Chapter 5 - Cardiovascular system and lymphoid organs

The objectives of this chapter are:

1. Describe the structure of the heart.
2. Describe the blood supply to the heart.
3. Define the systemic circulation.
4. Define the pulmonary circulation.
5. Describe the systemic arteries.
6. Describe the systemic veins.
7. Describe the main lymphatic vessels.
8. Describe the lymphoid organs.

1 - Elements of cardiovascular system

The cardiovascular system, also called the circulatory system, is an organ system that supplies the tissues with essential substances and removes waste.

The cardiovascular system is composed of:

- the heart, working as a pump pushing the blood into the vessels;
- the blood vessels, distributing blood throughout the body: arteries carry the blood away from the heart and veins carry the blood to the heart.
- the lymphatic vessels, returning the excessive fluid from the tissues into the blood vessels.

- the blood, a fluid running inside the blood vessels.
- the lymph, a fluid running inside the lymphatic vessels.

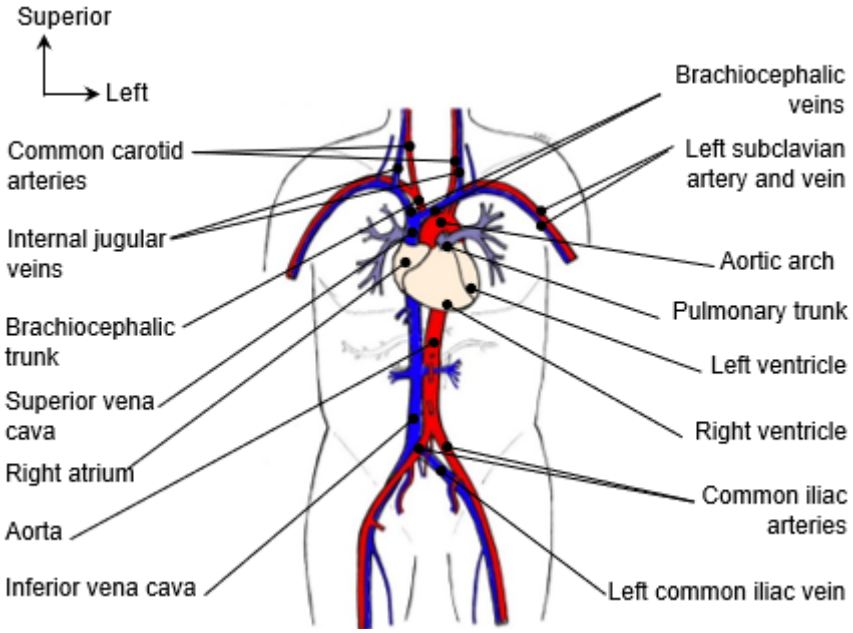

Figure 178: Diagram of blood circulation. Anterior view.

1.1 - Heart

The heart is a vital organ that is a central element of the cardiovascular system. It functions as a double pump, sending the blood in two blood circuits – the systemic circuit and the pulmonary circuit.

Structure and organisation of the heart

The heart is a hollow organ filled with the blood. The heart wall is formed by three layers:

- Myocardium is a muscular layer, composed of a cardiac muscle tissue.

- Endocardium is a thin membrane forming the innermost layer, lining the inner surfaces of the heart chambers, and forming the heart valves.
- Epicardium forms the outermost layer of the heart wall and the innermost layer of the pericardium, which is the sac enveloping the heart.

Cardiac septum divides the heart into the left and right side. Any communication between the two sides is pathological. On each side of the heart there are two heart chambers, atrium, and ventricle. Between the atrium and ventricle lies the atrioventricular valve. Opening and closing of the valve keeps the blood flowing in the correct direction – from atrium into the ventricle.

The right atrium receives deoxygenated blood from the superior and inferior vena cava, and the right ventricle pushes the blood into the pulmonary trunk. Between the right ventricle and the pulmonary trunk lies the pulmonary valve.

The left atrium receives the oxygenated blood from the two left and two right pulmonary veins, and the left ventricle pushes the blood into the aorta. Between the left ventricle and the aorta lies the aortic valve.

External morphology of the heart

The heart has a shape of a cone. The base of the heart is positioned postero-superiorly and to the right. It is formed by the atria. The apex of the heart is positioned antero-inferiorly and to the left. It is formed by the left ventricle. The heart can be described as having five surfaces: the anterior or sternocostal surface, the left and right pulmonary surface, the inferior or diaphragmatic surface and the posterior surface, which is the base of the heart.

The circumferential groove on the surface of the heart that separates the atria from the ventricles is called the atrioventricular sulcus or the coronary sulcus.

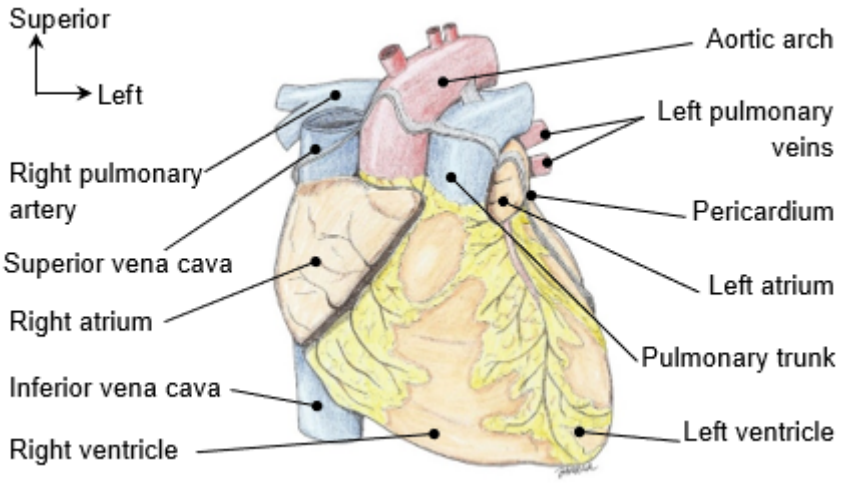

Figure 179: Anterior (sternocostal) surface of the heart.

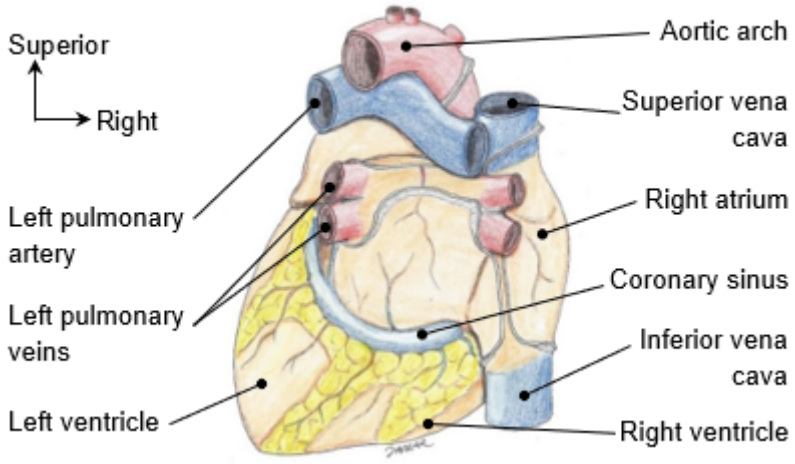

Figure 180: Posterior and inferior (diaphragmatic) surface of the heart.

Blood supply of the heart

The blood to the heart is supplied by two coronary arteries, the first two branches of the aorta.

The left coronary artery has a diameter of 7 mm and is only 3-4 cm long. Just before reaching the coronary sulcus, it divides into two

terminal branches: the circumflex artery and the anterior interventricular artery.

- The circumflex artery runs inside the coronary sulcus to the left, supplying blood to the lateral and partly the diaphragmatic wall of the left ventricle.
- The anterior interventricular artery runs in the anterior interventricular sulcus towards the apex, where it anastomoses with the posterior interventricular artery. It supplies blood to the anterior wall of the left ventricle, part of the anterior wall of the right ventricle and most of the interventricular septum.

  Branches of both arteries supply blood to the left atrium.

The right coronary artery has a calibre of 4 to 5 mm at its origin. It passes between the pulmonary trunk and the right auricle to reach the coronary sulcus, inside which it runs to the right. On the posterior side, it gives off the posterior interventricular artery which runs in the posterior interventricular sulcus towards the apex.

The right coronary artery supplies blood to most of the right ventricle, part of diaphragmatic wall of the left ventricle and posterior part of the interventricular septum. It also supplies blood to the right atrium.

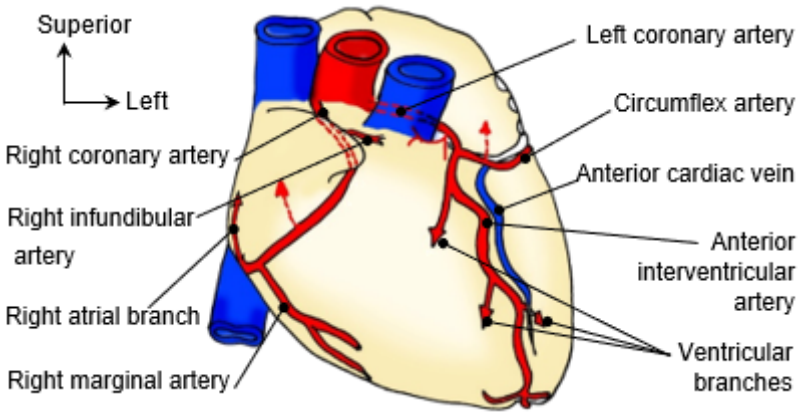

Figure 181: Blood supply to the heart. Sternocostal surface.

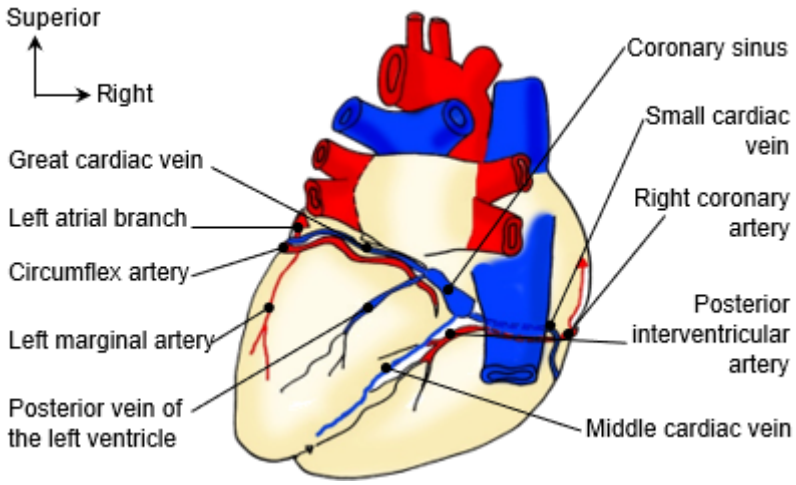

Figure 182: Blood supply to the heart. Diaphragmatic surface.

Most of venous blood from the heart wall is collected by the coronary sinus which lies inside the coronary sulcus on the posterior side of the heart and drains into the right atrium.

The great, middle, and small cardiac veins drain into the coronary sinus. The rest of the venous blood flows into the right atrium via the anterior cardiac vein, and into the atria and ventricles via numerous small veins.

Cardiac conduction system and innervation of the heart

The heart contractions are initiated and controlled by the conducting system of the heart – a network of specialised cardiac muscle cells that can generate an action potential on their own.

The parts of the conducting system of the heart are the sinoatrial node, the atrioventricular node, the atrioventricular bundle which divides into the left and the right bundle branch, and the Purkinje fibres (subendocardial branches).

The impulse for contraction is normally generated in the sinoatrial node and then conducted through the other parts of the conducting system to the myocardial cells.

The heart is innervated by the autonomic nervous system. The sympathetic nerve fibres innervate the conducting system, increasing the heartrate, and the myocardial cells, increasing the force of contraction. The parasympathetic nerve fibres travel to the heart via the vagus nerve and innervate the conducting system, reducing the heartrate.

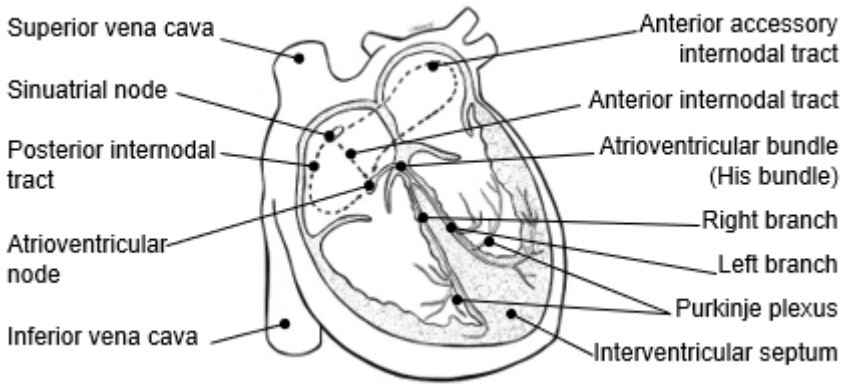

Figure 183: The conducting system of the heart.

Fibrous skeleton of the heart

The four heart ostia inside which the heart valves lie are surrounded by fibrous rings that form the fibrous skeleton of the heart.

The fibrous skeleton of the heart completely separates the myocardium of the atria from the myocardium of the ventricles, allowing the separated contraction of atria and ventricles. Through the skeleton passes the atrioventricular bundle of the conducting system, transferring the impulse for contraction from atrioventricular node to the ventricles.

The fibrous skeleton of the heart is connected to the membranous part of the ventricular septum.

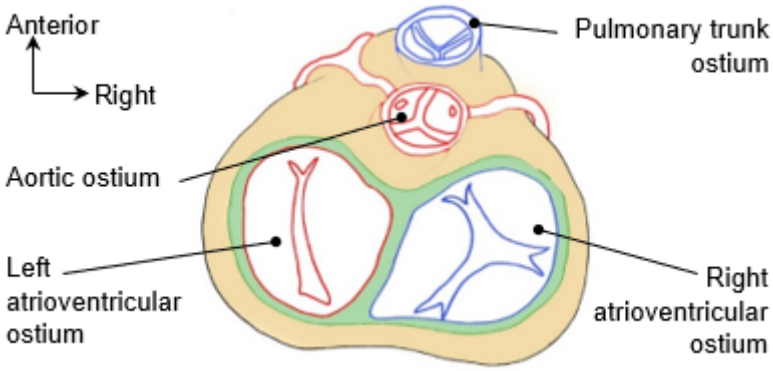

Figure 184: Fibrous skeleton of the heart.

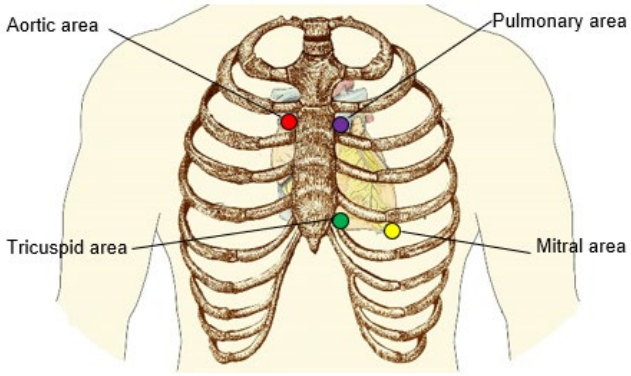

Figure 185: Heart auscultation points.

Blood flow through the heart

The heart is a double pump. The left side of the heart is pushing the blood into the systemic circulation and the right side of the heart is pushing the blood into the pulmonary circulation.

The major circulation or systemic circulation serves to transport oxygen and nutrients to the tissues and to remove carbon dioxide (CO2) and other waste products from the tissues. The left atrium receives the oxygenated blood from the pulmonary circulation. Blood flows from the left atrium to the left ventricle through the mitral valve. The left ventricle pushes the blood through the aortic valve into the aorta. The branches

of aorta, systemic arteries, finally branch into the systemic capillaries which give off the oxygen and the nutrients into the tissues and receive the carbon dioxide and other waste products of metabolism from the tissues. The deoxygenated blood is collected from the tissues by systemic veins, which finally drain into two great systemic veins entering the right atrium – the superior and the inferior vena cava.

The minor circulation or pulmonary circulation is responsible for enabling the oxygenation of the blood in the lungs. The deoxygenated blood flows from the right atrium to the right ventricle through the tricuspid valve. The right ventricle pushes the blood through the pulmonary valve into the pulmonary trunk. The pulmonary trunk divides into the right and the left pulmonary artery, which enter the right and the left lung, respectively. Inside the lungs they divide to the level of pulmonary capillaries. The pulmonary capillaries receive oxygen from the alveoli and give off carbon dioxide into the alveoli. The oxygenated blood is collected by pulmonary veins, which finally drain into two right and two left pulmonary veins which enter the left atrium.

Pericardium

The pericardium is a fibro-serous sac that surrounds the heart and the roots of the great vessels.

The fibrous pericardium completely envelops the heart. It consists of dense connective tissue and is not stretchable. It is firmly attached to the central tendon of the diaphragm, and merges with the outer, fibrous layer of the wall of the great vessels.

The serous pericardium lies inside the fibrous pericardium and is composed of two layers. The outer layer is fused to the fibrous pericardium which is called the parietal layer of serous pericardium. The inner layer is attached to the myocardium, forming the outer layer of the heart wall, the epicardium. It is also named the visceral layer of serous pericardium. Both layers are continuous with each other, enclosing the pericardial cavity. Inside the cavity there is a small amount of serous pericardial fluid which prevents friction during heart contractions.

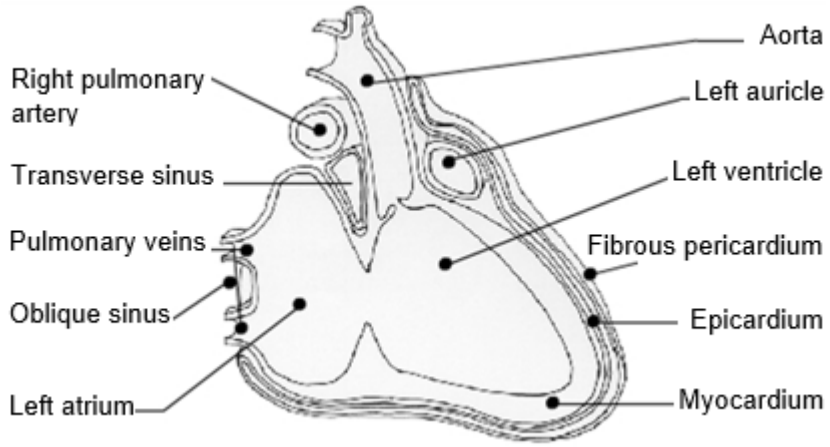

Figure 186: Section along the longitudinal axis of the heart showing the left heart chambers and the pericardium.

1.2 - Blood vessels

The blood vessels are contractile cylindrical channels through which the blood flows.

The wall of blood vessels has three layers:

- Tunica intima is the innermost layer and consists of epithelial tissue. It is lined by an endothelium, which is formed by a single layer of simple squamous epithelial cells.
- Tunica media is the middle, muscular layer and consists of smooth muscle tissue.
- Tunica externa (adventitia) is the outermost layer and consists of connective tissue.

The arteries have thicker wall than the veins, the thickest layer being the tunica media. The thickest layer of the venous wall is the tunica adventitia.

Depending on their calibre, arteries and veins can be divided into two categories:

- arteries / veins are vessels of bigger calibre,

- arterioles / venules are vessels of smaller calibre.

Arterial and venous systems are connected through the capillary network. Capillaries are the vessels of the smallest calibre. They have very thin and perforated wall which allows the molecular exchange between the blood and the surrounding tissues.

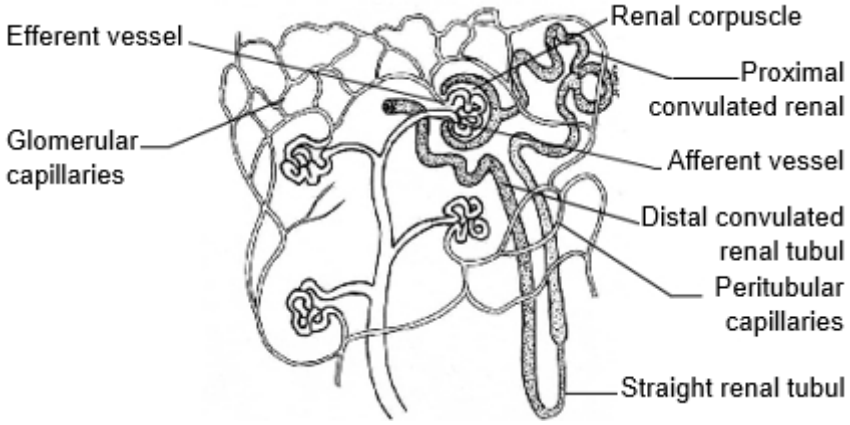

Figure 187: Arterial capillary plexus of the renal cortex.

Arteries of systemic circulation

The systemic arteries are vessels transporting the oxygenated blood from the heart to the tissues, supplying them with oxygen and nutrients.

The left ventricle pumps the blood into the arteries with each contraction, causing the distension of the arterial wall. This distension is followed by the arterial wall contraction, sending the blood further along the arterial system. Thus, formed arterial pulsations can be palpated on certain arteries allowing to measure the frequency with which the heart contracts (the heartbeat).

Two or more arteries can be connected to each other. Such a connection is called anastomosis. The anastomoses provide an alternative pathway for blood supply to the target organ or portion of organ in case the primary pathway is obstructed.

Terminal arteries are the arteries that are the only pathway for supplying a portion of organ.

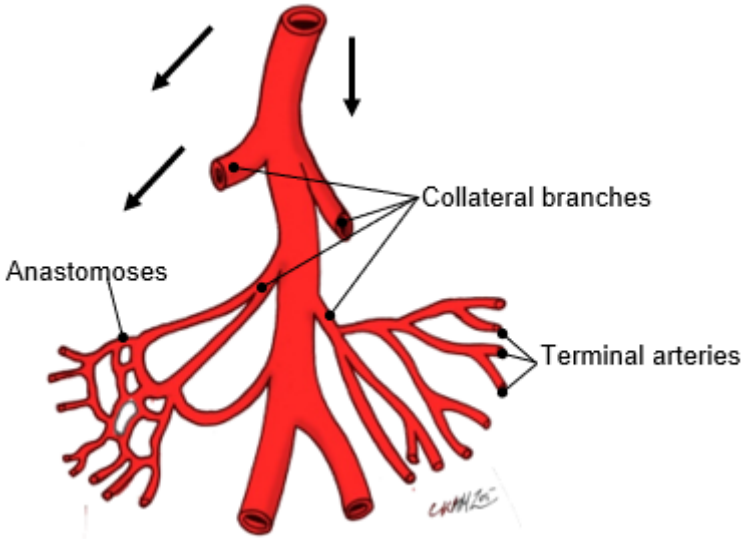

Figure 188: Anastomoses and terminal arteries.

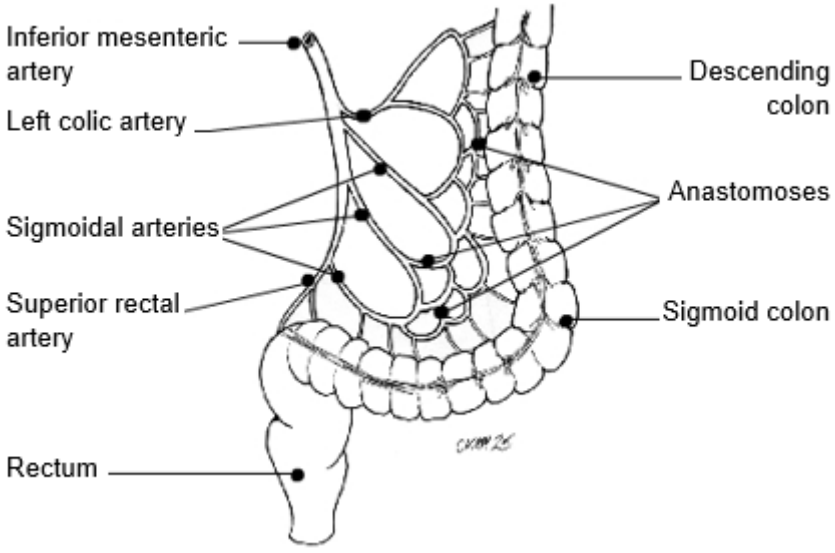

Figure 189: Anastomoses supplying the colon.

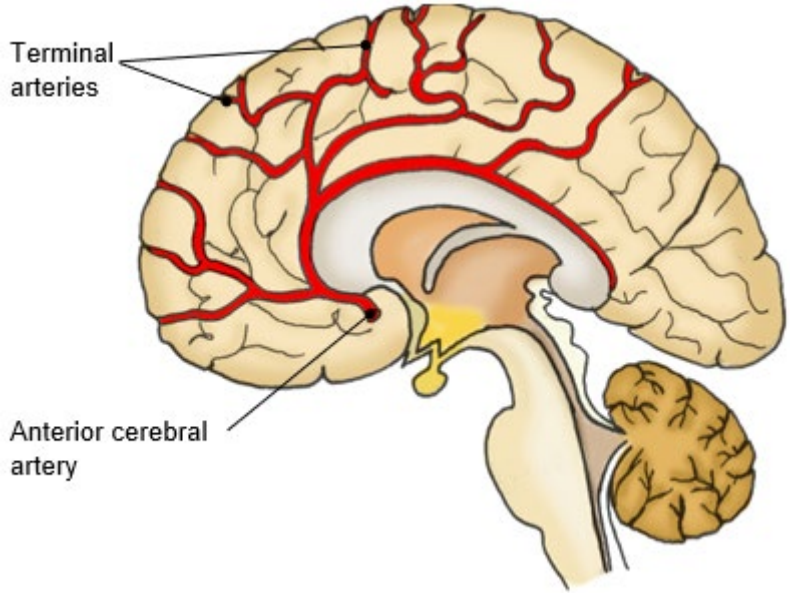

Figure 190: Terminal arteries supplying the brain. Median section, view from the left.

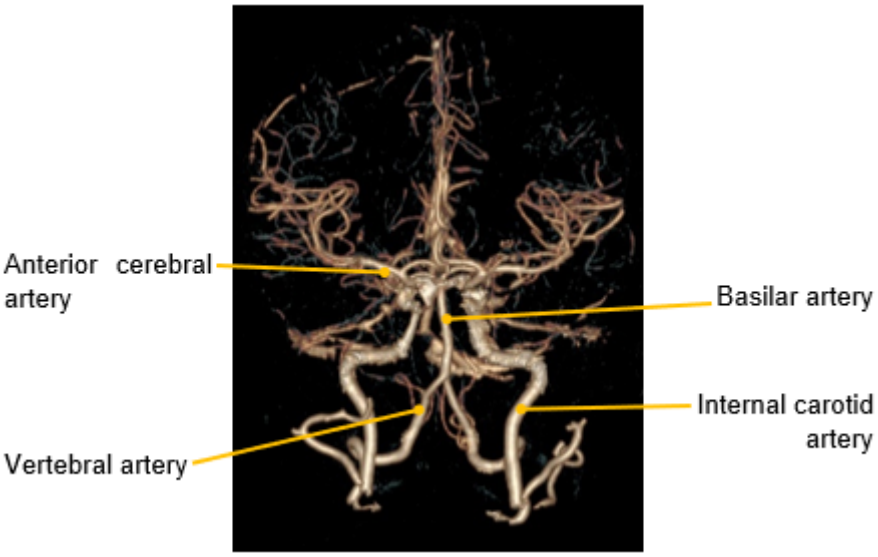

Figure 191: Reconstruction of the arterial supply to the brain. Anterior view.

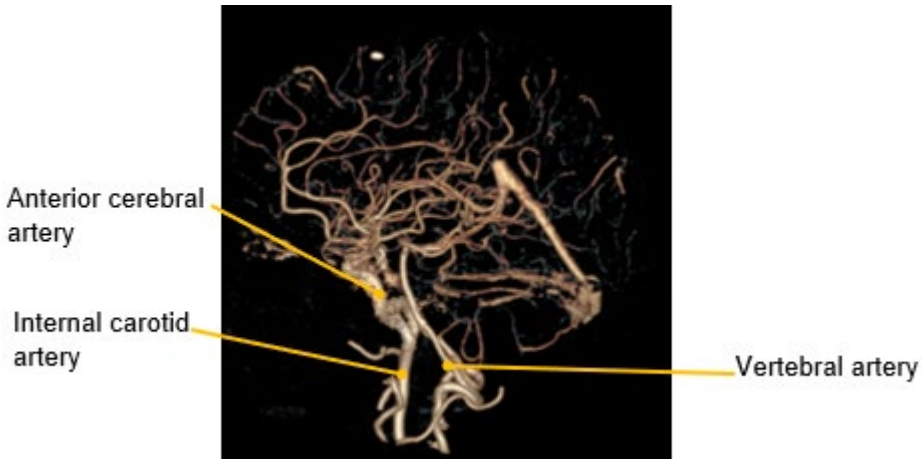

Figure 192: Reconstruction of the vascular supply to the brain. Left lateral view.

Collateral artery is a branch of a main artery that runs parallel to the main artery, maintaining the same direction of blood flow. The collateral and main artery can anastomose.

A recurrent artery is a branch of a main artery that after branching off turns in the direction opposite to the main artery. It can then run parallel to the main artery, but the blood flow inside it is opposite to the blood flow in the main artery.

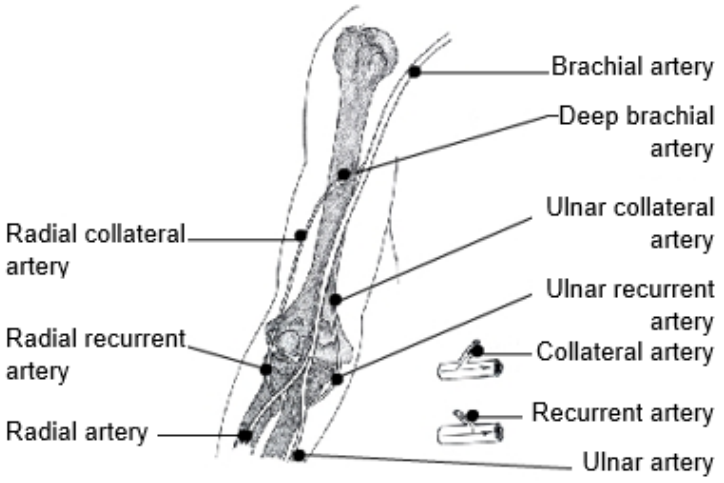

Figure 193: Arteries around the right elbow joint. Anterior view.

Aorta

Aorta exits the left ventricle and runs through the thoracic and abdominal cavity.

It has three parts: ascending aorta, aortic arch, and descending aorta.

Ascending aorta lies within the pericardium. It supplies blood to the heart.

Aortic arch lies in the superior mediastinum. It supplies blood to the head, the neck, and upper extremities.

Descending aorta lies along the left side of the vertebral column and passes the aortic hiatus in the diaphragm at the level of vertebra T12. According to the position in the thoracic or abdominal cavity, the descending aorta is divided into two parts: the thoracic aorta, which supplies blood to the thorax, and the abdominal aorta, which supplies blood to the abdomen.

At the level of the intervertebral disc L4-L5, abdominal aorta bifurcates into the right and left common iliac arteries, which supply blood to the pelvis and lower extremities.

The ascending aorta has two branches:

- right coronary artery,
- left coronary artery.

The arch of the aorta has three branches:

- brachiocephalic trunk,
- left common carotid artery,
- left subclavian artery.

The thoracic aorta has several branches:

- bronchial branches,
- oesophageal branches,
- pericardial branches,
- mediastinal branches,

- posterior intercostal arteries,
- subcostal artery,
- superior phrenic arteries.

The abdominal aorta also has several branches:

- inferior phrenic arteries,
- lumbar arteries,
- coeliac trunk,
- superior mesenteric artery,
- middle suprarenal artery,
- renal artery,
- ovarian / testicular artery,
- inferior mesenteric artery.

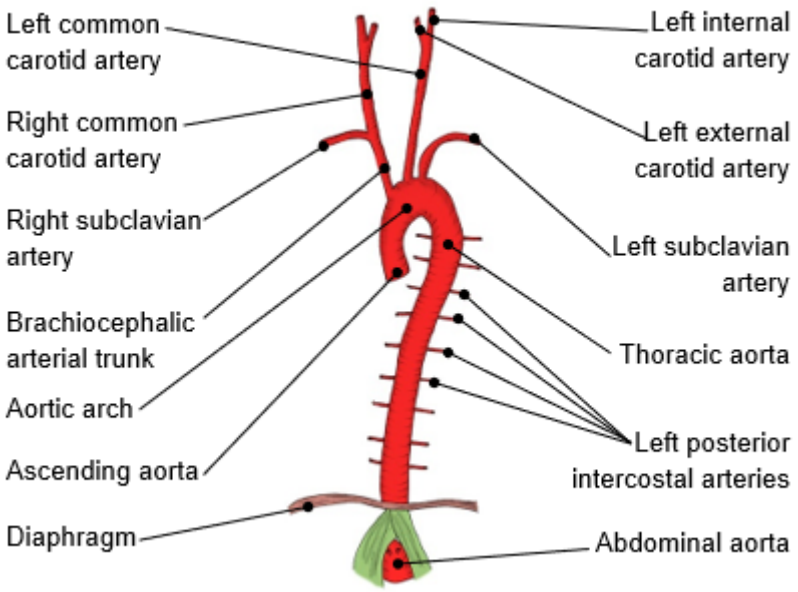

Figure 194: The thoracic part of the aorta and its branches. Anterior view.

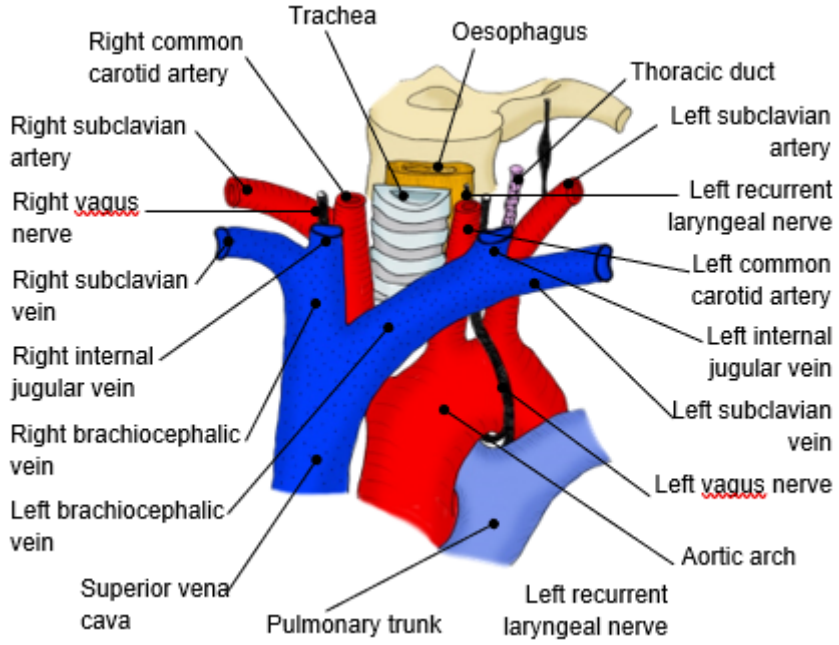

Figure 195: Topography of aortic arch. Anterior view.

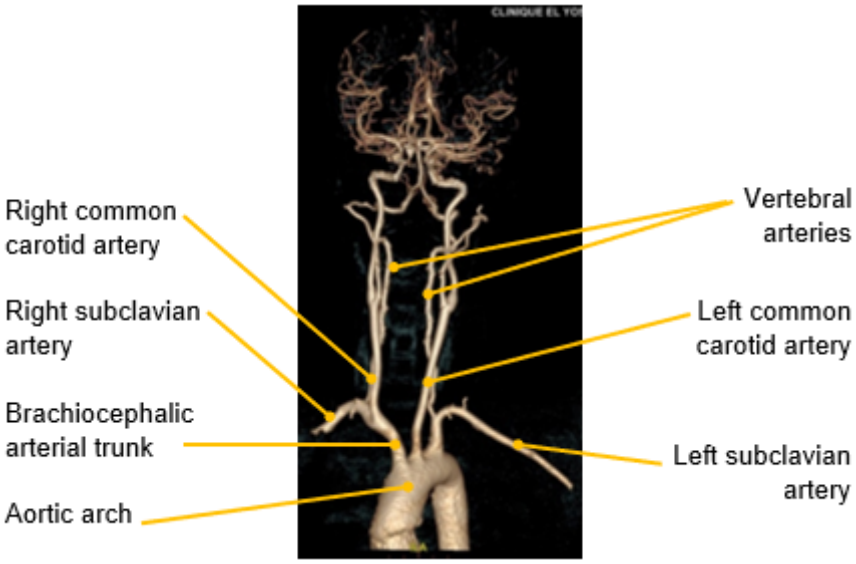

Figure 196: Reconstruction of the aortic arch with branches. Anterior view.

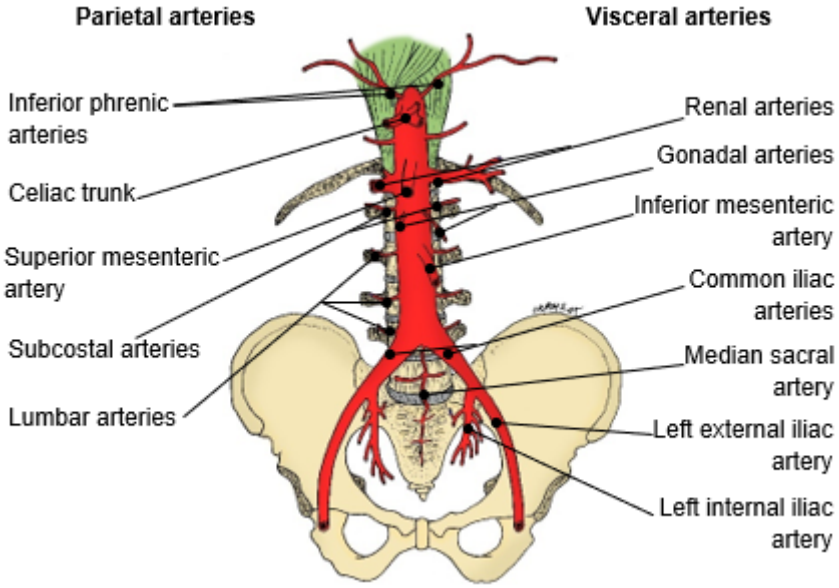

Figure 197: The abdominal aorta and its branches. Anterior view.

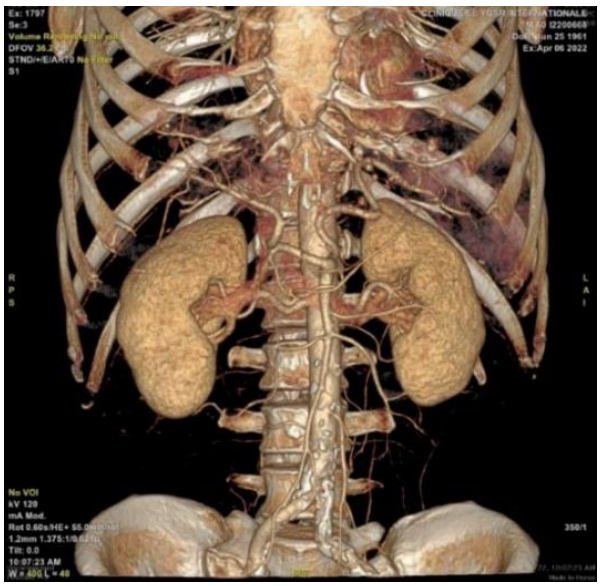

Figure 198: CT reconstruction of the abdominal aorta. Anterior view.

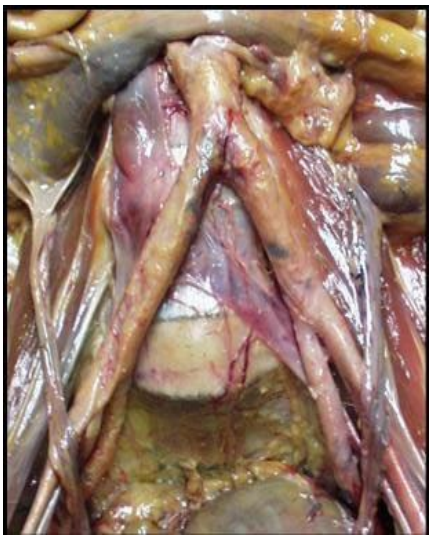

Figure 199: Aortic bifurcation. Anterior view.

Arterial supply of upper limb

The upper limb is supplied by the subclavian artery. The right subclavian artery arises from the brachiocephalic trunk, while the left one arises directly from the aortic arch.

The subclavian artery enters the upper limb passing through the superior thoracic aperture and then passing under the middle of the clavicle. At the lower margin of the clavicle, it changes its name to become the axillary artery. At the level of the inferior border of the pectoralis major muscle, it is renamed into the brachial artery.

The latter runs across the medial aspect of the arm and enters the cubital fossa on the anterior aspect of elbow, where it divides into two terminal branches: the radial and the ulnar artery.

The radial artery runs on the lateral side of the anterior compartment of the forearm and crosses the wrist laterally to reach the dorsum of the hand. Its final part pierces through the 1st intermetacarpal space and forms the deep palmar arch, anastomosing with the branch of ulnar artery. Branches of radial artery form the dorsal carpal network.

The ulnar artery, which runs on the medial side of the anterior compartment of the forearm, crosses the wrist anteriorly, and ends in the palm forming the superficial palmar arch, anastomosing with the branch of radial artery. On the proximal part of the forearm, it gives off a branch called the interosseous artery.

This artery runs deep in the posterior compartment of the forearm, just behind the interosseous membrane, and ends in the dorsal carpal network.

From the superficial palmar arise the palmar digital arteries, which supply the fingers. From the deep palmar arch arise the palmar metacarpal arteries which supply the metacarpus.

Palpable pulses in the upper limb are axillary, brachial, radial and ulnar pulse.

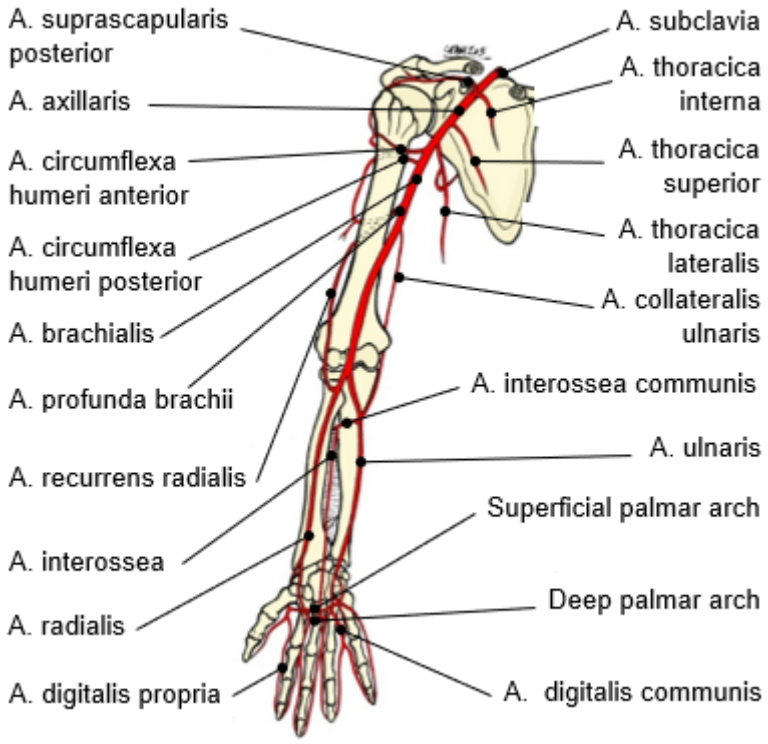

Figure 200: The arteries of the right upper limb. Anterior view.

Arterial supply of lower limb

The lower limb is supplied by the external iliac artery, which is the branch of the common iliac artery. Left and right common iliac arteries are the final branches of the aorta.

After passing behind the inguinal ligament, the external iliac artery changes its name to the femoral artery. The femoral artery runs from the inguinal ligament towards the knee on the anteromedial aspect of the thigh, between the anterior and medial compartment of the thigh. It then passes through the hiatus in the adductor magnus muscle where it changes the name to become a popliteal artery.

The popliteal artery runs just behind the articular capsule of the knee joint, deep in the popliteal fossa. At the proximal part of the leg, it divides into two terminal branches, the anterior tibial artery and the tibio-peroneal trunk. The latter divides after a short distance into two terminal arteries, the posterior tibial artery and the fibular artery.

The anterior tibial artery crosses the interosseous membrane of the leg and enters into the anterior compartment of the leg, where it runs in front of the interosseous membrane. It crosses the ankle to reach the dorsum of the foot where it is called the dorsal artery of the foot.

The posterior tibial artery runs in the posterior compartment of the leg, close to the transverse crural intermuscular septum. It crosses the ankle behind the medial malleolus and enters the sole of the foot, where it divides into the medial and lateral plantar artery.

The pulses palpable at the level of the lower limb are the femoral, popliteal, and two pedal pulses –the dorsal artery of the foot (from the anterior tibial artery) on the dorsum of the foot, and the posterior tibial artery behind the medial malleolus.

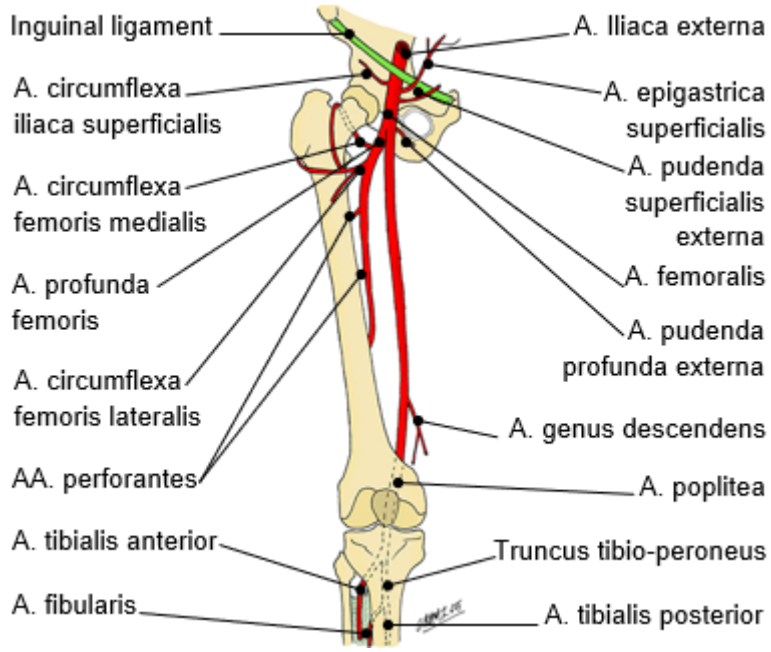

Figure 201: The arteries of the right lower limb, thigh region. Anterior view.

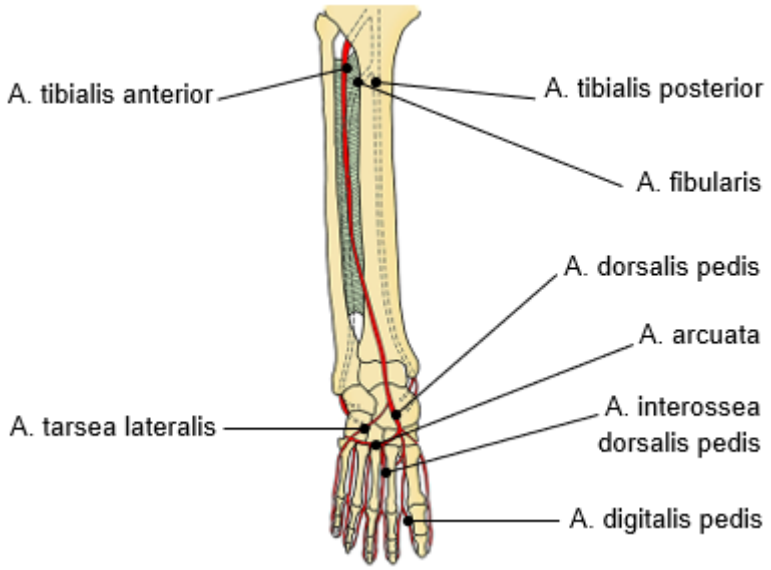

Figure 202: The arteries of the right lower limb, leg and foot region. Anterior view.

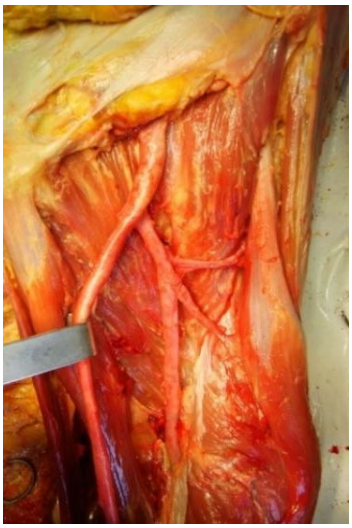

Figure 203: Dissection of the femoral triangle. The femoral artery and its branch, the deep femoral artery.

Veins of systemic circulation

The systemic veins are vessels transporting the deoxygenated blood from the tissues to the heart, removing the carbon dioxide and other waste products of metabolism from the tissues.

Unlike the arteries, the veins do not pulsate.

Many of the systemic veins have crescent-shaped valves protruding into the lumen at longer intervals, dividing long vessels into segments. The valves prevent the blood to flow away from the heart in the direction of gravity.

While arteries lie only in the deep compartment of the body, veins can be also found just beneath the skin, superficially to the investing fascia which divides the deep and the superficial compartment. The veins are therefore divided into two groups: the deep veins which follow the course of the arteries and the superficial veins in the subcutaneous tissue. The superficial veins eventually cross the investing fascia and drain into the deep veins. The superficial veins can serve as an access route for infusion of fluids in the body, injecting the therapy into the

bloodstream, and withdrawal of blood sample for the laboratory testing.

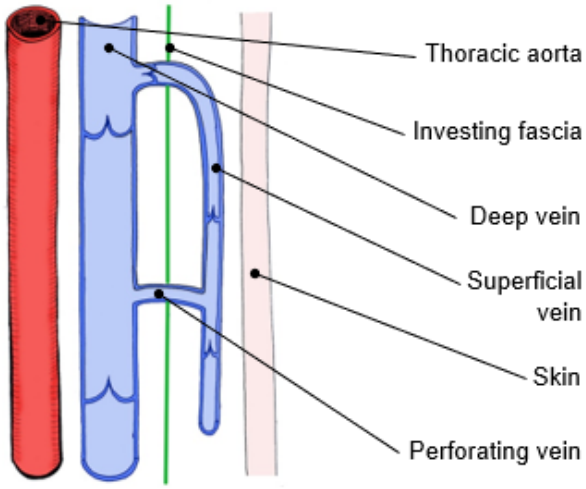

Figure 204: Deep and superficial veins.

The deoxygenated blood returns to the heart via two great veins that enter the right atrium: the superior and inferior vena cava. Both veins anastomose through the cavo-caval anastomoses.

Venous blood from the abdominal part of digestive system first collects in a special venous system called the portal venous system, and only after filtration in the liver it enters the caval system.

Superior vena cava

The superior vena cava lies in the thoracic cavity. It collects venous blood from the upper half of the body. It is formed by union of the right and left brachiocephalic veins and it ends at the level of the ostium of the superior vena cava in the right atrium.

The brachiocephalic vein is formed by union of the internal jugular vein and subclavian vein. The internal jugular vein collects venous blood from the head and the neck, and the subclavian vein collects venous blood from the upper limb.

The azygos vein drains directly into the superior vena cava. It collects venous blood from the thorax. The blood from the left side of the thorax is first collected by the hemiazygos vein and the accessory hemiazygos vein, which drain into azygos vein.

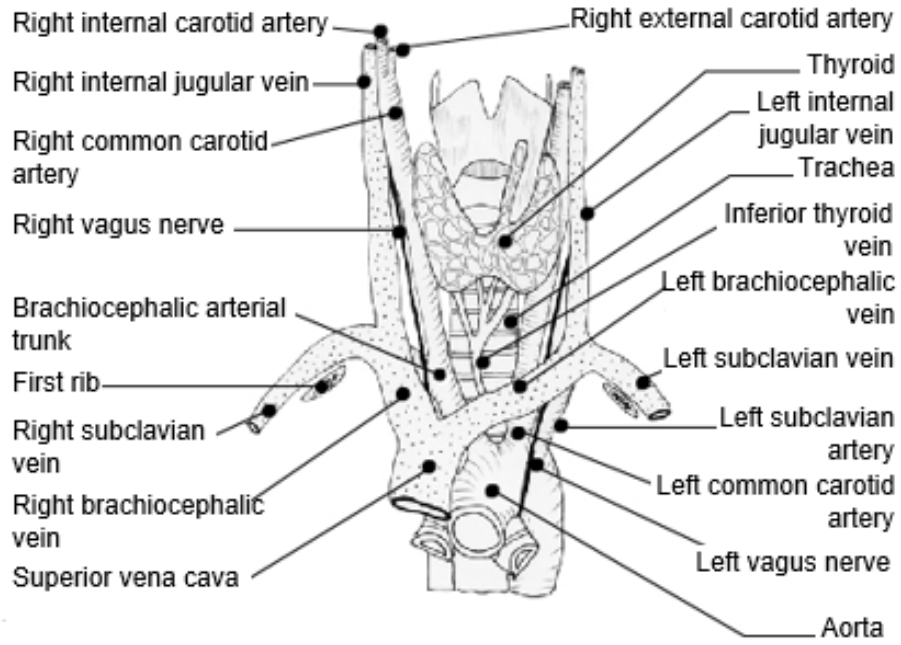

Figure 205: The superior vena cava.

Figure 206: The drawing of the left internal jugular vein.

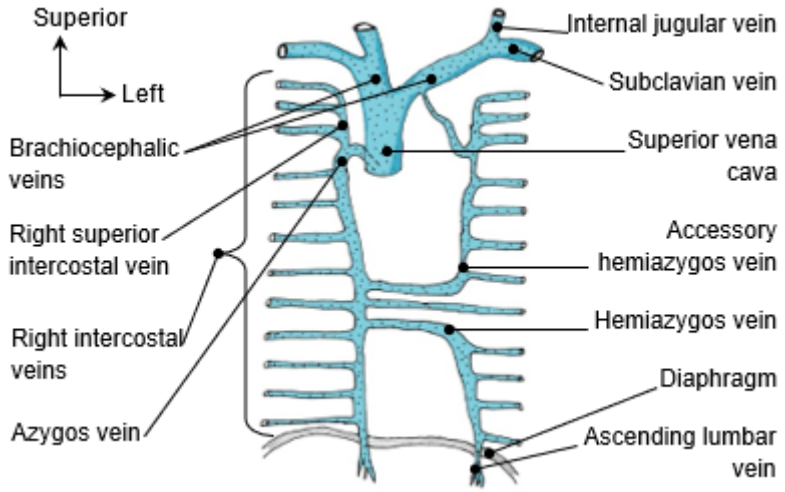

Figure 207: The azygos, hemiazygos, and accessory hemiazygos veins. Anterior view.

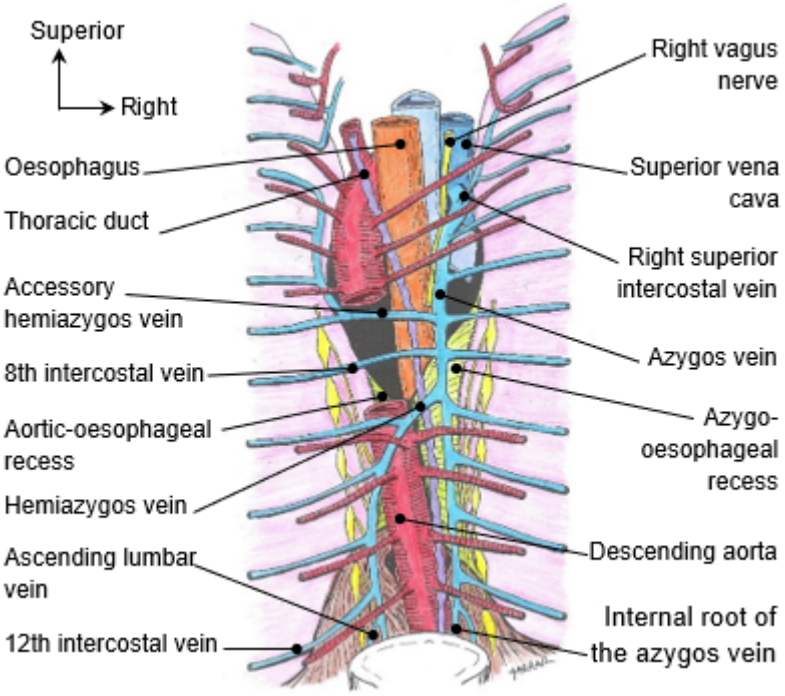

Figure 208: The azygos, hemiazygos, and accessory hemiazygos veins. Posterior view.

Inferior vena cava

The inferior vena cava lies in the abdominal cavity right to the abdominal aorta. It collects venous blood from the lower half of the body. It is formed by union of the right and left common iliac veins at the level of vertebra L5. It passes the caval foramen in the central tendon of the diaphragm at the level of vertebra T8, it immediately enters the pericardium and opens into the right atrium through the ostium of the superior vena cava.

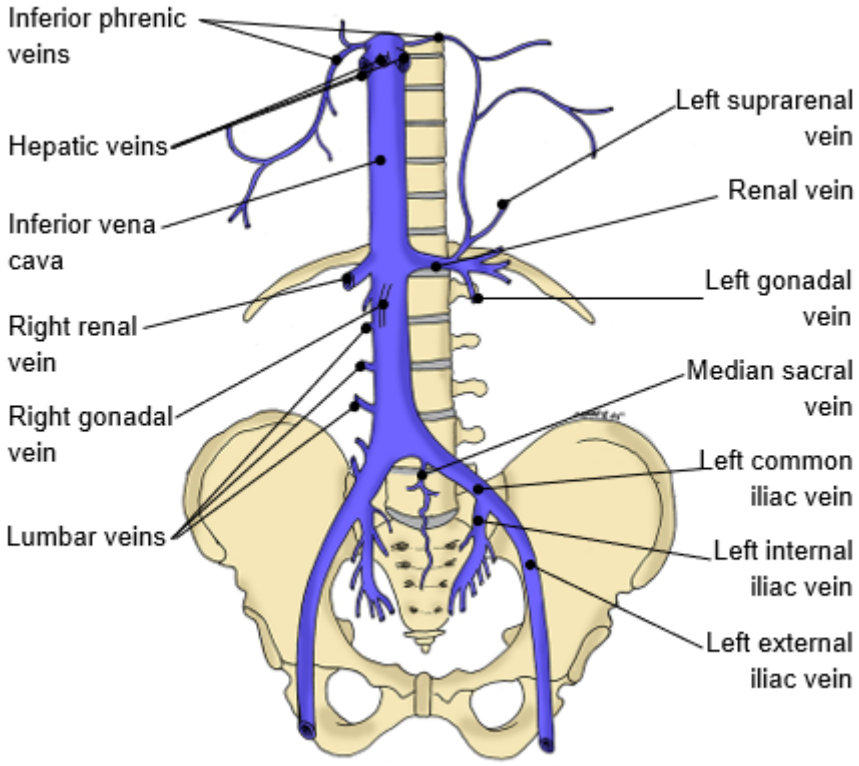

Figure 209: The inferior vena cava.

Portal venous system

A portal venous system is a connection of two capillary networks through veins, without passing through the heart.

Hepatic portal vein collects the venous blood from the capillary network of the abdominal part of the digestive canal, pancreas, and spleen. It delivers blood to the liver. During filtration in the capillary network of the liver, the substances absorbed from the food can be processed if necessary, before entering the inferior vena cava.

Superficial veins of the limbs

The upper limb has two main superficial veins: the basilic vein, which drains into the brachial vein and the cephalic vein, which drains into the axillary vein.

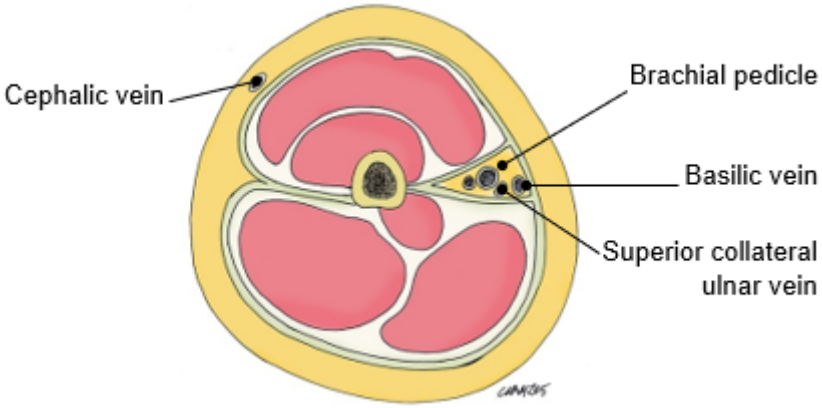

Figure 210: Transverse section of the middle third of the arm. The basilic vein already crossed the brachial fascia.

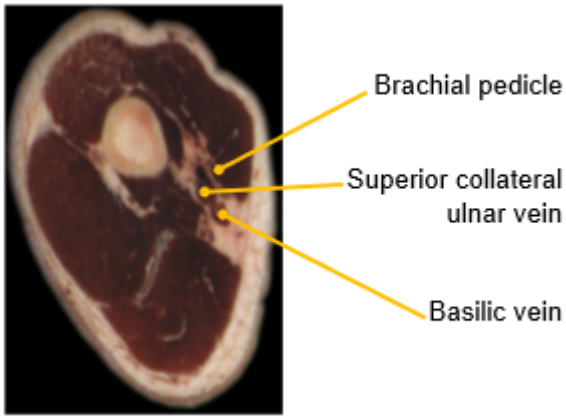

Figure 211: Transverse section of the middle third of the arm.

The lower limb also has two main superficial veins: the small saphenous vein, which drains into the popliteal vein and the great saphenous vein, which drains into the femoral vein. Dilated insufficient veins of the lower limbs form varicose veins.

1.3 - Lymphatic vessels

The lymphatic vessels are thin-walled vessels structured similarly to the veins. They carry lymph.

Unlike the blood vessels, which are arranged into a closed circle, the lymphatic vessels form an open system. The lymphatic capillaries begin blind-ended in the intercellular space of the tissue. They merge to form bigger lymphatic vessels, but even the biggest have only a diameter of 5 mm or less. The lymphatic vessels finally join the veins and in consequence the lymph enters the bloodstream.

The lymphatic vessels remove the excessive fluid from the tissue and thus maintain the fluid homeostasis. The pores in the wall of lymphatic capillaries are wider than pores in the wall of the blood capillaries. So the particles too big to enter the blood capillaries enter the bloodstream as part of the lymph.

Lymph from the lower part of the body and the left half of the upper part of the body is collected by the thoracic duct which drains into the left venous angle – the angle between the joining internal jugular and subclavian vein. Lymph from the right half of the upper part of the body is collected by the right lymphatic duct.

