# INTRODUCTION

This workbook is designed to give you an overview of the anatomy and physiology of the cardiovascular system.

It is intended that the workbook will be used as a reference tool while you are studying on the course.

There will be time for discussion and clarification of any areas you are unclear about during the two cardiac days of the course however it is *expected* that you will have reviewed *all the content* prior to attending the days. There are a number of student activities contained within the workbook for you to undertake.

Any good anatomy and physiology textbook will provide many of the answers and many of you may find the content revision rather than new knowledge.

# CONTENTS

# EMBRYOLOGY AND FOETAL CIRCULATION

## Embryology

The origin of cardiac tissue is the ***mesoderm*** of the embryo.

At day 18, during the third gestational week, a crescent or arch of mesoderm is formed from a pair of endothelial tubes. The endothelial tubes fuse and grow establishing a ***single straight primitive heart tube***. A rhythmic ebb and flow of blood (which precedes heart beats) is a chief characteristic of the primitive heart.

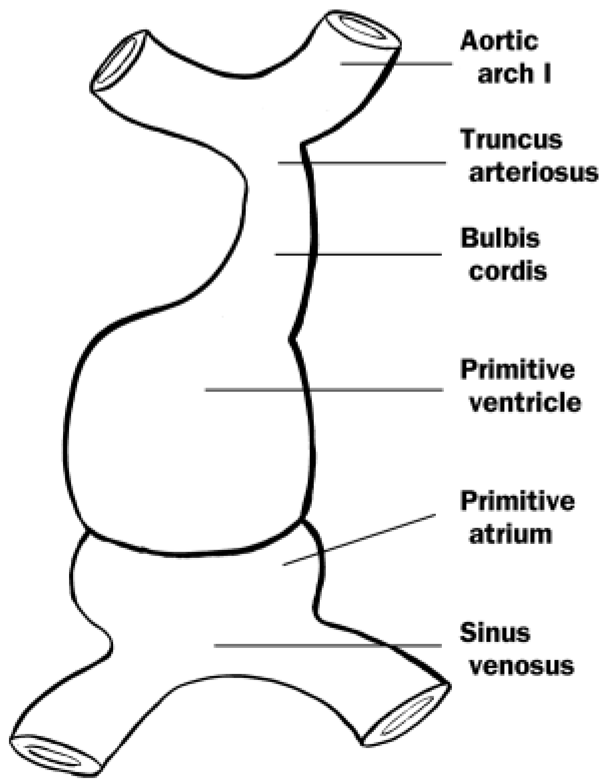


Figure 1: The Primitive Heart

**Activity 1**

- **Using resources available create a time line for the development of the foetal heart from 0 - 40 weeks**

The transition from a single heart tube to a complex 4-chambered heart is dependent upon several critical events;

- Endocardial cushion growth and fusion
- Bulboventricular looping
- Interatrial septum formation
- Interventricular septum formation
- Aortico-pulmonary septum formation

Below is a summary of some of the key facts relating to each of these processes.

➢ **Endocardial Cushions** are areas of the fibrous skeleton which forms between the atrium and ventricle. Endocardial cushions serve two important functions;

- They form a partition in the heart tube between the atrium and ventricle known as the AV canal. The resulting two channels represent sites for the future tricuspid and bicuspid valves.
- They provide a "scaffold" to which the interatrial septae and the interventricular septum will grow towards and fuse with.

➢ **Bulboventricular Looping** is a consequence of several changes;

*Dorsal folding*

The **first dorsal fold** forms an expanded primitive ventricle, referred to as the *bulboventricular loop*. This loop is subject to further changes, mainly of a haemodynamic nature.

*Ventricular growth*

Differential growth of the proximal ventricular tissue causes a *counter-clockwise* rotation of the folded heart tube. The site of ventricular growth marks the future left ventricle. Abnormal growth of the distal primitive ventricle causes *clockwise* rotation, an anomaly known as *dextrocardia*.

*AV canal partitioning*

The Atrio-Ventricular (AV) canal between the primitive atrium and ventricle has now been partitioned by the fusing endocardial cushions. The division serves to direct the blood preferentially through one channel.

