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# Cardiac anatomy, physiology and development

# 1

## WHY DO WE NEED A CARDIOVASCULAR SYSTEM?

The cardiovascular system serves to provide rapid transport of nutrients to the tissues in the body and allow rapid removal of waste products. In smaller, less complex organisms than the human body there is no such system because their needs can be met by simple diffusion. Evolution of the cardiovascular system provided a means of aiding the diffusion process, allowing the development of larger organisms. The cardiovascular system allows nutrients:

- To diffuse into the system at their source (e.g., oxygen from the alveoli).
- To travel long distances quickly.
- To diffuse into tissues where they are needed (e.g., oxygen to working muscle).

This is an active process requiring a pump: the heart. The functions of the cardiovascular system rely on a transport medium: blood. Blood is made up of cells (mainly red and white blood cells) and plasma (water, proteins, electrolytes, etc.).

## Functions of the cardiovascular system

The main functions of the cardiovascular system are:

1. Rapid transport of nutrients (oxygen, amino acids, glucose, fatty acids, water, etc.).
2. Removal of waste products of metabolism (carbon dioxide, urea, creatinine, etc.).
3. Hormonal control, by transporting hormones to their target organs and by secreting its own hormones (e.g., atrial natriuretic peptide).
4. Temperature regulation, by controlling heat distribution between the body core and the skin.
5. Reproduction, by producing penis erection and providing nutrition to the foetus via a complex system of placental blood flow.
6. Host defence, by transporting immune cells, antigens and other mediators (e.g., antibodies).

## ANATOMY OF THE HEART AND GREAT VESSELS

### Overview of the heart and circulation

The heart consists of two muscular pumps (the left and right ventricles). Each pump has its own reservoir (the

left and right atria). The two pumps each serve a different circulation.

The right ventricle is the pump for the pulmonary circulation. It receives blood from the right atrium, which is then pumped through the pulmonary artery into the lungs. Here it is oxygenated and gives up carbon dioxide; it then returns via the pulmonary veins into the left atrium of the heart, and then enters the left ventricle.

The left ventricle is the pump for the systemic circulation. Blood is pumped from the left ventricle via the aorta to the rest of the body. In the tissues of the body, nutrients and waste products are exchanged. Blood returns to the right atrium via the superior and inferior vena cavae.

The two circulations operate simultaneously and are arranged in series. Unidirectional flow is ensured by valves in the heart, pressure differences in the arterial tree and valves in the veins (Fig. 1.1).

### CLINICAL NOTE



As the heart consists of two separate pumps, failure of an individual pump is possible, e.g., right heart failure as a result of severe lung disease (cor pulmonale).

The circulatory system is made up of arteries, veins, capillaries and lymphatic vessels:

1. Arteries transport blood from the heart to the tissues.
2. Capillaries are where diffusion of nutrients and waste products takes place.
3. Veins return blood from the tissues to the heart. (The hepatic portal vein is an exception. This transports blood from the intestines to the liver.)
4. Lymphatic vessels return to the blood any excess water and nutrients that have diffused out of the capillaries.

### HINTS AND TIPS



Arteries carry oxygenated blood and veins carry deoxygenated blood. The two exceptions to this rule are the umbilical vessels (supplying the foetus) and pulmonary vessels where this is reversed.

The volume of blood ejected from one ventricle during 1 minute is called the cardiac output. The cardiac output of each ventricle is equal overall, but there may be occasional

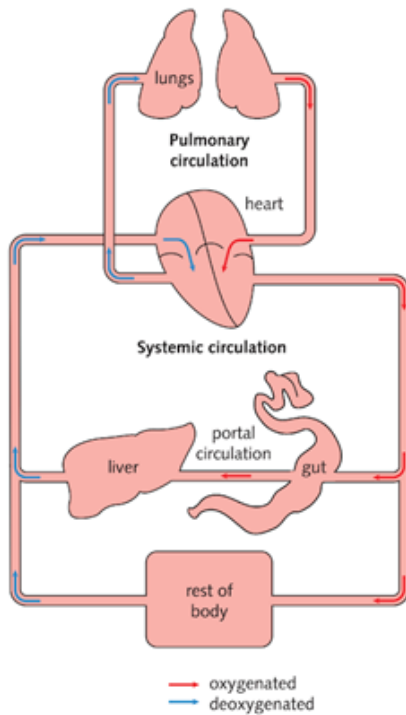


Fig. 1.1 Systemic and pulmonary circulations.

beat-by-beat variation. The entire cardiac output of the right ventricle passes through the lungs and into the left side of the heart. The cardiac output of the left ventricle passes into the aorta, and it is distributed to various organs and tissues according to their metabolic requirements or particular functions (e.g., the kidney receives 20% of cardiac output so that its excretory function can be maintained). This distribution can be changed to meet changes in demand (e.g., during exercise, the flow to the skeletal muscle is increased considerably).

Blood is driven along the vessels by pressure. This pressure, which is produced by the ejection of blood from the ventricles, is highest in the aorta (about 120 mmHg above atmospheric pressure) and lowest in the great veins (almost atmospheric). It is this pressure difference that moves blood through the arterial tree, through the capillaries, and into the veins.

## The mediastinum

This is the space between the two pleural cavities. It contains all the structures of the chest except the lungs and pleura. The mediastinum extends from the superior thoracic aperture to the diaphragm and from the sternum to the vertebrae and is divided into superior and inferior parts by the plane passing from the sternal angle to the T4/T5 intervertebral disc. The inferior mediastinum is then

further subdivided into anterior, middle and posterior parts (Fig. 1.2). The contents of each part are shown in Table 1.1. The structures in the mediastinum are surrounded by loose connective tissue, nerves, blood vessels, and lymph vessels. It can accommodate movement and volume changes.

The heart is in the middle mediastinum, and it has the following relations:

1. Superiorly, the great vessels and bronchi.
2. Inferiorly, the diaphragm.
3. Laterally, the pleurae and lungs.
4. Anteriorly, the thymus.
5. Posteriorly, the oesophagus.

The structures visible on a normal chest X-ray are shown in Fig. 1.3.

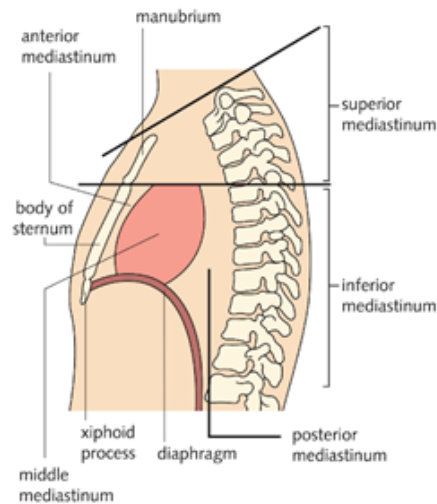
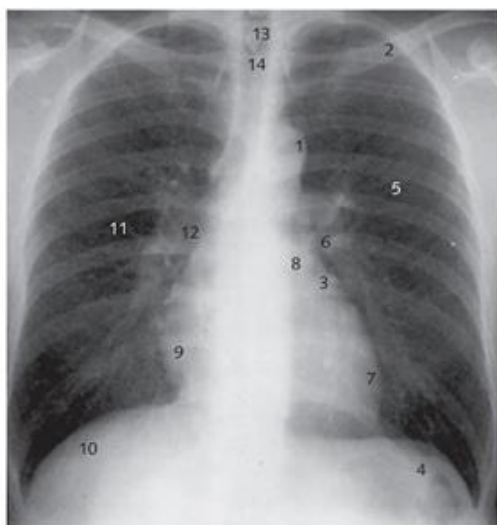


Fig. 1.2 Lateral view of the mediastinum.

Table 1.1 Contents of the mediastinum

Mediastinal compartment	Contents
Superior	Great vessels Thymus Trachea Oesophagus
Anterior	Internal thoracic arteries Thymus
Middle	Heart and pericardium Origins of the great vessels
Posterior	Descending aorta Oesophagus Sympathetic chain



**Fig. 1.3** Normal posteroanterior (PA) chest X-ray. 1, Arch of aorta/aortic knuckle; 2, clavicle; 3, left atrial appendage; 4, left dome of diaphragm; 5, left lung; 6, left hilum; 7, left ventricular border; 8, pulmonary trunk; 9, right atrial border; 10, right dome of diaphragm; 11, right lung; 12, right hilum; 13, spine of vertebrae; 14, trachea. (Courtesy Professor Dame M. Turner-Warwick, Dr. M. Hodson, Professor B. Corrin and Dr. I. Kerr.)

## Pericardium

This is the fibroserous sac that surrounds the heart. It consists of two layers, between which there is a small amount of pericardial fluid. The pericardium is fused with the central tendon of the diaphragm at its base, the sternum by the sternopericardial ligament anteriorly and with the tunica adventitia of the great vessels.

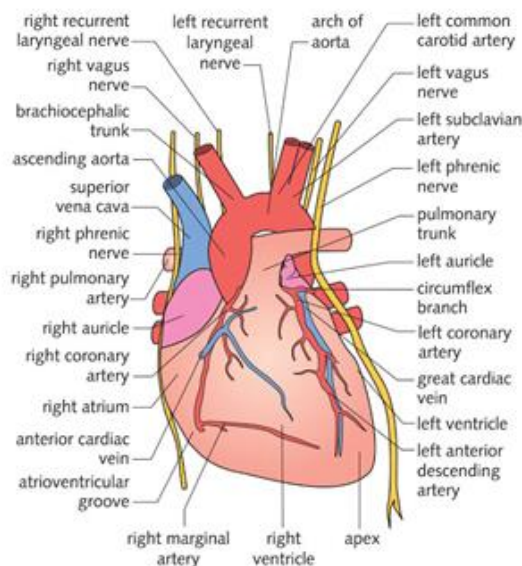
### CLINICAL NOTE

When fluid accumulates within the pericardial sac this is called a pericardial effusion. If it builds up quickly and begins to affect cardiac function this is called cardiac tamponade. (Both are described in Chapter 17.)

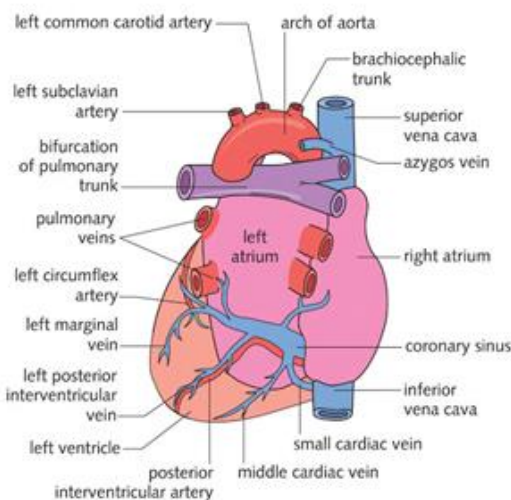
## External structure of the heart

The heart lies obliquely about two-thirds to the left and one-third to the right of the median plane (Figs 1.4–1.6). It has the following surfaces:

1. The base of the heart is located posteriorly and formed mainly by the left atrium.
2. The apex of the heart is formed by the left ventricle and is posterior to the fifth intercostal space.



**Fig. 1.4** Sternocostal external view of the heart.

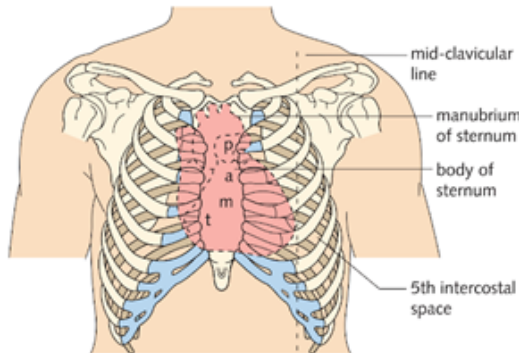


**Fig. 1.5** Posteroinferior external view of the heart. (Courtesy of Professor Dame M. Turner-Warwick, Dr. M. Hodson, Professor B. Corrin and Dr. I. Kerr.)

