# Chapter 11
Circulatory System

The circulatory system consists of a muscular, pulsing heart and a system of blood vessels.The blood vessels include: Arteries which will carry the blood and it's dissolved constituents from the heart to the capillaries. Capillaries which will serve as the site of exchange between the tissues of the body and the blood stream. In the capillary beds oxygen and nutrients are delivered to the tissues and wastes are removed from the tissues. Veins which will drain the capillary beds and return the blood to the heart.

11.1. The Heart

The heart is a muscular organ consisting of four pumping chambers. The <u>Right Atrium</u> receives blood from the superior and inferior vena cava and sends it to the right ventricle. This blood is deoxygenated and from systemic circulation. The <u>Right Ventricle</u> receives blood from the right atrium and will pump it into the pulmonary trunk so that it can enter pulmonary circulation. This blood will travel to the lungs where it will dump carbon dioxide and pick up oxygen; where it will become oxygenated. The <u>Left Atrium</u> receives this oxygenated blood from the pulmonary veins and sends it to the left ventricle. The <u>Left Ventricle</u> receives blood from the left atrium and pumps it into the aorta so that it can enter systemic circulation.
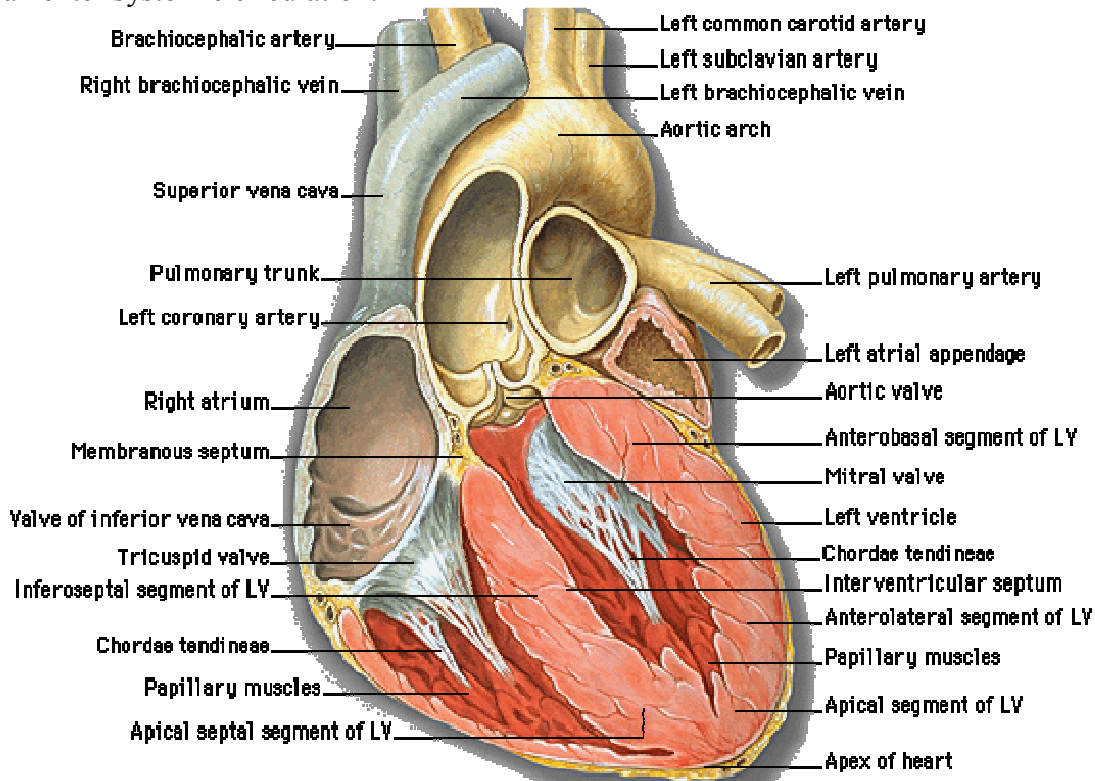
Fig.11.1. Structure of a heart

11.1.1. The Three Layers of the Heart Wall

a) Endocardium

The endocardium is the innermost layer of the heart wall. It forms the internal lining of the atria and ventricles. The endocardium has a layer of <u>Endothelium</u>, a simple squamous epithelium. This endothelium is continuous with the endothelium lining all of the blood vessels of the circulatory system. Along with lining the chambers, this endothelium also lines the heart valves, the chordae tendineae, and the papillary muscles. These heart valves are the <u>Right Atrioventricular/Tricuspid Valve</u>, the <u>Left Atrioventricular/Bicuspid/Mitral Valve</u>, the <u>Aortic Semilunar Valve</u>, and the <u>Pulmonary Semilunar Valve</u>.