*Shunting of venous return*

The development of the venous system causes an increase in right-sided venous return to the primitive atrium. Combined with the partitioning of the AV canal, the change in blood flow volume and directions assists in the outgrowth of the left ventricle.

Bulboventricular looping is essential in the establishment of normal haemodynamic patterns and thus normal development of septae and internal structures.

- **Interatrial Septum Formation**

The formation of the atrial septum must preserve the foetal shunting of oxygenated blood from the IVC across the atria to the systemic circulation, while allowing conversion to the normal blood flow pattern at birth.

The **septum primum** grows downwards from the atrial wall. The opening between the growth edge of the septum and the fused endocardial cushions is known as **foramen primum**. Blood from the inferior vena cava will flow across the atria, through foramen primum to the systemic circulation.

As growth progresses, the foramen primum is reduced in diameter. Apoptosis in the upper portion of the septum begins.

The growth edge of septum primum now fuses to the endocardial cushion mass. Apoptosis in the superior aspect of septum primum forms a new opening, the **foramen secundum**. Any defect in the fusion of septum primum to the endocardial cushion is referred to as a patent foramen primum. These are usually slight and of no physiological importance.

The left valve of the sinus venosus begins growth downwards as **septum secundum.**

Growth and fusion of septum secundum to the endocardial cushions leaves an opening, the **foramen ovale**. The superior-most aspect of septum primum apoptoses, freeing this edge from the atrial wall. The septum primum now acts as a valve for the opening in septum secundum.

- **Interventricular Septum Formation**

The interventricular septum (IVS) serves as the final event in separating aortic and pulmonary outflow from the heart. The division between IVS formation and aortico-pulmonary (AP) septum formation is done in order to highlight important features of each event. **In reality however, the two occur simultaneously.**

The IVS is characterised by two parts, contributed by three separate structures:

1. The muscular portion - the muscular wall grows upwards towards the fused endocardial cushions, separating the bicuspid and tricuspid valves (and thereby, in- and outflow).
2. The membranous portion - the membranous portion of the IVS consists of the fused endocardial cushions, as well as the descending bulbar ridges.

Once the interventricular septum is formed, the tricuspid and bicuspid valves are separated, thereby diving cardiac outflow into pulmonary and aortic streams.

- **Aortico-Pulmonary Septum Formation**

The aortico-pulmonary (AP) septum arises within the truncus arteriosus. The septum results from the downwards growth and fusion of bulbar ridges, induced by invasion of neural crest cells. The AP septum serves to divide the ventricular outflow between the pulmonary artery and the ascending aorta.

## Foetal Circulation

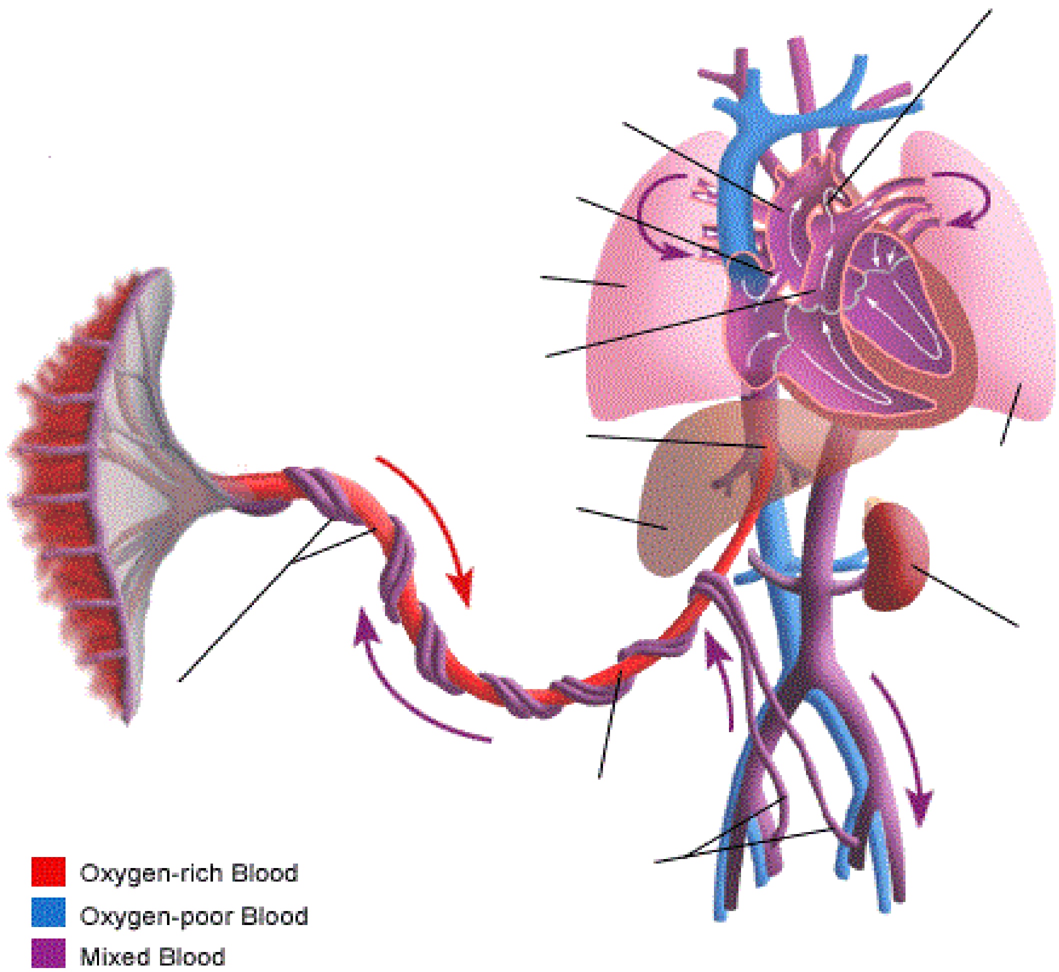


Figure 2: Foetal Circulation

**Activity 2**

1. **On the diagram above, identify the labelled components of foetal circulation**
2. **Describe the changes which take place in the transition between foetal and extra-uterine circulation**