3. The sternocostal surface of the heart is formed mainly by the right ventricle.
4. The diaphragmatic surface is formed mainly by the left ventricle and part of the right ventricle.
5. The pulmonary surface is mainly formed by the left ventricle.

The heart borders of the anterior surface are as follows:

1. Right: right atrium.
2. Left: left ventricle and left auricle.
3. Inferior: right ventricle mainly and part of left ventricle.
4. Superior: right and left auricles.



**Fig. 1.6** Surface markings of the heart (a, aortic valve; m, mitral valve; p, pulmonary valve; t, tricuspid valve). These are anatomical relations – see Fig. 5.5 for auscultatory areas.

#### HINTS AND TIPS



When examining the cardiovascular system, it is important to remember that the right ventricle lies anteriorly and faces the sternocostal surface. In certain conditions causing pulmonary hypertension, the right ventricle is forced to work excessively hard, and this can be felt as a right ventricular heave on the precordium.

### Internal structure of the heart

The internal structure of the heart is shown in Fig. 1.7. The right atrium contains the orifices of the superior and inferior venae cavae and coronary sinus. The right ventricle is separated from the right atrium by the tricuspid (three cusps) valve. The right ventricle is separated from its outflow tract (the pulmonary trunk) by the pulmonary valve. This has three semilunar valve cusps.

The left atrium has the orifices of four pulmonary veins in its posterior wall and is separated from the left ventricle by the mitral (sometimes referred to as bicuspid, i.e., two cusps) valve. The left ventricle is separated from its outflow tract (the aorta) by the aortic valve, which also has three semilunar valve cusps.

#### CLINICAL NOTE



In approximately 1% of the population, the aortic valve is bicuspid (has only two cusps). This usually goes unnoticed, but puts a person at increased risk of developing aortic stenosis at an earlier age.

### Coronary arteries

The coronary arteries are shown in Figs 1.8 and 1.9. The left coronary artery arises just distal to the left anterior cusp of the aortic valve. The right coronary artery arises from the right anterior aortic sinus just above the right anterior cusp of the aortic valve. The coronary arteries are the first branches of the aorta; the heart supplies itself with a blood supply before any other organ.

#### HINTS AND TIPS



Knowledge of the arterial supply to the myocardium is essential in determining which vessel is affected in ischaemic heart disease, and allows us to predict the sequelae of an event. For example, an inferior infarct caused by disease of the right coronary artery is more prone to bradyarrhythmia as this artery also supplies the sinoatrial (SA) and atrioventricular (AV) nodes.

### Coronary veins

The coronary veins drain mainly into the coronary sinus, which drains directly into the right atrium (Figs 1.10 and 1.11). There are some small veins that drain directly into the heart chambers. Generally, these drain into the right side of the heart.

### Great vessels

'Great vessels' is the term used to denote the large arteries and veins that are directly related to the heart. The great arteries include the pulmonary trunk and the aorta (and sometimes its three main branches: the brachiocephalic, the left common carotid, and the left subclavian). The great veins include the pulmonary veins and the superior and inferior venae cavae. The great vessels and their thoracic branches are illustrated in Figs 1.12–1.14.