Before reaching the bloodstream, lymph is filtered through the lymph nodes.

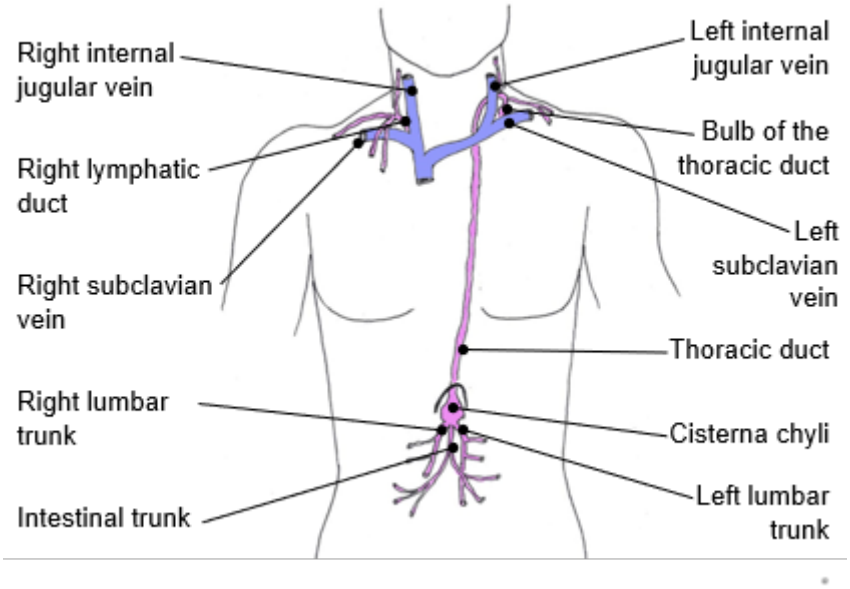

Figure 212: Lymphatic vessels.

Thoracic duct

The thoracic duct is 40-45 cm long and has a diameter of about 5 mm.

It originates from the upper end of cisterna chyli. The cisterna chyli is a dilated sac in front of the bodies of the vertebra L1 and L2, posteriorly to the abdominal aorta. It collects the lymph from the lower extremities, the pelvis and the abdomen through the right and left lumbar trunks and one or more intestinal trunks.

The thoracic duct passes the diaphragm through the aortic hiatus and ascends posteriorly to the aorta in front of the vertebral column in the posterior mediastinum. It reaches up to the level of vertebra C7 and finally terminates in the left venous angle.

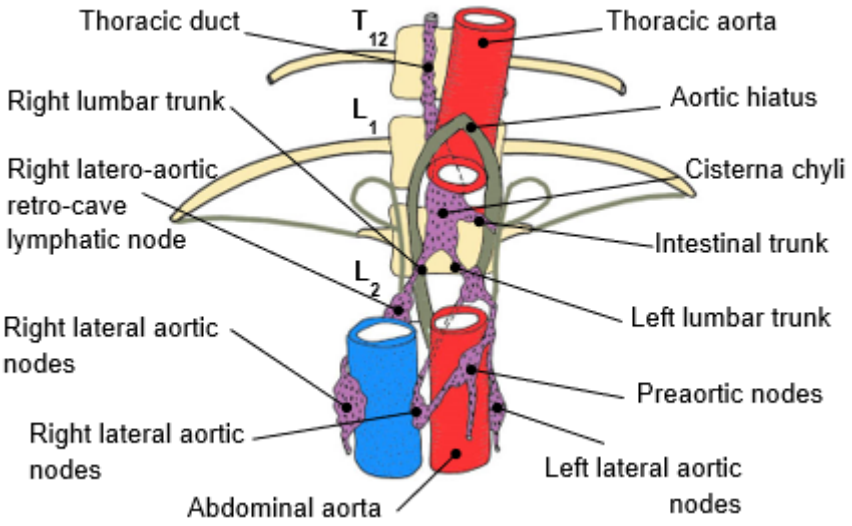

Figure 213: Origin of the thoracic duct.

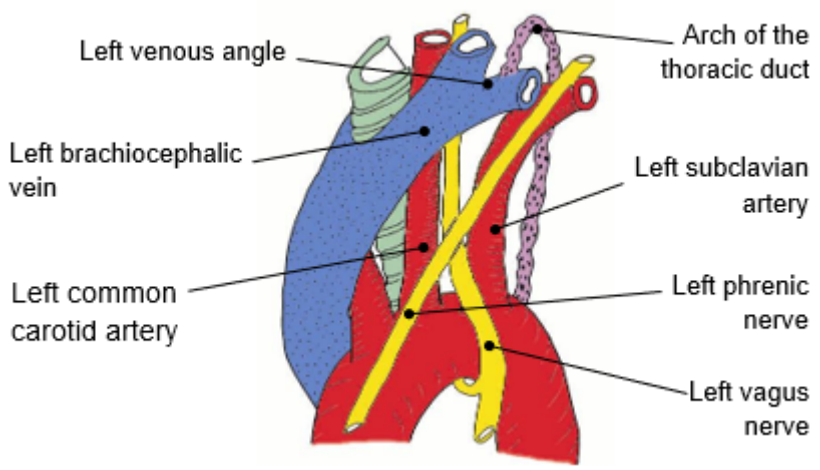

Figure 214: Termination of the thoracic duct.

Right lymphatic duct

The right lymphatic duct drains lymph from the upper right quarter of the body.

It arises from the union of various lymphatic vessels that drain lymph from the right upper extremity and the right side of the head, the neck and the thorax. It is 1-2 cm long and lies at the base of the neck. It terminates in the right venous angle.

2 - Lymphoid organs

The lymphoid organs are part of the immune system. Their function is to create an immune defence, protecting the body from infections and other diseases.

The lymphoid organs are divided into two groups:

- Primary lymphoid organs are red bone marrow and thymus. These are the organs in which new lymphocytes develop and mature.
- Secondary lymphoid organs are the spleen, pharyngeal lymphoid ring, and lymph nodes. These are the organs in which mature lymphocytes relocate, and in case of infection, activate and initiate the immune response.

Red bone marrow

The red bone marrow, also known as the hematopoietic bone marrow, is a semi-solid tissue that produces new blood cells. It is located in the cavities of the spongy bones or portions of bones.

The red bone marrow contains the hematopoietic stem cells that generate the three different classes of blood cells with a specific function which exit the marrow and become part of the blood:

- Red blood cells, erythrocytes, transport oxygen from the lungs to all the parts of the body. Erythrocytes make up about 40-45 % of the blood volume and give blood its red color.
- White blood cells, leukocytes, are part of the immune system. They protect body from infections and other diseases.

- Platelets, thrombocytes, contribute to haemostasis – the process of stopping the bleeding.

The spleen

The spleen is the largest lymphoid organ. Additional function of the spleen is the elimination of aged red blood cells. During the embryonic life, it is able of haematopoiesis.

The spleen lies in the abdominal cavity, underneath the left part of the diaphragm, along the ribs 9-11. It is a soft purple organ enwrapped in a fibroelastic capsule. From the capsule extend the splenic trabeculae, incompletely dividing the parenchyma.

The spleen has two extremities, a posterior and an anterior one, and two surfaces:

- diaphragmatic surface is orientated laterally, convex in shape and leaning onto the diaphragm;
- visceral surface is orientated medially and is in contact with the stomach, left kidney and colon; on this surface is the hilum through which the vessels and nerves pass.

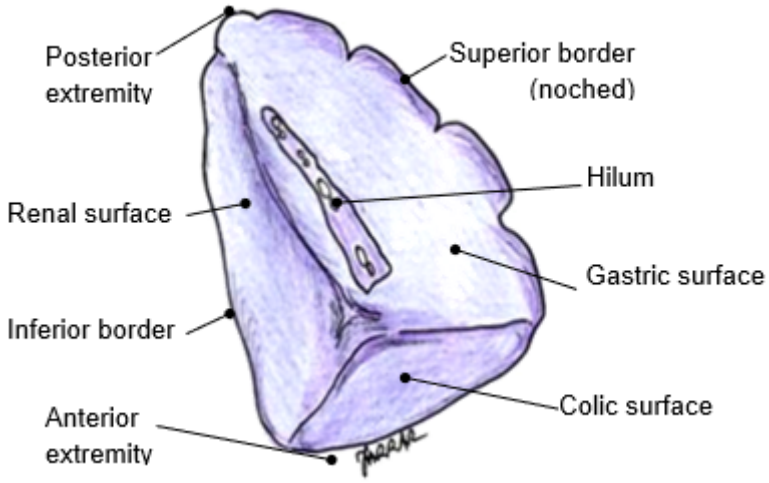

Figure 215: Antero-internal view of the spleen.

Figure 216: View of the spleen.

Microscopically, the parenchymal tissue of the spleen consists of two major components called the white pulp and the red pulp:

- The white pulp is composed of lymphoid tissue in which lymphocytes proliferate in response to infection.
- The red pulp is a complex system of interconnected spaces with numerous macrophages. When the blood runs through this system, the macrophages remove from the blood old erythrocytes, microorganisms, cellular debris, and other particles.

The spleen is supplied by the splenic artery, a branch of the celiac trunk.