Detoxification by the liver

The liver removes toxins from the blood and detoxifies them.

An important role of the liver is detoxification. Liver cells absorb toxic substances from the blood and convert them into non-toxic or less toxic substances, using a range of chemical conversions. For example, alcohol is converted into a less toxic substance by the enzyme ethanol dehydrogenase. The liver converts toxic ammonia into urea. The liver also works to detoxify biochemicals which are foreign to the organism's normal biochemistry such as poisons or drugs. One means by which the liver does this is to convert hydrophobic compounds into more easily excreted hydrophilic compounds.

D.4 The heart

Understanding

➔ Structure of cardiac muscle cells allows propagation of stimuli through the heart wall.
➔ Signals from the sinoatrial node that cause contraction cannot pass directly from atria to ventricles.
➔ There is a delay between the arrival and passing on of a stimulus at the atrioventricular node.
➔ This delay allows time for atrial systole before the atrioventricular valves close.
➔ Conducting fibres ensure coordinated contraction of the entire ventricle wall.
➔ Normal heart sounds are caused by the atrioventricular valves and semilunar valves closing causing changes in blood flow.

Applications

➔ Use of artificial pacemakers to regulate the heart rate.
➔ Use of defibrillation to treat life-threatening cardiac conditions.
➔ Causes and consequences of hypertension and thrombosis.

Skills

➔ Measurement and interpretation of the heart rate under different conditions.
➔ Interpretation of systolic and diastolic blood pressure measurements.
➔ Mapping of the cardiac cycle to a normal electrocardiogram (ECG) trace.
➔ Analysis of epidemiological data relating to the incidence of coronary heart disease.

Nature of science

➔ Developments in scientific research followed improvements in apparatus or instrumentation: the invention of the stethoscope led to improved knowledge of the workings of the heart.
Cardiac muscle cells

Structure of cardiac muscle cells allows propagation of stimuli through the heart wall.

Cardiac muscle tissue is unique to the heart. Like skeletal muscle, cardiac muscles are striated in appearance. The arrangement of the contractile proteins actin and myosin is similar to what is seen in skeletal muscle. However, cardiac muscle cells are shorter and wider than skeletal muscles and most commonly have just one nucleus per cell. Cardiac muscle contraction is not under voluntary control and many of the cardiac cells contract even in the absence of stimulation by nerves for the entire life of the organism. For these reasons, they have special structural features.

The cells are Y-shaped and are joined end to end in a complex network of interconnected cells. Where the end of one cell contacts the end of another cell, there is a specialized junction called an intercalated disc. This structure appears only in cardiac muscle. The intercalated disc consists of a double membrane containing gap junctions which provide channels of connected cytoplasm between the cells. This allows for the rapid movement of ions and a low electrical resistance. Being interconnected because of their Y-shapes and being electrically connected due to gap junctions allows a wave of depolarization to pass easily from one cell to a network of other cells leading to the synchronization of muscle contraction; that is, the network of cells contract as if it was one large cell.

Figure 1 shows a coloured transmission electron micrograph (TEM) of cardiac muscle fibrils (orange and blue). Mitochondria (red) supply the muscle cells with energy. The muscle fibrils, or myofibrils, are crossed by transverse tubules (narrow dark blue lines). These tubules mark the division of the myofibrils into contractile units (sarcomeres). In the centre is the intercalated disc (wavy dark blue line).

The sinoatrial node

Signals from the sinoatrial node that cause contraction cannot pass directly from atria to ventricles.

The cardiac cycle is a repeating sequence of actions in the heart which result in the pumping of blood to the lungs and all other parts of the body. The cycle represents all of the events from the beginning of one heartbeat to the beginning of the next. Cardiologists refer to contraction of the heart’s chambers as systole and relaxation as diastole. Figure 3 shows the sequence in which systole and diastole occur in the atria and ventricles. Figure 4 provides details of the events and pressure changes that occur in the stages in the cardiac cycle.

Within the wall of the right atrium, there is a collection of uniquely structured cardiac cells that spontaneously initiate action potentials without stimulation by other nerves. The initiation occurs rhythmically. This is the sinoatrial (or SA) node. The SA node is sometimes referred to as the pacemaker of the heart. Because gap junctions allow electric charges to flow freely between cells, the contraction which originated in the SA node spreads very rapidly across the entire atrium as if it were one cell. This causes the atria to undergo systole, i.e. they contract.
Signals from the sinoatrial node that cause contraction within the atria cannot pass directly from the atria to ventricles. Instead the signal from the SA node reaches the atrioventricular (AV) node. From there the signal spreads throughout the heart via specialized heart muscle tissue called Purkinje fibres. This signal causes the ventricles to undergo systole. This snaps the atrioventricular valves shut. After the ventricles are emptied the semilunar valves close.