# ANATOMICAL STRUCTURE OF THE HEART

## Gross Structure

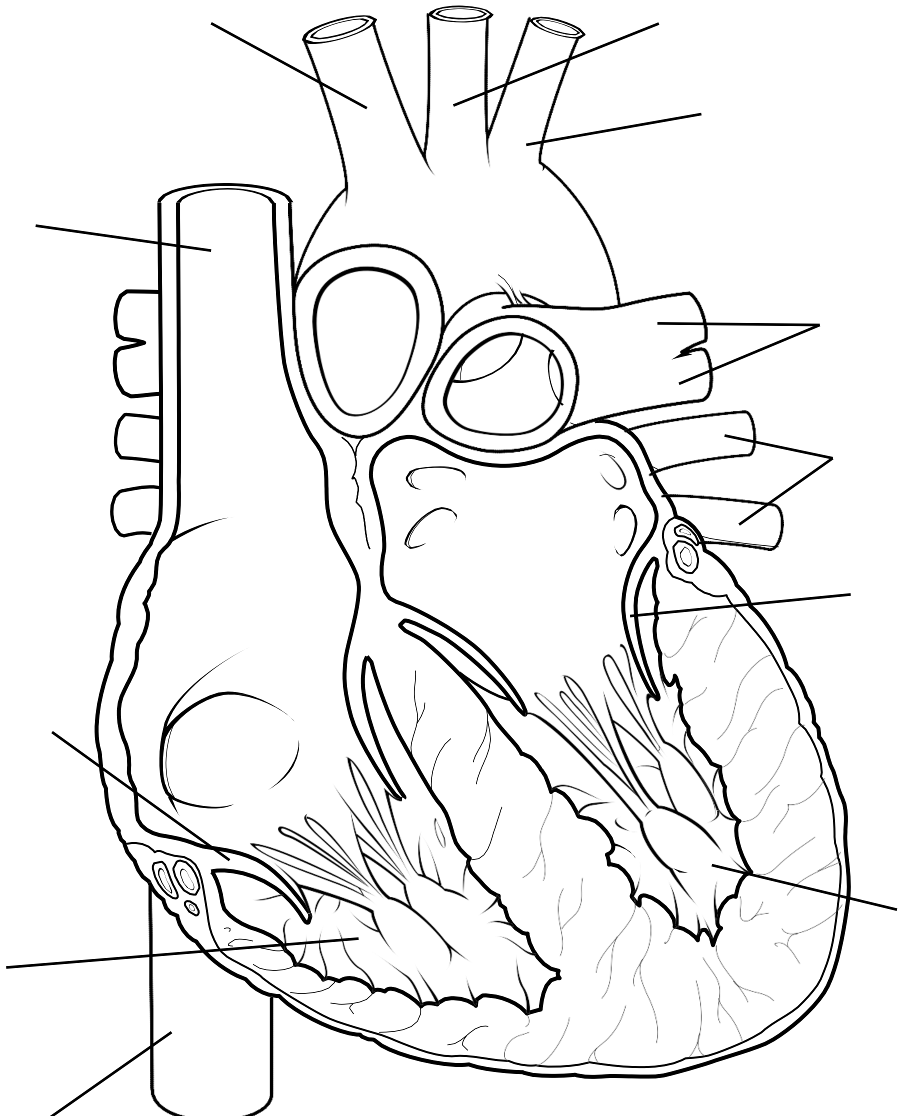

Figure 3: Sectioned view of the heart

Activity 3

On Figure 3 label the points and the direction of the blood flow through the normal heart

Activity 4

Describe the position of the heart anatomically and relate its position to other major organs

## Structure of the Heart Wall

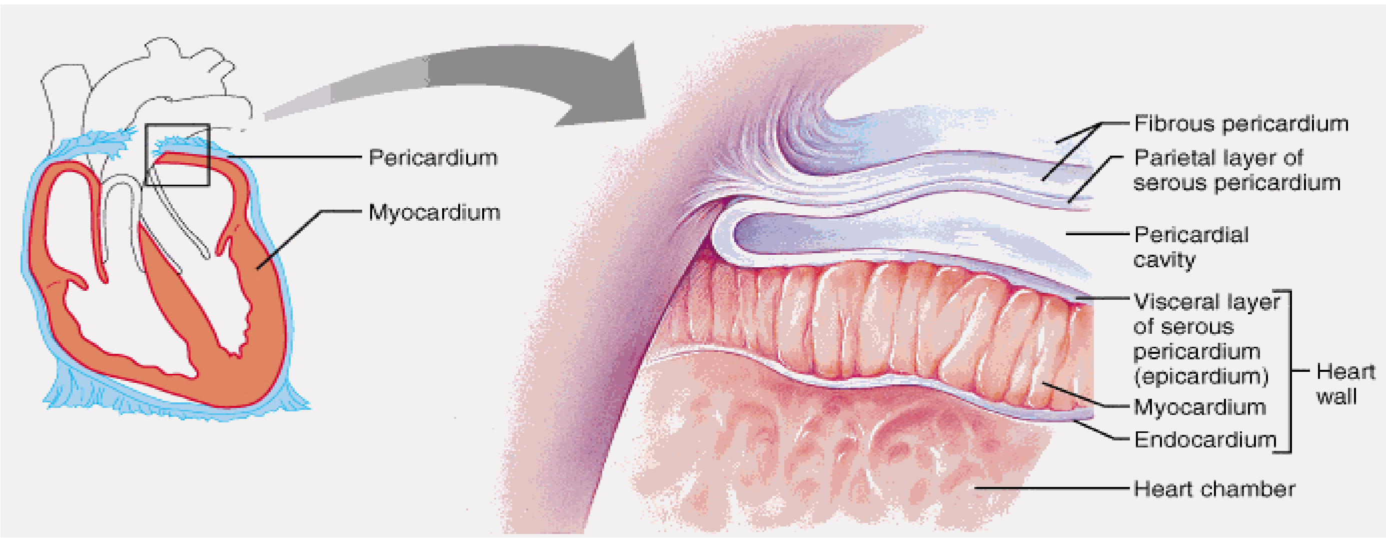


Figure 4: Structure of the heart wall

Activity 5

Briefly describe the composition and function of each of the layers of the heart wall identified in Figure 4