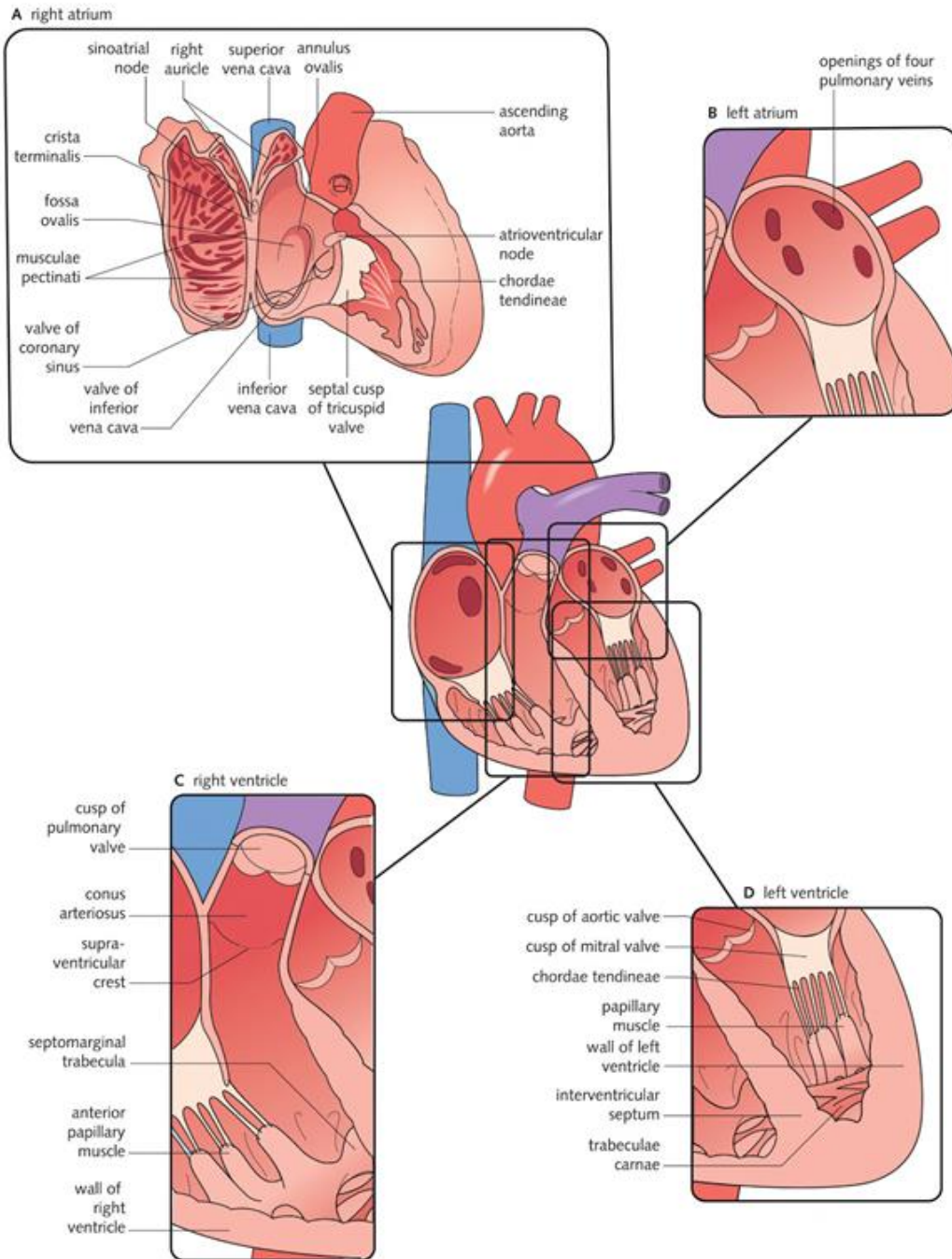
### Tissue layers of the heart and pericardium

Figure 1.15 shows the tissue layers of the heart and pericardium.

#### Pericardium

The pericardium consists of an outer fibrous pericardial sac, enclosing the whole heart, and an inner double layer of flat mesothelial cells, called the serous pericardium. The two layers of the serous pericardium are:

1. The parietal pericardium, which is attached to the fibrous sac.
2. The visceral pericardium, which forms part of the epicardium and which covers the heart's outer surface.



**Fig. 1.7** Internal structure of the four chambers of the heart. (A) Right atrium. (B) Left atrium. (C) Right ventricle. (D) Left ventricle.