungs. One inspiration is complete.

Mechanics of Expiration at Rest

Expiration at rest is a passive process. The two muscles responsible for inspiration at rest relax into their natural state, which decreases the volume of the thoracic cavity…
1 - The external intercostals relax, lowering the rib cage and sternum down and in
2 - The diaphragm relaxes and returns to its dome shape

As the external intercostals and diaphragm relax, the volume inside the thoracic cavity and space inside the lungs decrease. This increases the pressure above the atmosphere outside the body; therefore, air is pushed out of the lungs. One resting expiration is complete.

Mechanics of Inspiration During Exercise

As we start to exercise, the demand for oxygen and production of CO2 increases and so does minute ventilation. Tidal volume can rise from approximately 0.5 litres to 3 litres.

In addition to the external intercostals and diaphragm, additional inspiratory muscles can be recruited to give a larger force of contraction…
1 - Sternocleidomastoid
2 - Pectoralis minor

This creates a greater up and outward movement of the rib cage and sternum. The greater movement increases the volume and decreases the pressure inside the thoracic cavity more than at rest. This increases the depth of breathing and therefore the volume of air inspired.

Mechanics of Expiration During Exercise

When exercise begins, expiration becomes an active process. The natural relaxation of the external intercostals and diaphragm does not provide enough force to expire quickly enough for breathing rate to increase.

Additional expiratory muscles can be recruited to give a larger force of contraction…
1 - Internal intercostals
2 - Rectus abdominis

This creates a greater down and inward movement of the rib cage and sternum. The greater movement decreases the volume and increases the pressure inside the thoracic cavity more than at rest. This increases the rate of breathing and therefore the overall volume of air expired per minute.

Ventilation

How is ventilation controlled?

- The nervous system can increase or decrease the rate, depth and rhythm of breathing
- The respiratory control centre located in the medulla oblongata of the brain controls breathing
- An increased concentration of carbon dioxide in the blood stimulates the respiratory centre to increase respiratory rate

Respiratory Control Centre

- The inspiratory centre sends out impulses via the phrenic nerve to the inspiratory muscles
- The expiration centre stimulates the expiration muscles during exercise, when stretch receptors detect changes in the rate and depth of breathing

Control of Ventilation

During exercise, conditions in the body change, these changes are detected by…

- **Chemoreceptors** – Which detect changes in pH-blood acidity
- **Baroreceptors** – Which detect an increase in blood pressure
- **Proprioceptors** – Which detect movement in muscles and joints

Respiratory Regulation

Breathing rate and depth is continually adjusted to maintain the appropriate levels of oxygen and CO2 in the blood stream while expending as little respiratory energy as possible

Respiratory Regulation at Rest

- The IC is responsible for the rhythmic cycle of breathing
- Nerve impulses are generated and stimulate the inspiratory muscles causing them to contract, via the…

- Intercostal nerve to the external intercostals
- Phrenic nerve to the diaphragm

- This causes the thoracic cavity volume to be increased, lowering the lung air pressure
- The expiratory centre is inactive at rest due to the natural relaxation of the diaphragm and external intercostals

Respiratory Regulation During Exercise

Sensory nerves relay information to the RCC where a response is initiated by both the IC and EC…

- **Chemoreceptors** - Located in the aorta and carotid arteries pick up an increase in blood acidity, increase in CO2 concentration and decrease in O2 concentration.
- **Thermoreceptors** - Inform of an increased blood temperature
- **Proprioceptors** – Inform of motor activity in the muscles and joints
- **Baroreceptors** - Located in the lung tissue and bronchioles, inform of the state of lung inflation

- Chemoreceptors, thermoreceptors and proprioceptors inform the IC, which increases the stimulation of the diaphragm and external intercostals to contract with more force
- The IC also recruits the additional inspiratory muscles, sternocleidomastoid and pectoralis minor, to contract. This greater force of contraction increases the depth of inspiration.
- Baroreceptors inform the EC on the extent of lung inflation. If the lung tissue begins to become excessively stretched, the EC stimulates additional expiratory muscles, internal intercostals and rectus abdominis, to contract. This causes a forced expiration which reduces the time available for inspiration
- As exercise intensity increases, the combination of IC and EC control leads to an increased breathing rate and decreased breathing depth to maximise efficient respiration.

Key Words

- **Respiratory control centre (RCC):** A control centre in the medulla oblongata responsible for respiratory regulation
- **Inspiratory centre (IC):** A control centre within the RCC responsible for inspiration
- **Expiratory centre (EC):** A control centre within the RCC responsible for expiration

Partial Pressure and Diffusion

- **Partial Pressure –** The pressure exerted by an individual gas held in a mixture of gasses

Partial pressure of oxygen in the alveoli is higher than the partial pressure of oxygen in the blood
Alveoli PO_2 = 100mmHg
Blood PO_2= 40mmHg
This is because oxygen has been removed by the working muscles, so the concentration of oxygen in the blood is lower, therefore partial pressure is lower

- **Diffusion** – Where gasses move from an area with a higher partial pressure to an area with a lower partial pressure until equilibrium is reached

- **Diffusion Gradient** – The difference between any two pressure =60mmHg
The bigger or steeper the diffusion gradient the quicker diffusion will occur

Gaseous Exchange

Internal Respiration

- O_2 diffuses from systemic capillaries into cells
- CO_2 diffuses from cells into systemic capillaries

This occurs because of the following factors…

- Available surface area, which varies in different tissues
- Partial pressure gradient
- Rate of blood flow varies

External Respiration

- CO_2 diffuses from pulmonary capillaries into alveoli
- O_2 diffuses from alveoli into pulmonary capillaries

This occurs because of the following factors…

- The partial pressure of gasses in the alveoli differ from those in the atmosphere
- Humidification of inhaled air
- Gas exchange between alveoli and pulmonary capillaries

Factors influencing External Respiration…

- Surface area and structure of the respiratory membrane
- Partial pressure gradient
- Matching levels airflow to pulmonary capillary blood flow

Gaseous Exchange at the Alveoli

- **Alveoli –** Tiny air sacs in the lungs that take up the oxygen you breathe in and keep your body going

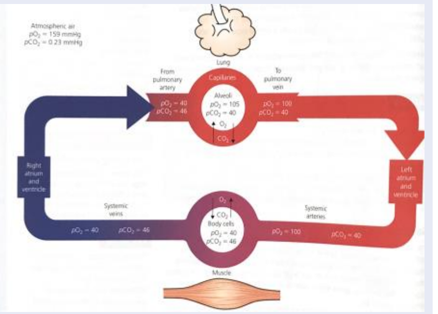
A dense capillary network supplies them with oxygen. Their walls are extremely thin (one cell thick) and together they create a huge surface area to allow for. Greater uptake of oxygen. Gasses can easily pass through the thin walls and travel into the blood stream. With training this process of gaseous exchange becomes more efficient and therefore improves performance.

- Gaseous exchange is promoted through a number of bodily functions…

- Capillaries very near to alveoli, so diffusion distance is very short
- Large surface area of alveoli allows diffusion to take place
- Vast network of capillaries surrounded alveoli which increases surface area further

- Gaseous exchange takes place at…

Lungs – Between alveoli and surrounding alveolar capillaries
Muscles – Between muscles and surrounding blood capillaries



Diffusion at the Muscles

High PO_2 in the capillary
Low PO_2 in the muscle
High PCO_2 in the muscle
Low PCO_2 in the capillary

Gases move from a high partial pressure to a low partial pressure across a diffusion gradient

Factors affecting diffusion

- Thin membrane - Alveoli and capillaries have thin walls so aids diffusion
- Short diffusion distance – Distance between the levels and the capillary
- Large surface area – Many alveoli
- Warm and damp conditions in the lungs this is an environment gasses like
- Maintaining diffusion gradient

Resting Partial Pressure of O_2 and CO_2 at the external site

	Alveoli	Direction of Diffusion	Blood Capillaries
PO_2	105	—>	40
PCO_2	40	<—	46

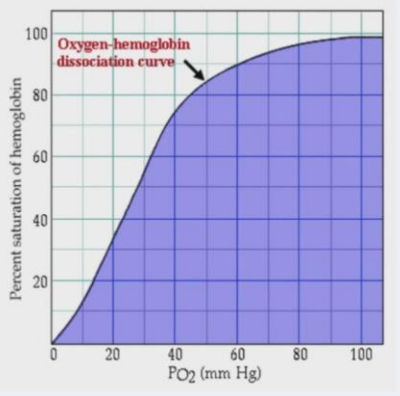
Resting Partial Pressure of O_2 and CO_2 at the internal site

	Muscle Cell	Direction of Diffusion	Blood Capillaries
PO_2	105	<—	100
PCO_2	40	—>	40

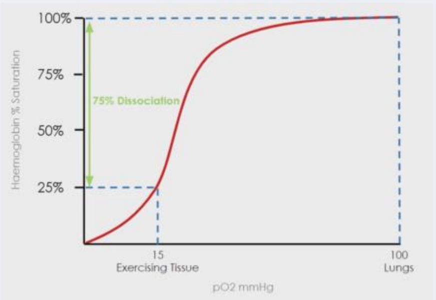
Resting and Exercising Partial Pressure of O_2 and CO_2 at the Internal site