The ventricles begin diastole, the atrioventricular valves open and the ventricles start filling with blood. Finally, all four chambers are in diastole and filling. When the atria are filled and the ventricles are 70 per cent filled, the cycle has ended.

**The atrioventricular node**

There is a delay between the arrival and passing on of a stimulus at the atrioventricular node.

There are mechanisms in place to stagger the contraction of the atria and the ventricle. The fibres which connect the SA node to the AV node carry the action potential relatively slowly. There is a delay of approximately 0.12 s between arrival of the stimulus from the SA node and initiation of the impulse with the ventricles.

The cells of the AV node take longer to become excited than the cells of the SA node. There are a number of features of the AV node that lead to the delayed initiation of contraction of ventricles by the AV node.

- The AV node cells have a smaller diameter and do not conduct as quickly.
- There is a relatively reduced number of Na⁺ channels in the membranes of AV node cells, a more negative resting potential and a prolonged refractory period within the cells of the AV node.
- There are fewer gap junctions between the cells of the AV node.
- There is relatively more non-conductive connective tissue in the node.
The delay in conduction

This delay allows time for atrial systole before the atroventricular valves close.

The delay in the initiation of contraction caused by the AV node is important because it ensures that the atria contract and empty the blood they contain into the ventricles first before the ventricles contract. The contraction of ventricles causes the AV valves to snap shut, so that contraction of the ventricles too early would lead to too small a volume of blood entering the ventricles.

Coordination of contraction

Conducting fibres ensure coordinated contraction of the entire ventricle wall.

Once through the AV bundle, the signal must be conducted rapidly in order to ensure the coordinated contraction of the ventricle.

The atroventricular bundle receives the impulse from the AV node and conducts the signal rapidly to a point where it splits into the right and left bundle branches. The bundle branches conduct the impulses through the wall between the two ventricles. At the base, or apex of the heart, the bundle branches connect to the Purkinje fibres which conduct the signal even more rapidly to the ventricles. These fibres have a number of modifications that facilitate them conducting signals at such a high speed:

- They have relatively fewer myofibrils.
- They have a bigger diameter.
- They have higher densities of voltage-gated sodium channels.
- They have high numbers of mitochondria and high glycogen stores.

The contraction of the ventricle begins at the apex.

The invention of the stethoscope

Developments in scientific research followed improvements in apparatus or instrumentation: the invention of the stethoscope led to improved knowledge of the workings of the heart.

Stethoscopes are one of the most recognizable symbols of the medical profession. They were invented in the 19th century by Rene Laennec though the original design has been significantly modified since then. Though not widely practised, practitioners would place their ears directly on the chest of patients to listen to the heart beat. In the 19th century, many patients were too obese for sounds to be heard by this method, washing was not the social norm and some patients were “infested with vermin” and if the patient was a female, modesty was an issue. While these variables were the main pressure behind the development of the tool, there were unintended benefits of the device. It became one of the first tools that allowed for the non-invasive investigation of internal anatomy. Different types of heart abnormalities result in different sounding heartbeats which can be detected through the stethoscope.
Causes of the sound of the heartbeat

Normal heart sounds are caused by the atrioventricular valves and semilunar valves closing causing changes in blood flow.

A normal heartbeat has two sounds, both of which are caused by the closing of valves. When the atrioventricular valves snap shut, there is a “lub” sound. After the ventricles are emptied the semilunar valves close, causing the second sound, the “dub” sound.

Variables affecting the heart rate

Measurement and interpretation of the heart rate under different conditions.

A number of variables that can influence heart rate can be assessed in the school laboratory setting. Some examples include types of exercise, intensity of exercise, recovery from exercise, relaxation, body position including lying down, breathing and breath holding, exposure to a cold stimulus and facial immersion in water.

Detecting heart rate can be done in a number of ways. Figure 7 shows how to detect the pulse of an artery in the wrist. The researcher uses fingers rather than the thumb. The side of the neck below the jaw has an artery where determining pulse is relatively easy. Data-logging equipment including hand-grip heart monitors, ear clips, EKG sensors and wrist watches can feed data into computers. The built-in cameras on some tablet computers can be used as a device to detect heart rate.

Data-based questions: Cold exposure and heart rate

The resting heart rate of a sample of students was determined through monitoring by a wrist band that measured heart rate. An ice pack was then placed on the forearm of these students for one minute. The heart rate was measured at the end of the one minute of cold exposure and then again at the end of each minute for two minutes of recovery.

1 Determine the mean resting heart rate.
2 Calculate the percent decline in mean heart rate with cold exposure.
3 Evaluate the conclusion that cold exposure suppresses heart rate.
**Artificial pacemakers**

Use of artificial pacemakers to regulate the heart rate.