## Intracardiac Valves

Four sets of valves in the heart ensure that blood flows in one direction only preventing increases in pressures within the atria and or ventricles which may cause damage to the structure or function of the myocardium

Atrioventricular valves (aka cuspid valves)

- Tricuspid valve (RA – RV) 3 leaflet valve
- Bicuspid valve (LA – LV) 2 leaflet valve (mitral valve)

These valves are held in place by the papillary muscle and in the right ventricle by additional structures known as the chordae tendineae.

## Semilunar valves

Consist of half-moon shaped flaps growing out of the lining of the pulmonary artery and the aorta.

The purpose of these valves is to prevent blood flowing back into the right or left ventricle from the pulmonary artery or aorta respectively at the end of ventricular systole

## Cardiac Muscle

The heart is a specialised muscle that has similarities to both smooth and skeletal muscle. Cardiac muscle consists of an organised group of muscle cells or fibres that branch and form a complex organ of the circulatory system.

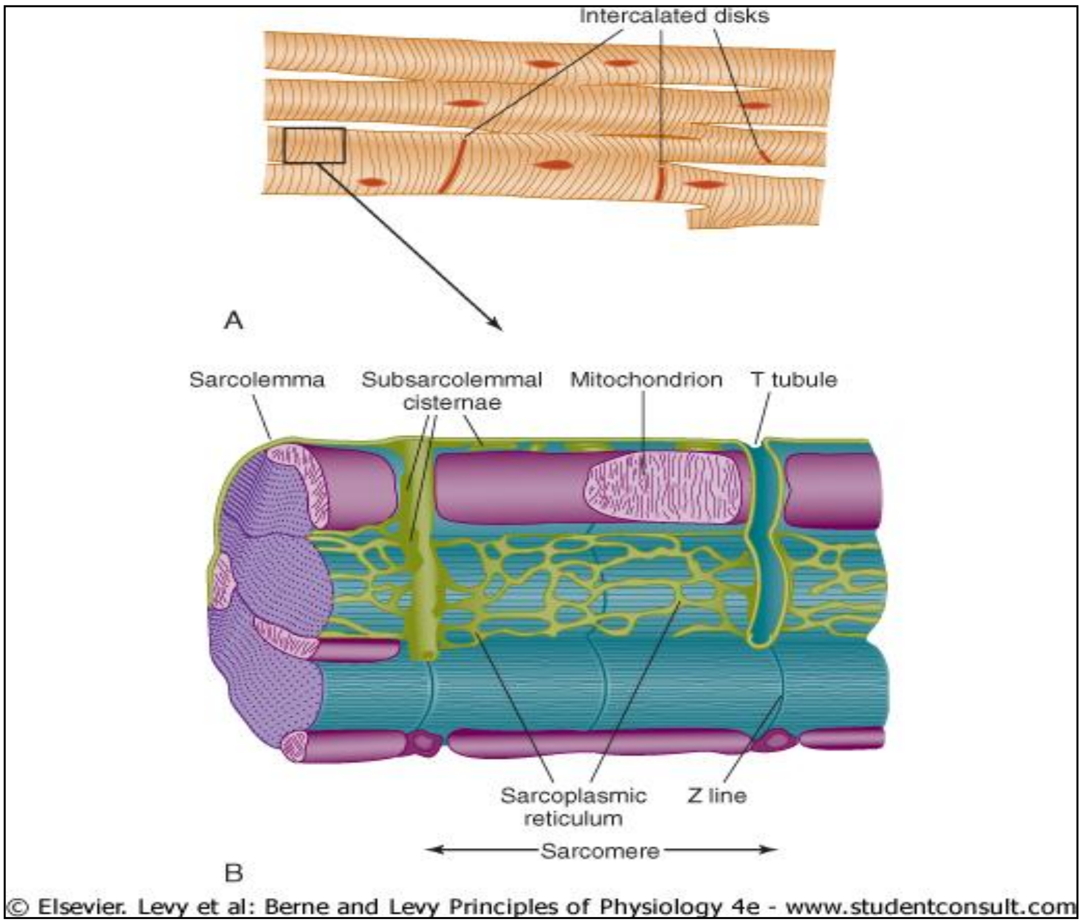


Figure 5: The structure of cardiac muscle

Activity 6

Using Figure 5 and other resources available to you describe the gross structure of cardiac muscle cells and identify the key differences between cardiac and skeletal muscle

## Coronary Circulation

The heart needs its own reliable blood supply in order to keep beating - the coronary circulation. There are two main coronary arteries, the left and right coronary arteries, and these then divide further to form several major branches. The coronary arteries are found in the aorta behind the flaps of the aortic semi-lunar valves.

- The ventricles receive their blood supply from branches of both of the coronary arteries
- The atria by contrast receive blood from a small branch of the corresponding coronary artery

The coronary arteries lie in grooves (sulci) running over the surface of the myocardium, covered over by the epicardium, and have many branches which terminate in arterioles supplying the vast capillary network of the myocardium. Even though these vessels have multiple anastomoses, significant obstruction to one or other of the main branches will lead to ischaemia in the area supplied by that branch.

### *Venous return from the coronary arteries*

Once blood has passed through the capillary beds in the myocardium it enters a series of cardiac veins before draining into the right atrium through a common venous channel known as the *coronary sinus*.

Several veins which collect blood from a small area of the right ventricle do not end in the coronary sinus but drain into the right atrium directly.

Activity 7

Label Figure 6 to identify the coronary arterial circulation

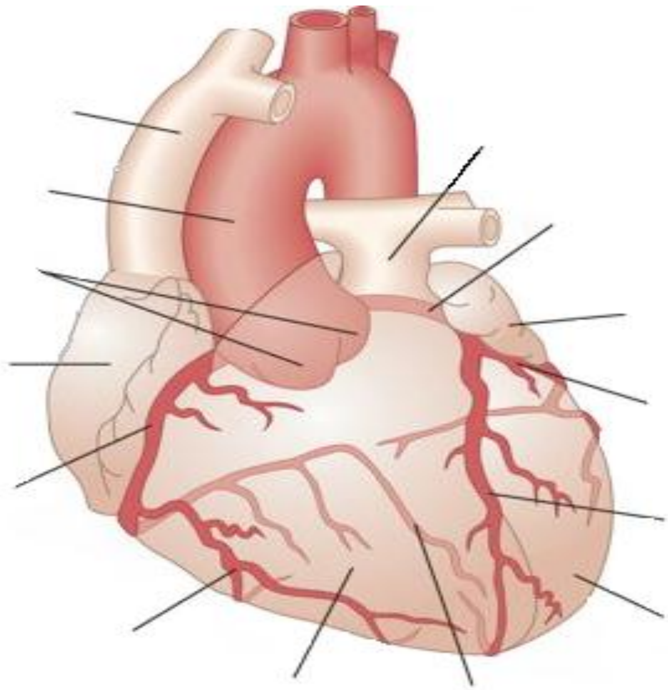

Figure 6: The Coronary Arterial Circulation

## Normal cardiac pressures and saturations

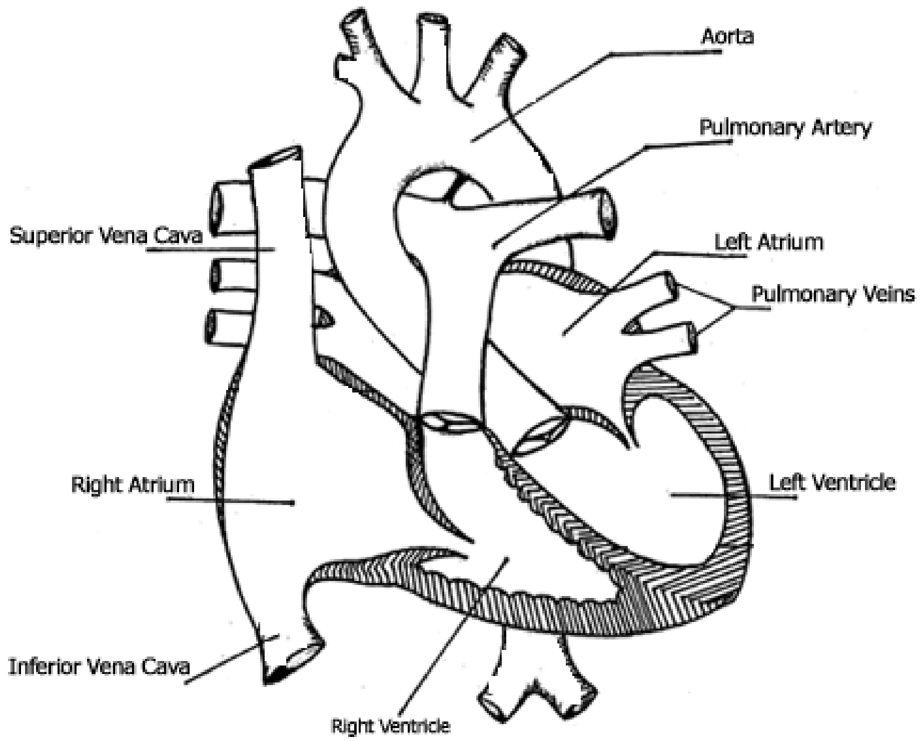


Figure 7: The normal heart

Activity 8

On Figure 7 identify the normal pressures and saturations for each identified area

**<u>Conduction System of the Heart</u>**

Both divisions of the autonomic nervous system send fibres to the heart.

- Sympathetic fibres are contained in the middle, superior and inferior cardiac nerves
- Parasympathetic fibres are contained in branches of the vagus nerve

These fibres combine to form the cardiac plexuses located close to the arch of the aorta. From the cardiac plexuses fibres accompany the coronary arteries to enter the heart where most will terminate in the SA node, some in the AV node and some in the atrial myocardium

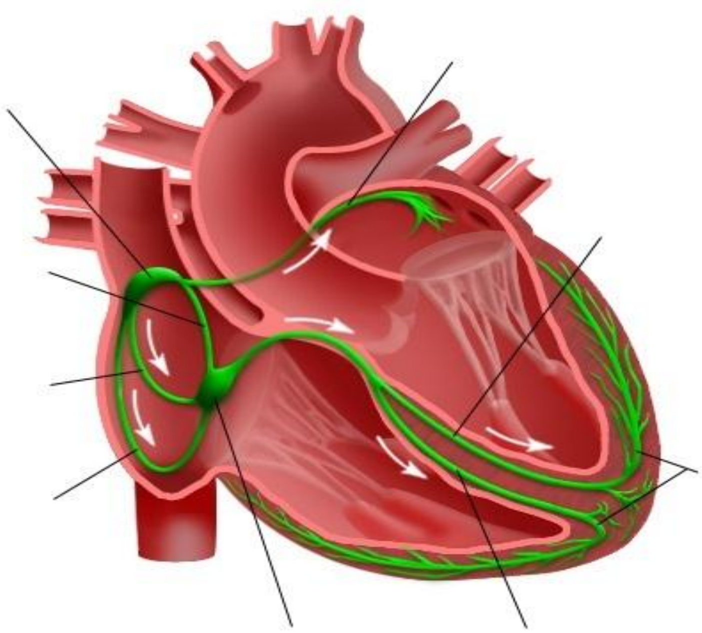

Figure 8: The conduction system of the heart

Activity 9

Identify the major components of the conduction system in Figure 8

## Cardiac Cycle

The ECG waveform provides a graphic representation of electrical activity within the heart. Each part of the single ECG waveform relates to the movement of blood through the heart known as the cardiac cycle.