	Muscle Cell	Direction and Gradient of Diffusion	Blood Capillaries
PO_2 Rest	40	<— 60	100
PO_2 Exercise	5	<— 95	100
PCO_2 Rest	46	—> 6	40
PCO_2 Exercise	80	—> 40	40

- The binding of O_2 to haemoglobin depends on the PO_2 in the Blood and the bonding strength, or affinity between haemoglobin and oxygen



- If PO_2 is low haemoglobin will release oxygen. Partial pressure is low at the muscle sites. When the haemoglobin releases the oxygen it is said to dissociate with oxygen. Now the haemoglobin is no longer fully saturated with oxygen
- Once oxygen dissociates from haemoglobin in the muscles it is picked up and transported to the mitochondria by Myoglobin
- In the muscle oxygen is stored by myoglobin. This has a high affinity for oxygen and stores the oxygen until it can be transported from the capillaries to the mitochondrial



- During exercise PO_2 in muscle cells decrease
- At 15mmHg O_2 in the muscle cells, approximately 75% oxygen dissociates from haemoglobin

The Bohr Shift

- When exercising there is an increase in acidity. This is caused by the increase in carbon dioxide in the blood, which results in an increase in the concentration of hydrogen ions in the blood lowering the pH

- During exercise haemoglobin will dissociate approximately 15% more oxygen to the working muscle tissues

- This means that at any given PO_2 for exercising tissue the percentage saturation of oxyhaemoglobin is for lower. Therefore, dissociation of oxygen to the respiring tissues is greater

Dissociation of Oxygen from Haemoglobin

- If PO_2 is high Haemoglobin will readily combine with oxygen to form Oxyhemoglobin
- When the haemoglobin combines with the oxygen to form oxyhemoglobin the haemoglobin is said to be saturated with oxygen

- **Association** – The combining of oxygen with haemoglobin to form oxyhemoglobin
- **Dissociation** – the release of oxygen from haemoglobin for gaseous exchange

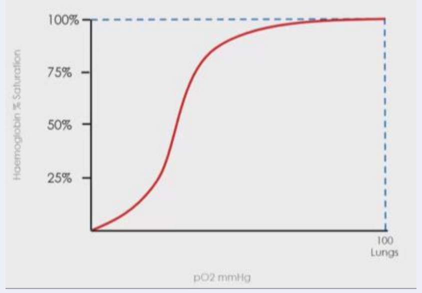
- **Mitochondria** - The sites in the muscles where aerobic respiration takes place

- There is a high PO_2 in the alveoli, therefore haemoglobin readily associates with oxygen to dome oxyhemoglobin

High PO_2 —> Haemoglobin associates with oxygen

- As PO_2 decreases in the respiring tissue, haemoglobin more readily dissociates with oxygen to release it for gaseous exchange

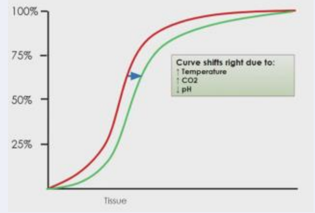
Low PO_2 —> Haemoglobin dissociates with oxygen



- At rest PO_2 in the resting muscle tissue approx 40mmHg
- Approx 25% of the oxygen has dissociated from the haemoglobin and is available for diffusion
- Approx 75% stays with the haemoglobin

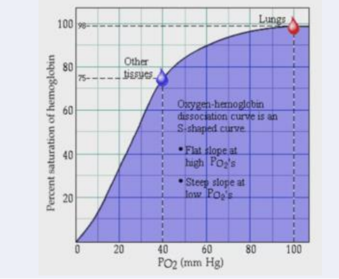
Summary

In the alveoli, PO_2 is high and oxygen readily diffuses into the capillary blood to associate with haemoglobin. The blood is fully associated with oxygen as it leaves the alveoli. In the muscles, PO_2 is low and oxygen dissociates from haemoglobin and diffuses into the muscle cell to produce energy for exercise. During exercise, a far greater volume of oxygen is released from the haemoglobin and diffuses into the muscles at a greater rate. This allows the muscles to produce energy, which means a performer can increase the duration and intensity of performance.



The Oxygen Dissociation Curve

- In the tissues of other organs a typical PO_2 is 40mmHg. Here haemoglobin has a lower affinity for O_2 and releases some but not all of its O_2 to the tissues
- When haemoglobin leaves the tissues it is still 75% saturated



Saturation is affected by…

- Decrease in blood acidity (pH)
- Increase in blood temperature
- Increase in partial pressure of Carbon dioxide concentration