Artificial pacemakers are medical devices that are surgically fitted in patients with a malfunctioning sinoatrial node, the part of the heart that initiates the heartbeat, or in patients with a block in the signal conduction pathway within the heart, which impairs the nerve impulses generated by the node. The purpose of the device is to maintain the rhythmic nature of the heartbeat when the heart does not beat fast enough or when there is a fault in the heart's electrical conduction system.

Pacemakers can either provide a regular impulse or discharge only when a heartbeat is missed so that it beats normally. The most common, basic pacemaker monitors the heart's rhythm and when a heartbeat is not detected, the ventricle is stimulated with a low voltage pulse. More complex forms stimulate both the atria and the ventricles.

Figure 9 shows an X-ray of the chest of a male patient with a heart pacemaker (upper right). The heart is the blue mass at centre right, in between the lungs (white). The pacemaker has leads (running from upper right to lower centre) to supply regular electrical impulses to the heart.

**Relating the cardiac cycle to the ECG trace**

Mapping of the cardiac cycle to a normal electrocardiogram (ECG) trace.

Cardiac muscle contracts because it receives electrical signals. These signals can be detected and quantified using an electrocardiogram (ECG or EKG). Data-logging ECG sensors can be used to produce a pattern as shown in figure 10. The P-wave is caused by atrial systole, the QRS wave is caused by ventricular systole. The T-wave coincides with ventricular diastole. Interval analysis can be performed on the EKG signal, for example on the times between the beginning of P and Q (P–Q), QRS, and Q to the end of T (Q–T) intervals. The height of the R-wave can be compared when the body changes position from standing to lying down. The overall pattern can be compared before and after mild exercise.

Specialists can use changes to the size of peaks and lengths of intervals to detect heart pathology.
Explaining the use of a defibrillator

Use of defibrillation to treat life-threatening cardiac conditions.

Cardiac arrest occurs when the blood supply to the heart becomes reduced and heart tissues are deprived of oxygen. One of the first negative consequences of this is abnormalities in the cardiac cycle such as twitching of the ventricles due to rapid and chaotic contraction of individual muscle cells.

When “first responders” reach a scene where a victim is not breathing, they will apply the two paddles of a defibrillator to the chest of the patient, setting up a diagonal line between the two paddles with the heart in the middle. The device will first detect whether fibrillation is happening and if it is, an electric discharge is given off to restore a normal heart rhythm.

Hypertension and thrombosis

Causes and consequences of hypertension and thrombosis.

Atherosclerosis is hardening of the arteries caused by the formation of plaques, or atheromas, on the inner lining of arteries (figure 12). Plaques are areas that are swollen and accumulate a diversity of debris. The plaques often develop because of high circulating levels of lipids and cholesterol. The plaques can reduce the speed at which blood moves through vessels. This can trigger a clot, or thrombosis, which can block the blood flow through the artery and deny the tissue access to oxygen. If this occurs on the surface of the heart, the consequence can be a myocardial infarction, or heart attack.

Greater resistance to the flow of blood can slow the flow of blood. The result is greater pressure on the walls of arteries, also known as hypertension. Hypertension has a number of consequences.

- Damage to the cells that line arteries can cause a cascade of events that ultimately leads to the arteries becoming narrower and stiff.
- Constant high blood pressure can weaken an artery causing a section of the wall to enlarge and form a bulge called an aneurysm. An aneurysm can burst and cause internal bleeding. They can form in any artery in the body but are most common in the aorta.

- Chronic high blood pressure can lead to stroke by weakening blood vessels in the brain causing them to narrow, leak or rupture. It can also lead to blood clots in the arteries leading to the brain potentially causing a stroke.
- Chronic high blood pressure is one of the most common causes of kidney failure as it damages both the arteries leading to the kidney and the capillaries within the glomerulus.

There are a number of factors that are correlated with a greater incidence of thrombosis and hypertension.
• Having parents who have experienced heart attacks indicates a genetic precondition to either condition.
• Old age leads to less flexible blood vessels. In children, the normal ranges are lower than for adults.
• Risk in females increases post-menopause correlated with a fall in estrogen levels.
• Males are at greater risk compared with females correlated with lower levels of estrogen.
• Smoking raises blood pressure because nicotine causes vasoconstriction.
• A high-salt diet, excessive amounts of alcohol and stress are also correlated with hypertension.
• Eating too much saturated fat and cholesterol promotes plaque formation.
• Height affects blood pressure.

Sedentary lifestyle, i.e. a lack of exercise is correlated with obesity and prevents the return of venous blood from the extremities leading to a greater risk of clot formation.