They are connective tissue structures that serve to prevent the back flow of blood. Deep to the endothelium is a dense irregular connective tissue layer consisting of elastic and collagen fibers. This dense irregular connective tissue layer is often called the <u>Subendothelial Connective Tissue</u>. This dense irregular connective tissue forms the <u>Cardiac Skeleton</u>.The cardiac skeleton forms: rings around the AV valves called <u>Annuli Fibrosi</u>, reinforcement for the origins of the aorta and the pulmonary trunk, the inner core of the interventricular septum, and the central core of the heart valves.

The core of the AV valves are dense collagen bundles. Extensions of these collagen bundles form the <u>chordae tendineae</u>. The chordae tendineae attach the AV valves to the papillary muscles and prevent them from prolapsing during ventricular systole. The papillary muscles are conical projections of smooth muscle in the ventricles. The semilunar valves have a strong component of elastic fibers in their cores, particularly on the ventricular aspect. These elastic fibers help them to do their job.

Supporting this layer of dense irregular connective tissue is the <u>Subendocardium</u>. The subendocardium is an irregular layer composed of adipose and irregularly arranged bundles of collagen. Branches of the coronary blood vessels will travel through the subendocardium. Deeper portions of the subendocardium may contain bundles of smooth muscle or elements of the cardiac conduction system. This portion of the subendocardium is thicker in the atria than in the ventricles. It contains the musculi pectinati.

b) Myocardium

The myocardium is the middle and by far the thickest layer of the heart wall. It is responsible for the pumping action of the heart. It is of varying thickness, based on functional needs, and is responsible for the disparate sizes of the heart chambers. It is a muscular layer composed primarily of cardiac myofibers whose endomysia are anchored into the subendocardium and to each other. The endomysium of cardiac myofibers may or may not contain some elastic fibers. They do in the atrial myocardia. They don't in the ventricular myocardia. The more superficial cardiac myofibers will have their endomysia inserting into the superficialmost layer of the heart wall, the epicardium. Most of the cardiac myofibers are anchored to each other by their intercalated discs. Some will insert into the cardiac skeleton of the heart. Medium sized coronary blood vessels will penetrate the myocardium.

c) Epicardium

The epicardium covers the outer aspects of the heart. The superficialmost portion of the epicardium is the <u>Visceral Pericardium</u>. The visceral pericardium is a serous membrane. A serous membrane consists of a layer of <u>mesothelium</u>, a simple squamous epithelium, sitting on a thin layer of loose connective tissue. The mesothelium is secretory producing a serous fluid called <u>Pericardial Fluid</u>. The visceral pericardium is contiguous with at

least part of the <u>Parietal Pericardium</u>. Together the visceral and parietal pericardia form the <u>Pericardium</u>. The parietal pericardium has two layers: It has a delicate inner layer called the <u>Serous Layer</u> which is contiguous with the visceral pericardium and also secretes pericardial fluid. It has a tough fibrous outer layer, composed of dense irregular connective tissue, called the <u>Fibrous layer.</u> Between the visceral and parietal pericardia is a fluid filled space called the <u>Percardial Space/Cavity</u>. Deep to the visceral pericardium is a thin layer of dense irregular connective tissue. Immediately deep to this fibrous layer is an irregular layer composed of loose connective tissue containing adipose and the larger coronary blood vessels. The connective tissue fibers of the this layer are continuous with the endomysia of the superficialmost myofibers of the myocardium. The adipose tissue of this layer is often found in close association with the coronary blood vessels

11.1.2. The Cardiac Conduction System

The cardiac conduction system consists of modified cardiac muscle cells called <u>Nodal Tissue</u>/<u>Nodal Fibers</u>. Cardiac myofibers have the capability of contracting independently, called <u>Inherent Rhythmicity</u>. They coordinate the heartbeat through the intercalated discs. Nodal tissue is modified cardiac myofibers. They take inherent rhythmicity a step further being more nervous-like in it's ability to initiate a wave of depolarization that will stimulate the contraction of the entire myocardium of the heart chamber. Overall, nodal tissue resembles cardiac myofibers under the light microscope.

The Components of The Cardiac Conduction System consists of:

1) The Sinoatrial Node - a mass of nodal tissue located in the right atrium, near the opening of the superior vena cava, that will stimulate atrial systole (in both atria simultaneously).

2) The Atrioventricular Node - a mass of nodal tissue located in the right atrium, near the right AV valve, that will stimulate ventricular systole (in both ventricles simultaneously). It is stimulated by the SA node. Due to the greater thickness of the ventricular myocardia, the distribution of the depolarization initiated by the AV node needs some assistance.

3) The Bundle of His/Atrioventricular Bundle - a fibrous mass of nodal tissue located in the upper interventricular septum that receives the depolarization from the AV node and carries it into the interventricular septum.

4) Bundle Branches - branches of the atrioventricular bundle that branch off of it at about the middle of the septum and carry the depolarization to the apices of the ventricles.

5) Purkinje Fibers - branches of the bundle branches which carry the impulse from the apices to the lateral walls of the ventricles. This allows the entire muscle mass of both ventricles to contract as a singular, coherent unit.

11.2. The Blood Vessels

The wall of the "typical" blood vessel, called the <u>Vascular Wall</u>, is divided into three <u>tunics</u> (however their nature will vary between the three classes of blood vessel):

a) Tunica Intima/Tunica Interna - the innermost tunic; it lines the lumen and is in direct contact with the blood. The tunica intima consists of:

a] <u>Endothelium</u> - a layer of simple squamous epithelium continuous throughout the circulatory system.

b] <u>Subendothelial Connective Tissue</u> - a layer of loose connective tissue

b) <u>Tunica Media</u> - the middle tunic. It typically consists of smooth muscle and variable amounts off differing connective tissue components.

c) <u>Tunica Adventitia/Tunica Externa</u> - the outermost tunic. It typically consists of connective tissue which will serve to anchor the blood vessel to surrounding structures. The tunica adventitia of larger blood vessels will be perforated by numerous small blood vessels which service the tissues of the vessel. These vessels will penetrate the tunica media but will not enter into the tunica intima. These small vessels servicing the tunics of larger vessels are called the <u>Vasa Vasorum</u>. The vasa vasorum includes small arteries, small veins, and capillaries.

11.2.2. The Arteries

Arteries are the vessels which will carry blood from the heart towards the tissues of the body. As a result they will carry blood at it's highest pressure and this is reflected in the structure of their vascular wall. They are the thickest walled blood vessels. There are three classes of arteries: elastic arteries, muscular arteries, and arterioles.

a) <u>Elastic/Conducting Arteries:</u> Elastic arteries are the largest arteries of the body and the first to receive blood from the heart. Ex; aorta, brachiocephalic a., common carotid a., common iliac a., pulmonary trunk, and pulmonary. Structurally elastic arteries can be divided into:

i <u>Tunica Intima</u> - endothelium and a thin layer of subendothelial connective tissue which will progressively thicken with age.

ii] <u>Tunica Media</u>- it is the thickest layer and is rich in elastic fibers. It consists of bands of elastic membranes, called <u>Elastic Laminae,</u> alternating with bands of smooth muscle cells and a limited amount of collagen. The elastic component allows theses arteries to expand when receiving blood and to recoil to help propel the blood.

iii] <u>Tunica Adventitia</u> - contains mostly longitudinally arranged bands of collagen. In larger elastic arteries this connective tissue layer will also contain some elastic fibers.

b) <u>Muscular/Distributing Arteries:</u> Muscular arteries are branches of elastic arteries and could be described as "medium sized arteries". Ex; splenic and brachial. Due to their high muscle component these arteries are proportionately the thickest walled of all the arteries and therefore of all blood vessels.

Features of Muscular Arteries are: One diagnostic feature of muscular arteries is that their tunica media has predominantly circularly/spirally arranged smooth myofibers forming a discrete muscular compartment. Another diagnostic feature found in all muscular arteries is a well developed <u>Internal Elastic Membrane/Lamina</u>. The internal elastic membrane is located between the tunica intima and the tunica media. The internal elastic membrane is often considered to be a portion of the tunica intima. However, since the elastic tissue is most likely synthesized by the smooth muscle myofibers (of the tunica media) it is actually a portion of the tunica media. In fact, the tunica media of the larger muscular arteries will contain a few scattered elastic lamina throughout. The smooth muscle cells will also produce a few reticular fibers and the proteoglycans of the tunica media.

The tunica adventitia will also contain a series of thinner elastic lamina called the <u>External Elastic Lamina/Membrane</u>. The tunica adventitia is dominated by abundant, longitudinally arranged bundles of collagen and occasional bundles of smooth muscle within the inner adventitia. The collagen will reinforce the walls to withstand high blood pressure. The smooth muscle is restricted to the inner adventitia. Vasomotor nerve fibers

will enter the adventitia. Their ganglia are also located in the adventitia. From the adventitia, the nerves will penetrate the tunica media where they will innervate the smooth muscle so as to regulate vasoconstriction and vasodilation. These nerves will innervate only the outermost layers of smooth muscle. Smooth myofibers will be coupled by gap junctions so all cells will receive the impulse. The tunica adventitia can be quite thick in some muscular arteries but **not** as thick as the tunica media.

c) Arterioles

Arterioles are the smallest of the arteries. They are generally between 20 um to 100 um in diameter. The arterioles will deliver blood to the capillaries. They also serve to regulate the flow of blood into the capillary beds. The Structure of the Typical Arteriole is as follows. Arterioles have a well developed internal elastic membrane separating the tunica intima and the tunica media. It gives a distinctive crenelated appearance to the tunica intima. The tunica media of arterioles is composed of circularly arranged smooth muscle which will regulate the flow of blood to the capillaries. A few small, unmyelinated axons of vasomotor nerves innervate the outer circumference of the tunica media. The tunica adventitia is usually poorly developed with little or no external elastic membrane component.

f) Terminal Arterioles

Terminal arterioles are the arterioles which give rise to the capillaries. Their tunica media is reduced to a cuff of smooth muscle located near the origination of the capillaries called the Precapillary Sphincter. The precapillary sphincter controls the flow of blood into the capillary bed. The tunica adventitia is extremely reduced. Along with giving rise to capillary branches, terminal arterioles will give rise to another type of branch. This branch is called the Metarteriole. The metarteriole will branch off of the terminal arteriole close to the capillary origin. It will give rise to it's own capillaries which will anastomize with the capillaries branching off of the terminal arteriole. The flow of blood into these capillaries is also regulated by precapillary sphincters. The metarteriole will also drain directly into a venule.

g) Atriovenous Anastomes

These are shunts between arterioles, which do not branch into capillaries, and venules. They function to divert blood away from capillary bed when required. Ex; There are many atriovenous anastomes in the skin to aid in thermoregulation.

11.2.3. The Capillaries

Capillaries are the smallest class of blood vessels and serve as the site of exchange between the blood and the tissues of the body. They are between 8 um to 10 um in diameter. To promote this exchange via diffusion, the capillary wall is very thin and simple in it's construction: It lacks the tunica adventitia, media, and most of the intima. The wall is composed of endothelium supported by a basal lamina and very few, very scattered reticular fibers. To further increase the thinness of this wall, the endothelial cell nuclei are elongated and aligned longitudinally along the vessel. Occasionally associated with the capillary wall is a scattered population of Pericytes/Perivascular Cells. Pericytes have cytoplasmic processes which will surround the capillary wall. Pericytes are multipotent stem cells capable of differentiating into: vascular smooth myofibers, fibroblasts, and a variety of other connective tissue cells.

a) The Three Classes of Capillaries

Based on structural modifications of the endothelium to facilitate the escape of the plasma filtrate into the interstitium.

1) Continuous Capillaries: These are the most numerous and most widely distributed class of capillary. They are the "typical capillary". The endothelium making up the wall of the continuous capillary is the same type as the endothelium lining arteries and veins. The endothelial cells are joined to one another by fascia occludens. This incomplete junction permits the escape of fluid into the interstitium. In certain specialized, less permeable continuous capillaries (such as those making up the blood brain barrier) the endothelial cells are joined by a tight junction, a zona occludens, instead. These borders completely seal the contiguous borders of adjacent endothelial cells and so make the vessel less permeable. Plasmalemmal Vesicles invaginate both the lumenal and the perivascular surfaces of the endothelial cells for the transport of materials across the vascular wall.

b) Fenestrated/Discontinuous Capillaries: These capillaries have pores, also called Fenestra, in their endothelial walls. Fenestra are regions where the cytoplasm has been excluded from between the lumenal and perivascular cell membranes. This modification makes fenestrated capillaries more permeable than are continuous capillaries and so are found in areas requiring a greater degree of permeability. Ex; intestinal villi, endocrine glands, the kidneys. Typically, the cell membranes remain and form a Diaphragm over the fenestrum. In some cases, where even more permeability is required, even this thin diaphragm is lost. These are called Modified Fenestrated Capillaries. Ex; the glomerular capillaries of the kidney where the lack of diaphragms aids in the filtration of blood and the formation of urine.

