PHY3171 Lecture Notes

Revision

The Cardiovascular System:

- Blood flows in a continuous loop through the cardiovascular system via a pressure gradient
- Systemic and pulmonary circulations are in series
- Pulmonary circulation
    - All blood goes to lungs
    - Right heart pump
    - Low pressure
- Systemic circulation
    - Blood is shared between different organs and tissues
    - Flow is parallel through all organs
    - Left heart pump
    - High pressure
- Total blood volume is approximately 7-8% of body weight
    - ~5L in a 70kg man
    - Approximately 80% of all blood is within the systemic circulation
    - Veins, venules and venous sinuses are a variable volume reservoir of blood

Flow of Fluid:

- Blood flow is defined as the volume of blood flowing through a vessel, organ or the circulation, per unit of time (mL/min)
    - Flows from high to low pressure
- Blood pressure is defined as the force per unit area exerted on the wall of a vessel by the blood (mmHg)
    - Contraction of the heart generates the pressure that drives the flow of blood through the blood vessels
- Resistance to flow (R) is the amount of friction blood encounters as it passes through the vessels

Flow = mean pressure / resistance

Cardiac output = heart rate x stroke volume

Mean arterial pressure = cardiac output x total peripheral resistance

Resistance to Flow:

- There are 3 factors determining the resistance to blood flow
    - Length of the tube – constant within the body
    - Radius of the tube – can and does change (vasodilation, vasoconstriction)
    - Viscosity of the fluid – relatively constant
- Resistance is directly proportional to the length of the tube – the longer the tube, the greater the resistance
- Resistance is inversely proportional to the radius of the tube – greater diameters equal less resistance
    - Small changes in diameter cause big changes to resistance due to the equation $R = 1/r^4$
    - Can be influenced by pathology (e.g. atherosclerosis, structural abnormalities) or factors affecting vasoconstriction/dilation (e.g. local chemical and physical factors, sympathetic nervous system, vasoactive hormones, endothelium-derived factors)
- Resistance is directly proportional to viscosity of the fluid – the greater the viscosity, the greater the resistance
    - Increased haematocrit = increased viscosity = increased resistance

The Heart:

- The heart contracts and relaxes in a rhythmic and coordinated fashion to achieve effective pumping of blood
- It is a closely integrated sequence of events termed the cardiac cycle
    - Systole – period of contraction
    - Diastole – period between contractions (relaxation)

- The heart's valves open passively and prevent backflow
    - Are always either open or shut depending on the pressure gradient across the valve
- Atrioventricular (AV) valves
    - Tricuspid – right atrium
    - Mitral – left atrium
- Semilunar valves
    - Pulmonary – right ventricle
    - Aortic – left ventricle

The Cardiac Cycle:

- Systole
    - Isovolumetric ventricular contraction
    - Ventricular ejection
- Diastole
    - Isovolumetric ventricular relaxation
    - Passive ventricular filling – atrial contraction
- Cardiac output is the volume of blood pumped by each ventricle per minute
    - Approximately 4.9L/min at rest (~70 bpm x ~70 mL/min)
    - Can increase 5-6-fold during strenuous exercise up to 25-30 L/min
    - Can be up to 35-45 L/min in highly trained athletes
    - Increases by ~50% during pregnancy
    - Any less than 3 L/min becomes life threatening

Stroke Volume:

- Stroke volume is the volume of blood pumped with each contraction (heartbeat)
- There are 3 major determinants
    - Preload – end-diastolic volume (degree of filling)
    - Contractility – force of contraction of individual ventricular muscle fibres
    - Afterload – pressure that must be exceeded before ejection of blood from ventricles can begin
- Preload is influenced by the duration of ventricular diastole (filling time) and venous pressure (passive filling)
    - Increased venous return automatically increases stroke volume
    - Increased filling of ventricles stretches cardiac muscle cells and therefore ventricles contract with greater force
    - Underlying basis is the length-tension relationship of cardiac muscle – Frank Starling Law of the heart
- Changes in contractility (and therefore contraction strength) are generally due to
    - Change in amount of calcium ions entering and being released in cardiac muscle cells
    - Change in affinity of the myofilaments for calcium ions
    - Change in the number of myofilaments available to participate in contraction
- Contractility can be influenced by
    - Certain drugs and hormones
    - Ionic changes in extracellular fluid
    - Increased sympathetic stimulation – NA and Adrenaline act on β-adrenoceptors on cardiac muscle cells to increase calcium ion entry into cell and evoke greater calcium ion release from sarcoplasmic reticulum
- Afterload is the pressure in the arterial system (aorta or pulmonary artery) that resists ventricular ejection
    - For ventricles to be able to eject blood, ventricular pressure must rise higher than the pressure in the respective arterial system
    - High arterial pressure (high afterload) can therefore reduce stroke volume

Ejection Fraction:

- The ejection fraction is an important indicator of cardiac health

    - Should be at least 55% in a healthy heart
- It is the stroke volume expressed as a fraction or percentage of the end-diastolic volume

Ejection fraction = stroke volume / end-diastolic volume

- Typical values at rest
    - EDV = 120 mL, ESV = 50 mL
    - SV = 120 – 50 = 70 mL
    - EF = 70 / 120 = 0.6 = 60%
- The ejection fraction increases when cardiac contractility increased
    - Can be as high as 90% in vigorous exercise

Heart Rate:

- Controlled by autonomic nervous system acting on pacemaker cells of the sinoatrial (SA) node
    - Decreased by parasympathetic stimulation ("rest and digest") – bradycardia
    - Increased by sympathetic stimulation ("fight or flight") and circulating adrenaline – tachycardia
- Other factors include potassium ion imbalance in extracellular fluid or high body temperature
    - These do not play a role in the normal control of heart rate
- Average values
    - ~70 bpm for normal resting heart rate
    - ~40 bpm in athletes
    - ~200 bpm upper limit
    - Lower limit = 220 – age

Arterial Blood Pressure:

- Rises and falls with cardiac cycle
- Pressure in large arteries essentially the same because of low resistance to flow
- Key definitions
    - Systolic pressure – highest pressure during one cycle
    - Diastolic pressure – lowest pressure during one cycle
    - Pulse pressure – systolic minus diastolic pressure
    - Mean arterial pressure – average pressure over one cycle (diastolic + 1/3 pulse pressure)
- Normal values
    - Systolic over diastolic pressure = 120 / 80 mmHg
    - MAP = ~93 mmHg

Week 1

Challenges to Cardiovascular Homeostasis

Changes in Total/Central Blood Volume:

- Reduced
    - Haemorrhage
    - Head-up tilt
    - Standing
    - Lower body negative pressure
- Increased
    - Blood or plasma transfusion
    - Head-out water immersion
    - Lower body positive pressure
- Changes in energy/organ flow requirements
    - Exercise
    - Diving
    - Alerting responses

Challenges to Cardiovascular Homeostasis: