Anatomical Principles of the Circulatory System

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Abstract

The circulatory system comprises two interrelated systems: the cardiovascular and the lymphatic vascular systems. The cardiovascular system is composed by the heart and its distribution network: arteries, veins, and capillaries [Color textbook of histology, Philadelphia, 2007]. Its ramifications are depicted inside this chapter. In parallel, the lymphatic system consists of an extensive network of vessels similar to veins that are spread throughout the body. These plexuses contain nodes in its path that are responsible for filtering and carrying back to the blood stream fluids from organs and tissues that did not return to the blood capillaries [Color textbook of histology, Philadelphia, 2007; Gray's anatomy: the anatomical basis of clinical practice, Edinburgh, 2008]. For a better understanding of the main problems and diseases related to this system it is extremely important to review the anatomy of the vessels and the heart before going to the next chapters.

Introduction

The circulatory system comprises two interrelated systems: the cardiovascular and the lymphatic vascular systems. The cardiovascular system is composed of the heart and its distribution network: the arteries, veins, and capillaries [1]. It is

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essential that the practitioner understands that this system plays a crucial role mediating different and complexes interactions, i.e., delivery, removal, transport, maintenance, and prevention. This system ensures a continued blood transport to meet the demands of oxygen, nutrients as well as working as a buffer removing carbon dioxide and metabolic products from cells, maintaining its pH levels under different circumstances (e.g., during physical activity) [1, 2]. Moreover, blood transports hormones from glands to target cells as well as it works to regulate the body's temperature. In parallel, the lymphatic system consists of an extensive network of vessels similar to veins that are spread throughout the body. These plexuses contain nodes in its path that are responsible for filtering and carrying back to the blood stream fluids from organs and tissues that did not return to the blood capillaries [1, 3].

We will first review the cardiovascular system: heart, vessel's anatomy, arterial and venous system. At the end of this chapter we will also revise the lymphatic system.

The Cardiovascular System

The Heart

As a central piece and the pump of the cardiovascular system, the heart is conical shaped and located between the lungs and right behind to the sternum inside the rib cage. Although the heart is a hollow organ, its wall is thick and made of involuntary muscle. This wall is divided into four layers that are disposed in the following order from outside the heart to the hollow part: pericardium, epicardium, myocardium, and endocardium (Fig. 2.1). The myocardium composes the greatest part of the heart's wall and it is made of cardiac striated muscle [4]. The sinuatrial (SA) node, the heart's natural pacemaker, is located in the epicardium between the superior vena cava and the right atrium and is responsible for starting the stimulation of the heart through the atria. After discharging the stimuli, the depolarization is transmitted to the AV node and its bundle to contract the ventricles [5].

This hollow organ is divided into four different chambers, two atria and two ventricles that are respectively responsible for receiving and pumping blood. Moreover, one can separate the blood flow into two circuits: pulmonary and systemic circuit that are responsible, consecutively, for the blood convey between heart and lungs, and heart and tissues [1] (Fig. 2.2).

Because the left ventricle is responsible for pumping blood at much higher pressure to the systemic than to the pulmonary circuit, it usually has the greatest hypertrophied wall of the ventricles [5].

Vessels' Wall: The Endothelium

The walls of vessels differ based on whether it is carrying blood from or towards the heart. Arteries are exposed to a much higher internal pressure and so are thicker and morphologically more complex than veins, which carry blood from tissues to the heart at a lower pressure [1].

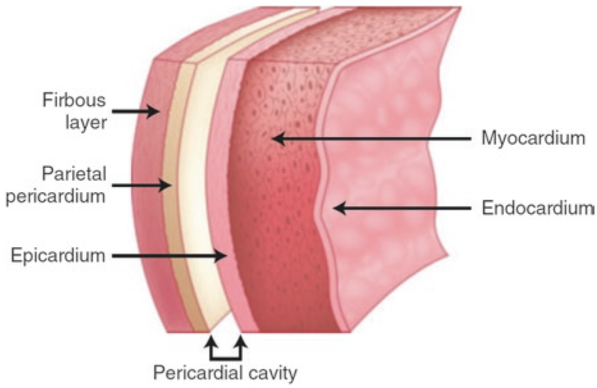


Fig. 2.1 Layers of the heart wall. Reprinted from *Davies A and Scott A. Cardiac Anatomy and Electrophysiology. In: Starting to Read ECG. Springer. 2015*

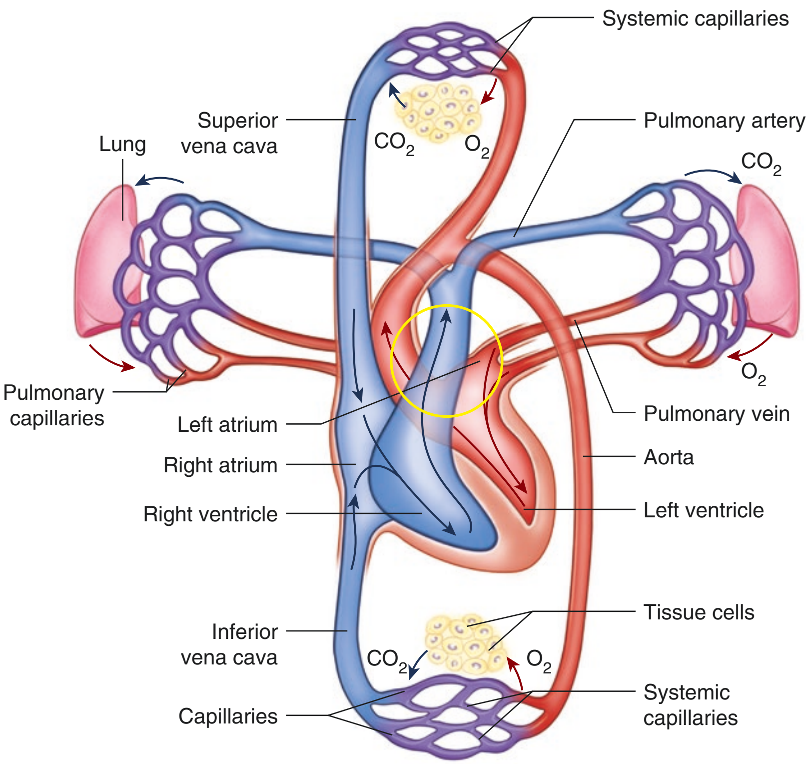


Fig. 2.2 Overview of pulmonary and systemic circuits

The endothelium is the inner cellular lining of all blood vessels, which come into direct contact with circulating blood or lymph [6] (Fig. 2.3). Endocardium is the endothelium of the interior surfaces of the heart chambers. Vascular endothelial

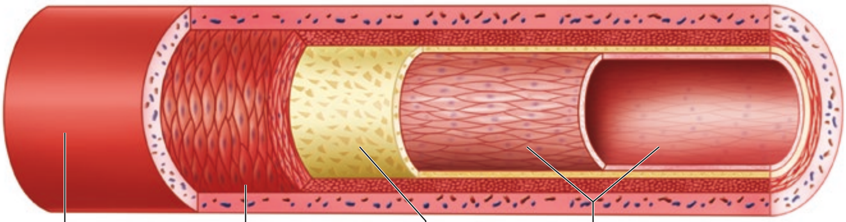


Fig. 2.3 Structure of vessels' wall

cells are those in direct contact with blood whereas those in direct contact with lymph are known as lymphatic endothelial cells. The endothelium acts also as a barrier and regulates the exchange of small and large molecules [7].

Endothelial cells are located on the inner layer of the blood vessels, the tunica intima. Endothelium has a substantial role in regulating the function of vasomotion by its ability to metabolize circulating vasoactive substances and responding to neurotransmitters and vasoactive factors [7, 8].

Endothelial cells are typically aligned in the direction of blood flow, overlapping immediately adjacent cells. They may be continuous (fenestrated or nonfenestrated) and discontinuous. Nonfenestrated continuous endothelium can be found in arteries, veins, and capillaries of the brain, lung, heart, or skin. In arteries and veins, they appear more continuous and thicker than those in capillaries [8]. Fenestrated endothelium occurs in locations of increased filtration or transendothelial transport, such as exocrine and endocrine glands, such as gastric and intestinal mucosa, choroid plexus, glomeruli, and renal tubules. Discontinuous endothelium exists in the liver [6]. The endothelium is indispensable for body homeostasis. It participates in both physiologic and pathologic processes including atherosclerosis, hypertension, pulmonary hypertension, sepsis, and inflammatory syndromes [7].

Coronary Irrigation

As a muscle pump, the external portion of the heart's wall requires its own blood supply, which is provided by arteries and veins surrounding its wall. Apart from that, the inner portion of the heart's wall, i.e., the endocardium, receives nutrients and oxygen supply directly from the chambers and so does not need vessels for its irrigation. Therefore, the atria and ventricles have both, arterial and venous supply [5].

There are two main coronary arteries composing the arterial supply of the heart, the **right coronary artery** (RCA) and the left coronary artery. The right coronary artery originates from the right aortic sinus of the ascending aorta and runs within the coronary sulcus between atria and ventricles (Figs. 2.4 and 2.5). It is responsible

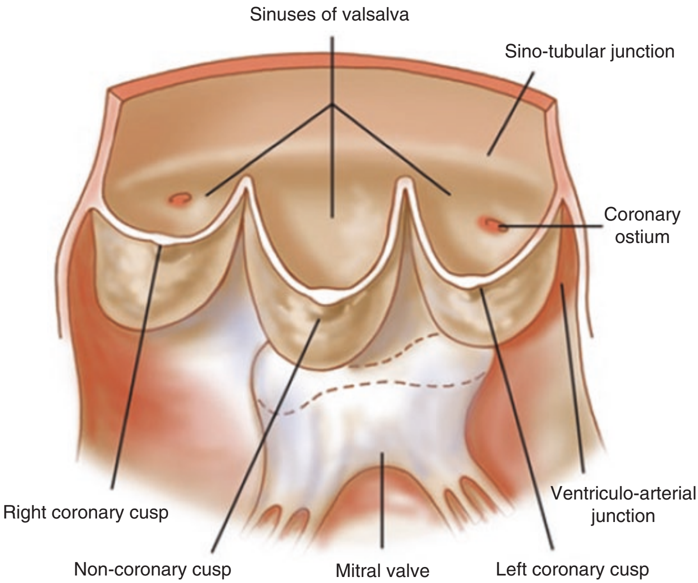


Fig. 2.4 Aortic sinuses of the heart. Reprinted from *Devarajan and Subramaniam. Applied Anatomy of the Aorta. In: Subramaniam K, Park KW and Subramaniam B. Anesthesia and Perioperative Care for Aortic Surgery. Springer. 2011*

for irrigating the right atrium, **sinuatrial** (SA) and **atrioventricular** (AV) **nodes** as well as the interventricular septum. Accordingly, from the right coronary artery arises a sinuatrial nodal branch to supply the heart's pacemaker, the SA node. However, in 40 % of people, the circumflex branch of the left coronary artery is that gives off the SA nodal branch. In its turn, the AV node is also supplied by a subdivision of the right coronary artery, the atrioventricular nodal branch. That arm arises from the right coronary artery in the posterior portion of the heart at the crux of the heart i.e., the meeting point between the four chambers. Moreover, a so-called right marginal branch emerges from the right coronary artery in its path within the sulcus towards the apex. The right border of the heart is supplied by the right marginal branch and does not reach its apex [5].

The ventricles area is supplied by the posterior interventricular branch, which also comes from the right coronary artery. The right coronary artery supplies most of the right ventricle and the diaphragmatic surface of the left ventricle.

In its turn, the **left coronary artery** (LCA) originates from the left aortic sinus running with the right coronary artery in the coronary sulcus on the left side of the pulmonary trunk (Fig. 2.4). Then, the left coronary artery splits into two arms: the circumflex branch and the anterior interventricular branch. As mentioned previously in this section, the SA nodal branch often emerges from the right coronary artery precisely from the circumflex branch of the left coronary artery. The circumflex branch arises from the right coronary artery and follows towards the posterior portion of the heart and to the left within the coronary sulcus [5]. It is then responsible for irrigating the left atrium and left ventricle. This comes to a great importance as

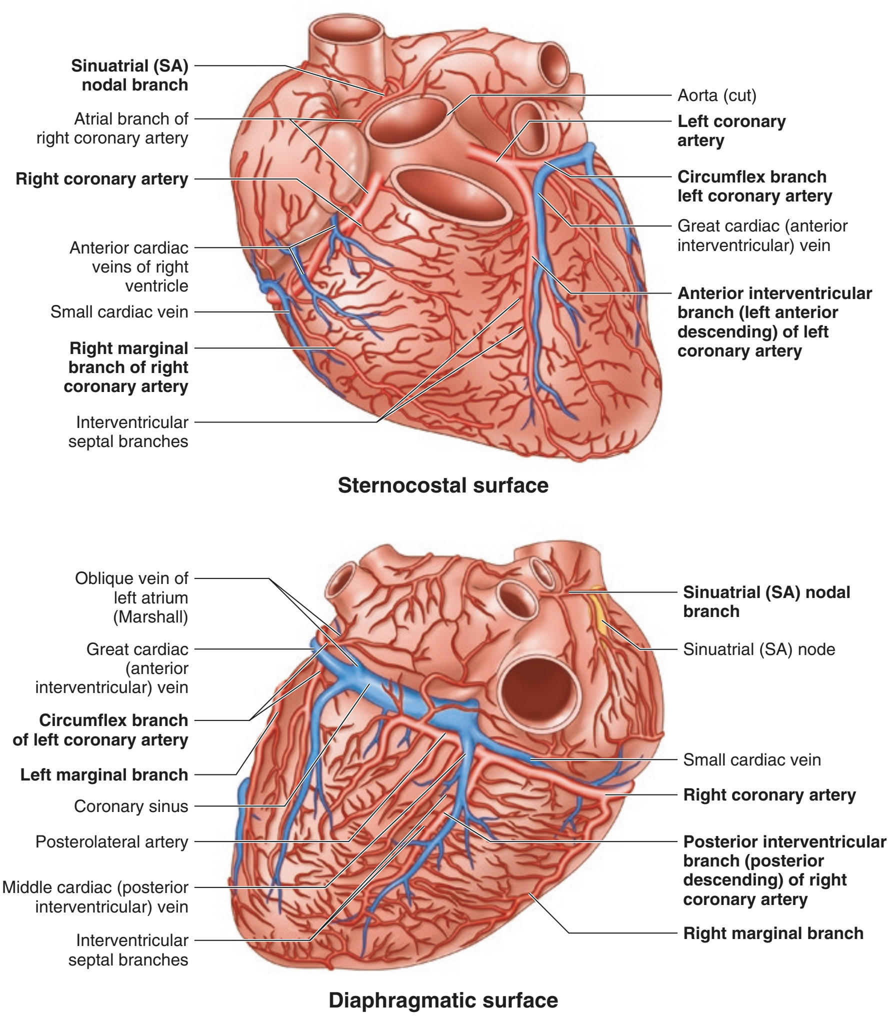


Fig. 2.5 Heart supply with overview of arteries and veins

anomalies of the circumflex branch have been reported. The second branch of the left coronary artery, the anterior interventricular, runs in the anterior interventricular sulcus towards the apex. It is the blood supply for the ventricles [5].

It is common that one's heart develops a collateral circulation should any closure in any main coronary artery occur (e.g., atherosclerosis). It occurs in the so-called functional end arteries [5].

When it comes to the venous supply, one needs to consider that the heart is greatly drained through veins that combine into a greater vessel, the coronary sinus. The second main drain course is through small veins that return blood to the right atrium [5]. Refer to Table 2.1 for details on venous supply of the heart.

Table 2.1 Main cardiac venous system [5, 10]

Vein	Origin	Path	Fuses into the	Drain
Great cardiac vein	Apex of heart ascending with the anterior interventricular branch of the left coronary artery	First: turns left at the coronary sulcus	Coronary sinus (opens into the right atrium)	Areas supplied by the left coronary artery
		Second: surrounds the left side of the heart together with the circumflex branch of the left coronary artery		
Middle cardiac vein (or posterior interventricular vein)	Cardiac apex	Ascends to the coronary sinus		Areas supplied by right coronary artery
Small cardiac veins (or Thebesius' vein)[a]	Between right atrium and ventricle	Follows the right marginal branch of the right coronary artery. Often merges with the right marginal vein		
Oblique veins of the left atrium[b]	Left atrium	Runs obliquely on the posterior wall of left atrium. Later fusing into the great cardiac vein		

Adapted from: *"Moore K, Dalley A, Agur A. Thorax. In: Moore K, Dalley A, Agur A, editors. Clinically oriented anatomy. 7th ed. Philadelphia, PA: Wolters Kluwer/Lippincott Williams & Wilkins Health; 2014. p. 71-180."* **and** *"Standring S. Heart and great vessels. In: Standring S, editor. Gray's anatomy: the anatomical basis of clinical practice. 40th ed. Edinburgh: Churchill Livingstone/Elsevier; 2008. p. 959–88."*

[a]Small cardiac vein: it may be absent

[b]Oblique veins of the left atrium: it usually atrophies before birth, but can be present in some adults

Blood returning from coronary walls that is not drained through vessels mentioned in Table 2.1 returns to the right atrium through small veins and the anterior cardiac vein [9].

The Arterial System

Aorta and Its Branches

Authors anatomically divide the aorta into the **ascending aorta, aortic arch, descending thoracic** and **abdominal aorta** [10] (Fig. 2.6).

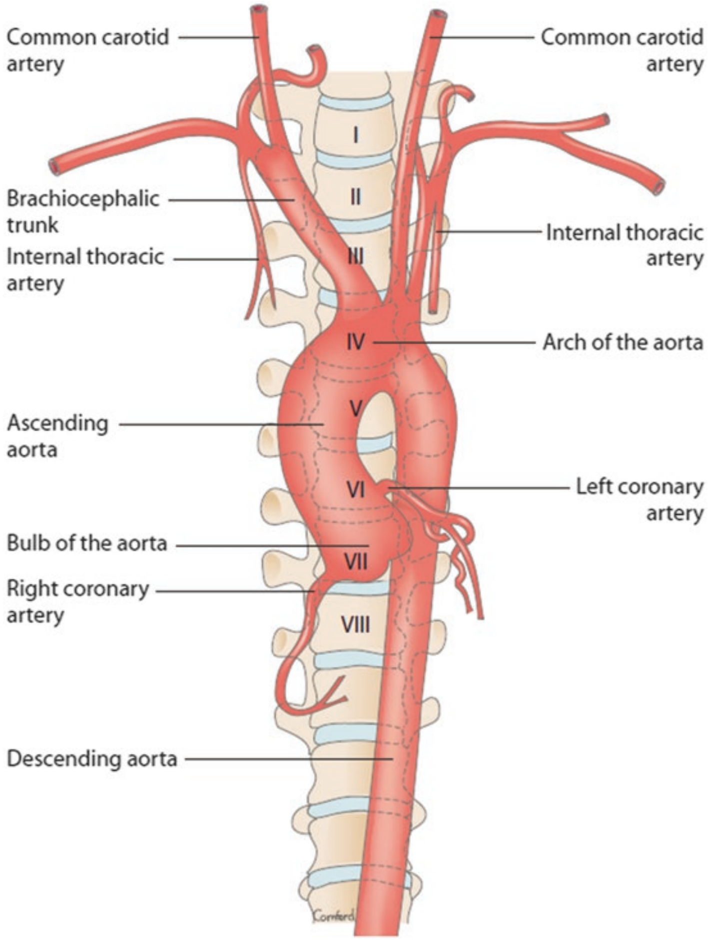


Fig. 2.6 Aorta course and ramifications. Reprinted from *Berdajs D and Turina MI. Surgical Anatomy of the Aorta. In: Operative Anatomy of the Heart. Springer. 2011*

The **ascending aorta** usually lengths 5 cm long [10] and its diameter is 2.5 cm on average [5]. It rises obliquely from the left ventricle, curving forward and to the right, at the level of the lower edge of the third left costal cartilage and it gives origin to the coronary arteries [10].

The transverse part of the aorta is named "**aortic arch**" as it bends to become the descending aorta. The arch begins to the second right sternocostal joint next to the sternal angle and leans to the left, following inferiorly. Three branches emerge from its upper edge: the brachiocephalic trunk, the left common carotid artery, and the left subclavian artery [10].

The **brachiocephalic trunk**, the largest ramification of the aortic arch, is 4–5 cm long [10] and emerges from the curvature of the aortic arch posteriorly. The trunk surges behind the manubrium and anterior to the trachea, it then goes up diagonally until it positions to the right of the trachea and to the sternum-clavicular joint. Then, it divides into right common carotid and into the right subclavian arteries [5] (Fig. 2.6).

The second branch of the aortic arch, the **left common carotid artery** (Fig. 2.6), arises posterior to the manubrium, posterior and to the left of the brachiocephalic trunk. Subsequently, it rises above the left subclavian artery and enters the neck passing posteriorly to the left subcostal joint [10].

The **left subclavian artery**, the third and last branch of the aortic arch, originates on the left side of the left common carotid artery and rises along the left side of the trachea [5] (Fig. 2.6).

The aortic arch has now turned into the descending thoracic aorta, and it descends approaching the medial plane by moving the esophagus to the right [10].

The **thoracic aorta** runs posteriorly to the root of the left lung, pericardium, and esophagus [10]. It begins on the left side of the inferior border of the T4 vertebra descending posteriorly in the mediastinum on the left sides of T5–T12 vertebrae [5]. It enters the abdomen through the aortic hiatus of the diaphragm where it changes its name to **abdominal descending aorta** (Fig. 2.6), starting close to the 12th thoracic vertebra and splitting at the level of the fourth lumbar vertebra [11].

The primary visceral branches of the abdominal aorta are:

1. The **celiac trunk** that supplies the foregut through its main branches: artery left gastric, artery splenic, and artery common hepatic
2. **Superior mesenteric artery**, which supplies the midgut through the middle colic artery, jejunal-ileal, ileocolic, and right colic
3. The **inferior mesenteric artery,** which supplies the hindgut, with the branches: left colic, sigmoid arteries, and superior rectal arteries

The **abdominal aorta** follows the thoracic aorta and it has its visceral branches in pairs. Its main branches are the renal, testicular or ovarian arteries [10].

Cervical and Intracranial Irrigation

The area between the chest and the neck is an important functional area in which main organs are comprised, such as thyroid, larynx, and glands [12]. Among major structures, we can highlight the carotid arteries, which carry blood supply to brain along the vertebral arteries.

The **internal carotid** and **vertebral arteries** provide the arterial supply to the brain (Fig. 2.7). After the common carotid artery bifurcates, internal carotid arteries rise up in the neck and into the carotid canal in the temporal bone. This system is responsible for irrigating the most anterior cerebral portion. The smallest terminal branch of the internal carotid is the anterior cerebral artery while the middle cerebral artery is the largest (Fig. 2.7) [13, 14].

The **vertebral arteries**, derived from the subclavian arteries, follow upwards in the neck passing through the foramen of the upper cervical vertebrae and pass the cranial opening across the foramen magnum [14]. It supplies major branches of the spinal cord, brainstem and cerebellum, and a significant portion of the posterior

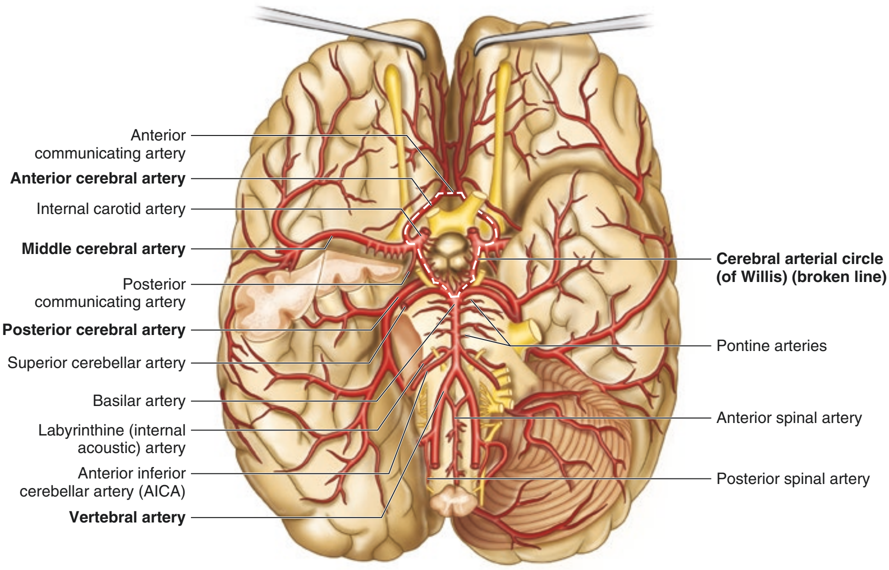


Fig. 2.7 Inferior view of arteries of the brain. Circle of Willis is depicted

cerebral hemispheres. The basilar artery is a large vessel formed by the union of the two vertebral arteries, and the posterior cerebral artery is the terminal branch of the basilar artery [14].

The **circle of Willis** is an arterial anastomosis formed by the branches of both internal carotid arteries and both vertebral arteries (Fig. 2.7) [15]. Should an artery occlusion occurs, this system is capable of redirecting blood to that area that is lacking irrigation. Therefore, that patient could remain asymptomatic as blood flow is reestablished [15].

Thorax and Upper Limb

The **subclavian artery** provides blood supply to the upper extremity (Fig. 2.8). After this artery crosses the side edge of the first rib, it becomes the axillary artery [16].

The **axillary artery** converts into the brachial artery near the lower border of the teres major muscle, thus following in the flexor compartment in the medial arm region [16]. The subscapular artery is the largest branch of the axillary artery [17], and the main branches of the axillary artery are illustrated in Fig. 2.8.

The **brachial artery** is divided into the radial and ulnar arteries distally to the elbow. These arteries have branches that form a rich network of anastomoses that carry blood to the hand, especially to the palmar face [17].

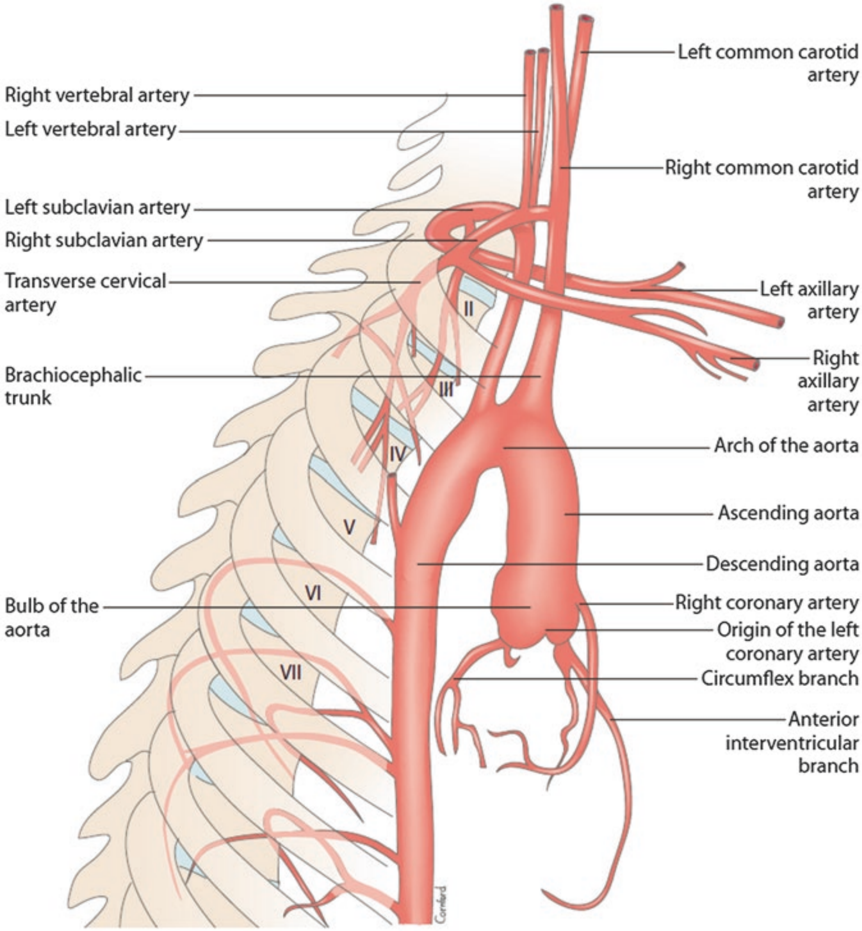


Fig. 2.8 Thorax overview of aorta ramifications. Reprinted from *Berdajs D and Turina MI. Surgical Anatomy of the Aorta. In: Operative Anatomy of the Heart. Springer. 2011*

Lower Limb

The lower limbs are responsible for creating propulsive force through the gait as well as providing a stable foundation to support body's weight during activities. Thereafter it an efficient irrigation system.

The **femoral artery** is the main arterial supply to the lower limb (Fig. 2.9, Flowchart 2.1). It enters the thigh behind the inguinal ligament as a continuation of the external iliac artery and follows its path almost vertically in relation to the adductor tubercle of the femur. Its distal portion passes through the adductor magnus muscle tunnel (adductor hiatus), entering the popliteal space to become the popliteal artery [18].

The **popliteal artery**, the continuation of the femoral artery, is the deeper structure in the popliteal fossa. It passes inferior-laterally across the tank and ends

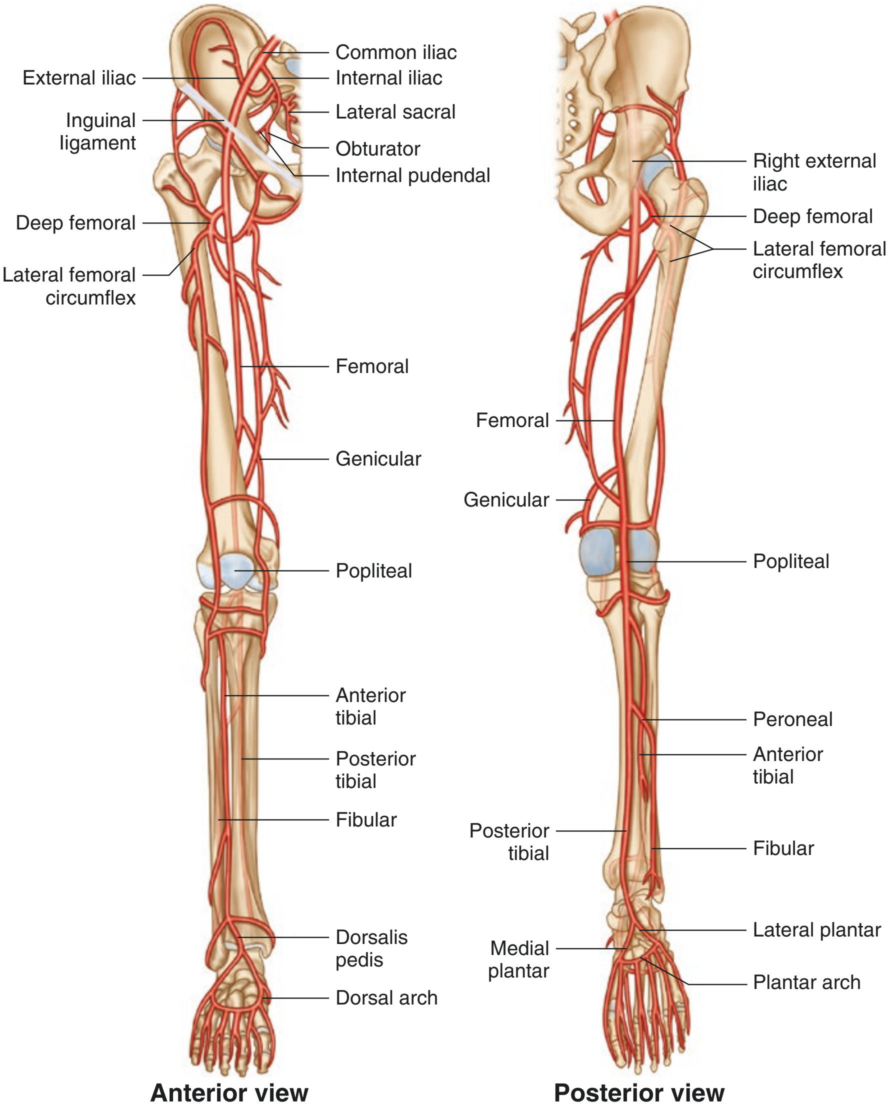
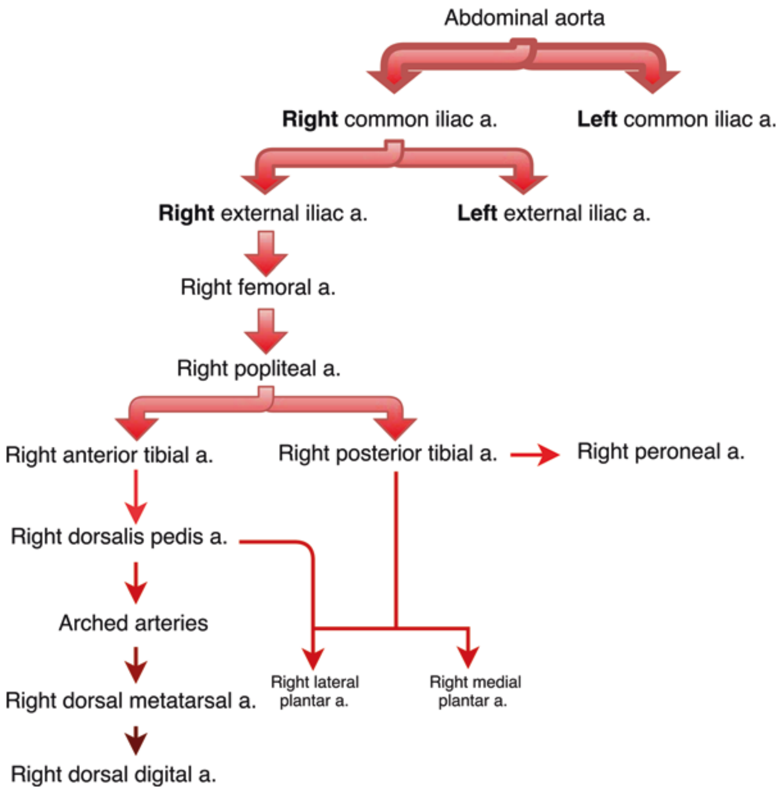


Fig. 2.9 Arteries of the lower limb

at the lower edge of the popliteal muscle divided into anterior and posterior tibial arteries. Five branches of the popliteal artery supply knee structures such as the capsule and ligaments. These branches participate in the formation of periarticular geniculate anastomosis that provides collateral circulation which is capable of



Flowchart 2.1 Scheme of the lower limb arteries

maintaining blood supply to the leg at a full flexion of the knee, which can double the popliteal artery [19].

One of the terminal branches of the popliteal artery, the smaller, is the **anterior tibial artery**, begins at the lower edge of the popliteus muscle, and passes through and above the interosseous membrane to then descend on the anterior surface of the leg. At the level of the ankle joint, the anterior tibial artery becomes the dorsalis pedis artery. The last and largest branch of the popliteal artery is the **posterior tibial artery**. This artery supplies the posterior compartment of the leg and foot, and it originates the peroneal artery, which runs on a parallel and lateral path to the posterior tibial artery. The other terminal branch of the popliteal artery is the posterior tibial artery. It descends with the tibial nerve and vein and supplies the posterior compartment of the leg and to the foot. At the level of the ankle joint, it splits into medial and lateral plantar arteries, as well as in arteries to irrigate the foot sole (Fig. 2.9). The **fibular artery**, the larger branch of the posterior tibial artery, arises at the origin of this artery and runs parallel to it [19].

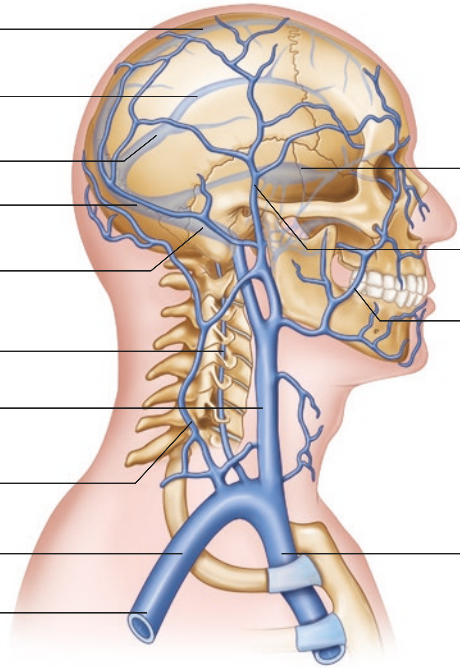


Fig. 2.10 Venous supply to the head. Lateral view of the right side

The Venous System

Cervical and Intracranial

A complex system of deep and superficial veins provides the cerebral venous drainage, which are valveless and have thin walls lacking of muscle tissue. These veins pierce the arachnoid and the inner layer of the dura mater and drain into the dural venous sinuses [14]. The **diploic veins**, developed fully at the age of two, cross the cranial vault and connect the skull's calvaria. The emissary veins connect the scalp veins of the venous sinuses being, hence, a relevant route of infection [15].

The venous sinuses are the upper and lower sagittal sinus, straight sinus, transverse sinus, the sigmoid sinus, the occipital sinus, the cavernous sinuses, upper and petrosal sinuses. They are located between the periosteum and the dura mater (Fig. 2.10) consisting of fibrous and thick walls and receive tributaries from the brain, skull bones, orbit, and inner ear [15].

Posteriorly to the jaw bone's angle, the **external jugular vein** is formed. It follows its course through the sternocleidomastoid muscle, running towards the subclavian vein, where it drains [15] (Fig. 2.10).

As an extension of the sigmoid sinus, the **internal jugular vein** follows inferiorly through the jugular foramen until it leaves the skull towards the heart. This large vein receives blood from the brain, face, and neck, then tracks down on the neck beside to the carotid and ends by joining the subclavian vein behind the collarbone [15].

Thorax and Upper Limb

A group of superficial and deep veins are responsible for the venous drainage of the upper limb.

The superficial group begins with the dorsal arch of the hand, which in its radial portion turns into the cephalic vein. The **cephalic vein** follows its path towards the shoulder rising along the radial portion of the arm and then pierces the fascia emptying into the axillary vein (Fig. 2.11). The **basilic vein** drains from the ulnar part of the dorsal arch of the hand, follows medially in the forearm, and pierces the deep fascia at the elbow to form the axillary vein. At the level of the cubital fossa, the **median cubital vein** connects the cephalic and basilic veins. The deep veins group follows the arteries and drains blood into the axillary vein, which then drains into the subclavian vein [16].

The **intercostal veins** accompany the arteries and intercostal nerves. Eleven posterior intercostal veins anastomoses with the anterior intercostal veins and eleven subcostal veins in each hemithorax. A greater extent of the posterior intercostal veins ends in the azygos/hemiazygos venous system which drains to the superior vena cava while the part of these veins of the first intercostal space drains right into the brachiocephalic (or innominate) vein [5] (Fig. 2.12).

The **right subclavian vein** and the **right internal jugular vein** come together to form the right brachiocephalic vein at the root of the neck. The left brachiocephalic vein has a similar origin and joins the right brachiocephalic vein to form the superior vena cava [9].

The **superior vena cava** is formed by the union of the two brachiocephalic veins and drains venous blood from the head, neck, and upper limbs into the upper part of the right atrium [9]. The azygos veins join the superior vena cava just before it enters the pericardium. They drain the posterior parts of the intercostal space, posterior abdominal wall, pericardium, diaphragm, bronchus, and esophagus.

The **inferior vena cava**, larger than the superior vena cava [9], enters the thorax anteriorly to the eighth thoracic vertebra through the diaphragm and it goes to the right atrium. Whilst, two pulmonary veins leaving the lung arrive in the left atrium carrying oxygenated blood [9].

Lower Limb

The veins of the lower extremities may be divided into three groups: superficial, deep, and perforating veins. The **superficial veins** are located above the fascia and under the skin and it is consisted of the great and small saphenous veins and its tributaries.

The **great saphenous vein** is a superficial vein and originates as an extension of the medial marginal vein of the foot and it ends in the femoral vein close to the

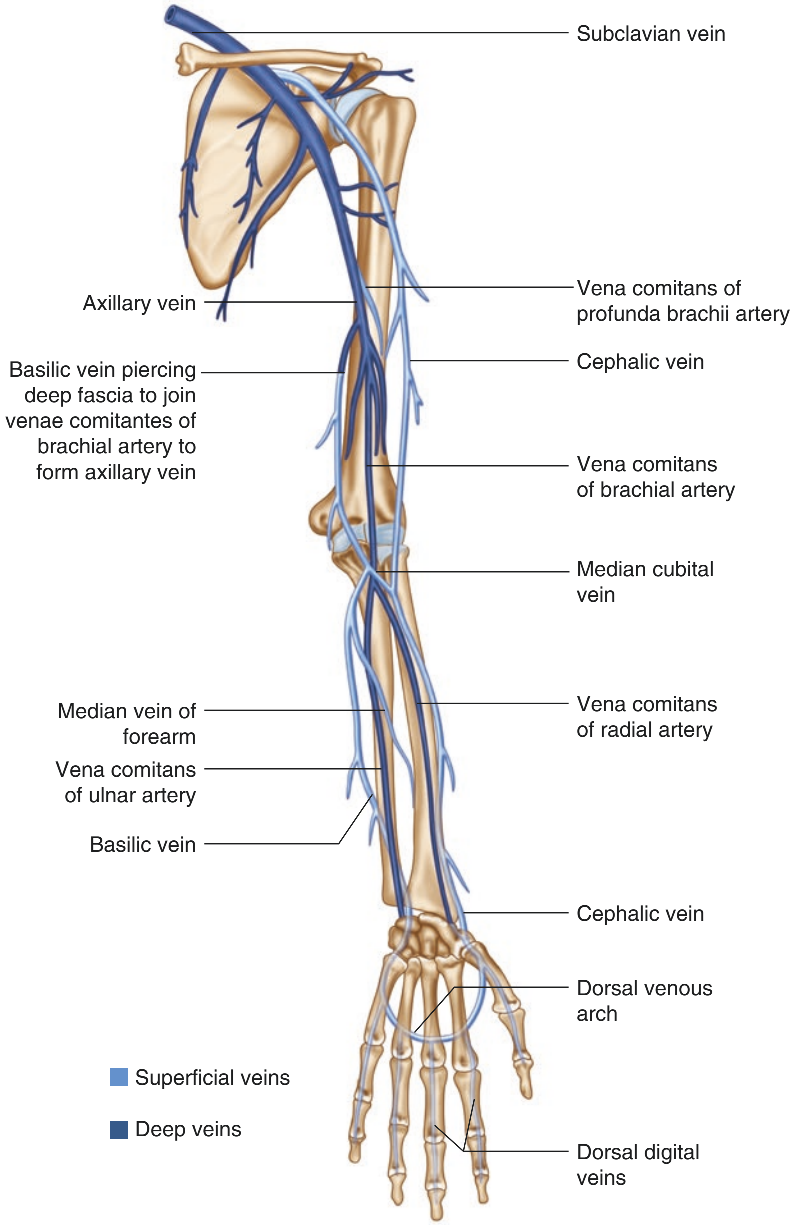


Fig. 2.11 Overview of veins of the left upper limb

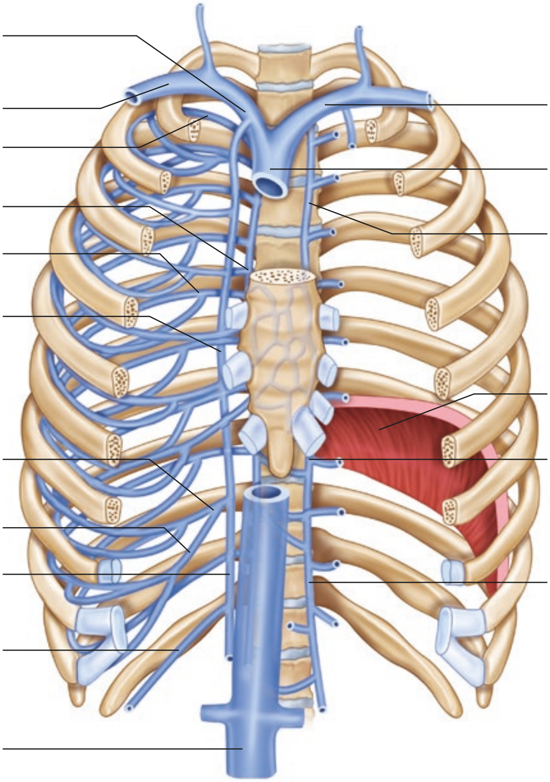


Fig. 2.12 Overview of the thoracic venous circulation

inguinal ligament [20]. It ascends anteriorly to the medial malleolus, crosses the surface of the tibia obliquely, and reaches the medial border of the tibia. Subsequently, it ascends behind to the knee, curves to the front around the medial thigh part, passes through the bottom of the saphenous hiatus in the deep fascia, and joins the femoral vein at approximately 2.5–3.5 cm below and laterally to the pubic tubercle [20].

A single vein is found in the calf in about two-thirds of individuals while the left third has a duplicated system. In most instances, the only great saphenous vein is dominant [21]. The great saphenous vein, the longest vein in the body [20], holds around 10–12 valves. Anatomically, these valves are found to a greater extent in the leg than in the thigh [19].

Branches passing behind the knee connect the great saphenous to the small saphenous vein, and several perforating veins join the saphenous with the deep veins. The superficial iliac circumflex, the superficial epigastric, and the superficial external pudendal veins are tributaries of the saphenous-femoral junction [18].

The **small saphenous vein** has several valves along its course. It arises near to the dorsal venous arch of the foot and rises behind the lateral malleolus, follows the

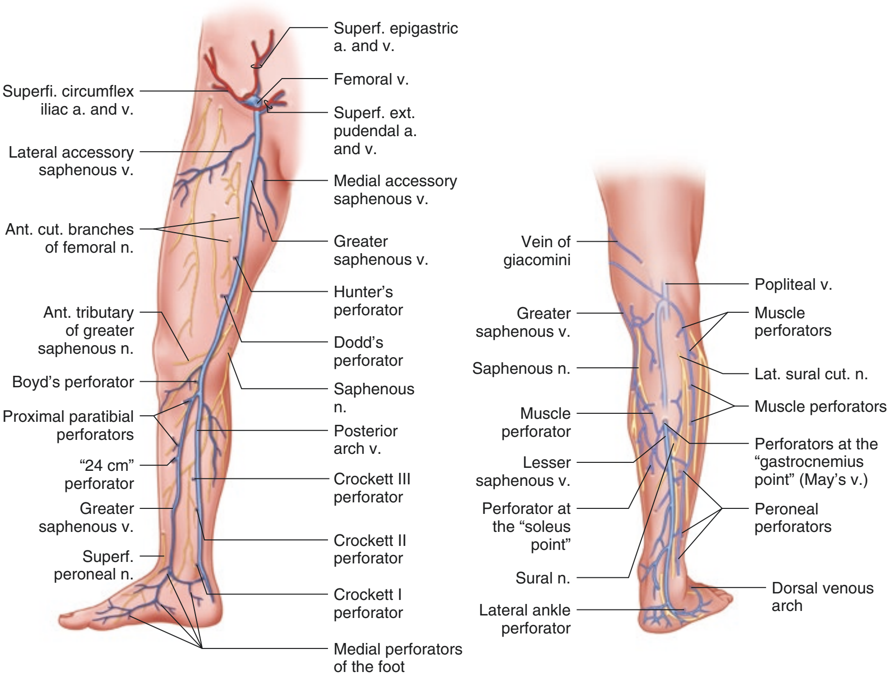


Fig. 2.13 Veins on the lower limb

lateral border of the Achilles' tendon and goes to the back of the leg (Fig. 2.13). This vein ends in the popliteal vein after piercing the deep fascia and passing between the two heads of the gastrocnemius muscle [18].

The deep veins are satellites to the major arteries, running in parallel to its courses, mostly paired. One characteristic of the venous system in the lower limb is that it has a greater amount of venous valves than in the arm [22].

The **posterior tibial veins** follow its course with the posterior tibial **artery**. This group receives tributaries from the calf muscles and connections from superficial veins and the peroneal veins. The peroneal veins run with a similarly named artery and receive tributaries from soleus and superficial veins [22]. The **anterior tibial vein** follows its course to form the dorsalis pedis artery. It leaves the anterior compartment between the tibia and fibula, and passes through the proximal end of the interosseous membrane. Both the anterior and posterior veins drain into the popliteal vein at the distal border of the popliteal [22]. The **profunda femoris vein** (or deep femoral vein) is situated anteriorly to its alongside artery, the femoral artery. Through its tributaries, it binds distally to the popliteal vein and proximally to the inferior gluteal vein. In some cases, the femoral veins drain the medial and lateral circumflex femoral artery [22].

Perforating veins are communicating vessels found mainly around the ankle and the medial side of the lower leg. They link the superficial (great saphenous vein) and deep veins of the lower leg. They have valves that are arranged to prevent the blood flow from deep to superficial veins [18].

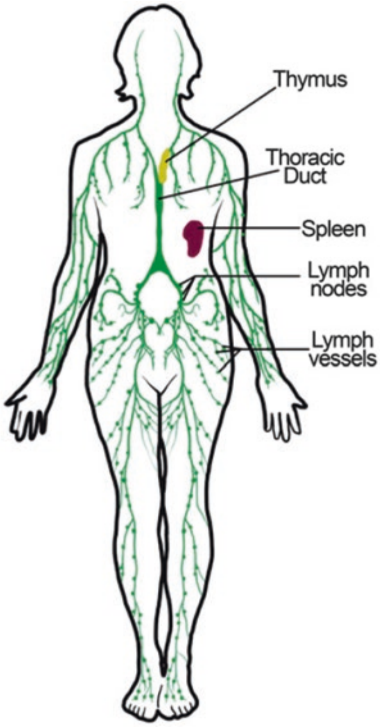


Fig. 2.14 The lymphatic system. Reprinted from *Iaizzo PA. General Features of the Cardiovascular System. In: Handbook of Cardiac Anatomy, Physiology and Devices. Springer. 2009*

The Lymphatic System

The lymphatic system is a blunt-ended linear system that plays a vital part of the transport and immune systems, operating in conjunction with the circulatory system [23]. Lymphatic system moves a clear-to-white fluid derived from interstitial fluid, the lymph. Lymph fluid consists of tissue fluid, proteins, fat, and white blood cells (predominantly lymphocytes). The lymphatic system is composed of a complex network of lymph vessels, termed lymphatics, lymph nodes and lymphoid organs [23, 24] (Fig. 2.14).

Lymphatic vessels are thin-walled capillaries, highly permeable, found in nearly every organ and blood vessel-containing interstitial tissue [24, 25]. They cannot be found in vascular structures and organs such as hair, nails, epidermis, cornea, brain, and retina [24]. Lymphatic vessels serve as a drainage system for excess fluid and large molecules or cells that cannot easily find their way back into venules [25].

Lymphatic capillaries (initial or terminal lymphatics) start blind-ended in the tissue, where they take up lymph. Lymphatic capillaries contain large gaps between their endothelial cells to enable passage of lymph fluid. The interstitial fluid, from the surrounding tissues, enters through the initial lymphatics, connected to collecting vessels by the precollecting lymphatics that combine to form large ducts and trunks [23, 25] (Fig. 2.15). Lymph is drained and transported through propulsion to

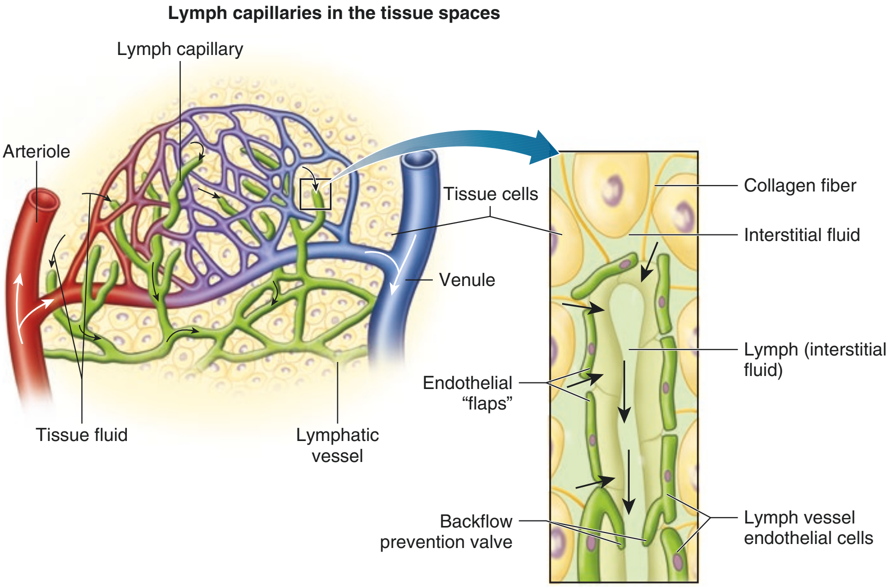


Fig. 2.15 Lymphatic capillaries and the arterioles and venules of the cardiovascular system

lymph nodes, before backing to blood circulation via the thoracic and lymphatic ducts that join to the subclavian veins [25, 26]. Lymph is moved forward by respiratory movement, arterial pulsation, skeletal muscle action, and the rhythmic contractions of smooth muscle in walls of collecting lymphatic vessels and affected by nerve and humoral mediators [6, 23].

Lymphatic Vessels

Initial lymphatic capillaries: The lymphatic system starts in connective tissue spaces in several regions of the body to which they are distributed and are bathed by the intercellular tissue fluids. At this level, a single layer of endothelial cells is present in an irregular wall comprising nonfenestrated endothelial monolayer cells with gaps that provide an entry for interstitial fluid (lymph) into the system. The diameter of initial lymphatics ranges from 10 to 60 μm with a wall thickness of 50–100 nm, blind-ended. Actin filaments support them, which are contractile. This structure allows them to act as a one-way valve system [6, 23].

Precollecting Lymphatics: Precollecting lymphatics drain fluid from the initial lymphatics to collecting vessels. They have segments which contain valves and are surrounded by a basement membrane and one or more layers of smooth muscle cells that may contract and begin the propulsion of lymph through the system [23].

Collecting Lymphatics: Collecting lymphatics are larger and classified as afferent or efferent to specify whether they carry lymph to or from the lymph nodes [27]. At this level, three typical layers of vessel wall are evident: the intima, media, and adventitia. The intima layer is composed of a monolayer of endothelial cells. The media layer has one to three layers of smooth muscle cells. And the adventitia layer is composed of fibroblasts, connective tissue, and terminal nerves [6, 23].

Lymphoid Organs

Lymph nodes: Lymph nodes are one of a number of organs nodes and the major sites of B cells, T cells, and other immune cells. It is a bean-shaped mass of lymphoid tissue enclosed by a capsule of connective tissue, covered with lymphatic smooth muscles [23]. Lymph nodes are situated in the course of lymphatic vessels so that the lymph passes through them on their way to the blood vessel. Lymph nodes filter the lymphatic fluid and store special cells that can phagocytose molecules and particles such as cancer cells or bacteria that are traveling through the body in the lymph fluid. Lymph nodes are distributed widely throughout the body. Collections of them are present in the inguinal and axillary regions as well as the neck, thorax, and abdomen [6, 27].

Lymphatic trunks and ducts: The lymphatic trunks and ducts are the largest vessels (diameters on the order of 2 mm) that drain lymph. The **trunks** collect fluid from organs, extremities, and trunk. The **ducts** transport lymph into the venous circulation [23]. Lymphatic trunks are formed by confluence of many efferent lymph vessels and drain into one of the two lymph ducts. The thoracic duct is the final branch of the lymphatic system. It receives flow from the left half of the thorax, left arm, and left side of the head and neck. Fluid from the right half of the thorax, right arm, and right side of the head and neck is drained to the right lymph duct [27]. The thoracic duct vessels usually start from the level of the 12th thoracic vertebrae (T12) and extends to the root of the neck. The right lymphatic duct courses along the medial border of the Scalenus anterior muscle, at the root of the neck.

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