11.2.3. Sinusoids

Sinusoids are odd microscopic blood vessels. Some consider them not to be capillaries but a class in their own right. They have a larger lumenal diameter than do other capillaries. They are irregular in shape and lack the normal tubular arrangement of a blood vessel. Along with endothelium, the vascular wall also has macrophages. Ex; the Kupffer cells of the liver sinusoids. Sinusoids have large gaps between their endothelial cells. These gaps are guarded by macrophages. The macrophages serve to remove foreign matter, debris, etc. These gaps will not only allow for the passage of dissolved substances and fluids but also formed elements in some cases.

11.2.4. The Veins

Veins carry blood from the capillary beds to the heart. The blood is first picked up by postcapillary venules and then flows into collecting venules, muscular venules, small veins, medium veins, and large veins. The veins carry blood at a much lower pressure than do the arteries and so have thinner walls with less muscle and less elastic fibers.

a) Venules

Venules are the smallest class of vein and serve to drain the capillary beds. Those venules closest to the capillary bed are structurally quite similar to capillaries. As the blood drains into larger venules, the walls of the venules become increasingly more complex and will begin to demonstrate the typical three tunic arrangement.

b) Postcapillary Venules

Postcapillary venules are the smallest venules and the simplest in construction. Postcapillary venules serve two purposes: They recover some of the fluid lost from the

capillaries. However, **most** of this fluid is recovered by the lymph capillaries. They allow for the passage of leucocytes. Leucocytes will exit circulation by squeezing through the postcapillary venule wall to reach the site of infection. This can be augmented by the release of inflammatory agents, such as histamine, by mast cells and basophils. The wall of the postcapillary venule consists of endothelium, a basement membrane, a very small amount of collagen, and frequently there will be pericytes associated with postcapillary venules. Pericytes will also be associated with the larger venules.

i) Collecting Venules: Collecting venules receive blood from postcapillary venules. They have thicker walls due to a greater complement of collagen. They have a tunica intima of endothelium and a basement membrane. They have a tunica adventitia made up of collagen.

ii) Muscular Venules: Muscular venules drain the collecting venules. They have even thicker walls. They have a tunica intima of endothelium and a basement membrane. They have a tunica media made up of a single layer of smooth muscle cells (from which they get their name). They have a tunica adventitia made up of collagen that is thicker than that of the collecting venule.

c) True Veins

1) Small and Medium Sized Veins

The tunica intima is similar to that of a similar sized vein consisting of endothelium and a subendothelial connective tissue layer. Small and medium veins are more muscular than are venules with increasingly thicker bundles of smooth muscle forming the tunica media. These bundles of myofibers, however, are interspersed with collagen bundles. So veins are less muscular than are similar sized arteries. Also, the muscular component of veins is less consolidated than it is in arteries. The tunica adventitia is distinctly thicker than is the tunica media in these vessels. The tunica adventitia is composed of longitudinally arranged collagen bundles and lesser amounts of elastic fibers. Small and medium sized veins will have valves. This is particularly true for veins of the limbs. These valves prevent the back flow of blood. These valves are semilunar folds of the tunica intima. They will lay flush against the vessel wall during normal blood flow.

2) Large Veins

a] Structural Specializations: Larger veins have a somewhat thicker subendothelial connective tissue layer. They have valves also. The tunica media is poorly developed. The tunica adventitia is by far the thickest layer. The inner aspect of the tunica adventitia consists of longitudinally arranged smooth muscle bundles. The outer aspect consists of longitudinally arranged bundles of collagen with some elastic fibers.

b] Sinuses: A sinus is a highly modified large vein. It has a tunica intima but it's tunica media and tunica adventitia are replaced by the surrounding tissues of the organ it is servicing. Ex; coronary sinus, intercranial sinus.