D.4 THE HEART

Figure 13 A blood clot (thrombus) in the coronary artery, showing red blood cells [purple] in a fibrin mesh [threads]. The coronary artery supplies blood to the heart

Interpreting blood pressure measurements

Interpretation of systolic and diastolic blood pressure measurements.

Blood pressure, or more accurately arterial pressure is the pressure that circulating blood puts on the walls of arteries. During each heartbeat, the pressure of blood within arteries varies from a peak during the ventricle systole to a minimum near the beginning of the cardiac cycle when the ventricles are filled with blood and are in systole.

Blood pressure measurements are often quoted in the pressure unit “mm Hg”. An example blood pressure would be “120 over 80”. The higher number refers to the pressure in the artery caused by ventricular systole and the lower number refers to the pressure in the artery due to ventricular diastole.

Figure 14 shows a pregnant woman having her blood pressure measured. Monitoring blood pressure during pregnancy is important. High blood pressure during pregnancy is called pre-eclampsia and it can be a life-threatening condition if it is not treated.

To measure blood pressure, a cuff is placed on the bicep and inflated so that it constricts the arm and prevents blood from entering the forearm. The cuff is slowly deflated and the nurse listens for the occurrence of a sound. This occurs when the cuff pressure is lowered below the systolic pressure. The sound is caused by the opening and closing of the artery. The cuff is further deflated until normal blood flow returns and there is no longer a sound. The absence of sound occurs when the cuff pressure is less than the diastolic pressure.
Data relating to coronary heart disease

Analysis of epidemiological data relating to the incidence of coronary heart disease.

Coronary heart disease (CHD) refers to the damage to the heart as a consequence of reduced blood supply to the tissues of the heart itself. This is often caused by narrowing and hardening of the coronary artery.

Ethnic groups can differ in their predisposition to CHD because of differing diets and lifestyles.

Gender groups, age groups, groups that differ in their level of physical activity, groups with different genotypes, groups with differing medical histories – all can have different probabilities of experiencing CHD. Epidemiology is the study of the patterns, causes and effects of diseases in groups of individuals or populations.

Data-based questions: Hypertension

High blood pressure (hypertension) is a major risk factor for coronary heart diseases. In a major study, more than 316,000 males were followed for 12 years to investigate the effects of high blood pressure (BP). Figure 16 shows the relationship between systolic and diastolic blood pressure and the effect on the death rate per 10,000 persons year⁻¹.

1. Determine the death rate for a systolic blood pressure between 140 and 159 mmHg and a diastolic blood pressure between 75 and 79 mmHg. [1]

2. Describe the effect of systolic blood pressure and diastolic blood pressure on the death rate. [2]

3. Calculate the minimum difference between systolic and diastolic blood pressure where the death rate is highest. [1]

4. Evaluate the impact of differences between systolic and diastolic pressure on death rate. [3]

![Figure 16 The effect of blood pressure on coronary heart disease](image-url)
**Data-based questions: Cholesterol**

Cholesterol and lipids are not soluble in the blood because blood is water-based. To solve this problem, lipids are transported in the blood in the form of lipoproteins called chylomicrons. The concentration of cholesterol in the blood as lipoproteins is a determining factor in the onset of coronary heart disease.

In 1998 the blood cholesterol level of 70,000 people in Mexico was measured. The people were divided into two age groups: 1 to 19 (young people) and 20 to 98 (adults). Mean blood cholesterol levels were calculated for the two age groups in each of the different states of Mexico.

Figure 17 shows the results. Each point on the graph shows the mean blood cholesterol level for the two age groups in one state.

1. State the relationship between cholesterol levels in young people and adults.

2. Predict, using the data in the graph, how the blood cholesterol level usually changes over a lifetime.

3. The maximum desirable blood cholesterol level is 200 mg/100 cm$^{-3}$ of blood. Suggest the implications of the survey of blood cholesterol levels for the population of Mexico.

![Figure 17 Relationship between blood cholesterol in adults and blood circulation in adolescents in different Mexican states]
Endocrine glands

Endocrine glands secrete hormones directly into the bloodstream.

Endocrine glands are structures that secrete chemical messages, called hormones, directly into the blood. These messages are transported to specific target cells (figure 1). Hormones can be steroids, proteins, glycoproteins, polypeptides, amines or tyrosine derivatives.

As an example, figure 2 shows a cross-section through a thyroid gland follicle. Thyroid hormones regulate the body’s metabolism. The follicle consists of a layer of cells (pink) around a central storage chamber. The cells produce the thyroid hormones and secrete them into the central chamber where they are stored in a viscous fluid colloid (yellow). The follicle is surrounded by blood vessels (red), which transport the hormones around the body.