**Activity 10**

Describe the cardiac cycle with reference to the ECG trace of a sinus rhythm and the movement of blood through the heart

| Event | Point on ECG trace | Blood flow / changes in pressures |
|---|---|---|
| Atrial Systole<br>(Ventricular Diastole) | | |
| Isovolumetric Contraction | | |
| Ejection | | |

| | | |
|---|---|---|
| Isovolumetric Relaxation | | |
| Ventricular Filling Phase | | |

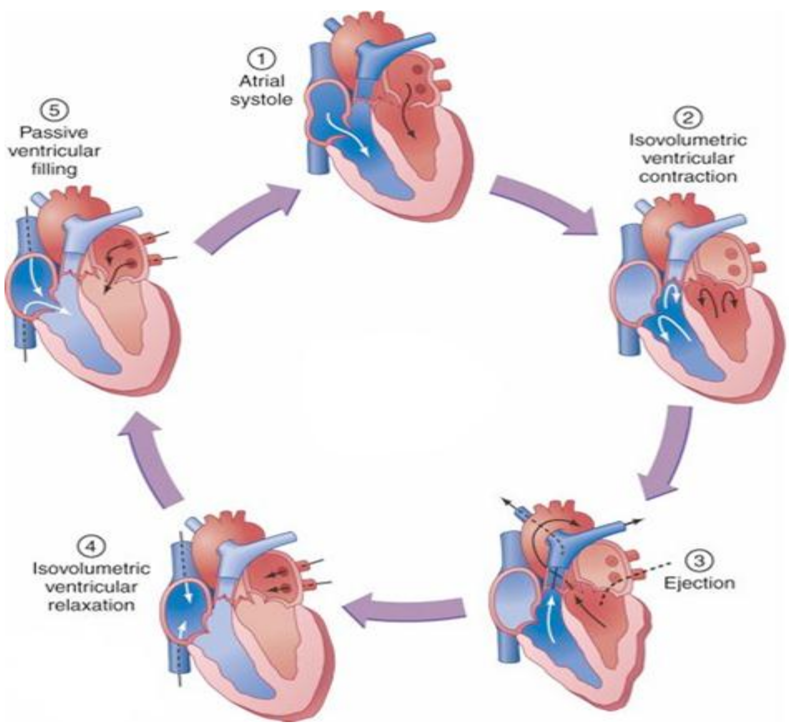


Figure 9: The Cardiac Cycle

## Cardiac Output

Cardiac output is defined as -the volume of blood ejected from the heart in one minute and it is determined by two things; heart rate and stroke volume (amount of blood ejected from the ventricle per beat). Stroke volume is relatively fixed in children due to the structural limitations of the developing heart; therefore cardiac output is essentially determined by the heart rate.

The **heart rate** is controlled through various components of the autonomic nervous system such as the *cardioacceleratory* and *cardioinhibitory* centres in the medulla, the *vagal nerve* as well as the *Sino-Atrial* and *Atrio-Ventricular* nodes. Baroreceptors located in strategic anatomical points also exert an influence on the heart rate. These receptors are found in the carotid sinus, the aorta and the atria. Finally a number of other factors affect the heart rate and may induce a tachycardia or bradycardia in the extreme.

External factors affecting heart rate include;

- Chemicals (Adrenaline / Nor-Adrenaline)
- Electrolytes ($K^+$ / $Na^+$ / $Ca^{++}$ / Magnesium)
- Age / gender
- Temperature
- Emotions

Stroke volume is determined by the interplay between four key components which are; *pre-load, afterload*, *compliance* and *contractility*. A change in any one of these components has the potential to affect one or all of the other three.

| Activity 11 |
|---|
| Using resources available define each of the four determinants of stroke volume and identify factors which may affect them |

**Control of Blood Pressure**

The measurement of arterial blood pressure provides valuable information relating to the child's cardiovascular performance.

The determinants of arterial blood pressure may be divided into physical and physiological factors.

Activity 12

1. Identify the determinants of blood pressure
2. What type of homeostatic feedback mechanisms control blood pressure?

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